preservation and restoration of moving images and sound

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FOREWORD

By the President of the current Preservation Commission

The Preservation Commission of the International Federation of Film Archives (FIAF) is an international working group which conducts research and publishes guidelines and recommendations on all technical aspects of moving image preservation.

The Commission was established in 1960 on the initiative of the late Mr Herbert Volkmann, then Director of the State Film Archive of the German Democratic Republic. Mr Volkmann later renamed it the International Commission for the Preservation of Audio-visual Media (Prescom).

During his 22 years as chairman, Mr Volkmann demonstrated a remarkable talent for involving in the work of Prescom not only the colleagues he selected as members, but also a wide variety of specialists from both inside and outside the archive world. The members' and consultants' knowledge and experience, and the information they compiled from many sources was collected in the 1965 FIAF publication "Film preservation". (The original edition of this report was published in German in 1963 and in 1967 translated into French). Further research led to a second publication "The preservation and restoration of colour and sound in films" in 1977, which was later expanded and is included in this book.

"Preservation and Restoration of Moving Image and Sound" embodies research carried out in collaboration with more than 40 scientists and archivists over a period of more than 10 years. The research was completed by Prescom in 1981, and despite failing health, Mr Volkmann managed to finish the editing in mid-1982. He died in August 1983.

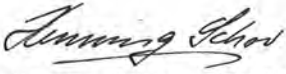
In 1983, the Preservation Commission was reconstituted by a new chairman, Dr Henning Schou of the (then) National Film Archive of the National Library of Australia. The members (refer list on pp. xxiii-xxiv) of this new Commission and its Subcommissions recognised that rapid technological development, especially in the area of electronic image recording, had overtaken some of the research drawn upon by Mr Volkmann and his colleagues in Eastern Europe. Revision of some of the text was therefore necessary.

While many people have contributed their expertise and advice to the preparation of this volume, we recognise that it is still far from being a definitive work.

The current Preservation Commission must therefore continue the publishing work of its predecessor. It is now compiling a user's manual on practical film and video preservation procedures; i.e., an archivist's "How to ...". The manual will cover such topics as basic film handling, nitrate preservation, decomposition of safety film (vinegar syndrome), dye stability data, scratch diminution treatments, sound on film, treatments against fungi and bacteria, storage in hot and humid climates, and a directory of major film stocks. The information has been and will be published relatively quickly, and updated regularly, in loose-leaf format in the style adopted by the Society of Motion Picture and Television Engineers (SMPTE). French, German and Spanish versions will be available.

The "FIAF Preservation Commission Technical Manual" binder together with the first two papers, "Basic film handling" by Harold Brown and Kevin Patton, and "Handling, preservation and restoration of cellulose nitrate film" prepared by the East European Subcommission, are available at a modest cost from the FIAF Secretariat, Coudenberg 70, B-1000 Brussels, Belgium.

For further technical information and advice, please contact your national film archive, the FIAF Secretariat or a member of the Preservation Commission.



Henning Schou, President
on behalf of the current FIAF Preservation Commission

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The Preservation Commission expresses its appreciation to Mr Jim Wheeler, Chief Engineer of Ampex, Mr Sam Kula, Chairman, and members of the Commission on Technology of the International Federation of Television Archives (FIAT), all of whom contributed valuable expertise.

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The compilation, editing and printing of "Preservation and restoration of moving image and sound" has been made possible by funding from Unesco. Even before the adoption of the "Recommendation for the safeguarding and preservation of moving images" by the 21st Unesco General Conference in 1980, Unesco considered it an urgent task to compile, in published form, the fruits of experience and scientific knowledge in the preservation and restoration of moving images so that it could be accessible to all interested parties. This publication is a contribution towards this end, supporting the intention of the recommendation which urges all nations and governments to take definitive action to safeguard and preserve their moving image heritage.

The overall credit for this book goes to the late Mr Volkmann and his Commission members and consultants.

H.S.

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PREFACE

After several years of intensive international co-operation, the FIAF Commission for the Preservation of Audio-visual Materials presents a system for the preservation of moving images.

Moving images have been in existence for nearly a century, but their value was not recognized until decades later, and it was much later still before anyone realized the problems associated with their preservation for future generations.

Following the destruction of a large film archive due to poor storage conditions, the International Federation of Film Archives (FIAF) formed the Commission for the Preservation and Restoration of Films in 1960, which later became, in line with archival development, the Commission for the Preservation of Audio-visual Materials.

In 1963 the first result of the Commission's work, published as 'Film Preservation' dealt mainly with black-and-white film but also gave hints on the handling of colour films and magnetic recordings. After a long interval, during which new findings were passed on to archives as 'directives', the Commission published 'The Preservation and Restoration of Colour and Sound in Films' in 1977.

While sufficient knowledge about the preservation of black-and-white film was held by the archives' technical officers and was available in print, the far more complicated problems of colour film and magnetic recordings required the participation of scientists (eg. chemists and physicists). The Commission was able to convince scientists, working in the related fields of research, of the importance of our task, and they co-operated with us without remuneration, in a good cause, despite the burden of their own research work.

We saw the close co-operation of scientists and archive specialists from East and West not as an experiment but as a good example. I thank everybody for the cordial atmosphere in which we were, and are still, able to work, and only regret that some scientists did not receive permission from their authorities to be co-authors, as planned.

The paper is a collective work. Apart from the authors listed above, contributions were made by the following people:

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Berlin, GDR
Brugge, Belgium
Versailles, France
Bucharest, Rumania

In each case, a remarkable number of experts from host countries, participated in the discussions.

Many thanks to all of them.

The scientists came from ten countries in the East and West. Despite the difficulties and delays which it involved, we spread the work over such a wide base so that economic interests and considerations would not influence the results.

In particular, I would like to thank those archives which, by their generous hospitality, enabled us to carry out this work:

Staatliches Filmarchiv der DDR, Berlin, GDR
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Last but not least we thank **Mrs. Irene Paul**, assistant to the editor, whose reliability and exactness was an important factor in this difficult international co-operation.

Many thanks to them.

We have to take for granted a basic knowledge of chemistry and physics, at least to the level taught in secondary schools. Complicated chemical or physical processes cannot be explained without a fundamental knowledge of physics and chemistry. Some chapters necessarily involve chemists and technicians because, due to its sophistication, the restoration of cine film can only possibly be carried out by highly qualified personnel. Any attempt made by unqualified people will almost inevitably result in the loss of the original material.

It would have been wrong if we had advocated a system of cheap but, in the long run, ineffective measures for the purpose of preservation of cinema films that is of no use to anybody. If we want to preserve cinema films until such time as it becomes possible to transfer them to a more durable medium of information, we must rely on scientific experiments. The results obtained so far show that it is a complicated matter. The problem of preserving cinema films cannot be solved by means of tricks and short cuts.

The knowledge of archives which preserve audio-visual materials, by which is meant events and works of art in moving images with accompanying sound, is still in its infancy. As with written archives, museums and libraries, their work is divided into three main areas:

a) preservation of the archival materials;
b) access to them; and
c) their utilization.

While the justification for an archive's existence lies ultimately in the utilization of its material, we are concerned here exclusively with the technical aspect of its preservation and restoration, the problems of which must be solved if archives are to exist at all.

We are sure that this book can, at the present stage of development, be of use not only to the young audio-visual archives which are springing up in all corners of the globe following the UNESCO resolution, but also to experienced colleagues.

Herbert Volkmann

President of the
FIAF Commission for the Preservation of Audio-visual Materials

Berlin, GDR, March 1982.

INTRODUCTION

By Herbert Volkmann, Former Director
of the State Film Archive of the German Democratic Republic

Only a few of the spectators in Paris and Berlin in 1895 who watched the first 'moving images' flicker on the screen suspected at the time that they had witnessed the birth of one of the most important mass media which, together with television, appearing half a century later, would extensively stamp the face of the twentieth century for future generations.

Neither 'film' nor 'television' was the invention of one man; many scientists and technicians from many countries took part over several centuries in the development of this epochal invention. Its exploitation was equally international in character: films have been made and shown in many countries for over eighty years.

Never before had there been an art form which reached so wide a public, nor such a possibility of influencing the thinking of humanity, nor any comparable prospect of transmitting to posterity such revealing historical documents. Audio vision is one of the great achievements of the twentieth century.

During these decades many thousands of films have been produced; good and bad, marvellous works of art and important documents as well as stupid rubbish or dangerous propaganda. From the very beginning there were people interested in collecting films, and everything concerning films, but many gradually abandoned their interest, much was lost in two world wars, others were deliberately destroyed by reason of profits and much was ruined by wrong treatment. As a result, it is no longer possible to show all the important productions of film history on the screen. In many cases a title or a memory are all that exist; in others only fragments or incomplete versions have survived, many in such a bad state that in their sad shadows one can hardly recognise the great works of art which they once represented.

This lamentable deterioration is the consequence not only of human neglect but even more of the chemical properties of the film material itself.

All types of cine film consist almost entirely of organic (i.e. perishable) materials: black-and-white film consisting of four or five layers of different chemical composition; colour film nowadays mostly consists of nine layers, each only a few μ in thickness (1 μ = 1/1000 mm).

The main constituent of the layers, apart from the base, is gelatin, a substance which is physically easily damaged, which reacts strongly to water, and provides a good nutrient medium for bacteria and fungi. The image-forming substances too have little stability: the silver particles which form the image in black-and-white film, can be caused to fade by processing residues, and the dyestuffs formed during chromogenic development, the main process of colour cinematography used nowadays, possess such adverse properties that they are unacceptable for paper and textile printing. In addition, the emulsion and the base have different co-efficients of expansion, which can lead to the separation of the emulsion during temperature variations.

But these unalterable characteristics inherent in the system are still not all; there are additional individual factors which can influence stability. All things considered, cine film is more difficult to preserve than any other archival material or museum resource.

Some decades after cine film, electronic pictures and magnetic sound recordings appeared. Together with electronic technology they made possible television which has since overtaken film in its public influence. The two systems are based on totally different scientific principles. It is of great archival importance that, for example, the colours are recorded not with the aid of dyestuffs but on magnetic tape.

Magnetic recordings cannot be fixed and may be erased by strong electromagnetic fields as well as by simple operational errors on the machines. The television picture does not have the same quality as a film image on a screen. The TV systems using 525 lines and 625 lines, developed in the USA and Europe respectively, are not compatible, i.e. unlike film, which is standardized world-wide, they are not interchangeable everywhere. And finally, the materials of magnetic recordings also consist of organic substances and have a layered structure. In this respect, therefore, they are comparable to the optical images. Magnetic recordings then, are not the ideal archival material, and can only be preserved for a limited period.

Scientific research continues. Recently, there has been significant advances in the area of film stability. The major research effort has been concentrated in the field of electronic media. There can scarcely be any doubt that in the foreseeable future it will be possible to store audio-visual recordings more safely, with better quality and less expense.

One might suppose that archives need only to wait for the new improved technologies to become available. That would be totally wrong and would certainly result in the loss of the 'old' holdings. On the basis of the present state of research it will be years yet before all the problems are solved and the transfer process itself will take the large archives decades to complete. Therefore, it is not just worthwhile but absolutely necessary for the present to continue to maintain air-conditioned film storage vaults or

build new ones. The task of audio-visual archives today is to preserve their holdings in the best possible condition until such time as they can be transferred onto new media.

For more than four decades now, the task of preserving these cultural treasures of mankind has fallen primarily to film archives. More than sixty film archives are united within FIAF - film archives from all continents, from the leading producing countries, old and young, large and small, but all with the aim of doing everything in their power to pass on the works of film art to the present and future generations.

Only recently, some FIAF archives have started to preserve magnetic television recordings. They should all be referred to by the umbrella term "audio-visual archives". The television archives, some of which have enormous holdings, have not yet been secured against losses through their use in new productions.

It is not accidental, that the richest film archives in East and West are state institutions supported by considerable subsidies. Film archives which exist on a more or less private basis, backed by a small group of film enthusiasts but without any other means of support, may carry on desperate struggles for the preservation of their film treasures. Their struggle deserves every praise, but the results are extremely poor. It is regrettable that, in many countries, the film is regarded as exclusively a private commmercial business and not as a cultural asset in the preservation of which the public interest should have priority. One of the first tasks of these film archives is to combat public indifference, to make clear the necessity of a state subsidy and to demand it.

Nowadays there is no more doubt that, as far as their cultural significance is concerned, audio-visual archives are on an equal footing with museums of fine arts and the large libraries and archives of registration. Like them, their objective is to protect significant works of art and important documents against disintegration and to make them available to serious researchers and to the public. Just like these, however, they cannot do justice to their task unless they operate without regard to commercial aims and receive sufficient support. This book will deal with the complexity of the task of preserving cine films and magnetic recordings over lengthy periods. It should be stressed at this point that it is very difficult nowadays to preserve audio-visual works of art of the past for future generations, and it is high time that works of cinematographic art and of television - being works of art as well as documents - are included in the category of cultural assets which must be protected.

For many years the film archives have conducted a lone struggle, but now they have gained an important ally: UNESCO, the United Nations' Educational, Scientific and Cultural Organization. After preparations at three General Assemblies, a resolution was adopted in 1980 as an appeal to all nations and governments of the world to safeguard moving

images and audio-visual recordings as a valuable cultural heritage of mankind and to pass them on to coming generations as a valuable artistic and documentary reflection of our turbulent epoch.

Our FIAF Commission for the Preservation and Restoration of Audio-visual Recordings has taken a considerable part in the drafting of this resolution.

In this way an individual no longer talks in isolation with his government but he is backed by the authority of this great organization of the peoples of the world. This resolution is of great use to us in our work, but its value depends on what we make of it. We must work with it and argue with it, and it will help particularly in recording life in the developing countries whose people in the course of their lives often traverse whole phases of the history of mankind in much the same way as the old industrial countries did in the course of centuries.

However, those audio-visual archives which are recognized and supported, and no longer need to devote all their energies to solving difficult financial problems should, through their ideas and experimental work, contribute to the task of improving and simplifying the work of preservation. There are good instances of this, from the past and the present. For example: Gosfilmofond (USSR) developed the first complex machines for cleaning and repairing films in one process; the Service des Archives du Film (France) worked on the mechanical production of colour separations on black-and-white film and their subsequent synthesis to colour films; the Staatliches Filmarchiv of the GDR developed a secure nitrate storage facility; the Svenska Cinemateket is testing a method of making refrigerated storage both simpler and cheaper through the use of sealed storage bags; the Nederlands Filmmuseum is testing current methods of transferring colour film recordings onto videodiscs. Such initiatives are of great value and further the work of all archives.

When the Preservation Commission took up its work more than twenty years ago, film archives were orientated almost exclusively towards the history of film. In one FIAF member only (Gosfilmofond) was the technical supervisor a graduate engineer. Now chemists, physicists and engineers are at work in several archives, and the remaining archives for their part have recognized that the struggle to preserve their holdings is their most pressing task. Naturally this facilitates co-operation with research workers in institutes and industry, which has been the basis of the Preservation Commission's work for over ten years now.

Our aim in this book is to present a system for preserving audio-visual recordings which is founded on scientific research and practical experience; and to furnish arguments for use in any discussions about its financial implications. We deliberately avoid dealing with individual manufacturers' products and confine ourselves to large groupings such as nitrate or safety film, black-and-white, colour film or

magnetic recordings.

A book such as this must also take account of the latest advances in knowledge, once they have been confirmed, but it can never have the up-to-dateness of the specialist periodical article. We strongly recommend our technical colleagues in audio-visual archives to read the specialist literature available in a language accessible to them to keep their knowledge constantly on the increase.

We will touch on historic developments, but have decided not to discuss research and inventions which have not been put into practice. Any recordings which resulted from such work will either be few and far between in archives or will only be in an experimental stage. By limiting the scope of this volume to what is necessary for daily work, we were forced to omit aspects such as these.

PART I

CINEMA FILM
ITS
PROPERTIES AND PRESERVATION

Chapter 1

THE STRUCTURE OF CINEMA FILMS

By Herbert Volkmann, Former Director
of the State Film Archives of the German Democratic Republic

1 Important historical dates

Film was the first audio-visual medium but today it is no longer the only one. Certain historical dates should be memorized as they may prove useful as a rough guide in the identification of material and in determining appropriate preservation methods.

The first films (black-and-white, silent and on a nitrate base) were exhibited in 1895.

Attempts were made to show films in colour as early as 1897. There were many experiments with various systems, none of which was to prove commercially practicable, until in 1915 when the process of printing Technicolor positive on the basis of two (and from 1932, three) colour separations was established.

In 1935 Kodak introduced their integral tripack colour reversal process, Kodachrome. In 1937 Agfa-Wolfen brought out a similar material. Both of these were chromogenic processes, that is, with colours produced in the development process. They are less stable than those produced by the printing process. Nowadays all colour negatives and most positives are produced by this method, and the task of preservation has thereby been rendered more difficult.

The first film with photographic sound (optical sound) was shown in 1923 and by the early 1930s sound film had quickly supplanted the silent film in the cinemas.

The beginning of the 1950s saw an important step forward: the nitro-cellulose base, which had originally been the only 35mm film base available (with a few exceptions), was replaced by triacetyl-cellulose base, and from then on safety film has been the only film produced for use in cinemas.

Since then there have been improvements, especially in colour quality and stability. Further developments have been concentrated on the possibility offered by television.

1.1 Motion picture film

Motion picture film is chemically and physically a very complicated multi-layered product consisting almost exclusively of relatively unstable organic substances. It

ranks as one of the most difficult of present-day archival or museum objects to preserve.

The destructive processes of film are determined by natural laws which we cannot alter. All we can do is to retard significantly the destruction of the material until it is possible to transfer its content onto a more stable medium.

Archives of moving images have to deal mainly with exposed 35 mm and 16 mm cine film.

1.1.1 Black-and-white film

Black-and-white raw film consists of five layers:

a) a clear gelatin layer without any additions which serves as a protective layer against mechanical damage;

b) the light-sensitive layer consisting of a suspension of silver salts in gelatin (the emulsion);

c) the adhesive substratum which binds the light-sensitive layer to the base;

d) the base or support consisting chiefly of nitro-cellulose (nitrate film) or of acetyl-cellulose (triacetate, safety film). The two bases look exactly alike, have comparable optical qualities elasticity and toughness. Because of their different chemical properties, however, they differ in their life expectancy, their flammability, and therefore the influence they can exert on their surroundings;

e) there may also be a further layer for anti-halation purposes; or a coating of gelatin to prevent curling; or a layer which serves both purposes.

1.1.2 Colour film

Colour film has an even more complex structure. It consists nowadays of as many as nine layers with different functions:

a) the protective layer of clear gelatin;

b) the blue-sensitive recording layer consisting of gelatin in which the silver salts and colour coupler are embedded;

c) a yellow filter layer which absorbs the blue rays of light not absorbed in the blue-sensitive layer but lets the green and red rays pass through;

d) a green-sensitive layer;

e) an interlayer of prepared gelatin which prevents the dyes produced, especially during development, from migrating from their own layer and hence spoiling the image;

f) the red-sensitive layer;

g) the adhesive substratum;

h) the base or support is usually made of cellulose triacetate or polyester;

i) the anti-halation layer which may also serve as the anti-curl layer.

1.1.3 Each of these layers must have a uniform thickness of only a few μ (1 μ = 1/1000 mm). For more than thirty years the colours produced through chromogenic development have generally been relatively unstable. Chemical changes take place constantly, and physical and biological damage occurs when certain critical conditions are departed from.

Some of the problems now facing audio-visual archives stem from this complex structure of relatively unstable dye substances, which are notoriously subject to destruction, causing change of the colour balance, even when stored in the dark.

1.1.4 On the basis of film structure we may therefore differentiate, according to the base:

a) nitrate film;
b) acetate film (diacetate, triacetate and mixed esters);
c) polyester film;

and according to the light-sensitive layer:

d) black-and-white film;
e) colour film.

The distinction between silent and sound film is of no real significance as far as storage is concerned.

1.2 The nitrate base

1.2.1 Characteristics

Up to the beginning of the 1950s, 35 mm cinematograph film (black-and-white and colour) was almost exclusively on a nitrate base. Other gauges (especially 8 mm, 16 mm and 70 mm) and magnetic films were from the beginning made on acetate or polyester bases. The nitrate base was used in the manufacture of cine film all over the world for more than five decades.

In the manufacture of nitrate film base, cellulose is esterified with nitric acid to make cellulose nitrate. The addition of organic plasticizers prevents brittleness. Along with its good optical and mechanical properties, the film base produced in this manner has two big drawbacks which have a decisive influence on preservation methods:

a) the chemical bond between cellulose and a nitro group is relatively unstable, and as a result the nitrate base decomposes even under favourable storage conditions. The nitro groups dissociate again;
b) like all substances in this group, which includes gun cotton, the nitrate base is highly flammable and it ignites

easily. New nitrate film ignites around 170° C, while old nitrate now being stored could ignite at lower temperatures. It burns very quickly; in large quantities explosively.

1.2.2 Decomposition of the nitrate base

The nitrate base begins to decompose from the moment it is manufactured. This autocatalysis proceeds slowly but, according to our present knowledge, irresistibly. In the process it releases nitrous gases, mainly nitrogen dioxide which combine with the water in the gelatin and in the air to form nitrous acid and nitric acid. These acids bleach the silver image or the colour in the emulsion and accelerate the decomposition of the base to the point of total destruction. The nitrous gases exert the same fatal influence on all the cinematograph film stored in the same area, irrespective of its age, and whether nitrate or acetate, black-and-white or colour.

Under favourable conditions the process of decomposition is very slow, extending over many years. For a long time the film shows no visible change; only in the final stage, which may last only a few months before the film is destroyed, are the following outward changes visible, in this order:

a) fading of the silver image, and a brownish discolouration of the emulsion; the film gives off a strong odour;

b) the emulsion becomes sticky;

c) the film becomes soft in parts ('formation of honey') and blisters;

d) the entire film congeals to a solid mass;

e) the base disintegrates to a pungent brown powder.

The fading of the silver image can also be traced back to the influence of chemical residues from processing, and may therefore occur with safety film as well.

During stages a and b the film can still be saved by treatment and copying.

When the third stage is reached parts of the film may perhaps be saved.

During stages d and e nothing more can be salvaged and the film must be destroyed at once.

It is important for us to know that the stage of decomposition which a nitrate film has reached before these external signs become visible can be determined by a physical-chemical test - the accelerated ageing test (see Chapter 18).

In these circumstances, how many years can we say that nitrate film will last? This is something we cannot put an exact figure on.

We know that a few original negatives and prints from the first year of the cinema, now about eighty years old, are still being preserved. On the other hand under poor storage conditions nitrate film has decomposed fully within ten years. One can safely assert one thing: that nitrate film now being stored in archives has already reached a dangerous age. The utmost caution is advisable.

1.2.3 Shrinkage

When nitrate or acetate films are stored in conditions which are too dry, the humidity in the emulsion and the plasticizer evaporate. The film shrinks, i.e. the distance between the perforations diminishes, leading to damage of the perforations during projection or copying. Shrinkage may become so marked that the film can no longer be projected or copied on normal apparatus. Ultimately it will become brittle and useless. At an early stage, humidifying in a filmostat is possible but any recovery of flexibility will last only for a short time outside a sealed can. It is impossible to reverse the shrinkage permanently.

1.2.4 Flammability

As we have already mentioned, nitrate film is highly flammable. New raw stock will ignite at around 170° C. As decomposition proceeds, however, the ignition temperature falls. It burns very quickly, creating temperatures of up to 1700° C. A roll of burning nitrate film cannot be extinguished. As the film base contains oxidizing nitro groups it burns even under water or carbonic acid snow. That is not to say that water or carbonic acid snow are useless: the latter prevents the formation of jets of flame, while water cools the surrounding and discourages the spread of the fire.

Laboratory tests in the USA in 1949 established that nitrate film stored in an insulated container could ignite at an external temperature of 41° C, i.e. at a temperature not far removed from those reached in midsummer even in temperate zones. As the tests were relatively few in number it is possible that insulated nitrate film in the final stages of decomposition may ignite spontaneously at even lower temperatures.

This may help to explain the fires which have occurred in film archive vaults in countries with such differing climates as for example Brazil, Canada, France and Finland.

A great deal of cinema films, in some cases irreplaceable has been destroyed in this way. It can prove fatal to close one's eyes to the problem and fail to ensure the best possible storage conditions and the speediest transfer of nitrate onto safety film.

1.2.5 Requirements for preserving nitrate films

1.2.5.1 The process of disintegration must be retarded. Since chemical reaction becomes slower as the temperature

falls, the first requirement is to store nitrate films at low temperatures. These temperatures should not exceed a maximum of 6° C (42.8° F). As all nitrate films are dangerous nowadays on account of their age, it is not wrong to refrigerate them at a maximum of minus 5° C (23° F). This presupposes that there is available a deep cold store especially suitable for nitrate film.

A reduction of 5° C in the storage temperature halves the volume of nitrate gases given off by the nitrate base (according to Kodak Publication 3-57-C-H), thereby slowing down the decomposition process and concentration of nitric acid. (A lowering of the temperature from 20° C to 4° C reduces the amount of nitrate gases released to 10% of the original).

The greater the humidity, the greater is the damage caused by the nitrate gases. It is therefore a question of storing film in conditions which retard the decomposition process yet do not encourage excessive shrinkage and brittleness. The range within which one can operate is relatively narrow, lying between 50% and 60% relative humidity (RH) for films stored at +6° C, and 25.30% for films stored at -5° C.

It follows from this that nitrate films must never be stored in airtight cans. As nitrous gases are heavy, they collect at the bottom of the can. If holes about 2 mm in diameter are punched in the lower part of the edge of the can, the gases released will be extracted from the floor of the vault by the air conditioning system.

1.2.5.2 Nitrate film must be stored in conditions which eliminate as far as is possible the fire danger both to the film and to its surroundings.

Almost all countries have statutory provisions covering such storage which are binding on film archives, and which in their own interest they should follow conscientiously.

Under no circumstances should nitrate film be housed in buildings which include living/work rooms. Care should be taken that no superfluous film is left lying around in rooms used for the examination of nitrate film.

Emergency exits must be provided as well as fire fighting appliances (hand foam extinguishers and fireproof covers). They cannot extinguish a nitrate fire, but can prevent the formation of dangerous jets of flame.

1.2.5.3 When signs of decomposition become visible (see 1.2.2), or if the accelerated ageing test (see Chapter 18) reveals an advanced state of decomposition, the nitrate copy must be transferred to safety film as soon as possible if the content of the film is to be saved. After copying, the original material must be destroyed. Since the decomposition process even under cool storage conditions is only retarded, but not stopped or reversed, there is no other choice in

such cases.

If there is no possibility of having the film copied immediately it should be stored individually in a separate bunker so as not to endanger the remaining film store.

Should the film archive be unable to copy the film within a short period, whether for financial or other reasons, and the copy in question is unique or represents the most complete or technically the best known version of an important film, then other film archives should be asked either directly or via the FIAF Secretariat, whether they are prepared to have the film copied. There is no doubt that in such cases other archives would be prepared to do so. The agreement reached between the archive holding the film and the copying archive should be in accordance with FIAF regulations governing permanent loans.

It is to be assumed though that generally the film will be copied in the country where it is being held. The movement of nitrate film in an advanced state of decomposition by means of public transport is unjustifiable, and every other method of long distance transport is very expensive.

1.3 Triacetate base

1.3.1 Properties

The first 'safety film' based on cellulose acetate was announced as far back as 1901. It was not yet usable in this form, however, having insufficient tensile strength and being too easily damaged. The tri-acetate base, which shares the optical and mechanical characteristics of nitrate base without its adverse qualities (release of nitrous gases and inflammability), was only made on a commercial scale almost fifty years later.

The composition of acetate base is different from that of nitrate base, and its chemical properties are quite different also. The basic substance is still cellulose, but it is esterified not with nitric acid but with acetic anhydride to form cellulose acetate (also known as acetyl cellulose). Once again a plasticizer must be added.

During the development of safety film, cinematograph film was manufactured using bases of cellulose acetate and butyrate, and cellulose acetate propionate; in recent decades a tri-acetate base has been used almost exclusively. As far as preservation is concerned all these films have practically the same characteristics, and are brought together here under the inclusive heading 'acetate film'. For archival purposes it is important to note that all 8 mm and practically all 16 mm films, all 70 mm films, all magnetic films, and since the beginning of the 1950s practically all 35 mm films have been made on acetate base.

1.3.2 Characteristics of acetate film

Acetate base has equally good physical and biological

characteristics as nitrate base, and in addition offers two big advantages:

a) it is much more stable than cellulose nitrate base. Admittedly acetic acid does become separated from the acetate film but in small quantities. Acetate film therefore has a longer life span than nitrate film in archival storage;

b) acetate base is less flammable than paper. It is not subject to spontaneous combustion, is difficult to ignite and, in small quantities, does not burn but smoulders.

1.3.3 Shrinkage

For purposes of long-term storage it is important to know that, when acetate film is stored in conditions which are too dry, its plasticizer can escape and the film becomes shrunk and brittle.

1.3.4 Harmful gases

Harmful chemical influences (of acid gases, and especially those produced by decomposing nitrate film) pose a threat to the preservation of acetate film. What has been said on the subject of nitrate film applies here.

1.3.5 Conclusions for the preservation of acetate base

1.3.5.1 Because acetate film is not flammable and does not represent a threat to its surroundings, no more fire precautions than are usual in large libraries need be taken. This is a point of especial significance in the construction of film vaults.

1.3.5.2 Acetate film does not produce harmful gases and exhibits no sign of decomposition under moderate storage conditions. In consequence there is no need for any special ventilation or particularly cold storage. (Unless the emulsion contains colour dyes).

The emulsion is the same as for nitrate film. Cool storage and moderate relative humidity are advisable to prevent the formation of fungus.

At all events a constant temperature (not above 12° C) and constant humidity (not exceeding 60% RH) must be provided for its storage.

1.3.5.3 The longevity of acetate film is endangered by the evaporation of the plasticizer from the base, causing the film to become brittle and therefore no longer able to be copied or projected. To avoid this the archive should be anxious to have a RH of 50-60%.

1.3.5.4 Some archives pack acetate films in special, watertight bags and seal them hermetically before placing them in cans, thus eliminating the problems connected with relative humidity.

However, acetate films should only be stored in water- and air-tight bags if before being packed they are acclimatised at room temperature and 30-50% RH.

1.3.5.5 As the gases released by decomposing nitrate film have a destructive influence on acetate film as well, the physical separation of acetate film and nitrate film in separate blockhouses is a prerequisite for the preservation of the former.

1.4 Polyester base

Polyesters are polymers formed by condensation of polybasic acids (generally maleic or terephthalic acid) with polyhydric alcohols (generally glycol or propylene glycol). They are manufactured in a wide variety of forms (as textile thread, elastic, soft and hard plastic etc).

1.4.1 Characteristics

Polyester used as a film base has the same requisite properties as nitrate and acetate base: it is fully transparent, and is elastic. Besides, it has greater tensile strength. Compared to other bases it has decisive advantages: it is unaffected by temperature changes or humidity and does not release harmful gases. Polyester could therefore be the ideal base for cinematograph film.

1.4.2 Unfortunately the coating of the light-sensitive emulsion on the polyester base is more difficult. Therefore polyester base was previously used mostly for 8 mm film and for 16 mm release prints. Nowadays it is also used for 35 mm films.

1.4.3 Despite all the advantages of polyester one should bear in mind that in the final analysis the life-span of a cine film is determined by the life-span of the recordings made on the light-sensitive emulsions and these are in any case shorter than the life-span of polyester.

1.5 Emulsion layer

1.5.1 The emulsion layer which carries the picture and sound records consists mainly of gelatin which because of its mechanical properties cannot be used without a support. In particular its extreme fragility is unequal to the stresses imposed on it in passing through recording, developing and projection equipment.

1.5.2 Gelatin is an organic product made by boiling collagen from animal cartilage, hide and other connective tissue. Tests have shown that given good storage conditions it is fairly durable.

1.5.3 However, it readily absorbs moisture and becomes swollen and sticky. Warmth encourages this behaviour which, if not checked, will lead to the total destruction of the film.

1.5.4 Furthermore, gelatin is an excellent nutrient for fungi and bacteria. Fungus spores are constantly present in the air and on finding favourable conditions (moisture and warmth) they grow quickly. Fungus growth on film emulsion mostly appears as a white, greenish or grey covering. Fungus mould penetrates the emulsion and if it is left to flourish undisturbed, the colours are altered and finally the entire emulsion is destroyed. In 1960, an entire film archive was destroyed in this way.

Such damage can be avoided if the environment in the film vault is constantly under control (relative humidity no higher than 60%) and the temperature is kept constantly low.

However, we must repeat the warning that there is a limit beyond which one should not lower the humidity. Film which is kept in conditions which are too dry (less than 20% RH) shrinks and becomes brittle.

1.5.5 We must distinguish between two kinds of recording layer in cinematograph film:

a) light-sensitive layers for black-and-white pictures and optical sound (see 1.1.1);

b) light-sensitive layers for colour pictures and optical sound (see 1.1.2).

1.5.6 As stated in 1.2 and 1.3, cellulose nitrate and cellulose acetate bases should be stored at different maximum temperatures because of their different chemical properties.

To this we can add that the different emulsion layers for black-and-white and colour require different maximum temperatures and different levels of humidity as well. Basically it can be said that:

a) films with black-and-white records may be stored above freezing point, with the storage temperature being determined by the base (a constant 6-12° C);

b) according to some recommendations archival storage of colour films should be below 0° C, at a constant temperature not exceeding minus 5° C and relative humidity not exceeding 30%.

It is not wrong to store all films at the lowest temperatures and corresponding relative humidities, but it is unnecessary and therefore uneconomic. The lower the temperatures, the higher the construction costs for the vaults and the greater the energy consumption of the air conditioning system. Access (taking films out of the store and putting them back) is more difficult with refrigerated film than with non-refrigerated film (see Chapter 15).

1.6 Special factors

Several special factors also affect the preservation of the

holdings in particular:

a) the purity of the materials used in the manufacture of the raw film stock;

b) the quality of the work carried out by the laboratory, especially:

c) the thorough washing of the film after it has been developed and fixed;

d) the conditions under which the film has been stored before its acquisition by the archive.

These are factors which may differ from film to film.

Chapter 2

THE BLACK-AND-WHITE IMAGE IN CINEMATOGRAPH FILM

By Herbert Volkmann, Former Director
of the State Film Archive of the German Democratic Republic

2 Introduction

2.1 Until about midway through the twentieth century, cinematograph film was presented to the public on the screen mostly as a black-and-white image.

2.1.1 The light-sensitive element which makes photographic recordings possible consists of silver halides, i.e. silver chloride, silver bromide and silver iodide, in the gelatin layer (see 1.1.1). Unless specially treated, however, they react only to ultraviolet light and rays from the short-wave third of the visible spectrum, (i.e. they are blue-sensitive only, they distinguish only between blue and non-blue). As a result, there were only contrasts without intermediate tones, black-and-white without grey tones.

Non-sensitized emulsions like this are called 'blind emulsions', and are still used nowadays for optical sound recording films.

2.1.2 If photographic images with correct tone rendering are to be obtained, the silver halide crystals must be made sensitive to visible rays of other wavelengths as well. Optical sensitization for mass production purposes was made possible by the addition of small quantities of certain dyes (e.g. cyanine group) derivative to the emulsion during manufacture of the photographic material.

Orthochromatic sensitization (Vogel 1870) caused the silver halide to react to rays from the green middle third of the visible spectrum in addition to the blue third. They were recorded photographically as grey tones corresponding to the colour values of the object in question. However, in this process the silver halide was not red-sensitive.

2.1.3 In the positive, the photographic black-and-white image obtained with the aid of orthochromatic sensitization recorded the coloured rays from the subject in the following way:

a) blue rays: white, black and all shades of grey;
b) green rays: white, black and all shades of grey;
c) red rays: very dark grey to black.

As the recording of the primary colours is not confined to their theoretical third of the visible spectrum but reach

over into neighbouring sectors, colour impurities result through faulty absorptions (see 4.6.1), which however, do not seriously affect the black-and-white image.

The first moving images found in this process a tried and tested photographic technique, which was used for nearly thirty years, before it became possible to reproduce the nuances of the final third of the visible spectrum.

2.1.4 Panchromatic sensitization of silver crystals encompasses the entire visible spectral range:

a) the short-wave blue third with inherent sensitization;
b) the green middle third;
c) the long-wave red third.

It was now possible to reproduce, in grey tones, the red rays according to their intensity, where previously they had been recorded in the positive as black.

All of this only applies to black-and-white film. For colour film, dyes had yet to be included in the photographic system (see Chapter 4).

2.2 Formation of the black-and-white image

2.2.1 The process of recording an object photographically, leading to its projection on the screen, falls into three main phases:

a) the sensitized raw film is exposed in the camera or printer to rays from the subject;

b) the exposed film is processed (developed, fixed, washed and dried);

c) the exposed film is projected on the screen with the aid of a projector.

2.2.2 When the black-and-white raw film is exposed in the camera or printer, a latent, invisible image of the subject is formed in the light-sensitive emulsion.

2.2.3 During subsequent processing of the exposed film in the developing bath, the silver halides are transformed into metallic silver which exhibits varying degrees of density, (i.e. grey tones). The picture becomes visible in this way, for the grey values correspond to the radiation received from the subject, in the case of positive film. If a negative film is exposed and developed the grey values are reversed (i.e. white becomes black, light grey becomes dark grey etc).

2.2.4 After the set development time the development process is halted and the grey tones are stabilized in the fixing bath. The film is then washed, dried and placed in the can ready for projection.

2.2.5 During processing, all the manufacturer's instructions must be followed exactly as the only way of

ensuring a satisfactory positive or negative image.

As far as archives are concerned, apart from the film's quality from a technical point of view, it is of particular importance that all residual chemicals from the process of developing and fixing are removed by thorough washing.

2.3 Preserving the black-and-white image

2.3.1 The useful life of a black-and-white film image produced in this manner is often determined by the film base (nitrate or acetate) which supports it, and it must be carefully handled, stored and protected against harmful influences.

2.3.2 A prerequisite for its preservation is the thorough fixing and washing of the film after its development. Residual chemicals in the film continue to exert an influence even after drying, and cause spotting, browning and bleaching of the image.

2.3.3 The products of the decomposition of nitrate base (see 1.2.2) are especially dangerous for the silver image. The acids produced during decomposition bleach the silver image, destroy the gelatin and finally attack the base, irrespective of whether it is nitrate or acetate film.

2.3.4 A similar influence is exerted by acid gases and other pollutants in the atmosphere (e.g. hydrogen sulphide and sulphur dioxide) which prevail in industrial areas and cities where coal is burned in large quantities. They too pose a serious threat to the preservation of the film.

2.3.5 Fungus growth on the gelatin (see 1.5.4) does of course affect the silver image as well. The structure of the gelatin is attacked by the biological action of the microorganisms, destroying it as a picture medium.

Chapter 3

THE RESTORATION OF DISCOLOURED BLACK-AND-WHITE FILMS

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3.1 Causes of discolouration

Chemicals left in the emulsion after the film has been processed have a harmful effect on the durability of the silver image.

Especially damaging are the thiosulphate residues produced during fixing, and the sulphur compounds, above all trithionate, which are gradually formed from the thiosulphate.

Under the influence of these chemicals, the finely distributed black metallic silver in the gelatin changes into various silver-sulphur compounds, which may take on any shade of colour from dark brown to a light yellow. Thinly covered sections of the original picture disappear completely, giving rise to the impression that they never carried any image. Frequently the transformation of the silver image leads also to a blurring of the contours. Black-and-white films which show such changes cannot be projected or copied while in that condition. The destruction of the image in films is caused not only by thiosulphate and its decomposition products, but also by residual silver complexes (arising from inadequate fixing) which combine with sulphide ions from the decomposing thiosulphate or react with substances in the atmosphere to cause discolouration.

In addition, the durability of the silver image is endangered by oxidizing substances, especially peroxide. One should therefore on no account use chemical means to destroy the residual thiosulphate in the film, as in all such procedures there is a great danger that in the long term unforeseeable reactions and products may result which can cause more damage than the residual thiosulphate. After the film has been processed, in the course of which much importance should be attached to fresh fixing and thorough washing, no additional chemicals should be introduced to the emulsion.

From this description of the causes of discolouration it is evident that this phenomenon occurs irrespective of the type of film base and can be traced back to improper treatment of the material during the processing stage. Naturally the silver image of nitrate material is particularly at risk from the effects of the acid gases and vapours from the

decomposition of the nitrate base.

3.1.2 Treatment of discoloured film materials

Where the discolouration is not far advanced, photographic material can be regenerated by simple redevelopment, which means bleaching the silver image in an oxidizing bath, e.g. of potassium hexacyanoferrate(III), and - after a thorough washing - bringing out the image once more by means of a normal developer.

This procedure has serious drawbacks, however, if applied to films where the discolouration is more advanced. In such cases it is not possible to recapture the black silver grain. Instead, the resulting images are of reddish or brownish hue, and are spotted and covered with a reddish or brownish fog.

Films which may once more be readily printed or projected, after the loss of definition brought on by discolouration has been reversed, are preserved following the restoration procedure given in DDR-WP 36 078. This calls for the treatment of the film in a powerful oxidation bath, followed by treatment with a tin chloride solution and lastly its redevelopment using a fast developer. This procedure is suitable for the machine handling of entire reels of archival film, and under controlled conditions has produced some very good results.

Silver sound tracks can of course be restored in the same manner. The oxidation bath consists of a potassium dichromate solution. After the bleach the film is thoroughly washed. However, after a tin chloride bath, the film need only be washed for a few minutes. No fixing is required after development as there are no unexposed silver halides to be removed; a final lengthy washing is sufficient. Moreover, a reloading of the emulsion with thiosulphate is avoided. The restoration process can take place in full daylight.

Caution is required when dealing with nitrate film, where under the influence of the acid gases and vapours from the decomposing base, the gelatin at times undergoes severe hydrolysis, thereby becoming soluble, so that during wet treatment the picture-bearing emulsion may separate from the base or dissolve. Therefore, before deciding upon restoration treatment, the condition of the layer should be investigated.

Faded or discoloured film should not undergo a routine post-fixing in the archive, as valuable silver, necessary for the restoration of the image, may thereby be lost in the form of soluble thiosulphate complexes.

Chapter 4

HISTORICAL DEVELOPMENT AND PROPERTIES OF THE COLOUR PHOTOGRAPHIC MATERIALS USED IN CINEMATOGRAPHY

By Dr Hubertus Pietrzok (retired), ORWO, Wolfen
German Democratic Republic

4.1 The invention of colour film and the first experiments

The discovery of how to reproduce natural colours on film is no more the result of one individual's genius than was the invention of the medium of film, the preservable moving image itself, which resulted from the collaboration of scientists and technologists from many countries. The realization of a suitable technology for large-scale production, processing and projection of colour film took at least eighty years from its first theoretical conception. During this period several generations of scientists worked on its development.

As early as 1802, C E Wünsch discovered the principle of mixing three primary colours, which was then developed by Young and Helmholtz. In 1855 Clerk Maxwell established that the three-colour principle could be applied to colour photography, and in 1862 Ducos Duhauron described the theory of the processes of beam splitting in recording and reproduction, the mosaic screen process, the integral tripack (three-layered film) and of the subtractive sequence of layers. He used coloured gelatin layers and dichromate hardening in the so-called pigment process. In 1881 Charles Cros discovered gelatin reliefs as matrices for coloured pictures, and Warnecke described hardening development for producing wash-off reliefs. In 1891 came Lippmann's interference process with standing light waves, and in 1893 P Richard succeeded in converting the silver image into a mordant image in colouring with basic dyestuffs. Two-colour photography goes back to Ducos Duhauron as well (1897). In 1904 Lumiére devised the colour grain screen, which was used in the 'Autochrome' plate.

Berthon's lenticular screen followed in 1908 and G A Smith exhibited Kinemacolor at the Royal Society of Arts in December 1908. The principle of colour formation during development had been discovered as early as 1912 by Fischer, and that of the silver-dye-bleach process by Schweitzer in 1914. Other significant steps on the way to modern colour film were H W Vogel's discovery of optical sensitization in 1873 and Hannibal Goodwin's invention of celluloid film in 1887.

Already in 1862 Ducos Duhauron had conceived the first camera for taking colour photographs. It was a beam-

splitting camera. In such a camera the light from the subject is split into three beams by semi-reflecting and semi-transparent mirrors. The beams are separately recorded as black-and-white negative images on three films behind three filters, blue, green and red. Positives are produced by printing these negatives. The colour image is obtained by projecting the three positives in superimposition on the screen using three projectors behind the same filters used in exposure.

The division of the light entering the camera into separate rays may also be achieved by ranging the filters in front of the lens and taking photographs either simultaneously with three cameras on three films or consecutively with the same camera on one film. Difficulties arise when moving objects are photographed. It is easy for fringing to occur, either through spatial parallax when the photographs are taken simultaneously with several cameras or through time parallax when taken consecutively with the same camera behind different filters. Using the latter method Smith and Urban produced in 1908 the first colour film on normal film stock. The process was called Kinemacolor. It was a two-colour process, in which the part colour images were arranged alternately on one film. In the Francita three-colour process, using the same method of photography, the part colour images are partly side by side and partly one under another. These processes came no nearer to representing a fully practical method of producing colour films than did the lenticulated films produced by the additive process. They were all stages on a long road. The decisive breakthrough which made colour films a practical proposition came only with the introduction of the subtractive process in conjunction with colour-forming (chromogenic) development, and with the Technicolor process. Technicolor was first introduced as a two-colour process. Initially the photography for this process was by means of a beam-splitting camera.

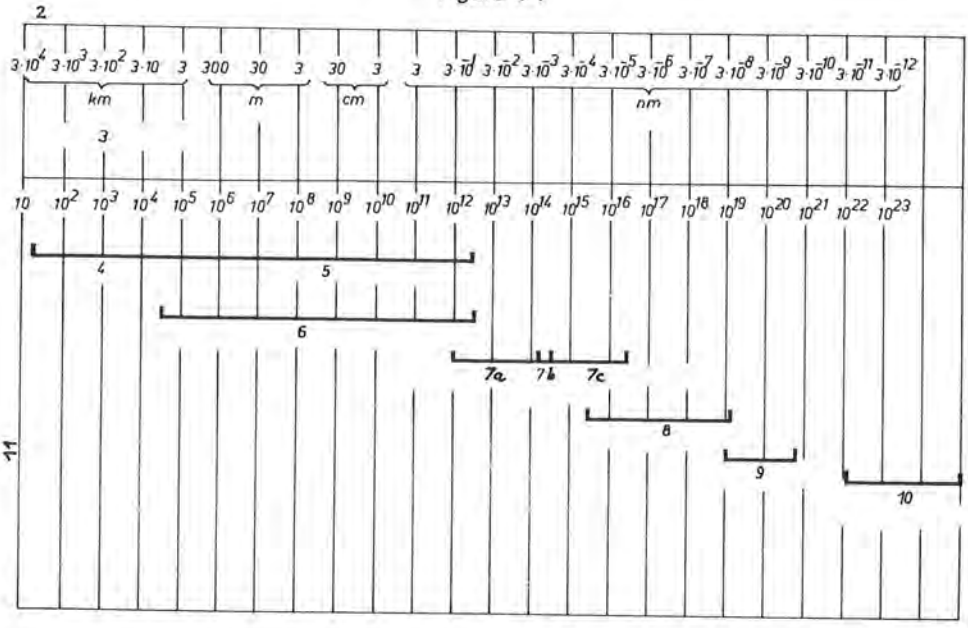
4.2 Optical principles of colour photography

All the photographic processes which were of any significance in the past and which have any significance today were, and are, based on the light-sensitivity of silver halides and the development of the latent image produced during exposure. The discovery of the principle of photography with light-sensitive silver salts goes back ultimately to the work of the Frenchman, Daguerre.

An important step in the realization of colour photography, apart from fundamentals of colour synthesis already mentioned, was the discovery of optical sensitization by H W Vogel (Germany, 1873). Only by developing his discovery was it possible to produce three photographic silver halide emulsions each sensitive to a different area of the spectrum of visible light.

A short explanation of the nature of light and of colour sensitivity will help towards a better understanding of the various colour photographic processes in practical use.

Figure 4-1

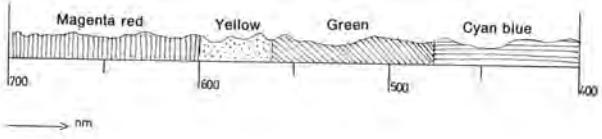


Electromagnetic vibrations.

2 Wavelength.
3 Frequency in Hertz.
4 Low frequencies.
5 High frequencies.
6 Long, medium, short, ultra-short waves.
7 Infra-red, visible, ultra-violet light.
8 X-rays.
9 γ-rays.
10 Secondary cosmic radiation.
11 Electric vibrations.

Figure 4-2





4.2.1 Light

Light can be thought of as visible energy. The forms of energy we can see are electromagnetic rays. They have the characteristics of wave motion. Waves are characterized among other things by their wavelength. The wavelengths over the entire scale of electromagnetic radiant energy vary by many powers of ten, from less than a millionth of a millimetre to lengths measured in kilometres, i.e. from gamma rays, X-rays and cosmic rays to radio waves. Within this overall range visible light occupies only a very narrow band, with wavelengths from 0.0004 - 0.0007 millimetres (mm) or 400 - 700 millimicrons (mμ) or 400 - 700 nanometres (nm; 1 nm = 10^{-9} m). The visible range is therefore extremely narrow in comparison with the entire range of electromagnetic radiation; only this tiny portion is detected by our eyes, only these rays do we see. (Refer Figure 4.1)

The visual impression we receive depends on which part of this visible radiation reaches our eyes. If it is all the wavelengths from 400 - 700 nm then we register the impression of 'white light', whereas a beam of light which consists essentially of one or of several neighbouring wavelengths appears to us as coloured light. The short wavelengths in the visible range produce the impression of 'violet' and 'blue', while long wavelengths are associated with the impression of 'orange' or 'red'. The middle range of wavelengths produce the impression of 'green'. Outside the visible range lie the even longer infrared wavelengths and the still shorter wavelengths of ultraviolet radiation. Although not visible to the human eye they can still affect a photographic emulsion.

The colour and the intensity of a beam of light depends on its origin. The most conspicuous light source is the sun. The energy for its light derives from nuclear reactions taking place in its core. This light forms part of a very broad scale of solar radiation which includes the invisible infrared, ultra violet and other rays.

4.2.2 The spectrum

One method of splitting white light into its component rays is to pass it through a prism where it is broken up into a rainbow-coloured band, the spectrum. If this experiment is carried out under proper conditions it is possible to identify more than a thousand different colours, their appearance determined by the continuously changing wavelength. For the sake of practical discussions it is usual to ignore these fine variations and divide the spectrum into three main bands - blue, green and red - with the secondary bands, violet, blue-green, yellow and orange (see Figure 4.2).

A beam of white light is broken up into its component rays because the degree of deflection which a ray of light undergoes when it strikes a glass surface at a given angle

varies according to the wavelength of the ray. Violet rays, which have the shortest wavelength in the visible range, are deflected the most while red rays, with the longest wavelength, are deflected least. If the dispersed rays are passed through a second prism so constructed as to bring them back together again, then white light is formed once more and the impression of colour vanishes. It is clear from this that the eye is no analytical instrument; it is not capable of recognizing the composite nature of the white light which it sees.

A light source such as the sun contains all wavelengths between 400 and 700 nm in its spectrum. The mixture of light of these wavelengths or colours gives rise to the impression we call white.

Most artificial light sources, such as incandescent gas mantles, tungsten filament lamps and flashbulbs, also produce a light approximating to white, with a continuous spectrum, though the energy distribution in the spectrum of incandescent light sources can differ markedly from that of sunlight.

Gas discharge lamps also normally give out a mixture of rays of different wavelengths. In these cases, however, the spectrum is not continuous but consists of certain well-defined wavelengths characteristic of the gas in the tubes, while some of the other wavelengths from the spectrum are missing. Some gas discharge lamps emit light which consists of a considerable number of wavelengths whereas others, such as the sodium lamp for example, emit light consisting of a narrow band of wavelengths. The resulting light may appear to the eye as white or coloured.

Finally, certain substances can transform invisible short-wave radiation into visible light of longer wavelength. This phenomenon, known as fluorescence, is used among other things in fluorescent discharge lamps, where a special coating on the inside of the bulb absorbs invisible ultraviolet radiation and emits its energy as visible light. Another example of its application is the x-ray fluorescence screen.

Incandescent lamps emit light with a continuous spectrum of rays which is registered as white by our eyes, as long as there is no possibility of a direct comparison, as for example with bright sunlight. If however, we are able to make this comparison, we find that the white light from different light sources is never the same; it may range from distinctly reddish or yellowish to perceptibly blue. If the sunlight is blocked out as a source of comparison, then after a while our eyes perceive the light from an artificial light source as white again. Colour film on the other hand registers very minutely the differences between sunlight and light from artificial sources. To obtain the best results with both light sources and correct colour reproduction it is necessary to balance colour films for either daylight or artificial light, or to filter the light entering the camera, as for example when a film balanced for artificial light is to be exposed with daylight.

4.2.3 Colour temperature

One generally accepted criterion by which it is possible to specify the composition of white light is its 'colour temperature'. It rests on two assumptions:

a) that the light source in question emits a continuous spectrum of all visible wavelengths

b) that the relationships of short - and long-wave radiation from such a source alter gradually as the temperature of the light source rises.

This assumption is roughly correct for incandescent light sources. The simplest example is a poker glowing in the fire. As it is heated it begins to glow, at first faintly, then brighter and whiter the hotter it gets. The radiation emitted becomes stronger and of shorter wavelengths. The colour of the light emitted by the glowing body does not depend so much on the material as on its temperature.

What then is the connection between the concept of 'colour temperature' and the light source, the light emitted, and its spectral composition? From the example quoted we see that the spectral composition of white light from a light source depends on the temperature of that source. To specify the whiteness of the light physicists use the 'black body', so defined that it obeys a mathematical relationship between temperature and the distribution of the radiation emitted. A black body emits only radiation which corresponds to its temperature, it does not reflect any light which strikes it. Using a black body the energy distribution of emitted light can be determined, for each temperature. This temperature is called the 'colour temperature' of the light reaching us.

The colour temperature of the light from a light source in practice, such as daylight or an incandescent lamp, is the temperature at which a black body emits radiation with the same spectral distribution in the visible range, and of the same colour.

Colour temperature is measured on the absolute Kelvin scale which has steps of the same intervals as the Celsius scale. The Kelvin scale begins at absolute zero, minus 273° C.

With light sources such as the incandescent filament lamp the colour temperature rises with the temperature of the filament, but the two temperatures are not the same.

Colour films are balanced for the light in which they are intended to be used. In general films are manufactured for daylight and for artificial light. Daylight films are generally balanced to 5500-6000° K and artificial light films to 3100-3500°K. For cinematography only artificial light film is used, for daylight filming conversion filters are placed in front of the camera, which adjust the colour temperature of daylight to that of artificial light before

it reaches the sensitive film.

4.2.4 The eye and colour vision

The physicist can define colour objectively. He can describe it in terms of wavelength and in the form of radiant energy.

To see a colour though is not the same as measuring it. When we see a colour we receive a physiological and psychological impression. A large part of the process of colour vision takes place between the instant the ray of light reaches the eye and the instant when we register it as an optical stimulus. We do not know precisely what really takes place as we still have no way of comparing the strengths of visual stimuli in different people.

Philosophers have argued for centuries about the nature of colour. Today we know rather more about how impressions of colour are influenced by physiological factors, but we still know very little about their nature.

Accordingly we are obliged to make a whole set of assumptions about the visual process and relate them as best we can to what we know about the physical nature of colour.

4.2.4.1 The eye

Our sensory organ for visual perception is both an optical instrument and the seat of complex biochemical and biophysical reactions.

Essentially the eye consists of a lens which forms the image, and a receptive surface for that image, the retina. The focal length of the eye's lens can be altered by muscles which change the curvature of the surface, so that objects at varying distances may be brought into focus. In front of the lens is the iris, controlled by a group of involuntary muscles which affect the relative aperture of the lens.

The image-sensitive part of the eye, corresponding to the light-sensitive emulsion in the camera, is the retina. Its surface is composed of two types of sensitive elements, formed like rods and cones. There are about seven million such elements in each eye. The rods, clustered more towards the edge of the retina are more sensitive to light than are the cones but not apparently colour sensitive. Because of their relatively large surface the rods can register an image of lower intensity. In the centre of the retina lies the fovea, where the cones are concentrated, each one connected to the brain by its individual nerve fibre. This is the area where vision is sharpest and colour is perceived.

4.2.4.2 The Young-Helmholtz theory

As early as 1801 Thomas Young established that the mixing of coloured light produces the impression of new shades of colour. By way of explanation he assumed that the eye contains three types of colour receptor, sensitive to red, green and blue light respectively. The varying strengths of

stimulation given to these receptors produces the widest variety of colour impressions.

If for example we look at a spectrum and let our eye drift from the blue region to the green and then the red, we can assume that the colour impression changes gradually with the change in the relative degree of stimulation given to the blue, green and red receptor mechanisms. Yellow, for example, stimulates the red and green receptors with equal strength, while white light, containing the entire range of spectral colours, stimulates all three.

Young's theory was later developed by Helmholtz. He postulated that the eye unconsciously analyses the composite radiation reflected by a coloured body. It divides the radiation into three intensities of stimulation. These relative intensities depend on the proportions of radiation in the blue, green and red sectors of the spectrum. The relative degrees to which the receptors are stimulated are interpreted as colour by the brain.

The three different types of receptors which were postulated have only recently been actually isolated. The hypothesis of three receptors is a most useful model, which explains more or less everything about colour as far as the photographer is concerned.

4.2.4.3 Primary and complementary colours

The three main spectral bands which have been considered so far in the mixing of colours - red, green and blue - are also known as primary additive colours, or for short, primary colours. If used as filters they each allow about one third of the spectrum to pass through. In as far as the sensitivity of the receptors in the eye is referred to, it is a matter of the wavelengths of the maximum transparency. In theory it should be possible to mix any colour by projecting the pure spectral colours red, green and blue onto a screen in differing intensities but this is not quite so. What we regard as primary colours therefore correspond in nature, not always with the necessary purity, to three special colours in the spectrum.

We have already established that by blending two of these primary colours (e.g. red and green) the impression of a third colour may be produced, namely yellow. This yellow therefore contains two thirds of the spectral range (from green to red) and is basically different from spectral yellow, which occupies a narrow spectral band only. The combination of green and blue light produces a wide-band blue-green, also called cyan, which differs from spectral blue-green in its energy distribution though not necessarily in its visual appearance. Finally, red and blue produce a range of hues from magenta to purple, none of which has a spectral equivalent.

These 'wide-band colours' - yellow, cyan, magenta - are also known as subtractive or complementary primary colours. The term 'complementary' stems from the fact that the

combination of one such 'wide-band colour' with the missing primary colour will produce white again (e.g. a beam of white light projected through a yellow filter plus one through a blue filter). Yellow is therefore complementary to blue, cyan to primary red, and magenta to primary green.

Any two of these complementary dyes or filters in superimposition allow to pass through only the light of the one primary colour which is common to both, so for example, yellow and cyan together produce the impression of a green dye or filter. That is the function of complementary dyes in a subtractive colour transparency. Yellow, cyan and magenta are the basic dyes used in subtractive colour films, hence the term 'subtractive primary colours'.

4.2.4.4 Colour sensation, brightness and colour adaptation

Colour may be specified in terms of three variables: hue, saturation and brightness, of which hue is to be regarded as the chief characteristic of colour. These concepts are subjective ones, that is, they help to define colour as it is seen. The corresponding objective criteria are essentially wavelength, purity and light intensity. When a colour is looked at, its brightness depends very much on the prevailing conditions, as the eyes vary greatly according to the level of illumination. Consequently, it is difficult to distinguish between illumination levels even when they differ by more than a hundred-fold for example, if reference points are not present nor direct comparisons possible. So for example, in a large well-lit room the great difference between artificial light and daylight can only be made obvious if both light sources can be directly compared by switching on and off in daylight. There is also no noticeable difference in the apparent colour of a painting, whether we view it from a close or distant standpoint. The same applies to colour transparencies which are illuminated with light of differing strengths. This is because the eye uses the surroundings or parts of a picture as a reference point for each individual colour.

One of the eye's most remarkable characteristics is its ability to adapt to many different levels of illumination. By varying the size of the iris the proportion of light energy falling on the retina can be varied by the eye's adaptation to brightness.

This variation in sensitivity covers a wide range of illumination levels to which the eye, unlike photographic emulsion, responds almost immediately. Such adaptability is valuable, it permits us to see under widely differing conditions, but it does cause difficulties for example in judging the actual light intensity as when determining lighting for photography. Not only does the eye adapt to the average level of illumination, but also it tries to alter its colour sensitivity so that the illumination appears colourless, that is, it tends to see the prevailing illumination as normal, in other words as 'white', and to judge colours in comparison.

In general we regard daylight as normal and in comparison artificial light appears yellowish. But if we remain for a short while in a room illuminated by lamplight the surrounding light appears white to us. The less the prevailing light differs from the normally accepted standard, the quicker we adapt to it. But even the view through a pair of tinted sunglasses appears normal after a few minutes.

4.3 The principles of colour photography

Nearly all colour photographic processes which have been devised have had two aims. The first is to imitate the colour analytical function of the eye, that is, to divide by photographic means the total light radiating from an object into intensities of stimulation in the three regions, red, green and blue, into which the spectrum is divided.

The second aim is to present these intensities to the eye as visual impressions of red, green and blue. There are two main methods: additive synthesis, the first method by which colour photographs were produced, and subtractive synthesis, which is the basis of all present day commercial colour processes.

4.3.1 Additive synthesis

Clark Maxwell investigated the production and blending of colours by the combination of coloured light. He was able to show that the way in which the eye's trichromatic receptors unconsciously carry out colour analysis could be repeated photographically if three photographic plates were to be exposed behind corresponding colour filters.

To demonstrate how this works, let us take a simple subject, namely red and yellow flowers with green foliage and a blue and white background. The red flowers appear red because they absorb all the rays from any white light which strikes them, except for those which produce the sensation of red - these they reflect towards the eye. If we look at the red flowers through a red glass (red filter), the red light will continue to reach our eyes because red rays pass through the red glass. If we replace the eye with a panchromatic sensitized film we can record the intensity of this red light and by developing change it into an equivalent silver density. This produces a negative image which is dark in those areas where red rays were registered. However, the green rays reflected by the green leaves are absorbed by the red filter, and in these areas the negative is transparent. The same occurs with the blue of the background. The yellow flowers appear yellow because they reflect both the red and green rays, the green rays are retained by the red filter, but not the red rays. The exposed film behind the red filter, when developed, will register yellow as a silver image of lesser density.

The red rays need not therefore necessarily come from a red object but may form part of the radiation reflected by an object of a different colour (e.g. the yellow flowers, or

the white background which reflects white light, containing the entire spectrum).

A second negative exposed through a green filter yields a silver image in all areas where the subject reflects green light. In our example namely the green leaves, the yellow flowers (red and green) and all the white parts, but not the blue of the background.

On a third negative exposed through a blue filter only the blue and white background will be reproduced as a silver image.

As each filter allows approximately one third of the visible spectrum to pass through, with their aid we have analysed and recorded as varying silver densities the proportions of red, green and blue in the light reflected by the subject.

The next step is to make positives from the three separation negatives. If we project the positive from the red separation negative with a red light onto a screen, then the red light will pass through the transparent parts of the positive to reach the screen and these correspond to the parts of the picture where the red third of the spectrum was recorded on the negative. We will therefore see a red image of the red and yellow flowers and of the white parts of the background.

Next we make a positive from the green separation negative and project it with green light onto the same screen, using a second projector. If we project the two images one over the other in exact register, the image of the green leaves appears in the correct place. Green light passes through the areas of the yellow flowers as well, superimposition over the red image of the flowers produces yellow. The red, green and yellow colours of the original are now correctly reproduced. The blue areas are still black and the white ones, receiving red and green light, are yellow.

To complete the picture the positive from the blue separation negative is projected with blue light in register with the two others. The blue light from this positive yields not only the missing blue of the background, but also makes up to white the yellow (from green and red) of the white background, which is of course a mixture of equal proportions of red, green and blue light (see Figure 4.3).

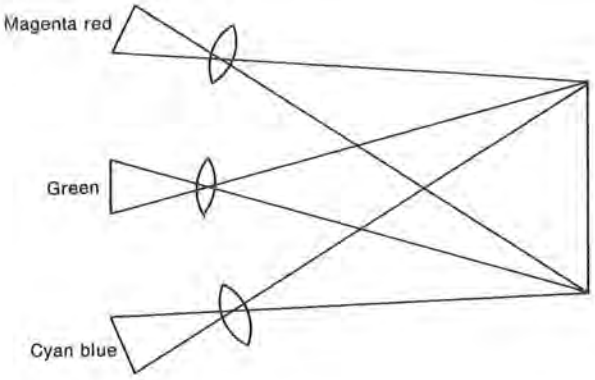
That is colour photography by additive synthesis, so called because the image is produced by addition of light of different colours on a screen which is initially dark.

4.3.2 Subtractive colour synthesis

Although the earliest colour photographic processes used the principle of additive colour synthesis, they proved in practice to be impractical. Present day colour processes use an alternative method; subtractive colour synthesis.

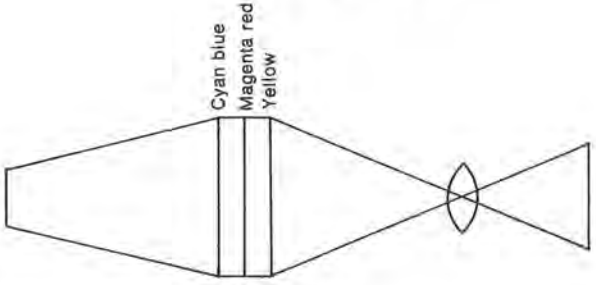
To understand how this works let us turn once more to the additive process.

Figure 4-3



Schematic representation of an additive colour process.
By way of three coloured light sources (blue, green and red) three black-and-white transparencies produced from the corresponding red, green and blue separations, are projected in superimposition.

Figure 4-4



Schematic representation of a subtractive colour process
A single light source illuminates three positive partial images, placed one behind the other. The complete picture is constructed from a Cyan-toned red record, a magenta-toned green record and a yellow-toned blue record.

In the additive process the positives made from the separation negatives are transparent in those places where silver is deposited in the negative following exposure through one of the filters, while other parts of the positive show a silver deposit of greater or lesser density. When projection takes place behind the appropriate colour filter the transparent areas allow the light to pass through entirely, whereas those areas with a silver deposit allow less through, depending on the density of the deposit. The silver therefore serves to regulate the red, green and blue light when the corresponding colour separation positives are projected.

However, instead of silver in the positives one can equally well use a dye which absorbs the light from a particular third of the spectrum. For the red filter positive such a dye would be a cyan one, which absorbs red light and allows green and blue light to pass through freely. It therefore regulates the proportion of red light during projection. A magenta dye acts in similar fashion in the positive made from the green filter negative, absorbing green light and allowing red and blue to pass through.

Finally, the silver image in the positive from the blue filter separation can be replaced by a yellow dye which absorbs blue.

If these three dye images, instead of the silver images, are projected from three projectors, each through its respective red, green or blue filter, the same effect will be produced as using the silver images.

If however, instead of the silver images we have three positives which have dye in place of the silver, we can go a step further. By superimposing the positives in register and projecting them with white light using a single projector we can dispense with the red, green and blue filters.

Let us consider how this principle works, remembering the example of the red and yellow flowers with green foliage in front of a blue and white background. The red flowers form silver in the red separation negative. In the positive no cyan dye is formed in these areas. In the other separation negatives the red flowers are not registered, so in the positive, magenta and yellow dyes are formed. In superimposition the three positive images absorb green and blue light in this area and allow red to pass through. The flowers again appear red.

The yellow flowers are registered by the red and green filter negatives. In the print therefore neither cyan nor magenta dye is formed. As no silver is deposited in the blue filter negative, yellow dye forms in the positive. In superimposition the three positives absorb blue light in this area and allow green and red through, which blend to form yellow.

The green leaves produce no magenta dye in the positive, but

yellow in the blue sensitive layer and cyan in the red sensitive layer. In superimposition, yellow and cyan absorb blue and red and allow green light to pass through.

The blue areas are registered as magenta and cyan positive images. Magenta and cyan absorb green and red, allowing only blue to pass through. Finally white is registered in all three negatives, the positives are colourless and white light reaches the screen.

At first sight subtractive colour synthesis appears to be very different from additive synthesis, but in fact the difference exists only in the use of the colour combinations and not in principle. (see Figure 4.4).

4.3.3 Additive colour photography

Maxwell's original method of producing colour pictures was too unwieldy in practice. But in 1868 Ducos Duhauron showed that the three records needed for additive process could be made on one plate if it was covered with red, green and blue filters of microscopic size.

In the first commercially successful process of this type, Lumiere's Autochrome plate, this mosaic is composed of red, green and blue coloured starch grains. Later systems used regular geometric mosaic screens (reseaus) produced by a photo-mechanical printing process.

The screen is covered with a panchromatic emulsion equally sensitive to all three spectral areas. During exposure in the camera the light must first of all pass through the screen, where it is divided into the three spectral areas, red, green and blue. The light from each spectral area reaches the light-sensitive emulsion only through the corresponding screen elements, while being absorbed by the two other differently coloured elements. Red light for example only reaches the emulsion through the red screen elements and is absorbed by the blue and green ones. A negative silver image results. This is developed and then the negative image is bleached and a positive image, produced by fogging development, which in our example, is clear behind the red screen elements and black behind the blue and green ones.

When the transparency is projected only the red filter elements allow the red components of the light to pass through, while the silver deposited behind the green and blue elements obscures the light. For the same reasons green and blue objects leave transparent areas in the finished transparency behind green and blue filter elements.

The additive colour screen system may be used not only in the reversal process but in the negative-positive process as well. In the latter case the negative image is printed onto another additive screen film. The screen elements in the image projected onto the picture screen lie close to one another, but under normal viewing conditions cannot be individually seen. However, if the image is enlarged the

screen structure becomes noticeable in a distracting way, more so with pictures produced by the negative-positive process than with reversal images.

To maintain a screen image of a given brightness, three to five times as much projection light is required as for a corresponding subtractive transparency, because each additive filter element absorbs two thirds of the spectrum. This does not apply to colour television where the screen elements themselves emit light.

Additive colour reproduction is used in modern colour television systems. The inside of the television tube carries a screen of red, green and blue phosphor dots, which form the fluorescent picture screen. The light from the original scene is divided into the three colour components which are received on three picture tubes by appropriate beam-splitting and filter systems. The signals from these tubes modulate three electron beams in the television receiver in such a way that each beam affects the screen element of one colour. Ultimately the picture screen shows simultaneously a red, green and blue image, these images are interwoven in the screen raster, so that their colour elements appear in close proximity.

Additive screen processes are no longer employed in the area of colour film materials having been replaced by subtractive colour systems.

4.3.4 The subtractive colour process

Current commercial methods of colour photography are all based upon one of the three following main processes:

a) The imbibition process: a mechanical assembly of individual positives, based upon printing-type processes from part-images. These are derived from colour separation negatives and are printed successively in superimposition onto a single support. Cyan, magenta and yellow dyestuffs are used. The matrices may be printed from separation negatives made in a beam-splitter camera, or from colour negatives. In cinematography it is essentially the Technicolor process which is of interest. The production of these positives involves a great deal of work and demands very strict control but it is most economical for long runs of colour prints.

b) Colour reversal materials in which the three separate colour images are produced on three correspondingly sensitized emulsion layers on one base. The negative images are transformed *in situ* into colour positive images. This can be done by a relatively simple series of steps, and reversal film produces in this way a positive image on the film that is exposed in the camera.

c) The colour negative-positive process which involves separate stages and separate materials for the production of colour negative and colour positive images. In the colour negative the three images are produced in three individually

sensitized emulsion layers on one base. The silver images are transformed into dye images. These are in the complementary colours to the colours of the subject and to the sensitivity areas of the emulsion layers, namely cyan to red, magenta to green and yellow to blue. The colour negative is used to produce positive colour prints on paper or film. The colour positive materials are likewise multi-layered materials with three differently sensitized emulsion layers, which record the blue, green and red components of the light coming from the colour negative. Three images in complementary colours to the sensitivity areas are produced simultaneously with the three silver images. The silver is bleached out leaving purely dye images.

4.3.4.1 Separation negatives and the Technicolor system

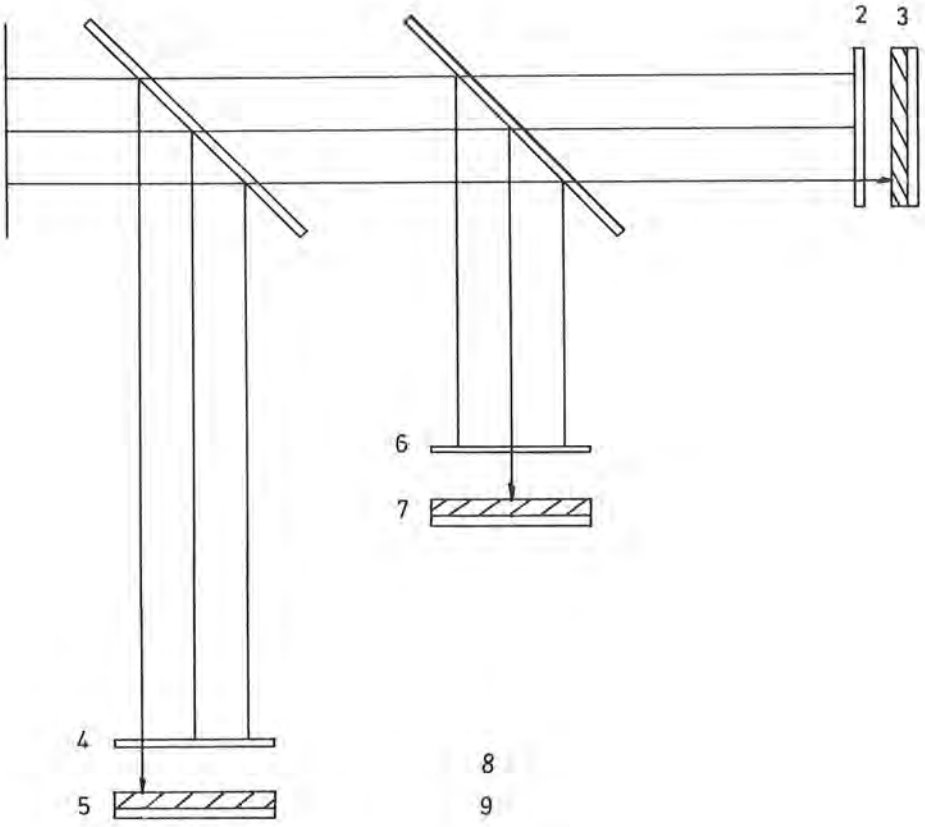
The system of separation negatives and the combination of three separate colour images prevailed for many years in professional colour still photography. It consists first of all of producing individual separation negatives by exposure behind red, green and blue filters, i.e. dividing the light from the subject into its red, green and blue components and recording them separately. In all colour systems the first step is such a division into the three primary colours. The production of three separate colour negatives was for decades a feature of the graphic industry's various processes. From these separation negatives are made separation positives toned in the subtractive primary colours which transfer yellow, magenta and cyan colour print images onto paper or film.

If the photographs are inanimate pictures of stationary objects, the three separation negatives can be made in a normal camera by consecutive exposures. However, if colour photographs of moving subjects are to be taken, methods must be used whereby all three negatives are produced simultaneously. Nowadays, we use multi-layered colour films for this purpose. Before these became popular, cameras with beam-splitting systems were used, in which the light was split up into three beams and recorded through filters on three separate films. Two semitransparent mirrors in the optical light path reflect parts of the light onto a film or plate which registers the blue element behind a blue filter, and parts onto a film which registers the red element behind a red filter. The rest of the light falls onto a third film or plate behind a green filter (see Figure 4.5).

In the Technicolor process the records were originally made on separation negatives and the positives dyed as gelatin reliefs using subtractive colours, the dyes being then transferred in register onto a special positive final print film.

The advantage of this process is that in photomechanical work using a single set of printing plates many thousands of prints can be produced at high speed. This is made possible by the mechanical way in which superimposed printing takes place. In the same way one of the advantages of the Technicolor process lies in the economical manufacture of a

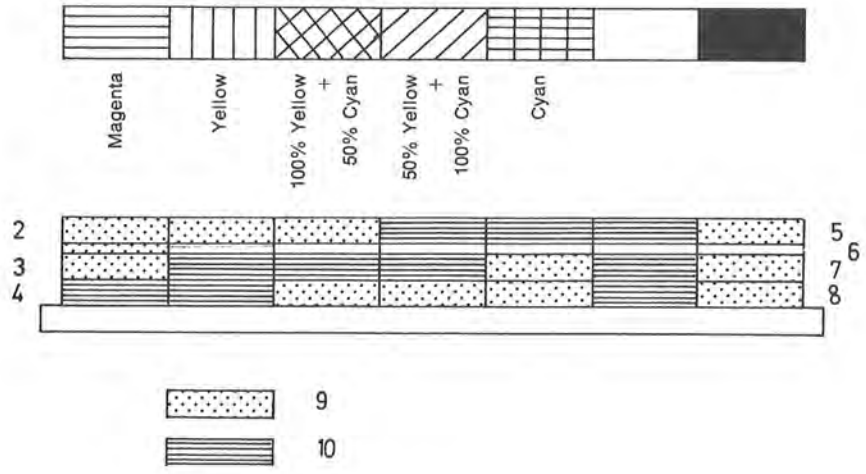
Figure 4-5



The arrangement of a beam splitter for the simultaneous production of the three separations.

2 Semitransparent mirrors.
3 Green filter.
4 Green separation.
5 Red filter.
6 Red separation.
7 Blue filter.
8 Blue separation.
9 The light beam coming from the lens is partly reflected at two semi-transparent mirrors and the corresponding separations are produced from the three beams with the aid of red, green and blue filters. These devices serve to avoid both time and space parallax during photography.

Figure 4-7



Schematic representation of a multilayer film.
(The various emulsion layers are firmly adherent to the film base)

1 Original.
2 Blue-sensitive.
3 Green-sensitive.
4 Red-sensitive.
5 Yellow dye.
6 Yellow filter.
7 Magenta dye.
8 Cyan dye.
9 Silver halide.
10 Latent image.

large number of colour positives.

4.3.4.2 Integral tripack films

The colour films currently used in cinematography are multi-layered films with three individually sensitized emulsion layers on one base (see Figure 4.7). The following, briefly, are its main uses:

a) Colour reversal film

a.a) Colour reversal film produces a positive colour image directly. Reversal films are balanced for daylight or artificial light photography.

a.b) Colour reversal copying film is used for producing colour copies from colour reversal originals.

Colour reversal films are used in cinematography particularly in narrow gauge formats (16 mm, 8 mm) for actuality work and as transmission copies for colour television.

b) Colour negative-positive process

b.a) Colour negative film produces a colour negative image in complementary colours and is balanced for artificial light. Daylight filming is done with a conversion filter.

b.b) Colour positive film is used in the production of cinema projection prints. Prints direct from colour negative are of high quality but must be produced in small quantities only because of the danger of damage to the original colour negative which is unique and therefore precious. Hence the intermediate stage via duplicate negatives.

b.c) Colour duplicate films

b.c.a) Intermediate film is a special film for producing colour dupe negatives.

* using intermediate film the production of duplicates takes place in two stages

- the first stage yields a low contrast positive which often has an overall orange cast. It is therefore not suitable for projection

- the second stage produces the duplicate negative by re-copying the positive from stage one onto intermediate film. In its essential parameters this negative corresponds to the original negative. As many duplicate negatives as are required can be produced in this way.

b.c.b) Reversal dupe negative film is a low-contrast colour reversal film. It produces directly a duplicate negative corresponding in its essential parameters to the original negative.

The scope of this chapter does not allow a discussion of the special problems which may arise when making duplicate negatives through one of these processes. Nor yet can we deal here with the range of specialized techniques and processes which have been developed to solve certain special problems.

4.3.5 The quality of colour reproduction

The description which we have given so far of additive and subtractive systems is a simplified and idealized account of what takes place during colour analysis and synthesis. In practice the use of three colours in the analysis and synthesis of colours in the original has certain limitations, especially with regard to accurate colour reproduction. The limitation stems, among other things, from:

a) the characteristic of the dyes used during the process and in the final picture;

b) the characteristics of the system used to analyse the colours of the original object, and to modulate the colours during reproduction;

c) the fundamental difficulties of obtaining a good colour balance using primary colours.

The limitations do not invalidate the principles of colour reproduction through the various processes nor prevent colour photographers from producing perfectly acceptable colour pictures if they keep to the processes recommended by the manufacturers. Methods of improving colour reproduction involve highly developed processes of colour control and correction, but are more of an elaboration than a modification of the principles of colour reproduction.

So much for the basic facts and their implications for trichromatic photography. The facts can be demonstrated, though their application does not automatically lead to good colour pictures. Many compromises are necessary because of inherent difficulties in the process and the shortcomings of the materials used, the methods of operation and handling, and mistakes on the part of the photographer.

There are several differences in the way in which good quality images are produced in colour photography and black-and-white photography. Some differences are fundamental ones, dictated by the necessity of taking colour balance and correction into account, while others derive from the ample opportunity for error that exists in colour reproduction.

If for the moment we ignore the limitations placed on the colour process by the imperfections of the materials used,

then we can assert that the basic difference between the production of black-and-white and colour images is that to obtain a black-and-white picture of a given density and contrast from a given negative, the copying process has to be undertaken once, whereas to achieve a good colour picture from a given negative, three primary colours must be matched both in density and contrast when processing colour films.

The opportunities for error are naturally much greater. It is surprising, for one thing, the extent to which the brightness of a black-and-white print can be varied without the results becoming obvious, whereas even slight variations in the density of one of the three component parts of a colour picture will produce considerable differences. This is because the eye is much more sensitive to differences of colour than to those of brightness.

If for example, we are faced with a black-and-white print which is too bright, a 50% increase in the exposure is required to achieve a noticeable difference in density.

A 10% variation in brightness stays practically unnoticed in a normal black-and-white print, while on the other hand 10% unwanted blue absorption can ruin a colour portrait by changing the delicate flesh tone into a yellowish corpse-like colour.

Every colour system must therefore allow for precise control at each stage to prevent errors of more than 5% in the colour balance of the finished print. This is a fundamental difficulty and, because of it, factors which can be overlooked in black-and-white work are of great significance in colour processing.

This makes it sound as if everyone should be frightened of colour photography but the manufacturers of modern colour films maintain that colour pictures can be produced almost as easily as black-and-white ones. That may sound paradoxical but behind it lies a great deal of automation and a long succession of compromises.

The production of a good colour print through the process of colour analysis and recomposition depends on the co-ordinating of many individual factors which generally allow little latitude for error. Yet, using this technique, experts in their laboratories have achieved results of the highest quality.

On the other hand modern colour films, and especially reversal films, have most of these controls built in. The characteristics of the individual emulsion layers determine to a large extent the quality of the end product. The majority of these films are processed either by the manufacturers themselves or by specially equipped processing laboratories. That relieves the photographer of numerous worries and ensures that permitted errors are kept within definite limits. The photographer has often merely to make sure the exposure and light composition are correct to achieve satisfactory results. Improvements in colour

faithfulness are subject to the 'law of diminishing returns'. Successive improvements are only possible at the expense of an inordinate expenditure in the construction of manufacturing and processing control. Beyond a certain point this makes a colour process totally uneconomic to use. To a certain extent cameramen and printing laboratories exert individually and together some control over the individual stages. The special requirements of any particular film material must be known and duly observed.

4.4 Colour development

By the action of radiant energy in the form of short-wave light certain high-energy conversions take place in the crystal assembly of the silver halide crystals. Thus is created, the so-called "latent" image which externally is not visible. Weak reducing agents, however, are able to reduce this activated silver halide under an enormous intensification of the effect and precipitation of metallic silver proportionally to the incident luminous energy. Silver halides intrinsically respond only to the short-wave rays of visible light and partly to certain ranges of ultraviolet light. However, chemical sensitizing agents also render them sensitive to other spectral ranges, even to infrared light.

The photographic developer is itself oxidized in the process of developing. From well-known developing agents such as hydroquinone or aminophenol, a quinonoid substance is produced as the final product of oxidation which reacts with sodium sulphite contained in black-and-white developers in a larger quantity to give hydroquinone sulphonic acid. In the absence of sufficient sodium sulphite, the quinonoid oxides precipitate along with the silver and there results a so-called residual image, which may be made visible by re-converting the silver into a silver salt by means of a mild oxidizing agent such as potassium ferricyanide, in the presence of bromide, and then fixing it out. A particularly strong yellow image is obtained when pyrocatechol without sulphate is used as the developer.

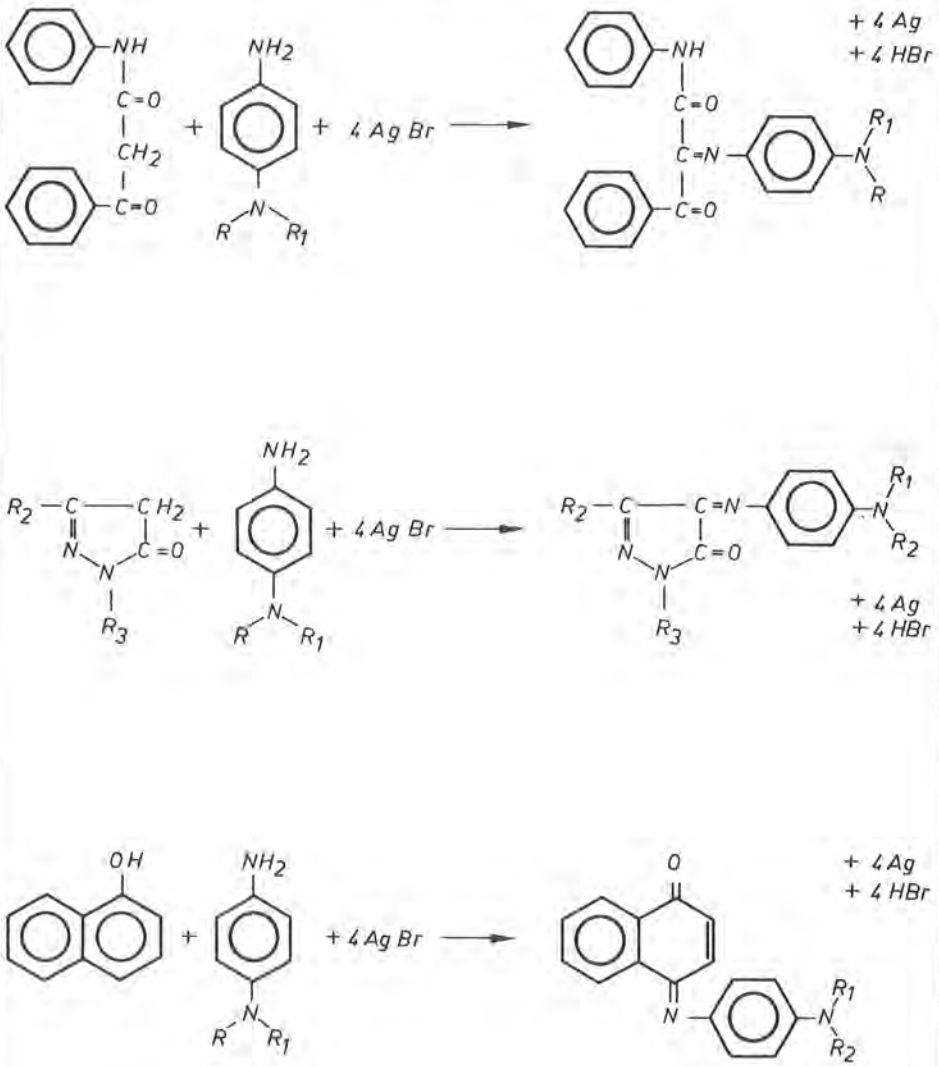
In 1907 Homolka discovered that certain dye-intermediate products - particularly those which lead to indigoid dyes - induce development of exposed silver bromide, while, in addition to the developed silver, there is also deposited a water-insoluble dye.

Such developing agents are indoxyl or 3-oxythionaphthene. The precipitated dyes are indigo and thioindigo respectively.

However, there are further possibilities to utilize the oxides of the developer for dye production. Particularly the oxides of a p-phenylenediamine derivatives; and among them, above all, those of the asymmetric dialkyl derivatives react very readily with the corresponding components to give dyes.

In the alkaline environment of the colour developer, certain oxidation products of asymmetric dialkyl-p-phenylenediamines condense with compounds containing active methylene groups to

Figure 4-6



Chromogenic development

Schematic representation of the generation of the three subtractive primary colours yellow, magenta, cyan in colour developing.

R and R_1 mean subst. or unsubst. alkyl residues

R_2 and R_3 preferentially subst. or unsubst. alkyl or aryl residues.

give yellow to purple azomethines; with phenols or α-naphthols with free para position to the hydroxyl group they react to give blue to blue-green indigo-aniline dyes. Among these dyes are many which correspond well in their optical characteristics to the three subtractive primary colours, as described in section 4.3.2.

In 1909 Rudolf Fischer found that the same dyes also form in the photographic development when exposed silver halide is developed with a dialkyl-phenylenediamine in the presence of naphthols, phenols or together with active methylene. As a rule the dyes are insoluble in water and simultaneously precipitate with the reduced silver (see Figure 4.6).

Fischer used this process of chromogenic development to produce monochromatic paper pictures. However, as the principle of subtractive colour photography has been known since Ducos Duhauron, Fischer made the proposal in patent specifications in 1911 to put the different dye-forming agents for yellow, magenta and cyan into the corresponding layers of a multi-emulsion film and then to develop them together with a developer of the p-phenylenediamine series at which yellow, magenta and cyan pictures should originate in the three layers in a single development. Neither Fischer himself nor others who later worked according to these patents, succeeded in realizing the proposal since the diffusion of the dye-forming agents made it impossible to localize them in a given layer.

4.4.1 Diffusion: migration of molecules

Diffusion is a well-known process in the science of materials. Matter cannot be dispersed as finely as one likes without a fundamental change and one finally arrives at atoms as the smallest building blocks. Atoms form molecules which can be linked by inherent molecular forces to form a regular crystal assembly. If, however, these molecular forces are surmounted by supplying sufficient kinetic energy such as heat the crystals can be transferred into the liquid or gaseous state, whereas the free path lengths of the molecules are greater in the gases than in the liquids.

The crystal assembly can also be neutralized (dissolved) by the action of liquids. Then it may be observed that the substance disperses homogeneously into the entire liquid after some time even without the application of mechanical means such as agitation.

The same phenomenon can also be observed when two different solutions are mixed. Gases mix with each other in the same way. Moreover, molecules in gases emerge from liquids (evaporation) and gaseous molecules shift into liquids (condensation). All of these phenomena are based upon molecular motion which can be considered the cause of the diffusion, (i.e. the migration of molecules).

This migration generally cannot be prevented even if insoluble colloidal substances are used as partitions

between the liquids or solutions. Such colloids for example can have the form of cloudy stable suspensions of solid or liquid substances in water. They are also called suspensions or emulsions. With a suitable composition they can pass from the liquid state (sol) into a peculiar solid state (a gel). Such colloids exhibit behaviour similar to that of gelatin, from which the term 'gel' is derived.

The cohesion of the gels is ensured by the absorptive force of water. The absorptive components of the gel are called 'micelles'. Other molecules can migrate (diffuse) through the micelle space. It is therefore obvious that aqueous solution of crystalline substances such as salts, dyes etc. diffuse in a gelatin gel.

This diffusion in gelatin is the very reason why photography is possible because not only is the gelatin capable of retaining the larger water-insoluble silver halides in the emulsion, but also it permits the molecules of the developers and other treatment baths to reach the silver halide without any hindrance. On the other hand the gelatin can retain only large, water-insoluble particles. The dyes developing during the colour development therefore can be retained in the gelatin layer only if they are insoluble in water and form larger crystalline or amorphous structures. If the resulting dye is water-soluble, coloured pictures cannot be obtained because the dyes bleed even during development and during the subsequent treatment baths or during the intermediate washes.

All the colour-coupling agents known to Rudolf Fischer had water-soluble properties. Despite efforts lasting decades it was not found possible to reduce the diffusion of the couplers (by such means as reducing their solubility) to the degree required to meet the practical requirements of multi-layer colour films.

We have to take into account here that the individual layers of colour films have a thickness of only a few thousandths of a millimetre for optical, mechanical and other reasons and that therefore a very small diffusion width does not allow the separation of colours in certain layers and their concentration on certain spots. Furthermore, the colour coupling agents can be quite insoluble in water but dissolve readily in alkaline baths (e.g. the developer) due to their phenolic or enolic hydroxyl groups.

4.4.2 The Kodachrome process

Because it was impossible in the beginning to solve the diffusion problem, another process which became very important was elaborated by the two American amateurs, Mannes and Godowsky, and adopted by the Eastman Kodak Company. This process has become known as the Kodachrome process. It is operated solely as a reversal process and uses a multi-layer black-and-white film which is subjected to black-and-white developing after exposure. To produce the dyes of the picture, the colour coupling agents are dissolved in the colour developer. One colour developer is used for each primary colour, which contains a special colour coupler,

apart from the colour developing substance, depending on the layer for which it is to be used.

The principle of controlled penetration was applied in the original version, i.e. the whole film is developed in a dye-coupling cyan developer after the second exposure, then a bleaching bath is made to penetrate into the layers to such an extent that the silver formed and the picture dye (cyan) are bleached out in the two uppermost layers. During this process the silver is converted into a silver salt which can be developed. Then it is treated again by means of a colour developer which produces a magenta picture.

Then the uppermost of the two magenta layers is bleached out and treated with a developer in the same way, which produces a yellow component picture in the uppermost layer only. After dissolving out the entire silver, only the respective dye remains in the individual layers.

Although the production of a multi-colour dye picture by this process is very complex and requires a high accuracy during processing to obtain good results, these results indeed are remarkably good. Later the more complex method of controlled penetration was replaced by the simpler and safer controlled colour post-exposure.

Even today, because of certain advantages, amateur and professional Kodachrome materials are processed by this method. The process necessitates a great deal of experience and exactness and requires personnel of many years experience.

4.5 Diffusion-proof coupling agents

To solve this problem, two entirely different methods were developed in Wolfen and Rochester in the middle of the thirties. The aim had been to produce the three component colour pictures in the subtractive primary colours, yellow, magenta and cyan, according to the idea of Ducos Duhauron, in one developing cycle in three layers arranged one upon the other (see Figures 4.6 and 4.7).

4.5.1 Two different principles of solution

The process which has become known under the term Agfacolor uses colour coupling agents which are soluble in aqueous alkali, the molecule of which, however, is awkward in its structure to such an extent that diffusion is no longer possible in the micelle interspaces of the gelatin gel layer of the photographic emulsion. This was achieved by the introduction of a long alkyl residue into the molecule of the colour coupling agent. To place the colour coupling agents into the photographic emulsion they are dissolved in aqueous alkali and this solution is stirred into the photographic emulsion. Care must be taken to avoid failure, by precise adjustment of the pH value of the emulsion. At that time Agfa obtained a patent for the use of alkyl residues of 5 carbon atoms or more. Alkyl chains of 14 or more carbon atoms proved to be most favourable in practice.

A similar solution to the diffusion problem was not available to Eastman Kodak once these patent specifications became known. It found another solution very quickly - the oil coupling agent which is insoluble in water.

According to their process of diffusion-proofing of the colour coupling agents, hydrophobic (i.e. water insoluble) coupling agents were used and dissolved in high-boiling solvents which are not miscible with water at a high concentration partly by means of solubilizers. Then these coupling agent solutions were dispersed very finely in the photographic solution so that they were present in the emulsion in microscopically small droplets.

The two processes differ from each other in the form in which the colour coupling agents are present in the layer. The colour coupling agents which are soluble in water have a relatively uniform distribution in the layer as alkali salts in a quasi-soluble form, while the so-called 'oil coupling agents' soluble in the high-boiling solvents are not uniformly present in the emulsion but have the form of very finely distributed droplets.

Diffusion-proofing by these two processes was the basis of the manufacture of colour materials for cinematography for more than four decades.

4.5.2 Film material with diffusion-proof coupling agents before 1939.

The first colour material produced in Wolfen according to this principle with diffusion-proof colour coupling agents soluble in water was a reversible colour film. This film material was used on a large scale for the first time to produce the documentary film "Olympic Games 1936 in Berlin". For a long time this film was the only colour film produced by means of a reversible colour material. About 1950 the Ansco Corporation tried to introduce a colour reversal process for cine purposes but failed due to the difficulties of the system.

The negative-positive system which had been developed in Wolfen as early as 1938-39 was adopted immediately by the cine industry although it had clear defects with respect to the colour reproduction, due to the very imperfect optical properties of the picture dyes and as to sensitivity which clearly was inferior to that of the then black-and-white films. At first there were only two types of colour negative films - one intended for artificial light and one for daylight - and one type of colour positive film, the structure of which was similar to the description above. They differed from each other with respect to sensitivity, sensitization and partly as to the coupling agents and gradation. The two gradations were adjusted in such a manner that their product equalled 1.5 to 1.6. This so-called product gamma is also maintained nowadays.

4.5.3 First post-war developments (1945 - 1950)

With the expiration of Agfa's patents after the Second World War, many firms had the possibility of producing colour films themselves according to the Wolfen principle. In particular the firms Gevaert, Ferrania, Ansco, Ilford and the Japanese firms Fuji and Konishiroku employed the Wolfen principle, put their colour film onto the market and also made vigorous efforts in research. Research in the field of colour films was put on a broad basis in the USSR, too, and colour film materials were produced. It was soon recognized that the first colour coupling agents developed in Wolfen were inadequate in many respects. To mention just a few very important factors: they were partly the reason for considerable colour falsifications - especially with the negative-positive process, and they adversely affected the sensitivity of the emulsion layers. There were difficulties in producing the films, difficulties in the storage of the raw films, and last, but not least, the durability of the picture dyes left much to be desired from an archival point of view.

These and some other properties which can be influenced by colour coupling agents of different constitution caused intensive research in the field of colour coupling agents in connection with the properties of colour films.

As described above the structure of the first cine material produced in Wolfen is the classic layer structure of blue-sensitive, green-sensitive and red-sensitive emulsion layers from top to bottom with a yellow filter layer made of colloidal silver between the upper and middle emulsion layers. On the back of the film was added a green-dyed, alkali-soluble, anti-halation layer. In the beginning, the negative films were manufactured with a sensitivity of 13 DIN and a gamma of about 0.75. The positive was made with the appropriate gamma of about 2.4. This classical sequence of layers is still in use today, especially for colour negative films.

In 1949 this series was completed by a duplicating film which was developed by the reversal process and immediately provided a duplicate negative when copying from the original negative. The development of this duplicate material has proved necessary because very soon the number of copies required could no longer be produced from the original negative. Moreover, the international exchange of films steadily increased and in correspondence to the practice in the field of black-and-white films this exchange was to have the form of duplicates in the field of colour films, too. The structure of the material corresponded to that of the other two cinematograph films with respect to the sequence of layers except that the selective sensitization of the positive film was combined with the colour coupling agent of the negative film in the red-sensitive layer.

During the Second World War, Kodak had developed and, shortly after, put on the market a colour film system which differed essentially from the Wolfen product in some

respects. Initially the system was offered with complete duplicating process included. The colour materials were composed as multilayer films according to the Kodak principle, (i.e. the colour coupling agents, dissolved in high-boiling solvents, were introduced into the emulsion as so-called 'oil coupling agents'). While the Wolfen films were still produced on a cellulose nitrate base (the complete change-over to cellulose acetate was carried out gradually within a few years) the Kodak films were immediately supplied on cellulose acetate. This change-over from cellulose nitrate base to cellulose acetate base was a decisive improvement to extend the life of films.

From the outset, the structure of the Eastman Kodak positive film differed from that of the Wolfen positive film. It has a structure according to the so-called principle of the interchanged sequence of layers. Such films have the following sequence of layers from the upper layer to the base with respect to their light-sensitivity: green, red, and blue. This means that the two sensitized layers are arranged above the blue-sensitive layer. Such a structure is only possible if silver-chloride emulsions, which have very little sensitivity in the blue spectral range, are used for the green and red-sensitized layers. A highly sensitive silver bromide emulsion with a corresponding gradation is required for the blue-sensitive layer.

This principle enables the production of visually sharper copies than with positive films having the conventional arrangement of layers. Because of the high sensitivity of the human eye in the green spectral range the magenta component picture of a multi-colour picture makes the greatest contribution to the visual impression of sharpness. If the layer which carries this picture is arranged as the uppermost layer in the positive film the magenta component picture can be imaged more sharply in the copying process.

The Eastman positive film in its original structure was considerably less sensitive than the Wolfen positive film. However, it did not need a filter layer and consequently permitted a substantially simpler processing in respect of sound track redevelopment.

For duplicating purposes a panchromatically sensitized black-and-white film (Type 5235) was offered on which the three colour records were produced separately. These three records were then printed in register onto a special colour duplicate negative. This procedure is used today. Similar colour-separations were also used by Technicolor to produce copies. This duplicating process was no doubt more difficult to handle than, for example, the colour reversal duplicating negative process offered by Wolfen in the beginning and it requires a great deal of experience to obtain good results. On the other hand, however, it offers the advantage for archives that a colour film can be stored as black-and-white material. This considerably facilitates storage which will be explained in detail later.

The duplication process underwent technical improvement and

simplification as a result of the introduction of a colour intermediate film and, later, of a colour reversal duplicate negative film.

The colour negative film of Eastman Kodak had the same sensitivity as the Wolfen material but characteristically differed in two properties. The gradation of the film was more flat at about 0.6 and it was the first camera negative film to have automatic dye masking. This achieved an essential improvement of the colour quality.

4.5.4 Colour reversal process

It should be mentioned in this context that the colour reversal processes could not penetrate the cinema industry except for the use of colour reversal negative films as duplicating films. One of the reasons for this is that there is practically no possibility of individual artistic shaping of pictures during shooting and in the copying process, at least as far as the colour information is concerned.

In more recent years, however, reversal processes increasingly have gained in interest. Reversal colour films are used particularly for topical telecasts in 16 mm size for direct transmission in colour television. In comparison with the negative-positive process they are of interest because of the shorter access time as there is no need to make a print. A short processing time is of great importance. Moreover, the higher sensitivity of the reversal film material is a decisive factor especially with artificial lighting. The scanning is normally carried out from the original, but sometimes from a copy if circumstances demand it.

4.6 Theory and production techniques of dye masking

4.6.1 Theory

It is not within the scope of this paper to discuss in detail the extensive field of masking and its different methods and applications. Since, however, masks of various kinds have been extensively used with cinematographic colour materials and photomechanical works in the colour sector for many years, it appears necessary to explain the purpose and mode of operation of the main process of automatic dye masks.

The term "masking" is used in the photographic and photomechanical industry to express different meanings. A mask can be defined as a photographic picture which is superimposed upon another photographic picture and thus changes the reproduction characteristics of the latter.

In the simplest case a mask can be used to change the density range and contrast of a photographic picture (e.g., a negative picture). For this purpose a photographic positive picture of a low contrast is used which is superimposed upon the negative picture. Let us look at the

picture of a step wedge on a black-and-white negative material as a photographic picture. If the silver densities are measured step by step after developing and the values measured are plotted against the logarithms of the respective exposures, one obtains the so-called characteristic curve of the material.

In the same way is obtained the characteristic curve of the mask picture, which has the opposite direction of the curve of the negative picture. These curves characterize the essential properties of the photographic material and give information on the light sensitivity and the contrast range. The tangent of the angle of inclination of the straight-line part is called the gamma and is a measure of the gradation.

The results of the combination of masks of different gradation with a negative picture the gamma-value of which is 1.0 are represented in Figures 4.8 a-c. If a mask picture, the gamma of which is 1.0, is combined with a negative picture of gamma = 1.0 as shown in Figure 4.8a the sum of all corresponding mask and negative densities is the same over the entire exposure range of the pictures (i.e. a uniform density; dotted line).

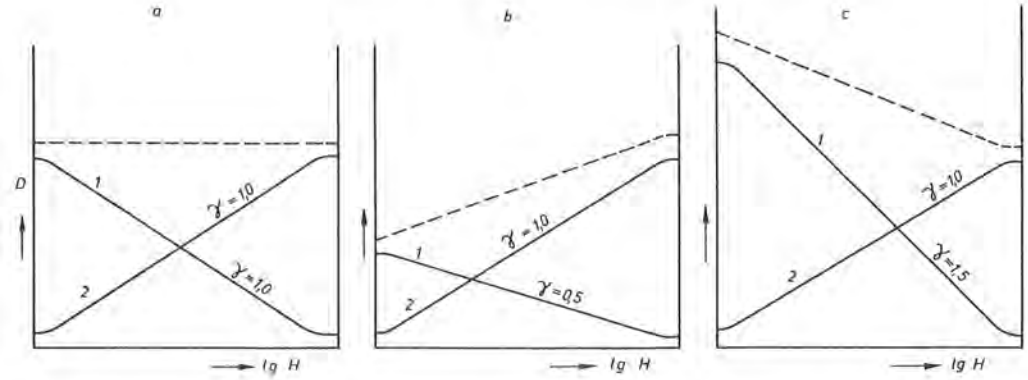
If a negative picture is combined with a mask with a gamma which is lower than that of the negative, a negative picture with a reduced contrast results. The combination of the negative which has a gamma of 1.0 with a mask which has a gamma of 0.5 is represented in Figure 4.8b. A flatter negative with a gamma of 0.5 results from this combination.

If the positive mask picture is steeper than the negative picture then combination of both of them results in a positive picture. In the case of Figure 4.8c the result is a positive picture which has a gamma of 0.5 (from a negative of gamma 1.0 and a positive of gamma 1.5).

When the principle of masking by superimposition of one photographic picture on another is applied, the photographic information content of the latter is modified or extinguished. It has been used successfully in the field of colour cinematography for decades.

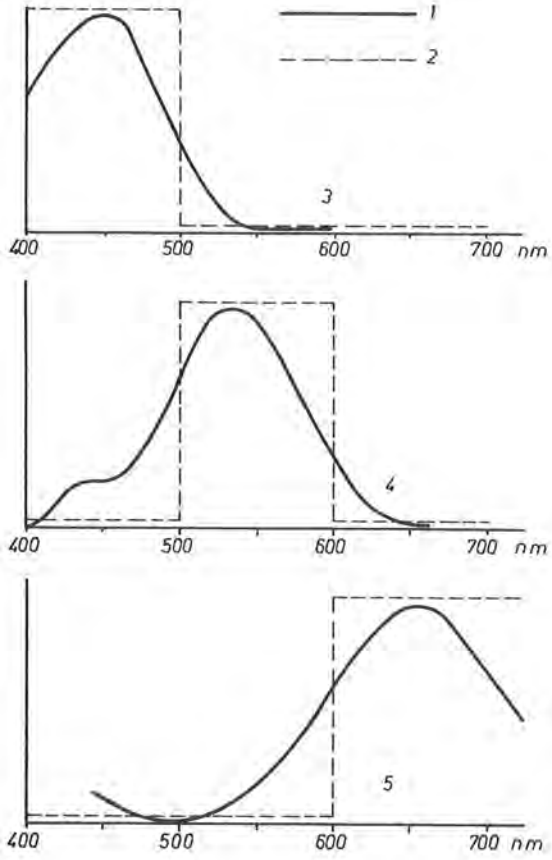
Modern colour photographic processes exclusively use the method of subtractive colour synthesis (i.e. the subtractive primary colours, yellow, magenta or cyan, are produced one in each of the three layers of a colour photographic multilayer material, proportional to the amount of silver precipitated). Each of these three subtractive primary colours theoretically should absorb one third of the spectrum of the white light and totally transmit the two other thirds. This means that the cyan dye should absorb the red portion of the light completely, and transmit the blue and green portions completely. In the same way the magenta dye should absorb completely the green third of the spectrum only and transmit the blue and red portions without loss and finally yellow should absorb the blue rays only and transmit the green and red ones.

Figure 4-8 (a-b-c-)



1 Mask.
2 Negative.

Figure 4-9



1 *Practical absorbtion curves.*
2 Theoretically ideal absorbtion curves.
3 Yellow.
4 Magenta.
5 Cyan.

The absorption curves of the subtractive primary colours theoretically should show flat maxima of the same height only in the respective third of the spectrum and all together enclose the whole visible spectrum. If this is not the case they cannot absorb the whole visible radiation and thus cannot permit correct colour reproduction.

However, this theoretical demand is not met by any dye in practice, even the best ones still absorb light in spectral ranges in which they should not absorb and still transmit light where they should absorb it completely.

Figure 4.9 shows that the magenta and cyan dyes have quite considerable faulty absorptions and only the best yellow dyes approximate the theoretical requirements. The faulty absorptions have adverse effects on the colour reproduction. Here are two examples to explain this briefly. Since the cyan dye does not transmit as much green and blue light as it should, the green and blue tones which are formed from the green and blue available are too dark. The magenta dye absorbs too high a proportion of blue light and therefore all red shades are reproduced to yellow.

The faulty absorptions of the dyes become especially apparent in copying processes. The negative picture dyes control the light reaching the colour positive. The selectivity of the dyes is of particular importance in this process because each picture dye of the negative is to control only the light for one layer of the positive in each case (i.e. the yellow dye should control the light reaching the blue-sensitive layer) the magenta dye should control the light reaching the green-sensitive layer and the cyan dye the red-sensitive layer of the colour positive.

As a result of the side absorptions, however, they also produce a picture impression in other layers of the positive (e.g. the magenta dye exerts some influence in the blue-sensitive layer and the cyan dye in the green-sensitive layer and to a lesser extent in the blue-sensitive layer). It is a common practice in the cinematographic industry to obtain the major part of projection prints from duplicate negatives. Therefore several copying processes are involved before the final colour positive is obtained and the faults described accumulate.

As a result, colour reproduction in projection prints is unsatisfactory. The prints exhibit considerable colour displacements, desaturated colours without luminosity, and the intermediate tones are unsatisfactorily reproduced or are largely missing. In total the image suffers from excessive contrast. With the aid of masking processes it is possible to compensate to a large extent for the faulty absorptions of the picture dyes and to lower the contrast of the positive image. The intermediate tones are reproduced satisfactorily. It is only by the use of masking processes that it is possible to produce duplicate negatives from which satisfactory prints can be made.

One can imagine that for example the magenta dye in practice

is composed of the ideal magenta dye plus a certain portion of a yellow dye; and the cyan dye is made up of the ideal cyan dye, plus a magenta component and a small yellow component. If one succeeds now in eliminating the yellow component from the practical magenta dye and the magenta component out of the cyan dye, almost ideal dyes remain. The removal of these faulty absorptions can be obtained by using correspondingly coloured dye masks according to the same principle as described above for black-and-white films.

The characteristic curve of a negative magenta dye wedge is represented in Figure 4.10. It was obtained by measuring a wedge behind a green and a blue filter. Measuring behind the red filter was omitted for the sake of clarity.

It can be seen that the magenta dye also has a considerable density in the blue third of the spectrum in addition to that one in the green main spectral range and consequent transfer picture information in approximately two thirds of the spectrum. In the copying process, the dye influences not only the green-sensitive layer of the colour positive according to its main dye density but also its blue-sensitive layer. This, of course, results in shade displacements and a loss of colour saturation in the copy.

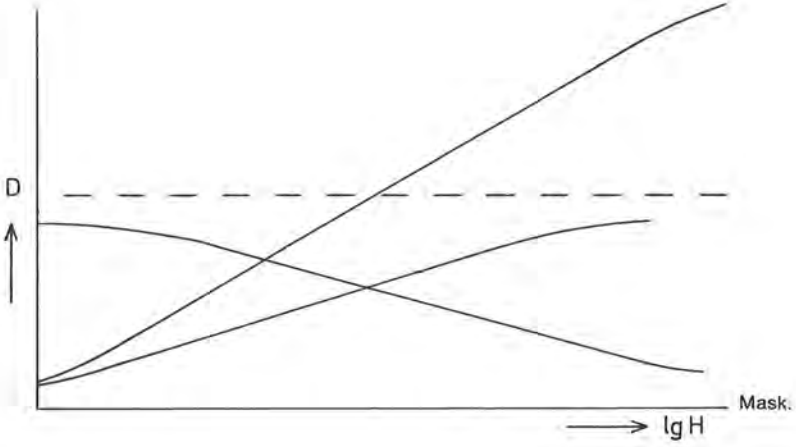
If one succeeds now to superimpose upon the negative magenta dye picture, a weak positive yellow dye picture (dye mask) the side density of the magenta dye in the blue spectral range is thereby changed. It can be eliminated completely if the two yellow dyes are matched in their properties and if the gradation of the mask picture and that of the picture of the side absorption of the magenta dye are equal. In the same way the undesired side absorption of the cyan negative picture dye can be eliminated.

4.6.2 Applied techniques

Large-sized pictures are generally used as a printing pattern for photomechanical work. Here it is possible to produce the mask pictures on some other material in separate operations and then unite them with the printing pattern.

Such a procedure is not possible in the cinematograph industry. The colour mask has to be produced in the colour negative material itself. For example, this can be obtained by uniting the mask formation with the colour coupling process. If one uses coloured colour-coupling agents for the negative instead of the usual colourless colour-coupling agents, namely yellow dyed magenta-coupling agents and yellow-red to red colour-coupling agents for cyan, from which the chromophore group is separated during the colour coupling process while forming the magenta and cyan picture dyes respectively, then the required colour masks are produced automatically for the magenta and cyan component pictures respectively. Suitable colour-coupling agents which meet these requirements, for example, are certain azo dyes of magenta and cyan coupling agents. If one uses such colour-coupling agents in colour negative films, then the azo residues are separated in the colour coupling while forming the magenta azomethine and cyan indoaniline dyes. The colour masks are thus formed from the portion of the coloured coupling agent not used

Figure 4-10



for the colour-coupling and consequently their density is in the opposite direction to the density of the colour picture.

The same effect can also be obtained when the residual coupling agent remaining after the colour-coupling is later converted into the appropriate dyes. All those systems which require a special bath for this during processing have not prevailed in practice, although the results obtained will stand comparison with those already described.

A different process is used by Agfa-Gevaert. Auxiliaries incorporated in the emulsion layers together with the residual coupling agent which was not converted to picture dye in the colour development are coupled with the mask dyes in the bleaching bath during the normal processing operation.

The dye masks belong to classes of dyes which are at least as durable as the picture dyes and very durable under the conditions found to be optimum for them.

4.7 Coupling agents insoluble in water without oil forming agents

It was not until the 1960s that a third type of diffusion-proof colour-coupling agent made its way in practice for cinematograph materials. This method is almost a combination of the two methods mentioned under 4.6.1. Hydrophobic coupling agents which have longer alkyl chains are firstly dissolved in low-boiling solvents which are partly miscible with water and are secondly placed in the emulsion. The solvents are removed during the drying process. The coupling agents are thereby finely dispersed in the emulsion in an insoluble form.

This process was introduced by the firm Perutz in the middle of the fifties for the Perutz amateur reversible colour film C 18 and it has continued to be used ever since. Coupling agents incorporated in the individual layers in different ways are used with the reversible colour films type 600, 605 and 615 (for use by television) and with the colour positive film type 985 of Gevaert. While the yellow and magenta coupling agents are soluble in water (according to the Wolfen principle) the cyan coupling agents are insoluble in water without oil-forming agents.

Coupling agents insoluble in water without oil-forming agents are considered more diffusion-proof and better coupling with the dye. The dyes formed, however, do not differ colorimetrically from those made of water-soluble colour coupling agents. Certain cyan water-insoluble coupling agents have the advantage of a better resistance against moisture, heat, and, above all, light. The firm Foma of the Czechoslovak Socialist Republic has used water-insoluble coupling-agents (without oil forming agents) for yellow and magenta - not, however, for cinematograph film but for the colour paper PM 20. However, mixtures of water-soluble and water-insoluble coupling agents within a single layer are practicable.

Water-insoluble colour couplers are protected by the patents of various manufacturers such as Kodak, Fuji, Konishiroku, 3M.

Since the oil-forming agent which, according to the original Kodak process, must be used in a ratio of at least 1 : 1 to the colour coupler, is actually a buffer material, it can be expected that the full advantage of the water-insoluble couplers will be obtained. However, it is undisputed that the oil forming agents favourably influence the physical-mechanical properties of the layers, especially the swelling, the drying times during processing and the flat position of films. Because of the advances in emulsion technology and chemistry of high polymers, it is possible to produce emulsions very rich in silver and poor in gelatin on the one hand and use suitable plastics to form layers on the other. In this way, the problems of swelling, cure and flat position (also due to more recent knowledge in base manufacture) can be influenced in the desired direction by controlled dosage of gelatin, plastics and other additives.

4.8 The development of colour film materials since 1950

4.8.1 Cinematograph films

The process of automatic colour masking was first introduced by Kodak with its colour negative film in 1950. In 1951 the internegative film followed as a masked material and the intermediate film in 1956. Both of the latter materials serve to produce duplicate negatives.

The Wolfen factory offered its first masked film, the reversal dupe-negative film later called DC2, in 1954. Masking is based on the principle of the azo dye coupling agents both with the Wolfen films and the films of the Soviet film factories. As mentioned above they differ from the Kodak coupling agents by having long alkyl chains for diffusion-proofing. This masking process was introduced by the Wolfen factory and the Soviet film factories using diffusion-proof azo dyes also with their colour negative and duplicate films for the negative-positive-dupe-process. The films in question are Orwocolor Negative NC 3 (1970) and DC 6 (1970) of the Wolfen factory and the colour negative films DS 5, LN 5, LN 7 as the duplicating materials KP 4, KP 4 U and KP 5 of the Soviet film factories.

The colour negative films of the Japanese firms Fuji, Konishiroku and Sakura as well as the Ferrania (now the 3M) colour negative film, are all made by the Kodak process, employing azo dye masks.

Later Kodak offered the Eastman Color Intermediate film (type 5253) as colour film for duplicating purposes. This film was subsequently replaced by an improved product (type 5243). The duplication process is simplified by using this film. It is a very fine-grained film which has approximately the sensitivity of colour positive film, a flat gradation of theoretically 1.0 (but slightly higher in practice), has

automatic colour masks in the lower and middle layers, (i.e. the red and green sensitive layers) and it permits production of a duplicate negative in a two-stage process. Although it has the sensitivity of a colour positive film, the colour-coupling agent of the lower layer corresponds to that of a colour negative film.

Since about 1970, Kodak has also offered a reversal dupe negative film (type 5249) which corresponds to the Orwocolor Duplicating Film DC 2 with respect to structure and function and which also is masked both in the lower and middle layers.

A duplicate film KP 4 corresponding to the Eastman Intermediate has been offered by the Soviet film factories since about 1967. This film has been improved with respect to the reproduction of the colour values and the physical-mechanical properties in the meantime and now is offered as KP 5.

In addition to the reversal-dupe-negative film DC 2 the Wolfen factory has offered the film DC 6, which also corresponds to the Eastman Intermediate, since about 1969.

There are a great number of positive films. Colour positives are supplied by all of the firms mentioned above. There were great changes to the positive films with respect to their structure and their photographic properties in course of time. The colour positive films produced by all firms, except Eastman Kodak, were composed according to the so-called classical sequence of layers. In the beginning their colour coupling agents were of the Wolfen type: they had no separate yellow filter layer made of colloidal silver, their processing thus was simpler than that of the Wolfen colour positive film type 4 (i.e. the application of bleaching paste to the picture part was not necessary) which meant that a process step which involved many sources of error was not required.

Initially, the films were adjusted in their gradation to colour negative films with steep gradation. As the Eastman Color Negative Film made its way into the film studios more and more of the remaining firms adjusted their colour positive films in their gradation to the flat gradation of the Eastman film. They also matched their own negative films to the Eastman Color Negative Film more and more. In the beginning these colour positive films which had a steeper gradation still had the conventional sequence of layers. When, however, Eastman Kodak dyed the colour positive film for the first time about 1960 to reduce the diffusion halo by using washable filter dyes, this film was so clearly superior to the other colour positive films with respect to its definition performance that the majority of the other firms such as Gevaert, Ferrania and the Japanese film manufacturers also adopted the exchange of layers and dyeing for their colour positive films. Nowadays all notable manufacturers of cinematograph films, except Wolfen and the Soviet film factories, produce colour positive films according to this principle.

In recent years there has been another fundamental change in the field of cinematograph films which was carried out by all factories except Wolfen and the Soviet film factories. There has been a unification of processing of cinematograph films. Processing of both the colour negative films and the colour positive films is carried out uniformly according to the formulae of Kodak. Consequently most firms adopted the method of Kodak for the colour-coupling agents with the exception of Agfa-Gevaert with its cinematograph films which partly use coupling agents soluble in water without solvents and partly coupling agents insoluble in water.

From an Archive's point of view, dye stability is the weakest point in the entire colour film system. In its publications concerning its LF films and new release print stock 5384, Kodak has made known that it has succeeded in making a considerable improvement in the stability of cyan. This certainly represents progress.

4.8.2 Television films

In the last decade the development of colour television has opened a new field of application for the colour film because colour films are used on a large scale for colour transmissions in addition to magnetic picture recordings.

As far as the 35 mm size is concerned the same materials are used as in the feature film industry. They also employ the negative-positive process. The films in question essentially are television films which are produced according to this process. In this connection it should be noted that in Britain and Japan, scanning is done directly from the original or dupe negative. For economic reasons they are anxious to establish as close a connection as possible between colour television and the cinema business (i.e. to show television films in the cinemas and vice versa).

Different aspects are important for television news films. Here the aspect of being up-to-date is decisive. That is why the proportion of magnetic recordings is larger; but here too the film has an essential share due to the mobility of the equipment. Here the 16 mm size is preferred and reversal colour films are used almost exclusively. Short processing operations are preferred partly at an elevated temperature (the Kodak E4 process). Copies are produced on suitable conventional or new special duping material for the exchange of programmes or for the initial transmission. In addition to this, magnetic picture recordings are transferred to film in many cases. The treatment of the magnetic recordings for keeping in archives will be described in detail later.

Photographically the television reversal films differ from the amateur films by flatter gradation and lower maximum density. The duping materials are even flatter in gradation and lower in maximum density. These special needs result from the particular conditions of electronic scanning and reproduction.

Kodak offers as camera films suitable for television, Ektachrome EF and ER for daylight and 7241, 7242, 7257 and 7258 for artificial light, and Ektachrome print film 7389 as a duplicating film.

Agfa-Gevaert produces the camera films Type 600, 605 for artificial light and Type 615 for daylight and Type 902 as duplicating film.

Orwo offers, for special use in television, Orwocolor Reversal Film Type UF 1.

The sensitivity of the camera films - except Gevaert film Type 600 - lies between 21 and 23 DIN or 100 to 160 ASA or 90 to 180 GOST.

4.9 Durability of the picture dyes

Despite the fact that there were other major problems in the beginning such as improving the colour reproduction, increasing the sensitivity, stabilizing the processing etc., it must be stated that the unsatisfactory durability of the picture dyes very soon led to studies directed to their improvement.

4.9.1 Cause of instability

It is regrettable that the colours in these films, especially the positives, fade with time. Furthermore, the three dye components fade at different rates so that there is a distinct change of colour balance. Some copies - mysteriously - have exhibited better durability. The resistance of the picture dyes against light, moisture and temperature are different. While the yellow picture dye faded first, being the upper layer next to the light in the classical sequence of layers when exposed to light, the cyan dye (lower layer) was the least durable when stored in the dark. The first copies on the Wolfen material showed a considerably poorer durability of the cyan dye in comparison with the other two so that the copies showed a colour character which had shifted towards yellow-red to such an extent after a one year storage at room temperature that they were useless for further showings.

Studies showed that two negatively acting complexes affect the durability of dyes:

a) system-conditioned properties and
b) external influences upon the film

The system-conditioned factors are the dye-classes of the picture dyes, the influence of the base, residual chemicals of processing baths, the pH value of the emulsion layers of the films processed.

These factors can be changed only by the use of other materials and the introduction of new techniques, i.e. by the raw film production and film processing.

External factors acting upon the film are: light, temperature, moisture and air pollutants.

Here both the film manufacturers and processors and the archives can provide optimum conditions favourable for durability which, however, are limited by the frame imposed by the system-conditioned factors.

4.9.2 Accelerated ageing tests

It was necessary to work out accelerated ageing tests for a directed research into the field of the durability of picture dyes by means of which good reproducible results could be obtained. Till now, however, the transfer of the results of these tests to the behaviour of the dyes is rather uncertain with long-term storage under room conditions, irrespective of whether it is a matter of normal environmental conditions or of lowered temperature and relative humidity. On the whole, results of the accelerated ageing tests can only give hints of the behaviour of the dyes under the conditions of long-term storage. This is a fact which does not simplify the treatment of this complex problem. The conversion of the results of the tests by means of the Arrhenius equation can only give approximate values for the behaviour of the dye. More exact results can only be obtained by prolonged observations under the conditions of storage. This, of course, renders the treatment of this field more difficult. However, one can notice that an improvement of the durability has been achieved in all colour materials.

4.9.3 Dye classes

The dyes themselves rank first among the system-conditioned factors. The durability of the picture dyes of different processes differs very much. The dyes which are used for dye-transfer processes (Technicolor) and dye-destruction processes (Gasparcolor) are substantially more durable than those dyes which result from chromogenic development.

4.9.4 Azo dyes

The Technicolor system was developed as a printing process for copies. It uses azo dyes for printing. Whether three black-and-white separations were produced directly in a beam-splitting camera or whether the photographic recordings were made on a multi-layered colour negative film from which the three colour separations were made, printing was always carried out using three matrices dyed in the subtractive colours (yellow, cyan, magenta). Given favourable conditions of storage, these prints have a relatively long life.

The same applies to the colour films which were produced by the silver-dye-bleach process (Gasparcolor) which was used at one time. This process is based on the fact that certain azo dyes are bleached catalytically in the presence of metallic silver as a function of the amount of silver. When to a photographically sensitized emulsion is added an azo dye complementary to the sensitizing range and the silver picture is developed after the exposure, then the azo dye can be

bleached out subsequently in a special bleaching bath. A positive colour picture remains after the removal of the residual silver which is carried out according to well-known processes.

The disadvantage of the process is the very poor light-sensitivity due to the high density of the film caused by the picture dyes. Consequently this process was only employed for making copies and is no longer in use. More recently a form of this process has attained some importance as a copying material (Cibachrome) but it has not yet made its way into cinematography. The Ilford Company was granted a patent for a masking process employing the silver dye-bleach procedure. Because of the complicated processing, however, it was not used in practice. As azo dyes the picture dyes are much more durable than those of the chromogenic processes.

The higher durability of the azo dyes, of course, is of great importance for the preservation of colour films. However, it would be a disastrous error if the archives considered the problem of the preservation of important colour films to be solved by this. Although the azo dyes are at least three to four times more durable than the classes of dyes to which the azomethines and indoanilines belong, they too are not colourfast and infinitely durable. They also need optimum conditions of storage if they are to survive until some nearly indestructible information medium becomes available.

4.9.5 Azomethines and indoanilines

It is even more difficult to preserve films produced by chromogenic development. Some important problems and findings are already indicated in the first studies in the context of the durability of picture dyes in colour films with which the dyes are produced in the development process. It was already known from the dye chemistry that the azomethine and indoaniline dyes which result during chromogenic development cannot be used (e.g. as dye-works dyes) because of their poor resistance against the influences of heat, moisture and light. It thus was to be expected from the beginning that these picture dyes of the colour films would cause problems for long-term storage. It should have been clear that certain limits could not be exceeded with respect to their durability because it is expensive to keep vast quantities of colour film at subzero temperatures for long periods of time.

4.9.6 Influence of the base

The base can be considered another system-conditioned factor. As indicated earlier, cellulose nitrate has an adverse influence on the durability of the picture dyes because of its strong tendency to self-decomposition. Nitrous gases are liberated during the decomposition of cellulose nitrate. Nitrogen dioxide is especially aggressive. It has already been found that a content of 0.1% of nitrogen dioxide in the ambient air can cause a

density reduction of 10% in chromogenically developed dyes in 24 hours at room temperature.

Moreover it was found that the change of base influenced the durability of the cyan picture. The cellulose nitrate base then commonly used had an adverse effect especially on the durability of the dye of the lower layer which was more durable on a base made of cellulose acetate but did not reach the degree of durability of the dyes of the other two layers. It was only by changing the cyan coupling agent that the durability could be approximately matched in all of the layers.

4.9.7 Constitution and incorporation of the colour-coupling agents

The constitution of the colour-coupling agents and the method of their incorporation are also system-conditioned.

It became evident that the vast number of synthesized colour-coupling agents of different constitution also supplied differently durable picture dyes. It was possible by various means to influence the constitution of the colour-coupling agents. In accordance with the experience of the dye chemists, regularities could be derived from the studies which became available about the structure of colour coupling agents which formed especially durable picture dyes. Electronegative substituents adjacent to the coupling group generally yield dyes of a better durability. Dyes which have a linear structure are less durable. Generally, the magenta dyes are more durable than the cyan and yellow dyes.

The colour developers also influence the durability. In this case there is a relationship between the durability and the length of the alkyl chains at the tertiary nitrogen atom of the p-phenylenediamine. Among the three developers used in cinematography, the one derived from toluenediamine generally provides more durable dyes than the derivatives of p-phenylenediamine.

To summarise, it can be stated that the knowledge of the relationship between the constitution and the durability of the picture dyes was put into practice as far as it was possible. It has been indicated already that quite a number of properties of colour film such as colour reproduction, colour purity, physical-mechanical properties of the finished layer etc. are influenced by the constitution of the colour-coupling agent and the way of incorporating these coupling agents. It is for these reasons that coupling agents cannot be selected solely on the basis of the durability of the resulting dyes. Moreover, the resistance of the dyes against temperature and moisture are within the limits set by the classes of dyes of azomethine and indoanilines. Until now these limits have not been exceeded. For chromogenic development, researchers have not found a picture dye which has the resistance of, e.g., an azo dye. It has also been proved that the different ways of incorporating diffusion-proof colour-coupling agents described above, in principle have no decisive influence on the durability of the picture

dyes produced.

Of course there are, however, some differences in the durability with each kind of incorporation, e.g. hydrophobically incorporated cyan coupling agents generally form more durable dyes than the coupling agents soluble in water. On the other hand it is known that magenta dyes made of pyrazolone coupling agents react with the residual coupling agents to form colourless compounds. This reaction takes place very readily with "oil coupling agents". A special final stabilizing bath is therefore necessary by means of which the residual magenta coupling agent is inactivated. The reaction described, which results in a colour shift towards green in positive copies, is thus avoided. This final bath has proved to be very advantageous for colour film materials which contain the other types of coupling agents.

4.9.8 Residual chemicals

Even residual chemicals, which are present after developing and fixing, have a destructive effect on the dyes. The components of the processing baths are difficult to remove from the gelatin layers. Considerable amounts of colour developer substance, for example, are retained (about 25 g diethyl-p-phenylenediamine in 1000 metres of 35 mm film). Surplus developer adversely affects the durability of the picture dyes according to studies by Soviet authors. Before the film gets into the bleaching bath, however, the developer has to be removed completely because otherwise it would cause the formation of bleaching fog, i.e., the colour developer is oxidized and the oxidized products react with the residual coupling agent and form dyes. The magenta layer especially is susceptible in this respect.

The sodium thiosulphate is retained very persistently and it proved that a thiosulphate content in excess of 4 $\mu g/cm^2$ causes an accelerated destruction of the picture dyes the rate of which increases proportionally with the thiosulphate content. The durability of the magenta dye is mostly influenced by a too high content of residual thiosulphate. The other two component pictures are decomposed somewhat more slowly but to the same extent. During storage the major part of the thiosulphate very quickly changes to polythionates which cannot be detected by a number of analytical methods. The determination by reduction with boron hydride to sulphide under the formation of methylene blue is considered the safest method.

4.9.9 pH values

The pH value of the layer structure can also be influenced by the processing. Obviously there are different optimum pH ranges for films of different structures. The term "optimum pH range" does not mean a range within which there is practically no decomposition of the picture dyes, but a range within which it takes place as slowly as possible, and at the same rate for all component pictures so that the colour balance of the picture is preserved for a long time.

The dependence of the picture dyes on the pH value of the layer structure obviously has not yet been studied for all the cinematograph materials. Comparable values are available on the behaviour of the Eastman Color Positive Film Type 5385, the Orwocolor Positive Film PC 7, and the Soviet Positive Film CP 8. The optimum pH value ranges are pH 5-6 for type 5385 and pH 7-8 for PC 7 and CP 8. With the type 5385 the yellow dye is most unstable in the acid range and the cyan dye in the alkaline one. With PC 7 and CP 8 the cyan dye is more unstable in the acid range than the other two dyes and the yellow dye is more unstable in the alkaline range. The magenta dyes can be influenced least of all in all films by different pH values and the decrease of the dye densities of all three component pictures is least of all different in the ranges mentioned so that colour balance of the picture is preserved for the longest period of time by observing these conditions. It would be welcomed if these studies were extended to the other colour films to be stored in film archives and the method was developed so that it can be applied as a routine test in film archives without great expense.

4.9.10 Humidity, temperature, light

In addition to these factors there are still a number of external factors determined by storage conditions. The most essential factors are relative humidity and temperature. The higher the values of both of them the quicker the decomposition.

Studies have shown that the decomposition of all picture dyes increased proportionally with the increase of the values of relative humidity and temperature but the clear difference in the durability of the yellow and magenta dye component picture compared with the cyan one remained the same.

In Kodak's LF films and new release print stock 5384, the stability of the cyan dye has been improved, so that it exceeds the stability of the yellow dye. It is therefore no longer the prime factor in the disturbance of the colour balance.

Generally, the destruction of the yellow picture dye is due to hydrolysis producing a colourless hydrate. This hydrolysis of the dyes is temperature-dependent, the lower the storage temperature and also the lower the relative humidity in the storage facility the slower it takes place. With regard to this there are certain optimum conditions which are determined by a number of factors which will be indicated in the following chapter.

The resistance against light does not change necessarily in parallel to the resistance against heat and humidity. There is the possibility of increasing the light resistance considerably by using substances which absorb ultraviolet light. The light resistance generally is sufficient for cinematography and does not play the same role as the dark-storage durability. The situation is quite different for pictures which will be exposed to light for a longer period

of time.

Of course, it is not only the colours that have to be considered, but the entire complex of gelatin layers and support as well. As yet there are no exact test results in this area. Unfortunately, accelerated ageing tests do not yield reliable results, and the first deep cold store, which was designed to operate to Kodak's recommended level of minus 18° C (0° F), had to be shut down shortly after being put into service because of severe frost damage caused by structural deficiencies. In the meantime some audio-visual archives have acquired colour film storage facilities at minus 6° C or minus 7° C. In a few years time these should provide exact, i.e. measured, results on the storage of frozen film. No one else can carry out such large scale long-term observations.

4.10 The precedence of the chromogenic development

It is noteworthy that azomethine and indoaniline dyes which are considered completely unsuitable for dye-works due to their poor durability have gained such a world-wide significance in colour films.

For professional colour film work at present there is exclusively this one production process, which adversely affects the preservation of works of art and record. There are a number of reasons, of course, for the increasing successful use of the chromogenic development process in colour photography:

a) The technology of the chromogenic development of multi-layered colour films was so closely related to that of black-and-white film processing that it was possible to use the worldwide network of photographic processing machines for colour film processing as well, with very few modifications. If a decision had been taken in favour of the more complicated dye-transfer or silver-dye-bleach processes, this would not have been possible.

b) The fact that such universal picture recording processes use silver halide is the basis of the colour development process.

c) The colour development process is practically as simple to handle as the black-and-white process using silver halide.

d) Of all the colour processes known till now, the colour development process is the most universal and most flexible.

The weak point is the storage stability but steady improvements of the durability have been achieved by structural changes of the dyes by means of colour developers and, above all, colour-coupling agents.

It is certain, however, that the strict observance of the storage and processing conditions found to be favourable provides the prerequisites to preserve the picture dyes

created by colour development for decades, until the transfer of audio-visual records without loss onto a new generation of really durable recording media is possible.

4.11 Summary

4.11.1 The processes of colour photography are based on colour analysis of the radiation coming from the object. This is achieved through three sensitive systems, each one responding to a particular area of the spectrum. The resulting images are used to convey colour sensations simultaneously to the eye.

4.11.2 Colour analysis is alike for all systems. It consists of producing three separate images, by, for example, photographing the object consecutively through red, green and blue filters. The first image then registers all red areas of radiation as silver densities, the second one all the green areas and the third all the blue ones.

4.11.3 The simplest method of additive synthesis is to make positives from these negatives and project the appropriate positives with red, green or blue light respectively. If the individual images are projected in register on a screen a visual impression of the original is obtained. Commercial processes achieve the same result by mosaic screen systems.

4.11.4 In subtractive synthesis three positives are formed as complementary colour images, which are superimposed in register. When viewed with white light such a combination reproduces the visual impression of the original.

4.11.5 The most significant subtractive processes are the dye-transfer process, colour reversal films and the negative-positive systems.

In the now almost obsolete dye-transfer process (Technicolor), complementary colour positives are made from separation negatives and printed in exact superimposition onto a suitable base. Colour reversal films contain on one base three individually sensitized emulsion layers to divide the colour. The negative silver images in the three layers are converted to positives on the same material by a second exposure and, by colour development, are transformed into complementary colour images.

In colour negative films three complementary colour negatives are formed on the same base in three layers each sensitized for a particular sector of the spectrum. The resulting colour negative is then printed onto colour stock of similar construction to produce a positive colour image.

4.11.6 In practical colour photography it is necessary to ensure that the three separate colour images are precisely balanced with respect to each other. The latitude for error is very narrow in comparison with black-and-white photography. This is because the eye is more sensitive to differences of colour than to differences of brightness.

4.11.7 Nowadays many controls are included in the manufacture of colour films and the processing of colour photographs. This makes work with colour films, despite their theoretical complexity, almost as easy as with black-and-white materials. However, the scope for correcting the inherent shortcomings in the system is limited.

Chapter 5

THE PRESERVATION OF DYES IN DEVELOPED COLOUR FILMS

By Herbert Volkmann, Former Director of the
State Film Archive of the German Democratic Republic

5.1 Technique and economic prerequisites

5.1.1 It has been described earlier how colour films are much more difficult to preserve than black-and-white materials. This is particularly true of the dyes produced by chromogenic development. This is the process which for three decades has been used for almost all colour negatives and positives used in both cinema and television.

Previous bleaching and printing techniques used for making colour film records produced very fine colours. The dyestuffs used were considerably more stable than the ones used nowadays. However, the manufacture was much more complicated, and the bleaching method was abandoned at the beginning of the 1950s when the raw film manufacturers brought on to the market film stocks and processes for chromogenic development. This dealt a heavy blow to colour film preservation and hence to the work of film archives.

What has one to understand by the term "long time" from the point of view of the archivist? An archivist reckons in centuries and for archives of documents and document paper such a reckoning is absolutely real because paper can be kept, if well treated, at least for two to three centuries.

5.1.2 It is different with audio-visual records as far as they are based on optical film. The possibility of preserving such records improved very considerably when - after more than fifty years of film production - cellulose nitrate was replaced as the base material by cellulose triacetate which is much less flammable and does not emit harmful gases which destroy the picture. This applies even more to polyester base, which is increasingly being used for cinema films. The life of colour film, too, has been extended by these new bases; but this has not diminished the effect of other harmful factors.

According to the technical press, over 90% of film production for cinema and television in Europe, North America and Japan consists today of colour films. The colour in the film has thus become a major preservation problem.

This chapter is concerned with the possibility of preserving the dyes in original colour films. Nobody can foresee exactly how long a colour film will be able to be copied and

shown. That depends on many factors. However, it is certain that after a few years, colour films are very often not useable because of gross changes of colour balance. One can say with certainty that dye-image films of any kind which are being stored without special measures of preservation will have only a limited useable life. This has been proved true in practice and by scientific investigations.

5.1.3 Economy plays a very important part with regard to the existence of audio-visual archives. All equipment needed, in order to be really able to ensure the preservation of the records for a long time, is very costly. But if one were to renounce the building up of audio-visual archives at the present time, then invaluable historical and artistic works would be lost forever.

We are today in a transition period: we worry about the preservation of less stable materials but science and technology are already developing completely new information media which may facilitate our task. Thus the task of the archivist today consists in saving, with the support of his government, everything that is worth keeping in audio-visual records, and has been created in our century up to a time in which it may be possible to preserve audio-visual records for posterity with greater safety and less cost.

In view of the high costs involved in properly preserving colour films, it is understandable that less expensive methods may be sought. However, it must be emphatically pointed out here, that while emergency solutions may prolong the life of colour films to some extent, they cannot ensure their survival until the time when it will be possible to transfer the records onto some really durable medium.

5.2 Injurious factors outside the control of archives

The injurious factors which may totally destroy the film dyes, are enumerated in section 4.9.1.

The system-limited factors, viz. the factors which are inherent in the film material itself and which deteriorate without any external influence, are beyond the control of the archive.

5.2.1 Dyestuffs

Decisive for the preservation of colour in films is the choice of the class of dyestuffs employed in them, and in their associated, more-or-less stable character. As in the case of the introduction of the system of dye couplers, the archivist must leave this to the research scientists and film stock manufacturers, who find their limits in the laws of nature.

Damage due to destruction of the dyes is difficult to correct. The possibilities of restoration and regeneration are reported in Chapter 7. The sole means of retarding the destructive process is optimum climatic conditions of storage (sections 5.3.2 and 5.3.3).

5.2.1.1 Among others, this problem was highlighted by the outcry of film artists led by the American film director Martin Scorsese over the highly impermanent nature of the colour film which the film manufacturing industry offers to them as the sole working material for their creative efforts. Considering their artistic investment, their indignation is understandable. They have our full sympathy.

Their attack is directed towards the inherent weaknesses in the technical system of present-day colour film. To overcome these would mean switching to a completely new system, which would involve an enormous investment on the part of the entire film industry worldwide.

Kodak's response to this was a series of publications concerning its new LF emulsions (LF = low fade) and new release print stock 5384, which have a considerably longer life expectancy than previous colour films.

It transpires that Kodak is talking about an improvement in the stability of only one of the three basic colours, namely cyan. Kodak itself points out that tests using artificial ageing furnish little proof, and that the use of the Arrhenius equation is dubious, in the case of a product which has a very complex chemical composition.

It should be recognised that the life expectancy of a colour film record depends on that of the least stable colour. It only needs one of the three basic colours (yellow, magenta or cyan) to fade, for the colour balance to be disturbed to such an extent that the film is no longer fit for exhibition or printing.

Previously, cyan was the most unstable colour in release prints. Now, in the LF emulsions and release print stock 5384, yellow is the least stable. Raising the stability of the most unstable colour represents progress.

5.2.2 Bases

The support is today no longer a decisive factor on the colour. In general, nitrate-based colour films must be copied onto acetate base as soon as possible; both for their own preservation and for the safety of the surroundings. Cellulose acetate gives off no harmful gases; however, it shrinks which can be a serious matter for colour separations (Chapter 6).

Polyester fulfils all the requirements of a base, i.e. it gives off no gases and endures long in storage. Present-day bases offer no threat to the dyes in colour film.

5.2.3 Residual chemicals

The third factor, associated with the film process itself, is the consequence of incorrect developing, fixing and washing of the film. In this case also the archivist usually has no control since he is not usually the owner of

the laboratory which carried out the processing, and thus cannot ensure that the processing procedures, laid down by the film stock manufacturer, are exactly adhered to.

The danger lies in any residue of chemicals remaining in the film at the end of processing, particularly the fixing chemicals, which can cause the image-forming dyestuffs to fade or change hue. The effects of residual chemicals occur more quickly in dye-image films than they do in black-and-white silver-image films.

There are a number of methods for determining the presence of residual chemicals but most of them are complicated, and there is difficulty in employing them in practice to check a large collection. It is necessary to understand that the original negative of a feature film normally consists of several hundred individual shots, which were not necessarily developed all at the same time, or in the same processing bath, or even in the same laboratory. Therefore, in order to monitor such an assembled negative fully, it would be necessary to test every single shot.

At Gosfilmofond, Moscow, special facilities were constructed for the purpose of carrying out such tests on all shots, but the procedure had to be abandoned, since it was so laborious that it was not feasible. It is true also of normal copies, from which it is necessary to take several tests, since a copy is not always consistent throughout all the reels. Desirable as it would be to have exact knowledge about the level of residual chemicals in the films, there is no procedure by which it is practicable to examine more than some particularly precious film which warrants special protection. Gosfilmofond is the first archive to adopt the procedure with all film entering the archive (old or new, colour or black-and-white) of thoroughly re-washing, or treating with chemicals which eliminate harmful residues. However, re-washing may remove silver salts which could be used to re-develop faded film.

5.2.4 pH values

There is a danger that excessive washing will have a destructive effect during storage. Of importance here, is that the pH value does not deviate from the standard value for the film. The raw stock manufacturers provide processing instructions concerning pH values. It is next pointed out that optimum storage climate helps to minimize the effect of too high a pH value.

The processing laboratory is responsible for checking pH values, but during subsequent storage of the films (at max. 60% relative humidity for black-and-white film and max. 30% RH for deep frozen colour film) the original pH values can change.

5.2.5 Harmful gases

There is a harmful effect from gases, especially industrial exhaust gases (e.g. sulphur gases) which are contained in the

air. It has already been mentioned above that in industrial areas there has been established a strong concentration of such gases even 40 to 50 kilometres from the point where they arise. The best protection against this is, of course, to transfer archives to areas in which industrial gases are not present (e.g. in extended woodland). However, in modern industrial nations such areas have become extremely rare, they are always far away from the large cities and therefore in such condition the transport problem becomes more serious for the archive.

There is, of course, also a protection against these gases by the installation of appropriate air filters, which can be easily done in air-conditioning installations which are here a prerequisite. The filters must be fitted in such a way that they keep all the harmful gases away from the vaults.

Although there exist only comparatively small amounts of colour film on nitrate base, it is necessary to point out that, unless safety film is very thoroughly isolated from nitrate, any conservation measures applied to the safety base film is wasted, since the gases from the nitrate film will damage the images on the safety film. Colour films will be affected more quickly than black-and-white films. It is not sufficient separation to store the two types in adjoining rooms. The best thing is to keep them in entirely separate buildings. It is strongly recommended that the safety regulations for storing nitrate film in the relevant country are strictly adhered to.

5.3 Harmful factors within the control of the archive

Whereas with the instability of the dyes and processing errors the archivist is unlikely to be in a position to have direct control over the harmful effect, this is, to a great extent, possible with regard to other factors. From the moment the film arrives at the archive it is the responsibility of the archive's technicians to avoid any further harmful effect. Damage caused by wrong storage and/or wrong treatment beforehand can only be corrected with difficulty. The checking of the film before storage will show whether any colour changes have already advanced to such an extent that the costly storage in the archive is no longer worthwhile.

5.3.1 Light

One factor which has a damaging influence on the film dyes is light, especially ultraviolet radiation. Light is the factor which is the least worry to the archive. The film is stored in closed tins which do not admit any light and generally also in dark rooms. The effect of light is also relatively minimal. The light to which film is exposed when showing or copying may be very intense, but the duration of exposure is so brief that it has no significant effect upon the dyes.

Only upon examination and restoration is the film likely to be exposed to light for a prolonged period. In the case of

normal examination there is hardly any danger. One can be more sure, if one excludes light sources with high content of ultraviolet rays, e.g. by placing UV filters on the windows in such rooms. If one wants to be quite sure one can equip the winding table for prolonged restoration work with covers over the reels of film.

5.3.2 Temperature

A factor which has considerably more importance is the temperature at which the film is treated and stored. The higher the storage temperature the quicker the colours change. It was described in chapter 4 how the colours change in different ways; that in some types of film cyan changes quicker than the other dyes, and in other types of film yellow is the fastest fading dye. The fading of one colour is sufficient to disturb the colour balance and to make the film unusable, i.e. it depends on the rate of the fastest fading colour how long a film can be used.

5.3.2.1 A wide range of temperatures have been advocated as the optimum for storage of colour films. These data fluctuate between plus 20° C and minus 18° C. It is self-evident that such a temperature range cannot be correct. As a general rule, colour films should be stored as cold as possible, preferably at temperatures below the freezing point of water. The Preservation Commission of FIAF recommends minus 5° C.

5.3.2.2 The Commission considered the moisture in film, which called into question the expediency of storage at very low temperatures. Only pure water forms ice at 0° C. Water with added substances, or which has been added to other substances (e.g. water in gelatin) has different freezing points. It will not be possible to give a precise freezing temperature which would be constant for all film types, as here also there are variable factors present (e.g. the water content in the emulsion during freezing). Gelatin is able to absorb approximately twenty times its own weight of water. Any excess of water in the emulsion (i.e. "free" water which is not bound to water-saturated gelatin) will turn into ice crystals when frozen. However, if the film has been in equilibrium with air of 50% relative humidity (RH) and 20° C prior to freezing, ice crystals will not be formed - according to Eastman Kodak's research scientists.

A further danger is the possibility of freeze-drying the films. If a temperature of minus 18° C is to be maintained in the storage space, then the temperature applied by the cooling coils of the refrigeration system must be much lower still. (Domestic freezers, for example have a storage temperature range of minus 15° C to minus 18° C, and to achieve this the applied temperature may be around minus 30° C. The water in the film may ultimately be deposited as ice upon the cooling coils, and one is left with an irreparably brittle film, fit only to be destroyed.

5.3.2.3 This storage at minus 5° C means indeed considerable savings of money at the whole installation of

Figure 5-0

Temperature of air	Relative Humidity %							
°C	60%	65%	70%	75%	80%	85%	90%	95%
	Dew point temperature °C							
6	−1	0	1,0	2,0	3,0	4,0	4,5	5,0
7	0	1,0	2,0	3,0	4,0	5,0	5,5	6,0
8	1,0	2,0	3,0	4,0	5,0	6,0	6,5	7,0
9	2,0	3,0	4,0	5,0	6,0	6,5	7,5	8,0
10	3,0	4,0	5,0	6,0	7,0	8,0	8,5	9,0
11	4,0	5,0	6,0	7,0	8,0	8,5	9,5	10,0
12	5,0	5,5	7,0	8,0	9,0	9,5	10,5	11,0
13	5,5	6,5	8,0	9,0	10,0	10,5	11,5	12,0
14	6,5	7,5	8,5	10,0	10,5	11,5	12,5	13,0
15	7,5	8,5	9,0	10,5	11,5	12,5	13,5	14,0
16	8,5	9,5	11,0	11,5	12,5	13,5	14,5	15,0
17	9,0	10,5	11,5	12,5	13,5	14,5	15,5	16,0
18	10,0	11,5	12,5	13,5	14,5	15,5	16,5	17,0
19	11,0	12,5	13,5	14,5	15,5	16,5	17,5	18,0
20	12,0	13,0	14,5	15,5	16,5	17,5	18,5	19,0
21	13,0	14,0	15,5	16,5	17,5	18,5	19,0	20,0
22	14,0	15,0	16,0	17,5	18,5	19,5	20,0	21,0
23	15,0	16,0	17,0	18,5	19,5	20,5	21,0	22,0
24	16,0	17,0	18,0	19,5	20,5	21,5	22,0	23,0
25	17,5	18,0	19,0	20,5	21,5	22,5	23,0	24,0
26	18,0	19,0	20,0	21,0	22,5	23,5	24,5	25,0
27	18,5	20,0	21,0	22,0	23,5	24,5	25,0	26,0
28	19,5	20,5	22,0	23,0	24,0	25,5	26,0	27,5
29	20,5	21,5	23,0	24,0	25,0	26,5	27,0	28,0
30	21,5	22,5	24,0	25,0	26,0	27,0	28,0	29,0
31	22,0	23,5	25,0	26,0	27,0	28,0	29,0	30,0
32	23,0	24,5	26,0	27,0	28,0	29,0	30,0	31,0

the vaults compared with minus 18° C. Nevertheless, it means considerable changes in the construction of stores and also requires additional facilities.

Three things should be noted in particular:

a) Sufficient insulation of the entire construction, so it is guaranteed that at highest summer temperatures the temperature of the air-conditioned storage rooms will not exceed minus 5° C.

b) The safeguarding of the foundations of the building against possible damage caused by frost.

c) The acclimatization of the films when it is put in and when it is taken out.

For more information about the construction of vaults, see Chapter 15.

5.3.2.4 If one comes from the winterly cold, enters a heated room and wears spectacles, these are immediately dimmed because droplets of moisture condense upon the surfaces of the lenses.

The same applies when an object such as a can of film is taken from a cold to a warm environment without considering the dew point. Water vapour from the surrounding air condenses onto the cold object. If this is not eliminated immediately after warming by drying the film, it will certainly destroy the film.

Films have to be acclimatized also before they are put into a deep cold vault, otherwise the different coefficients of expansion of the emulsion and the support may lead to damage to the adhesive substratum during very sudden changes of temperature, and hence to the possible separation of the emulsion. Such damage is almost irreparable.

There are two methods of preventing this, namely the natural and the artificial re-acclimatization. These methods serve the same purpose and also have the same effect, but the difference is the time required and that is not an unimportant factor.

With natural acclimatization the film reels which are to be adapted to the storage climate, are stored in sealed cans in rooms the temperature of which is below the dew point and which have low humidity. (See Figure 5.1).

According to the temperature of the environment and the format of the films there will be an adaption of the temperature during a period of up to 6 hours for 35 mm film. Then the cans may be opened in order to permit the film to come into equilibrium with the external humidity. Depending upon the difference in humidity within the store and outside, and the format of the film, the necessary length of time will vary up to 30 days. Thus a 70 mm film which had been stored in a humidity of 30% may need as much as 30 days

to reach equilibrium with the external humidity. The same time would be necessary before placing films into store. These are periods which are not practicable in the normal operation of an archive.

Therefore the possibilities of artificial acclimatization have been explored. The Staatliches Filmarchiv of the GDR has constructed special cupboards for the acclimatization of 200 reels, each of 1,000 feet, at a time. These plants have been in continuous use for more than 12 years and permit the safe change of temperature from plus 25° C to minus 5° C or vice versa in a period of 8 hours. It is considered that, if the lower temperature required was minus 7° C, the time necessary would probably rise to 24 hours.

5.3.3 Humidity

Of even greater importance than temperature is humidity. It has been stated in Chapter 4 that an increase in humidity accelerates change in some dyes. It is therefore desirable to have as low humidity as possible.

On the other hand, too low humidity causes shrinkage and brittleness of the film. Therefore it is recommended that, at max. minus 5° C, the relative humidity should not exceed 30%, nor fall below 20%.

In deciding the air-conditioning values for the storage construction it is necessary to remember that the conditioning installation is affected by the environment; and therefore allow the necessary tolerances (plus/minus 1° C and plus/minus 5% RH). Concerning air-conditioning and insulation of the storage buildings, see Chapter 15.

5.3.4 Possibilities of preservation

Archives have attempted to ensure the preservation of their holdings in the various ways open to them, mostly within the system of cinematograph film, but also now by transfer into electronic systems:

a) by storing three colour separations on black-and-white film (see Chapter 6);

b) the advantage of this method is that it increases the time of survival of the content of the film to the level of the black-and-white silver image. The disadvantages are the very high costs involved and the need for more storage space;

c) by freezing the film.

Lowering the temperature slows down chemical reactions, and therefore the destructive processes also. The advantage is a significant increase in the life of the colour film (50 years, 100 years) at a constant minus 7° C and 25% RH. The disadvantages are increased difficulty of access, and the economic implications (in most cases, the construction of new, insulated vaults; acquisition of an air-conditioning system capable of maintaining low temperatures; an increase

in the running costs of storage).

Nevertheless, for large collections, this is today the only practical and secure solution.

Transfer onto newly developed media is not yet practical, because, although they already exist, they are not yet ready for archival use.

5.3.5 The Archive of the Swedish Film Institute is testing a new method of storage. The film is cooled to minus 25° C, the usual temperature of cold storage houses for meat and other food which may replace expensive deep freezing film vaults. At the same time the film is dried to about 30% RH (the intended storage humidity) and the conditioned film is straight away placed in a multilayer plastic and aluminium bag, which envelops it tightly as virtually all the air is extracted from between the film and the bag during sealing, in order to have the least air content in the bag so that air cannot take up humidity from the film, or vice versa. After being sealed, this bag is placed in a second bag, from which the air is extracted during sealing. The film is then put in a can and placed in the store, which has been cooled to the required temperature.

The key question is how long the bag remains airtight.

It is greatly to be hoped that the Swedish Archive's experiments meet with success, as this would mean that refrigerated storage could be carried out more simply and more cheaply.

However, during packing, two aluminium and plastic bags are drawn over the conditioned film and individually sealed. This suggests that there is some doubt as to the extent to which the bags will remain airtight. As the process of becoming permeable is a matter of chemical reactions, there is no reason why both bags should not become useless at the same time, or more or less at the same time. If the bags remain airtight for only a year or two, the process becomes too time-consuming for large archives, and quite expensive as well.

The process is not a new one. FIAF's Preservation Commission discussed it some years ago and instigated some experiments. Its introduction at that time foundered on the lack of a suitable material which would make possible a hermetic seal which was both uncomplicated and long-lasting (10 years). It was then published as an interim solution for those archives which still had no refrigerated store (see "The Preservation and Restoration of Colour and Sound in Film", FIAF 1977 page 65, paragraph 2.4, and the following recommendations).

We have dealt with these experiments in such great detail because they make plain how complex the problems of preserving audio-visual recordings still are today. As soon as one problem is solved, then others just as serious frequently take its place.

5.4 Aids for the temporary protection of colour films

Everything that has been said so far about the necessary measures for the maintenance of the stocks of colour films and in particular of the dyes in the film, was based on the knowledge that there are cogent demands for permanent storage which are difficult to fulfil. The reality is, that there are very few large archives which are able to create these necessary facilities although, in recent years, archive technology has made much progress in many countries. But those archives which have to work without sufficient support of the state, are not in a position to do everything immediately in order to create the best conditions of preservation for their stocks. They too must be helped by advice as to how they can lengthen the existence of the endangered colours for a certain period until they also can hope to be able to create optimal conditions.

It must be emphasized that the following statements are only dealing with temporary measures which can serve for a short period for the preservation of colour but which are by no means replacements for those necessities which are described in paragraphs 5.2. and 5.3.

5.4.1 Stabilisation of humidity by hermetic sealing

First and foremost we talk about the control of humidity, which is the most important element for the preservation of colour. How important it is to achieve optimal relative humidity can be seen from the fact that at 20° C and 60% RH, the yellow dye fading is twice as high as it would be at 40% RH.

It is known that temperature and relative humidity are interdependent. It is further known that humidity must be kept within certain limits so that there do not arise on the one hand the destruction of the colour and/or the black-and-white picture, and on the other hand increased shrinkage and brittleness. A transitionary solution can only be that the undesirable humidity and temperature exchange between the contents of the can and the surrounding atmosphere is prevented.

This can be achieved in the following way. The colour film must be acclimatized in a special room at the temperature of the subsequent storage and the relative humidity amounting to no more than 30%. The procedure of acclimatization takes several days with 35 mm film. The humidity can be maintained within the limits envisaged by an air dehumidifier with automatic defrosting. The equipment which can also be erected in the vaults will operate at temperatures from minus 5° C to plus 30° C.

In the same room the acclimatized film will be put into cans, closed with impermeable, self-adhesive plastic tape and hermetically sealed. The hermetic seal can be obtained by using multilayer aluminium and polyethylene bags which have approximately the same size as the tin, see paragraph 5.3.5).

An air exchange, and in particular, a humidity exchange will thus be prevented.

Upon removal of the film from storage and opening of the polyethylene bags, the dew point of the air in the room must be taken into consideration.

Sealing of the film containers should of course only be done if the film has a triacetate or polyester base. Nitrate base must on no account be treated in this manner. Desiccating agents such as silica gel, must not be used because, on the one hand, the quantity to be used must be related to the weight of the film and, on the other hand, silica gel decomposes to a dust which will become dangerous when showing or copying the film.

5.4.2 Regulation of temperature

It is necessary to ensure that the film is stored at a constant temperature. It must be remembered that any room which is not fully air-conditioned will show seasonal variations of temperature. These variations may be minimised by using a "cellar climate", i.e. one takes the sealed film to a dry room underground or one creates similar conditions by means of the nature of the construction of the building, as it was done by the National Film Archive in London (see Chapter 15).

In middle latitudes the temperatures of cellars in summer are 9-12° C and in winter 2-4° C. These variations are within reasonable limits, but a constant temperature below 0° C cannot be obtained in this way.

This combination of low humidity and low temperature, where the films are hermetically sealed and stored at as constant a temperature as possible, will only be effective for certain periods. The process must under all circumstances be repeated at least once every year. The best season for this is, of course, winter with relatively low temperatures except in tropical latitudes.

The sealing of the film in air-tight bags will of course avoid the effects of harmful gases from the air.

5.4.3 The imperfections of these interim solutions

The imperfections of such auxiliary systems are clear:

a) a completely constant temperature below 0° C with the least fluctuation is not possible to achieve without full air-conditioning.

b) the welding-in of the sealed film cans in plastic bags or other material does not prevent a slow exchange of heat with the surrounding air.

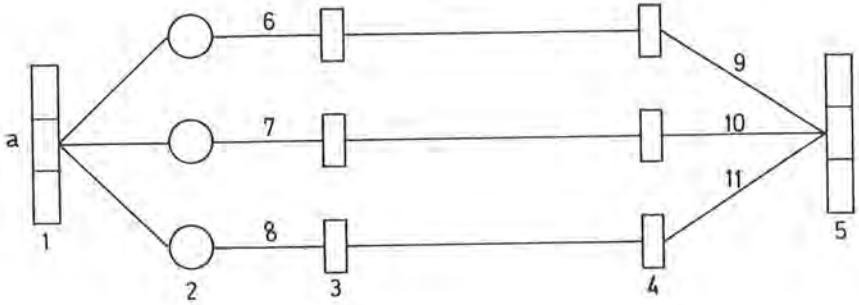
The destructive influences are thus more pronounced here than with the full air-conditioning on optimal level mentioned above. Only a somewhat longer life of the colour

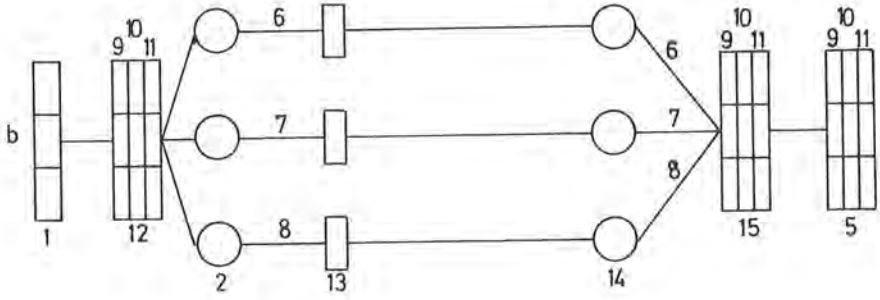
films can be achieved by this.

It is important to note that if one succeeds in storing the films for longer periods in low temperatures and with a minimal humidity by such means, that it will be necessary to carry out acclimatization before opening the seals just as is done upon removal from a deep-freeze vault (see 5.3.2).

It has already been repeatedly said, and cannot be emphasized often enough, that all those solutions are nothing but interim solutions. It is imperative that the time gained must be used in order to obtain from the government the necessary means for planning and installing plants which will provide better preservation.

Figure 6-1





Illustrative scheme of photographic reproduction of the colours by means of b/w extractions.

1 Original.
2 Selection filters.
3 B/W negative.
4 Matrix.
5 Positive copy.
6 Blue.
7 Green.
8 Red.
9 Yellow.
10 Magenta.
11 Cyan.
12 Colour negative.
13 B/W positive.
14 Strict filters.
15 Internegative.

Chapter 6

PRESERVATION OF COLOUR FILMS BY MEANS OF COLOUR SEPARATIONSON BLACK-AND-WHITE FILM

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6.1 Colour analysis

6.1.1 Any colour photographic process may be shown as a system consisting of a group of interdependent operations from which we can emphasize three distinct stages:

a) colour analysis into three basic spectral zones: blue, green, and red;

b) the gradation of colours; i.e., the relationship between the amount of light acting on the photographic emulsion and the amount of dye which is finally formed;

c) synthesis or recombination of the three separate colour records.

In Figure 6.1, a colour photographic process is shown schematically. During photographic exposure, the light coming from the multicoloured object (1; refer Figure 6.1) is divided into three basic spectral zones: blue, green, and red (2). These form a triad of optical images which, in contact with the photosensitive layer and under the influence of the chosen parameters for exposure, form three latent photographic images (3). By developing these to determined parameters (4), we obtain three distinct photographic images called colour separations (5) which are images formed by blue, green, and red light, respectively. By recombination of these three colour records (6), we obtain the complete colour photographic image (7) of the photographed object. Both exposure and development of each triseparation can be adjusted so optimum quality is obtained.

6.1.2 The colour analysis may be achieved in either of two ways:

a) by means of three colour filters each of which transmits only one of the three primary colours: blue, green, and red;

b) by using three photosensitive emulsions each of which is sensitive to only one of the primary colours.

The images obtained by the colour analysis may be recorded on black-and-white panchromatic film or on a multi-layer colour film.

The triad of photographic images obtained on black-and-white panchromatic film is called "black-and-white colour separations" or "triseps". These can be negative or positive.

6.1.3 In the past, colour separations were used in the original colour photography; i.e., separation negatives were created in the camera.

The modern method of colour photography is based on the use of colour photosensitive materials and chromogenic development. In this case, the colour photographic process is far more complex than that shown in Figure 6.1, because intermediate stages and disturbing supplementary effects are involved.

Although the colour analysis is basically a division of light into three spectral components, in terms of a real colour photographic process, the optical phenomena are affected by properties of the photographic materials.

6.1.4 According to the general principles of the subtractive colour photographic process, the colour synthesis has the following basic requirements. The absorption dyes of the negative and the spectral sensitivities of the positive materials must be such as to ensure that the formation of each dye in the positive is controlled by a single dye in the negative. This means that the absorption of the dyes and the sensitivity of the photosensitive layers must be limited to a third of the visible spectrum so as not to penetrate into any other part of the spectrum.

In practice both the spectral sensitivity of the photosensitive layers of the colour photographic materials and the spectral absorptions of the dyes, which form during the processes of chromogenic development, are far from ideal.

6.1.5 The character and the degree of the colour distortions caused by the deficiencies of the colour analysis may be various and they depend on:

a) the original colour;

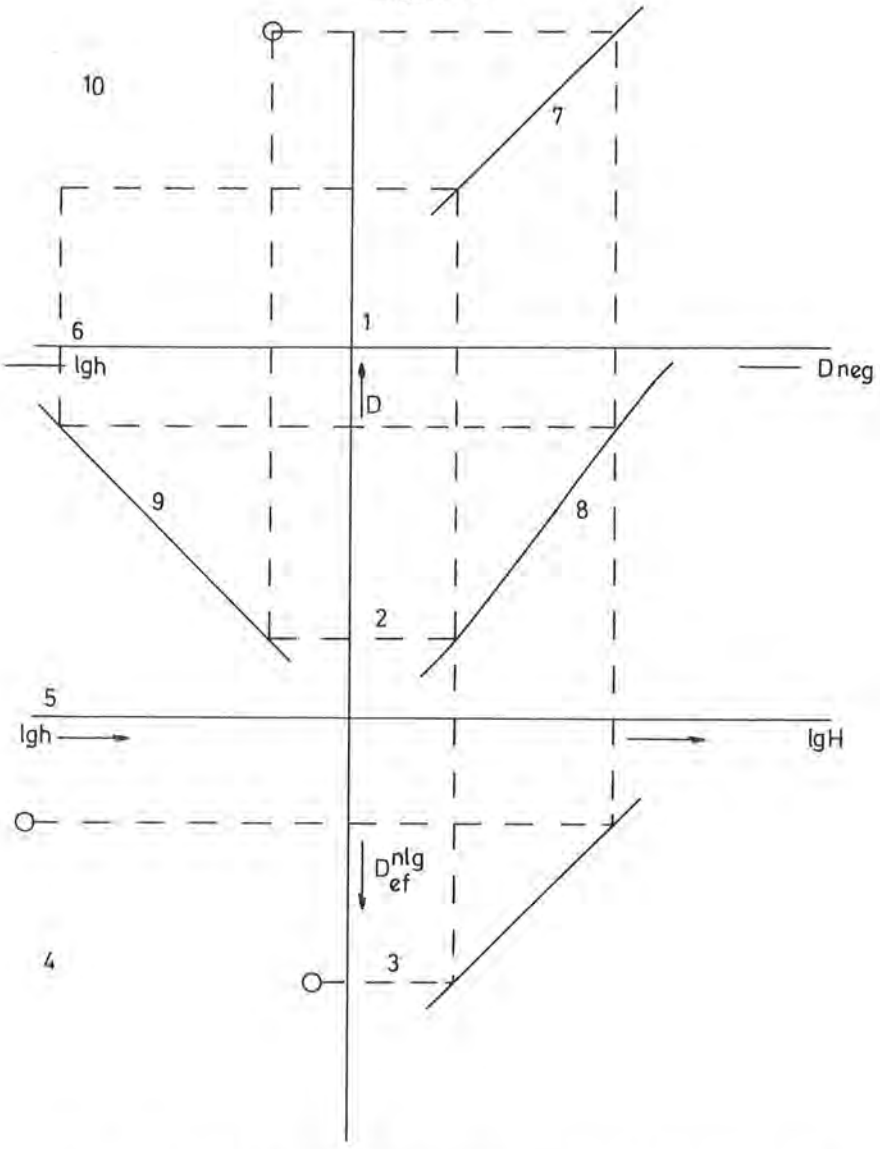
b) the spectral sensitivity of the elementary photosensitive layers of the exposed materials;

c) the spectral absorption of the dyes of the separation intermediary forms of the colour (e.g. the dyes of the elementary layers of the colour negative);

d) the spectral characteristics of the absorption media used during the exposure (e.g. filters);

e) the presence of some auxiliary phenomena like developing effect and the diffusion of the sensitizers and the couplers etc.

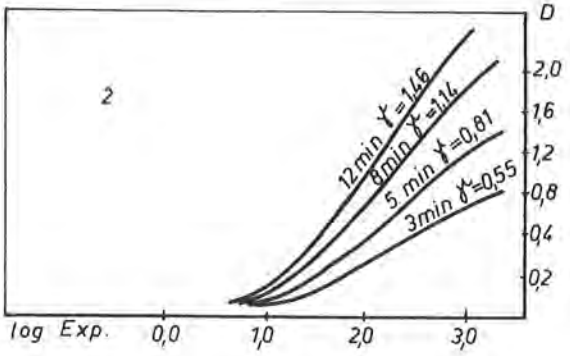
Figure 6-2

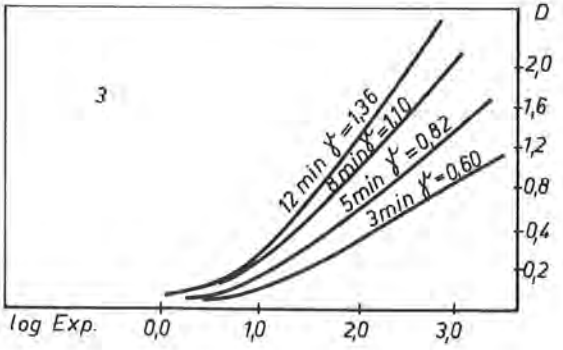


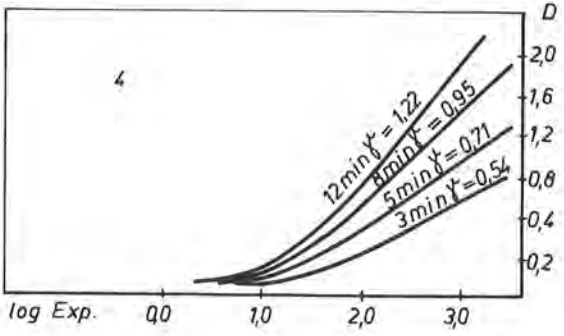
Illustrative diagram of the reproduction of tones for the process of realisation of colour contretypes by means of b/w separation films.

1 Quadrant 1.
2 Quadrant 2.
3 Quadrant 3.
4 Quadrant 4.
5 Quadrant 5.
6 Quadrant 6.
7 Internegative.
8 Reproduction curve.
9 Separation panchro film.
10 Transfer curve.

Figure 6-3







Adaptation of Eastman Separation panchro film type 5235.

2 Exposure with wratten filter nr 70.
Development in bath D_{76} at 20° C.

3 Exposure with wratten filter nr 98 of 47 B + 2 B.
Development in bath D_{76} at 20° C.

4 Exposure with wratten filter nr 99 or 16 + 61.
Development in bath D_{76} at 20° C.

6.2 Colour separation on black-and-white photo-sensitive materials

6.2.1 A particular case of the usage of the colour analysis process is represented by the achievement of black-and-white colour separations. Nowadays motion picture technique benefits from a special film for this type of work, namely the Eastman Panchromatic Separation Film types 5235 (35 mm) and 7235 (16 mm); (see Figure 6.3).

The colour separations achieved on this type of film are employed to obtain colour duplicate negatives (internegatives). Note that the matrices used in the Technicolor dye-transfer printing process were derived directly from the original colour negative.

6.2.2 Film archives may be particularly interested in the process of duplicating colour films through black-and-white positive separations.

According to this process (see Figure 6.1) the original colour negative image is printed through three narrow-band filters (blue, green and red) onto the separation black-and-white panchromatic film. At this printing stage, the dyes of the original colour negative control the light reaching the separation film. Three separation positives are printed each through a filter of one of the primary colours (blue, green and red). Then these colour separations are printed in exact superimposition onto an Eastman II intermediate-type film using the same set of narrow-band filters used in the printing of the separations.

After processing the exposed intermediate film a colour duplicate negative is obtained, which makes it possible to obtain a colour positive print similar to a positive print obtained from the original colour negative. This requires that the process is so controlled that the densities of the internegative (D^{IN}), corrected with the values from its printing program tape, are the same as the densities of the negative (D^{N}) also corrected with the values from its printing program tape. In other words, the actual printing values of the densities of the two materials must be the same:

$$D_{act}^{IN} = D_{act}^{N}$$

6.2.3 An effective method for qualitative estimate of the whole duplicating process may be the reproduction diagram or graph of the tones.

In Figure 6.2, the diagram of the reproductions of the tones in the colour duplicating process with black-and-white colour separations is shown in schematic form.

6.2.3.1 The reproduction fidelity of the tones is estimated in this diagram by the resulting reproduction curve which, in a correctly executed process, is plotted by a straight line lying at 45 to the two co-ordinate axes

D^{IN}_{act} and D^{N}_{act} .

6.2.3.2 To achieve a good separation of the colours we must ensure the following conditions:

a) the spectral absorption zones of the selected filters must correspond to the spectral absorption zones of the dyes which form the three partial images of the colour negative;

b) the spectral absorption zones of the narrow-cut filters used to recombine the separation images must correspond to the maxima of the spectral sensitivities of the three photosensitive layers of the intermediate film.

6.2.3.3 For making black-and-white separations of films produced on Eastman II colour negative film, we recommend the use of the following filters:

a) Kodak Wratten filter N98 or N47B + N2B (blue separation)

b) Kodak Wratten filter N99 or N16 + N61 (green separation)

c) Kodak Wratten filter N70 (red separation)

6.2.3.4 The correct reproduction of the tones is possible, as we see in the diagram, only if a few principal conditions are observed as follows:

a) the interval of the densities of the original negative D^{N}_{act} (quadrant 1) must be placed on the rectilinear portion of the characteristic curve of the separation film (quadrant 3);

b) in the recombination of the three separation images onto the intermediate film, the maximum densities of the colour separations must be placed at the beginning of the rectilinear portion of the characteristic curve of the internegative (quadrant 5);

c) the processing of the three colour separations must produce the same printed contrast factor for the three images ($\gamma = 1,0$). It is important that the contrast factor is conditioned also by the spectral composition of the light with which printing is done. This is why the three colour separations require various processing times to obtain the same contrast. The separation in red light, for instance, will be processed less than the separation in blue light.

6.3 The preservation of colour films in the form of black-and-white colour separations

6.3.1 The black-and-white colour separations, which are formed of metallic silver, can be a technological solution with real preservation advantages over coloured photographic images. This is because the silver image offers a much higher resistance to the action of the external factors (temperature, humidity, light etc.) than an image formed of dyes.

With that in mind, one can use the separation technology and store colour film in the form of black-and-white positive separations under less stringent conditions. In uncommon cases, when the original colour negative is not available and there is only a colour positive, it is possible to make separation negatives from this, on panchromatic duplicating negative film.

Colour separations may be made on three separate rolls of film or by printing blue, green and red record frames successively onto the same roll of film.

6.3.2 The preservation of colour films on three distinct black-and-white films presents serious difficulties such as:

a) the three separations which are printed on separate films may present difficulty in printing back onto the colour intermediate film, if they have suffered different degrees of shrinkage while in storage. Printing colour separations on films with polyester base could offer a substantial contribution to the avoidance of this problem. Unfortunately the manufacturers do not yet produce this type of film on polyester base; however, Kodak has stated that they are prepared to supply black-and-white duplicating stocks on polyester base;

b) the superimposing of the three images onto a single film requires special high precision printing equipment;

c) the colour film duplicating technology by means of colour separations is very complex from the technical point of view and demands specialized staff and equipment for film processing. The superimposing of three images can only be done with the same accuracy as the original printing of the separations. It is necessary to use the same particular perforations to register the film when recombining as was used for registration in making the separations;

d) the use of this preservation procedure for colour films involves increased film consumption and additional storage space.

6.3.3 The difficulties arising from different shrinkage of the base of the three separations prompted the idea of developing a preservation method for colour films in the form of black-and-white colour separations printed on a single strand of film.

The three separation images could be printed upon a single film by different methods. Jean Vivié proposed some arrangements which could have practical advantages as described in the following paragraphs.

6.3.3.1 Images in succession

The most elementary arrangement of the three separation images can be printed on 35 mm film by making every third frame one of the given colours.

It is possible to reduce the amount of film used by choosing to advance the film in intervals of 3 perforations, i.e. 14.25 mm. The three separations can be recorded, in this case, in 1:1 ratio according to the format 1:1,65 (13,25 x 22 mm) or with a slight reduction of the normal format 1:0,87 which will give images of 14 x 19,5 mm (see Figure 6.4a).

6.3.3.2 Triad of normal images on 65 mm film

The use of 65 mm film to obtain the colour separations offers new possibilities for arranging the images. Thus in the variant shown in Figure 6.4b, the three normal format images (16 x 22 mm) are placed on the width of the film, while leaving a space for the sound track as well. The recording in this case is achieved by a single exposure with the help of an optical block and the film is advanced five perforations at a time.

Another arrangement is shown in Figure 6.4c. According to this variant, the image is recorded with the help of a quadruple optical complex and the film is pulled down alternately with 4 and 7 perforation intervals.

6.3.3.3 Use of unequal sized images

The images of a tri-chromatic separation do not contribute equally to the quality of the colour image which is printed from them. The green separation is of primary importance. With this in mind, a method was suggested to print the images with unequal areas (Painlevé-Dufour process) in the form of two reduced images placed side by side and above them a normal sized one (see Figure 6.4d). The advance of the film in this case is at 6 perforation intervals (28,6 mm).

6.3.3.4 Reduced images triad

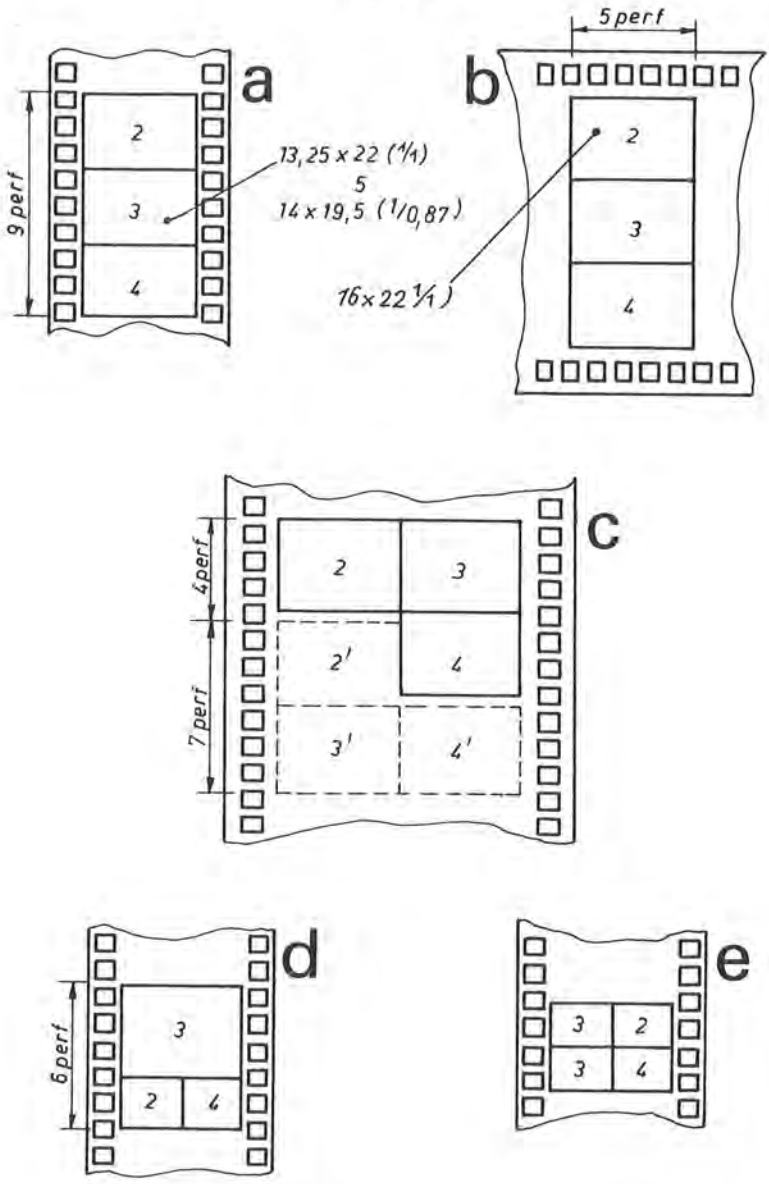
The most economical solution to this problem is the employment of a "Rouxcolor" type quadruple optical block supplying four reduced frames of 8 x 11 mm within the area of a normal 35 mm academy frame (see Figure 6.4e). For a minimum loss of definition it is possible to obtain two green images, the other two being the blue and red images. This solution is similar to the preceding variant shown in Figure 6.4d.

6.3.4 The preservation system of a colour film in form of black-and-white colour separations recorded on a single band has two disadvantages which cannot be ignored. These are

a) the impossibility of developing the colour separations to different contrasts. This situation can have repercussions upon the reproduction process of the tones, which, as we have seen, requires control of grading of each separation. Within some limits ($\gamma \simeq 0.3$), the contrast of a separation can be modified (i.e., reduced by a uniform supplementary lighting);

b) the necessity of using high precision printing equipment both when making the separations and when re-combining them onto intermediate colour film.

Figure 6-4



Possibilities of the disposition of colours on one single film.

2 Blue.
3 Green.
4 Red.

Existing restoration methods using colour separations do not permit mass production which limits the use of this method to individual examples. For these reasons, as well as the uncertain quality of the end product, the large-scale experiment which the Service des Archives du Film (Bois d'Arcy) has conducted, using a machine built by Armand Roux from Jean Vivié's ideas, has now practically been abandoned. In Rumania there has been some research to obtain the correct gradation of three colour separations recorded on a single film.

During 1985, Paul de Burgh of the London Archive successfully re-combined four feature films from separations made on nitrate film in the late 1930s and early 1940s.

Chapter 7

REGENERATION AND RESTORATION OF THE COLOUR IN MULTILAYER COLOUR FILM

By Dumitru Moruzan, Director,
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The poor stability of the dyes which form the image in current colour films result in the gradual degradation of the colour images, and hence to the destruction of the artistic and documentary values they represent.

The restoration of colour films which have suffered colour deterioration during the years is one of the most acute problems of film archives.

7.1 Ascertainment of the degree of the degradation of the dyes

The restoration of the colour images raises particularly complex technical and technological problems. Film archives preserve colour pictures made upon different types of films. The image of these films can present different colour degradations depending on the chemical nature and individual properties of the dyes, the photochemical processing and the storage conditions. This is why the development of a general technique for the restoration of the images is not possible. Each film constitutes a particular case and requires the choice of the most adequate technical process of restoration. The restoration of colour films is a difficult problem due to the necessity to ensure an irreproachable reproducibility of the results of the restoration process performed on each frame and the whole film. This condition practically excludes the possibility of performing a manual operation of restoring each frame of a colour film. This is why one must use only industrial technologies and modern film processing equipment.

As a general rule, the restoration of a work of art or of a historical document (paintings, printed matter etc.) is done with the help of a system of operations performed directly upon the original piece (fresco, painting or printing). In the case of films, the image seen on the screen is not usually the original and the restoration may therefore be performed at various stages in the production of the final print.

The correct control of the restoration process requires an objective system of estimating as precisely as possible the degree of dye fading.

Unfortunately, archives cannot make an objective assessment

if no test frames, grey scales or typical scenes survive. In these conditions it is difficult to determine what initial distortions the image had and what was later added.

The difficulties are greater in the case of negative colour images in which the colours are complementary to those of the positive print, and with the naked eye it is difficult to appreciate from the colour balance of a negative how the colours will appear in a positive print. Television techniques can assist in the assessment of negatives. The Hazeltine-type grading equipment provides a positive image on a television screen, from which one is able to estimate the level of chromatic distortions and their type.

Using the above techniques, archives could organize a periodic inspection and take the most efficient measures to preserve and restore their colour films. For this purpose, a closer co-operation between film archives and film processing laboratories is often required.

7.2 Methods of restoration

Taking into account the current techniques of recording and preserving information, film archives could approach the problem of colour image restoration by either chemical or photographic means.

At present the possibility of restoring the colour images by using video techniques is limited because the picture resolution is insufficient. Moreover, few archives have access to these techniques.

7.2.1 Chemical restoration

Chemical restoration of colour images consists of chemical treatments, including selective reduction and intensification of the degraded original colour images in an attempt to restore the colour balance.

The dyes which form the three colour images (yellow, magenta, cyan) respond in different ways to various chemical reagents such as acids, oxidizing and reducing agents etc. It is therefore possible to reduce the density of the dominant dye image. For instance, under the action of acids, the magenta azomethine dye is easily destroyed while the cyan indoaniline dye is much more resistant. In this way the magenta partial image can be reduced with weak acids without the cyan and yellow partial images being modified.

Other chemical agents with selective action can also be used. The specialized literature and the film manufacturers recommend various reducing agents for the correction of dominant colours. In the field of motion picture films, film archives have not yet sufficiently verified these recommendations. Their application requires extreme care.

The chemical reduction of colour images is not possible when the initial density is so low that a further reduction would worsen the situation. In this case it it necessary that the

image, which has already suffered some fading, should be intensified.

Colour images which have been produced by colour development processes using non-diffusing colour couplers can be intensified.

However, chemical restoration of colour images has a reduced applicability due to its disadvantages:

a) the risk of irreversible destruction of the image due to insufficiently controlled action of the chemical agents;

b) the risk of a mechanical destruction of the films during the chemical treatments;

c) the uncertainty that the results of tests are reproducible.

7.2.2 Photographic restoration

Photographic restoration consists of the correction of colour image distortions through printing onto other films, using the corrective possibilities of the photographic process both in the printing and the development stages.

The restoration of colour images by photographic means ensures a maximum safeguarding of the original film, and possibilities of establishing reliable and reproducible technologies based on objective assessments.

Photographic restoration offers controlled correction of both the dominant colour and the chromatic imbalance between the lights and shadows in the image.

Photographic technologies of restoration are based upon the normal techniques of film processing laboratories which are as follows:

a) The image density and its dominant colour are corrected during the printing process by using appropriate printing light.

b) The chromatic imbalance between the light and the shadows of the image is corrected by modification of the contrast of the film onto which the image is printed. To do this, it is necessary to modify independently the contrast of each partial image by

ba) selective and homogeneous pre-exposure of the photosensitive emulsions (flashing) or

bb) printing of a set of black-and-white separations or

bc) printing with masks (using the flashed dupe mask method).

c) The colour distortions generated by the parasitic

absorptions of the dyes could be eliminated only by the corrective masks of the colour separations. With that end in view, one extracts the images formed by the parasitic absorption of the dyes upon panchromatic black-and-white film using appropriate filters.

The printing process using colour separations can be achieved either by means of colour separation upon black-and-white panchromatic films or by successive printings through narrow-band filters onto colour stock.

Taking into consideration the technologies used by the film processing laboratories, it should, theoretically, be possible to use the schemes of photochemical restoration shown in Figures 7.1 and 7.2.

The variants of colour restoration which make use of colour separations have undeniable advantages, namely:

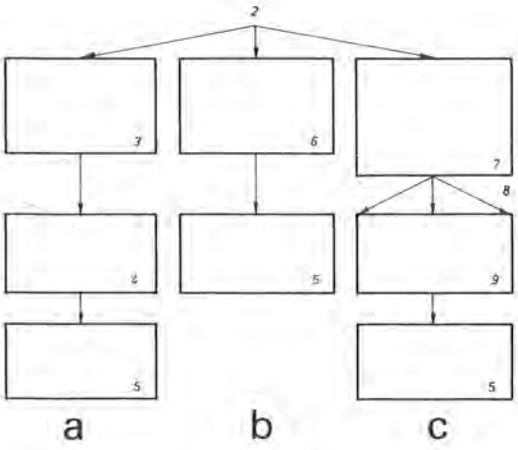
a) they permit the correction both of the fundamental dominant colour and of the balance of the chromatic contrast;

b) they permit the correction of the parasitic absorption by use of external masking of the colour images;

c) the black-and-white colour separations offer better conditions for long-time preservation of the colour images.

The technologies for printing colour separations require special printing equipment which ensures the exact superimposition of the three separate images in the process of re-combination onto a single film.

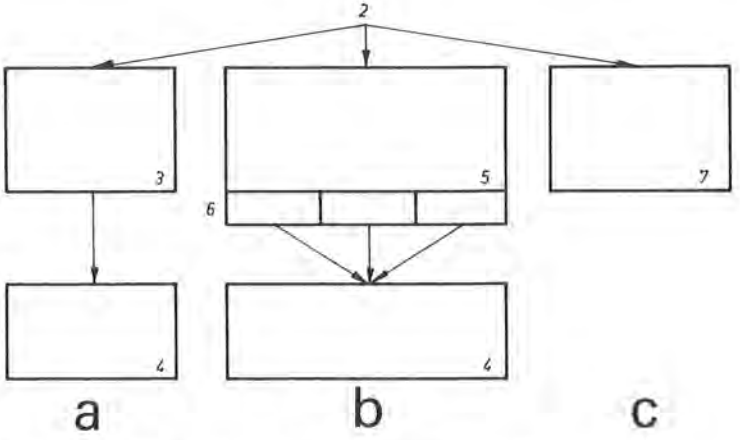
Figure 7-1



Restoration of negative colour images by correcting printing.

2 Original colour negative.
3 Dupe colour positive on intermediate film.
4 Dupe colour negative on intermediate film.
5 Colour copy on positive colour film.
6 Dupe colour negative on reversible intermediate film.
7 Dupe black-and-white positive separation on panchromatic separation film.
8 Blue – green – red.
9 Dupe colour negative on intermediate film.

Figure 7-2



Restoration of positive colour images by correcting printing.

2 Original colour positive.
3 Colour negative on negative colour film.
4 Copy on positive colour film.
5 Colour selections on dup panchromatic negative film.
6 Red – green – blue.
7 Copy on reversible colour film.

Chapter 8

SOUND IN FILMS
HISTORICAL DEVELOPMENT AND PRESERVATION METHODS

By Anatoli Polischko, Former Head
of the Sound Department of Gosfilmofond, Moscow

8.1 Sound recording methods used in cinematography

8.1.1 Brief historical survey

Thomas Alva Edison produced his Phonograph in 1877. He then sought means of making pictures to accompany the sound and thus created the Kinetoscope. This he linked mechanically to the phonograph to form the Kinetophone, making it possible to present sound and picture together.

Attempts to provide sound accompaniment for motion pictures were made in the earliest years of the "golden age of silent films". The French film historian Georges Sadoul reported that Louis Lumière instructed somebody to read the actors' lines from behind the screen. Since 1900 a number of devices for motion picture projection with sound on gramophone records were used (Charles Pathé, Oskar Messter, Leon Gaumont, and others). The main drawback of this method was that image and sound were recorded on different media and their simultaneous reproduction during projection was a problem.

The most technically promising invention was made by Eugene Lauste (1906) who worked out a system of photographic recording of sound oscillations onto film. From 1910 efforts were made to use commercial cinema films with photographic sound. However, due to the low quality of sound, the recommended systems did not find widespread application. Some systems of sound cinematography were introduced in the late 1920s. In the 1930s dialogue, music and separate effects were recorded independently onto three films. During the final cutting they were mixed onto a 35 mm negative sound track intended for printing release prints; precise synchronisation of sound and image being provided. Among the successful systems was the Triergonfilm (Vogt, Engl and Macholle in Germany).

In the late 1940s magnetic sound recording was introduced. Magnetic sound recording is used primarily in post-synchronization of motion-picture films in studios as it allows immediate replay, provides the possibility of multiple recording on one and the same area of magnetic tape and is of higher quality than a photographic sound track.

Most release prints for movie theatres are still produced with photographic sound track. This is due to the fact that photographic track and image recorded on one and the same medium is less expensive; and more convenient in exploitation. At the same time, motion picture films with multichannel stereo sound are produced with either magnetic sound or Dolby optical sound track.

8.1.2 Photographic (optical) sound recording

Photographic (optical) sound recording is based upon the physical principle of transforming sound oscillations into variations of light flux which affects the light-sensitive emulsion; after development a sound track is formed (see Figure 8.1). Light-modulating devices modulate the length, width (90^{o} to film direction) or illumination of a recording slit in accordance with a recording signal. Changes in the slit width lead to a variable-area recording, while changes in the slit length or the modulation of its illumination result in variable-density recording (refer Figure 8.2).

The reproduction of the optical sound track is based on the changes in the light flux which passes through it to reach the photocell. In the course of recording and reproduction the film moves at a speed of 24 frames per second (45,6 cm/sec and 18.3 cm/sec for 35 mm and 16 mm films respectively).

Types and characteristics of optical sound tracks depend greatly upon the type and characteristics of the light-modulating devices (galvanometers and light valves) used in recording. Their classification is given in Figure 8.3.

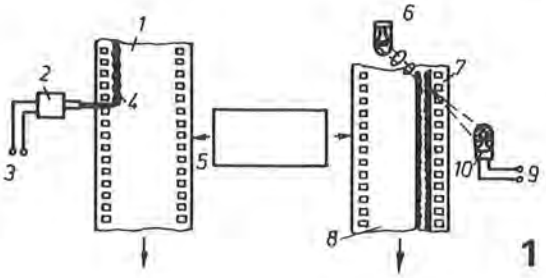
Modulators used for some time in the early 1930s modulated the light flux by means of various electro-optical phenomena (for instance, in the Klangfilm and Tagephone systems). They produced variable-density sound records. The same years saw the application of electro-mechanical modulators (RCA electro-magnetic and magneto-electric devices, such as the Alexander Shorin tape oscillograph and the mirror modulator of the Klangfilm system). In this case both unilateral and bilateral variable-area sound tracks and variable-density tracks were obtained.

Magnetoelectric mirror galvanometers were mainly developed between 1930 and 1937.

The problem of expanding the dynamic range of sound transmission has resulted in the invention of devices for making the sound track noiseless by reducing the level of the noise due to the film itself. The exposure value was reduced when recording variable-density sound tracks (at signals of low value and during unmodulated passages). Noise reduction in such systems is about 6-8 dB.

Light-modulating devices with noise reducing shutters were introduced into variable-area sound recording. According to the envelope of the recorded signals, the shutters move up

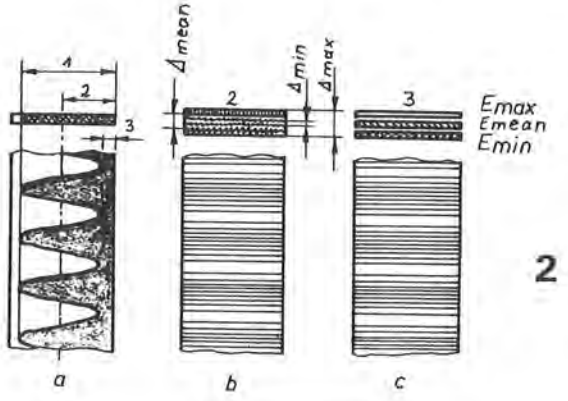
Figure 8-1/2/3



1

1 Principles of photographic sound recording and reproduction

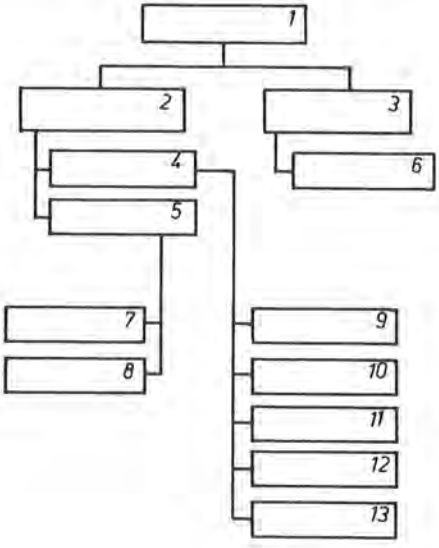
1 Light sensitive film.
2 Light modulator.
3 From recording amplifier.
4 Recording beam.
5 Sound record development and printing.
6 Exciter lamp and optics.
7 Scanning beam.
8 Film with printed sound record.
9 To sound reproduction amplifier.
10 Light sensitive element.



2

2 a variable-area and b and c variable-density of sound records.

1 Maximum.
2 Mean.
3 Minimum.
4 Δ max Δ mean Δ min
5 E max E mean E min

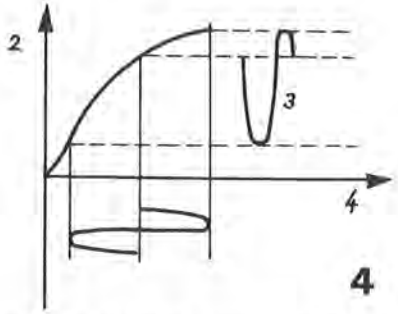


3

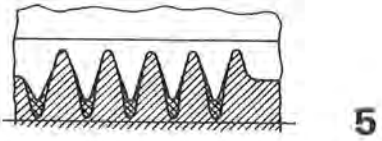
3 Classification of light modulators used in sound recording and reproducing equipment.

1 Light modulators.
2 Electromechanical.
3 Electro-optical.
4 Magneto-electrical.
5 Electro-magnetic.
6 Kerr cell.
7 Mirror-type with movable mirrors.
8 With movable shutter.
9 Coil mirror, rotating type.
10 Coil mirror, pull-in type.
11 Loop mirror type.
12 Tape oscillograph.
13 Loop oscillograph.

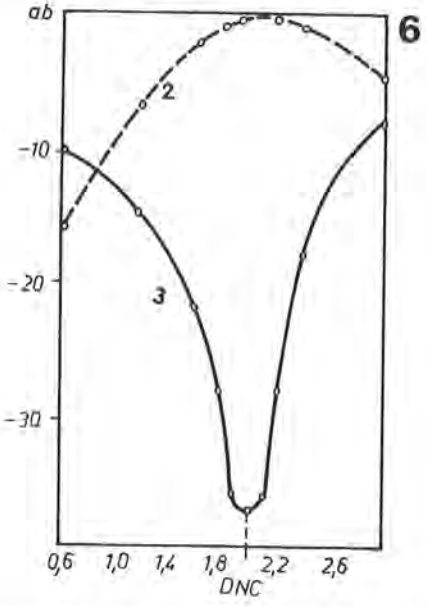
Figure 8-4/5/6



4 *Non-linear characteristic of photografic transmission distorting the signal shape.*
2 Tr
3 $Tr = {}_1(H_N)$
4 H_N



5 *Thunder effect in variable-area sound record.*



6 *Graphic determination of compensating density of sound record negative D_{NC}*
2 Output.
3 Distortions.

and down (parallel to the width of the slit) relative to the mechanical slit and thus vary the illuminated areas of the recording slit.

In some systems used during the early 1930s, the film noise is reduced by displacement of the centre line of the sound track. In this method both audio frequency current and low frequency current are applied to the galvanometer, the latter current corresponding to the envelope of the sound signal and inducing an additional turn of the mirror, which results in the displacement of the centre line of the film sound track. In these cases noise reduction is about 8-10 dB.

Another problem in obtaining optical sound records was sound transmission with minimum non-linear distortions. Proportional relation between the value of the transmission factor of individual areas of the positive and the values of the exposures of the corresponding areas of the sound record negative is the condition for undistorted signal transmission for variable-density sound records. Figure 8.4 shows distortions due to the non-linear photographic characteristic of sound transmission. Linearity of the characteristic can take place only if the Goldberg condition is observed:

$$\gamma_{neg} \times \gamma_{pos} = 1$$

where γ_{neg} and γ_{pos} are the gammas of the sound negative and sound positive.

Sensitometric tests of the negative and positive films can be used to control variable-density sound records. Their characteristic curves provide the means for plotting a curve which is used to set the negative exposure, recording amplitude and printing conditions under which non-linear distortions are small. Due to its features, however, this method does not provide high accuracy in choosing the optimum conditions for recording and printing sound records. The delta-decibel method, applied for a long period in the USA, is more efficient. It consists in the checking of the linearity of the entire region of the characteristic under different recording conditions.

The method of intermodulation has been used since 1946 to control the distortions of variable-density sound records. Special measuring signals with different unmodulated densities were recorded on the negative. After development, measurements were taken to determine the relation between the output and non-linear distortions on the positive density at different negative densities which provided a higher accuracy in choosing the optimum recording and printing conditions.

The conditions for recording and processing variable-area sound tracks have their own different problems from the point of view of undistorted sound transmission. The reason for this is the effect of the filling-in of the troughs between successive modulations when these are very fine

(high frequency sounds). This filling-in is due to diffusion of light within the emulsion (image spread). See Figure 8.5.

The filling-in of the troughs results in the appearance of low frequency components in the recording which, when reproduced, are heard as booms on sibilant sounds. This phenomenon (known as the thunder effect) was discovered as far back as 1925 by the specialists of the Siemens firm when recording was made over the entire area of a 35 mm film.

To reduce the distortion due to image spread, an attempt was first made to reduce the light diffusion in the emulsion, for which purpose a special fine-grain negative raw stock was used. It was later discovered, however, that it was possible to cancel the effect of image spread, provided that the image spread in the negative was matched by the image spread in the positive. Cancellation is achieved by selecting appropriate densities of the negative and positive. The instrumental method of determining the required densities is the most efficient. This method is as follows: Special signals are recorded on the negative at a range of densities. From this a positive is printed at the optimum density (between 1.2 and 1.8). Measurements are taken to determine the relationships between output and non-linear distortion. The curves thus obtained (see Figure 8.6) are used to determine the value of negative density at which greatest cancellation occurs, distortion is at a minimum, and there is sufficient output.

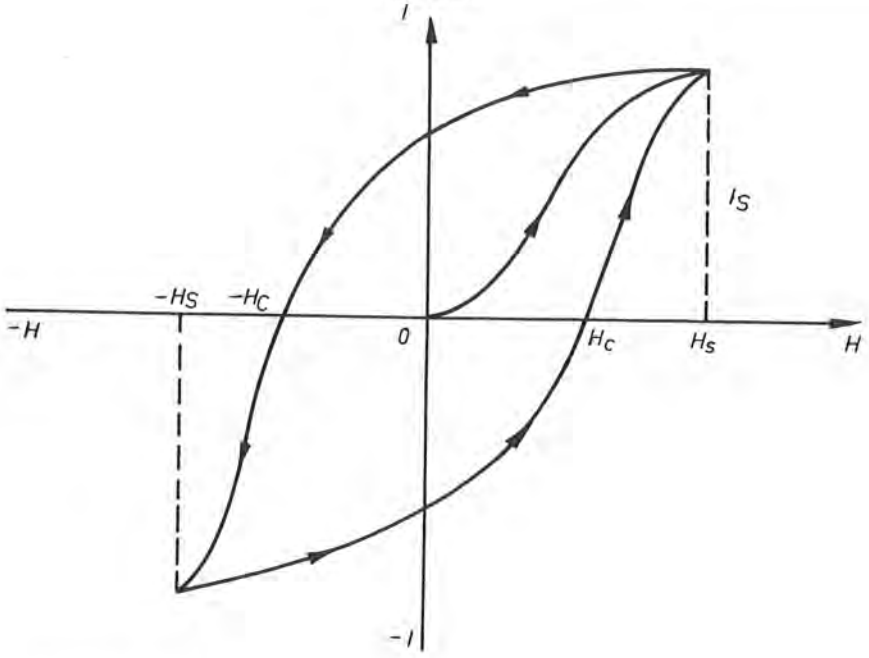
During the 1930s, there was considerable improvement in the performance of printing machines, prompted by study of their behaviour when printing sound tracks. The improvement enhanced the quality of the picture also.

8.1.3 Magnetic recording

Magnetic recording is based on the ability of ferromagnetic materials (iron, cobalt, nickel and chromium dioxide) to become magnetized under the influence of external magnetic fields and to retain a residual magnetization. In the simplest case, the change of magnetic field intensity from 0 to +H, then to -H and again to +H can produce a diagram illustrating the process of ferromagnetic body magnetization, limiting hysteresis loop (see Figure 8.7; here J_{rm} is the maximum residual magnetization of a ferromagnet; H_c, the coercivity; H_s, the magnetic field intensity resulting in magnetic saturation of a given body, and J_s, the saturation magnetization. Residual magnetization of a ferromagnet depends on the intensity value of the effecting external magnetic field, its magnetic susceptibility and relative permeability.

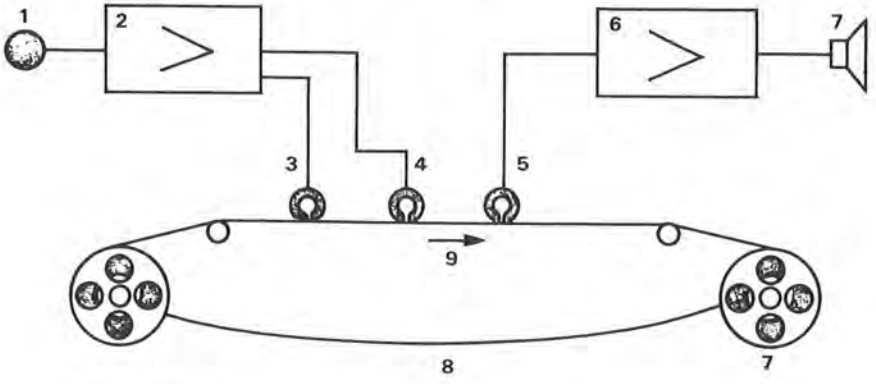
Figure 8.8 shows the functional diagram of a sound transmission chain based on magnetic recording and reproduction. As a medium for sound recording, a magnetic tape is used which consists of a plastic base (cellulose diacetate, cellulose triacetate or polyester) coated with a thin magnetic layer containing fine particles (fractions of

Figure 8-7



Hysteresis loop.

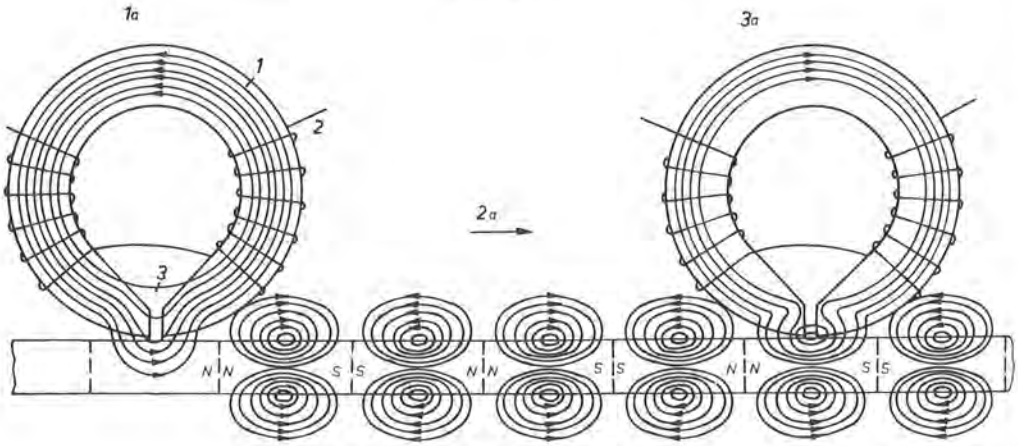
Figure 8-8



Magnetic sound recording and reproducing diagram.

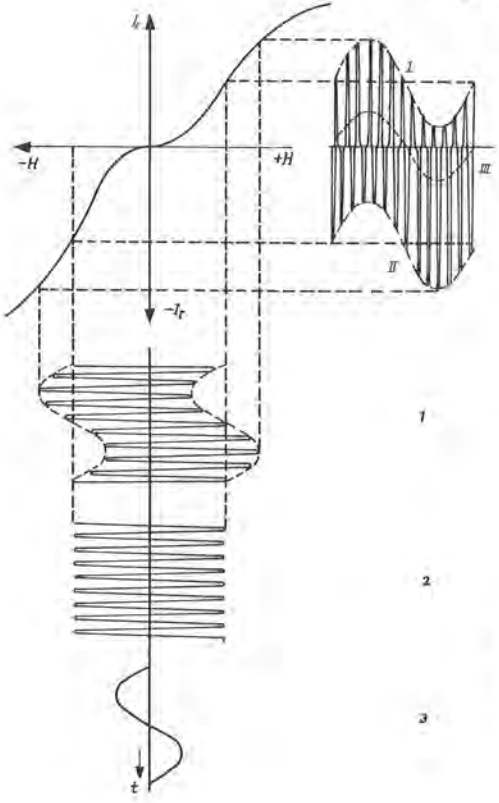
1 Microphone.
2 Recording amplifier.
3 Erasing head.
4 Recording head.
5 Reproducing head.
6 Reproduction amplifier.
7 Loudspeaker.
8 Pick-up.
9 Pick-up movement direction.

Figure 8-9



Magnetic recording on tape and its reproduction.
1a Recording head.
2a Tape movement direction.
3a Reproducing head.

Figure 8-10



Method of recording with high frequency biasing.
1 Total recording field.
2 Additional ultrasonic field.
3 Field of recorded signal.

a micron) of ferromagnetic material.

Recording is made in the following way. The recording head (winding 2 in Figure 8.9) is fed with acoustic frequency current which creates magnetic flux in core 1. A part of the magnetic flux is closed over the outer side of the core via air at the recording gap 3. It is that part of the magnetic flux which affects the ferromagnetic layer of the tape closely contacting the recording head surface at the gap when moving with a constant speed. After being magnetized, the tape comes from the magnetic field retaining its residual magnetization which varies along the tape length and thus forms a magnetic sound track.

The fact that the $J_r = f(H)$ relation is non-linear is the main reason for non-linear distortions in sound transmission. To reduce such distortions, sound recording with high frequency biasing, proposed by Heinrich Braunmühl and Hans Weber in 1941, was introduced.

This method involves passing a 60,000 Hz ultrasonic signal through the recording head winding simultaneously with the recorded signal. A composite signal (ultrasonic frequency alternating current whose mean value changes in accordance with the law of recorded oscillations) is formed in the recording head (see Figure 8.10). The mechanism of recording with high frequency biasing is complex and its theory has not yet been fully explained. When passing the working gap of the recording head, each element of the magnetic tape changes the direction of its magnetization several times; however, after coming from the magnetic field action zone, the tape is magnetized in accordance with the recorded signal. Residual magnetization during periods of no signal is practically zero and, hence, the background noise is also very low.

The maximum output of the recorded signal at the minimum non-linear distortion of each roll of magnetic tape is ensured by the setting of the optimum value of high frequency biasing current in recording.

A play-back head is used for reproducing the signal from a magnetic sound record. Lines of magnetic force of the sound record external magnetic field are closed through its core; as a result, electromotive force transmitting the recorded signal is induced in the head winding. In case of undistorted transmission the given signal must be proportional to the value of residual magnetization formed on the magnetic tape when recording.

Figure 8.11 shows the frequency characteristics of individual components in the magnetic recording and reproducing channel. They are rather non-uniform. The level of high frequency transmission in the recording and reproducing heads is reduced due to the finite width of the working gaps and their azimuthal skewness, finite size of the heads, eddy currents in cores, etc. For correcting the frequency response of transmitted signals, a control for increasing the high frequency components is provided in the

recording amplifier. To avoid overmodulation the relative increase of the highest frequency in recording is not to exceed 14 dB. Therefore, if a large amount of frequency correction is required, it is made additionally during reproduction.

In reproducing amplifiers a constant rise of frequency response at low frequencies of 6 dB per octave and adjustable high frequency correction are provided. The non-uniformity of the resulting frequency response does not exceed, as a rule, ± 2 dB.

8.2 Sound records

8.2.1 Types of optical sound records

Since the invention of sound film, two types of optical sound records have been used, namely variable area and variable density sound records. Depending on their purpose and recording features, sound records can be classified as shown in Figure 8.12. Further, each of these sound records can be negative, positive, black-and-white or colour.

The main advantage of variable-density sound records as compared to variable-area sound records is a smaller effect on sound quality of errors of uniform illumination. Such sound records were recorded by the apparatus of the Fox Case Movietone, Western Electric (later Westrex), RCA, Tagefon, early Klangfilm and Maurer systems.

Variable-area sound records permit the transmission of signals at the standard value of acceptable non-linear distortion with greater dynamic range (about 42 dB as compared to 35 dB in case of variable-density sound records). These sound records could be recorded by the apparatus of the Westrex, RCA, Maurer, Tobis, Auricon, Klangfilm, Reevesound, Lenkenap and British Acoustic systems.

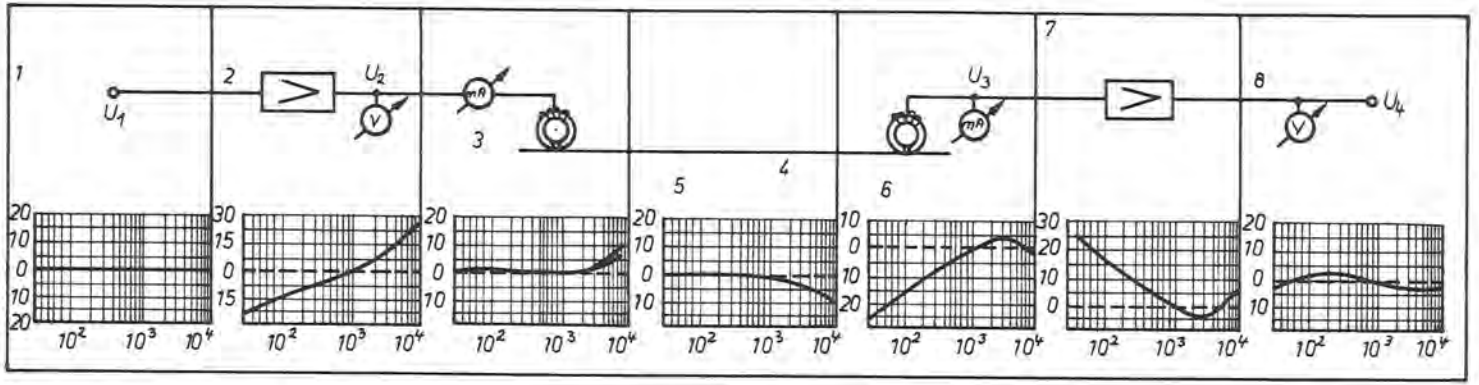
For both types of sound records, roll-off in the high frequency region is approximately the same due to light scattering in the photographic layer. The upper limit for the recorded frequency band is about 8 KHz on 16 mm film, 10-11 KHz (mono) and about 13 KHz (stereo) on 35 mm film.

It should be noted that it is difficult to differentiate between sound records of the same type recorded by the apparatus of different systems.

The sound quality of any type of sound record is determined by non-linear and frequency distortions, by the value of the transmitted signal dynamic range, and by background noise.

The sound records of the early 1930s are characterized by a high level of background noise (the dynamic ranges for variable-density and variable-area sound records were about 23 dB and 33 dB, respectively), by sharp sound change-over on spliced film sequences and discrepancy in the recording levels of speech, music and effects when heard

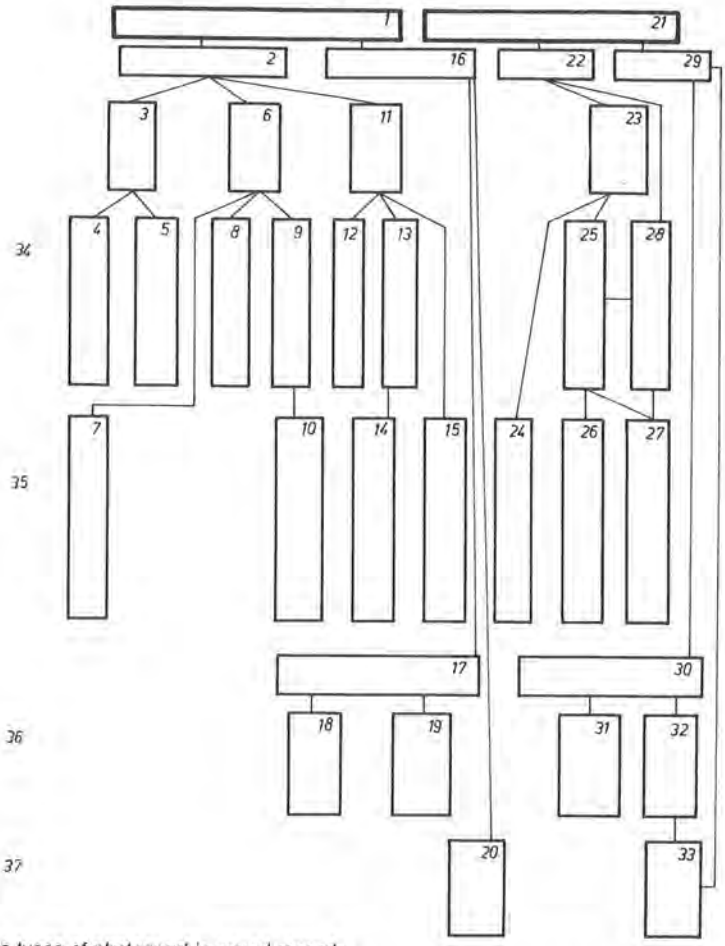
Figure 8-11



Frequency response of recording/reproduction channel.

1 Input signal.
2 Recording amplifier.
3 Recording head.
4 Tape.
5 Magnetization.
6 Reproducing head.
7 Reproduction amplifier.
8 Output signal.

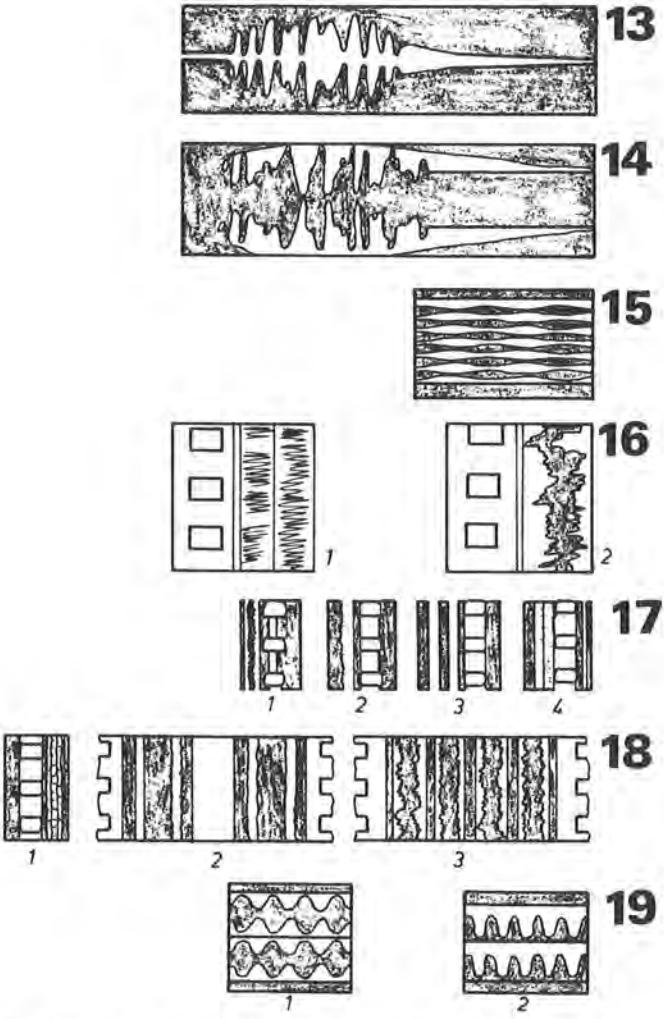
Figure 8-12



Basic types of photographic sound records.

1 Variable area sound track.
2 Single track.
3 Unilateral.
4 Noise reduction through displacement.
5 Noise reduction by schutters.
6 Bilateral.
7 Bilateral (class 'A').
8 Centre line displacement.
9 Noise reduction by shutters.
10 Bilateral (Class 'A') with noise reduction shutters.
11 Multitrack ('multitooth').
12 By centre line displacement.
13 Noise reduction by shutters.
14 Multitrack (class 'A') with noise reduction by shutters.
15 Multitrack (class 'A').
16 Multitrack.
17 With control track.
18 With amplitude modulation.
19 With frequency modulation.
20 Multichannel stereophonic.
21 Variable-density sound.
22 Single-track.
23 Constant area.
24 Class 'A'.
25 By mean density reduction.
26 Class 'A' with noise reduction.
27 Class 'A' with controlled area.
28 By controlling background area.
29 Multitrack.
30 With control track.
31 With amplitude modulation.
32 With frequency modulation.
33 Multichannel stereophonic.
34 Methods of sound transmission with noise reduction.
35 Methods of sound transmission with pushpull sound records.
36 Methods of sound transmission with control track.
37 Multichannel sound transmission.

Figure 8-13 tot 19



13 *Variable-area sound record rendered noiseless through the centre line displacement.*
14 *Double-track variable-area sound record rendered noiseless by special shutters.*
15 *Multitrack (6 tracks) photographic sound record.*
16 *Push-pull photographic sound records.*
1 Variable-density.
2 Variable-area.
18 *Different types of photographic sound records with controlling track.*
18 *Three-channel stereophonic sound records.*
1 ERPI Movitone.
2 Bell Telefon Laboratories (3 main and 1 controlling).
3 Fantasound (3 main and 1 controlling).
19 *Double-track photographic sound records.*
1 Bilateral.
2 Unilateral.

simultaneously.

The recording systems began to be improved by making bilateral variable-area sound records. Noise reduction equipment was first used in the mid-1930s; compression and limiting systems were used in the 1940s. Figure 8.13 shows a variable-area sound record rendered noiseless by displacing the centre line of the sound track, while Figure 8.14 shows a double-track sound record rendered noiseless by special shutters.

Later on, multi-track variable-area sound records with up to 14 tracks were used (see Figure 8.15). These records had a number of advantages such as lower non-linear distortion, less sensitivity to azimuth errors of the scanning beam and non-uniformity of its illumination. Multi-track sound records may be found in the film archives and a magnifying glass may be necessary to distinguish them from variable-density sound records.

In the late 1940s film studios used push-pull variable-area and variable-density sound records (mainly of Class "A") as intermediate recordings (see Figure 8.16). These sound records comprise two tracks recorded in a reverse phase mode (180° displacement). If they are reproduced on an ordinary apparatus, no useful signal is detected. During playback the light fluxes, after passing through each half of the sound track, have to be divided optically and fed to two separate photocells, and then the electric signals are summed, one being 180° out of phase with the other.

The sound quality of such sound records is much higher (broader frequency band, smaller effect of splicing etc.), but they found no wide application due to the need to have special playback equipment. This need was confined to the studio as the equipment was only used in the course of production - not on release prints. Their value for this use was overtaken by magnetic recording in the early 1950s.

Film archives may have sound records with a control track carrying a signal controlling volume level of the main recording, and permitting extension of the dynamic range by up to 7 dB. Figure 8.17.1 shows a control track consisting of a transparent strip of variable width in the spaces between the perforations. Figure 8.17.2 and Figure 8.17.3 show control tracks near the main sound track, and Figure 8.17.4 shows control tracks outside the perforations. Such sound records found rather limited application in sound films.

In the late 1930s, a number of countries conducted research to obtain stereophonic accompaniment for motion picture films on the basis of optical sound records. Among the most notable of these was Walt Disney's "Fantasia" which used three 200 mil push-pull optical programme tracks and a fourth control track adjusting the levels of the programme tracks. Various kinds of multi-track sound records were suggested (see Figure 8.18). But the research did not go beyond the frame-work of an experiment. It was only in the

1950s, when magnetic recording was mastered, that stereophonic sound transmission found practical application.

The double bilateral track has been in almost universal use since the 1950s, however the last decade has witnessed the widest application of double-track, noiseless variable-area sound records in release prints, which are characterized by lower non-linear distortions during playback as compared to single-track sound records (see Figure 8.19).

Another type is represented by sound records on multi-layer colour film. Colour sound films appeared in the late 1930s.

When printing sound records on multilayer colour films, special correcting filters control the spectral transmittance of the dense part of the sound track. The combination of cyan and magenta filters forms the sound record only in the upper, blue-sensitive, emulsion layer of the positive multilayer film (visually, such a sound record is yellow). The combination of cyan and yellow filters results in an image in the middle, green-sensitive layer (a magenta sound record), and the combination of magenta and yellow filters results in an image in the lower, red-sensitive layer (a cyan sound record).

Depending upon the photochemical processing employed, a sound record on multilayer colour film can be either dye only, or dye plus silver, or silver only. Due to a number of peculiarities of colour film, processing a dye-plus-silver sound record has the widest use. It is composed of both silver and dye, and its characteristics depend upon the content of silver as well as on the spectral characteristics of the exciter lamp radiation and photocell sensitivity.

In former times sound reproduction equipment used two types of vacuum photocells: antimony-caesium and oxygen-caesium. Germanium and silicon semiconductor photodiodes have recently been employed.

For printing colour films, the sound negative is made on a black-and-white sound-recording film. The method for selecting the cancellation density for a sound record negative does not differ from that of selecting the cancellation density for a negative in printing black-and-white films.

8.2.2 Magnetic sound records

Magnetic sound records have a number of advantages over photographic ones. The recording of sound on a magnetic tape ensures the transmission of signals with 50-60 dB dynamic range, the non-linear distortion coefficient being not more than 1.5%, and frequency band of 30-16,000 Hz.

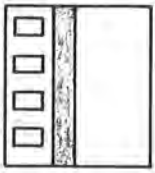
Magnetic sound tracks do not deteriorate as much as optical tracks as a result of wear.

The main drawback of magnetic sound tracks lies in difficulties in their editing, due to the invisibility of

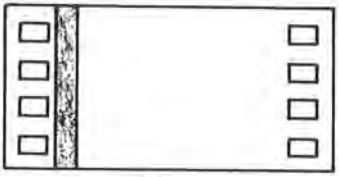
Figure 8-20



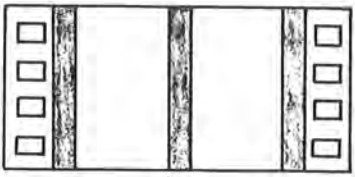
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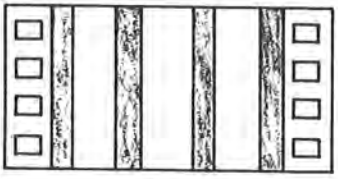
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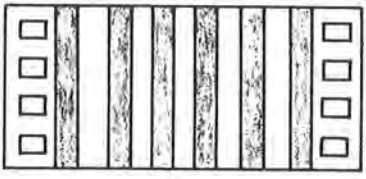
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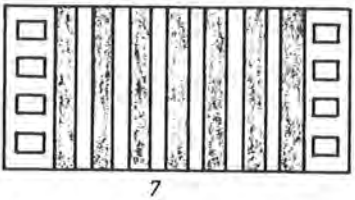
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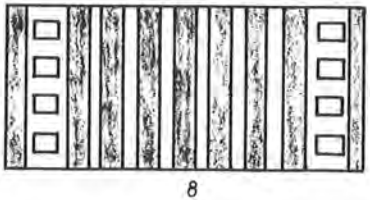
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6



7



8

Types of magnetic sound records.

1 On 6.25 mm tape.

2 On 17.5 mm tape.

3-8 On 35 mm tape.

the track, in difficulties in combining an image with a track on the same film, and their exposure to external magnetic fields. Film studios use magnetic sound records mainly to obtain intermediate and final-mix recordings. 6.25 mm (1/4") tape and 17.5 and 35 mm perforated film are used for this purpose. Figure 8.20 shows the various locations of the tracks on these films.

The recording on magnetic tape or film is invisible, which renders it difficult to determine the type of a magnetic sound record (the number of tracks). To render them visible, magnetic development methods are used. One of them is to cover the magnetic layer with carbonyl iron suspension in heptane or benzine. The volatile substance quickly evaporates and iron particles are concentrated on the magnetized parts of the surfaces, thus showing the recording trace. A special device (visualizer) can be used for this purpose. It is placed upon the magnetic layer of a sound record and the sound track becomes visible through its glass window.

Magnetic originals for mixing are produced on 35 mm film in the form of a single-track recording (Figure 8.20.3). The USA, Rumania, Poland, Great Britain and a number of other countries use a recording original which is a three-track magnetic sound record with separately recorded dialogue, effects and music (Figure 8.20.4). Such a sound record is used for release printing (the signals from the three tracks are mixed to be recorded on a optical sound negative). Effects and music tracks only are used for dubbing when the film is dubbed into a foreign language.

Beginning with the 1950s, the development of widescreen and later wide-format films resulted in practical application of stereophonic systems. For this purpose, 4-, 6-, 7- and 9-channel sound transmission systems were worked out. Re-recording magnetic originals were produced on 35 mm films with 4 to 9 channels (see Figure 8.20.5-8).

8.2.3 Sound tracks on release prints

Motion picture theatres use combined prints (image and sound) produced on 16 mm, 35 mm and 70 mm films. On them narrow, normal, widescreen, wide-format and panoramic pictures are printed. Sound tracks on them may be either magnetic or photographic and of different types with various numbers of channels.

In the early 1930s a optical sound record on a 16 mm release print was produced by optical reduction printing from a 35 mm sound negative. By the end of the 1930s, machines existed for recording sound on 16 mm film, and copies were then made by contact printing.

The sound quality of a 16 mm optical sound track is

inferior to that of a 35 mm track. The upper limit of the transmitted frequency range is usually about 8 kHz, while the reproduced dynamic range is 30-35 dB. Application of magnetic tracks on 16 mm release prints doubled the frequency range and increased the signal-to-noise ratio in reproduction up to 50 dB. The drawbacks of 16 mm release prints with magnetic sound records include their higher cost and unreliability: a sound record can be demagnetized and the magnetic track may be peeled off under unfavourable storage conditions. Therefore, optical sound records are mainly used in 35 mm, 16 mm and lately 8 mm prints. Figures 8.21 and 8.22 show the location of sound tracks on 16 mm and 35 mm release prints, respectively.

Scanning beams of 1.8 mm in width and up to 0.015 mm in length are used for reproducing 16 mm optical sound prints. In case of 35 mm optical sound prints, the figures are 2.15 mm and 0.023 mm, respectively.

Figure 8.23 shows the location of magnetic tracks on 35 mm Cinemascope prints with stereo sound. The main stereophonic sound record is on the first, second, and third wide tracks to be reproduced by three loudspeakers behind the screen, while the fourth, narrow track is used for recording effects reproduced by the loudspeakers located around the perimeter of the hall.

There is a type of Cinemascope print which has both a magnetic and optical sound track (the so-called "mag-optical" print). This type of print has a narrow magnetic track which occupies half the width of the normal optical sound track area (see Figure 8.24). This type of print is capable of being shown on installations which have either only magnetic or only optical track reproduction facilities.

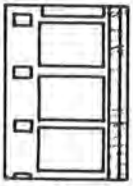
Figure 8.25 shows the location of magnetic tracks on a 70 mm print. The main sound, reproduced by loudspeakers behind the screen, is recorded on tracks 1 to 5; and effects on the sixth track.

In the 1950s and 1960s the USA and the USSR produced several panoramic films (three films were used for shooting). The sound record was recorded on a separate 35 mm magnetic film and reproduced simultaneously with the image projection. The American Cinerama system included sound on seven tracks, while the Soviet system used nine tracks (see Figure 8.20.7-8)

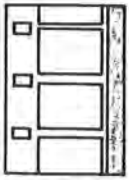
Since the film movement is intermittent during picture projection and during sound reproduction the film must move smoothly, the sound is always shifted with respect to the corresponding image in combined prints. In 70 mm prints, the sound delay is 24 frames; in 35 mm prints with optical sound, the sound is advanced 20 frames, and in 35 mm prints with magnetic sound, the sound is 28 frames behind the corresponding image. In 16 mm prints with optical sound, the sound is 26 frames ahead of the image, and in prints with magnetic sound, the sound is advanced 28 frames.

Figure 8-21 to 25

21

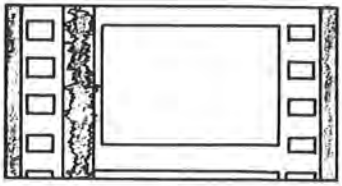


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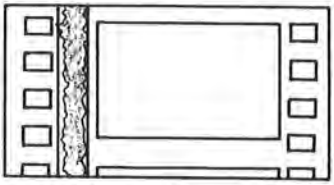


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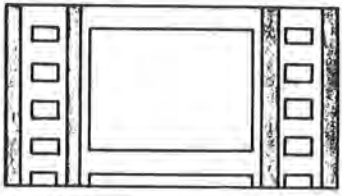


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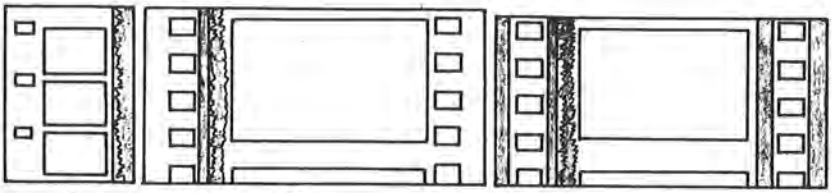


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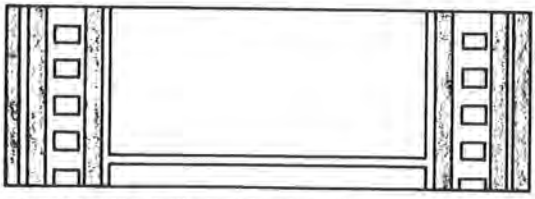


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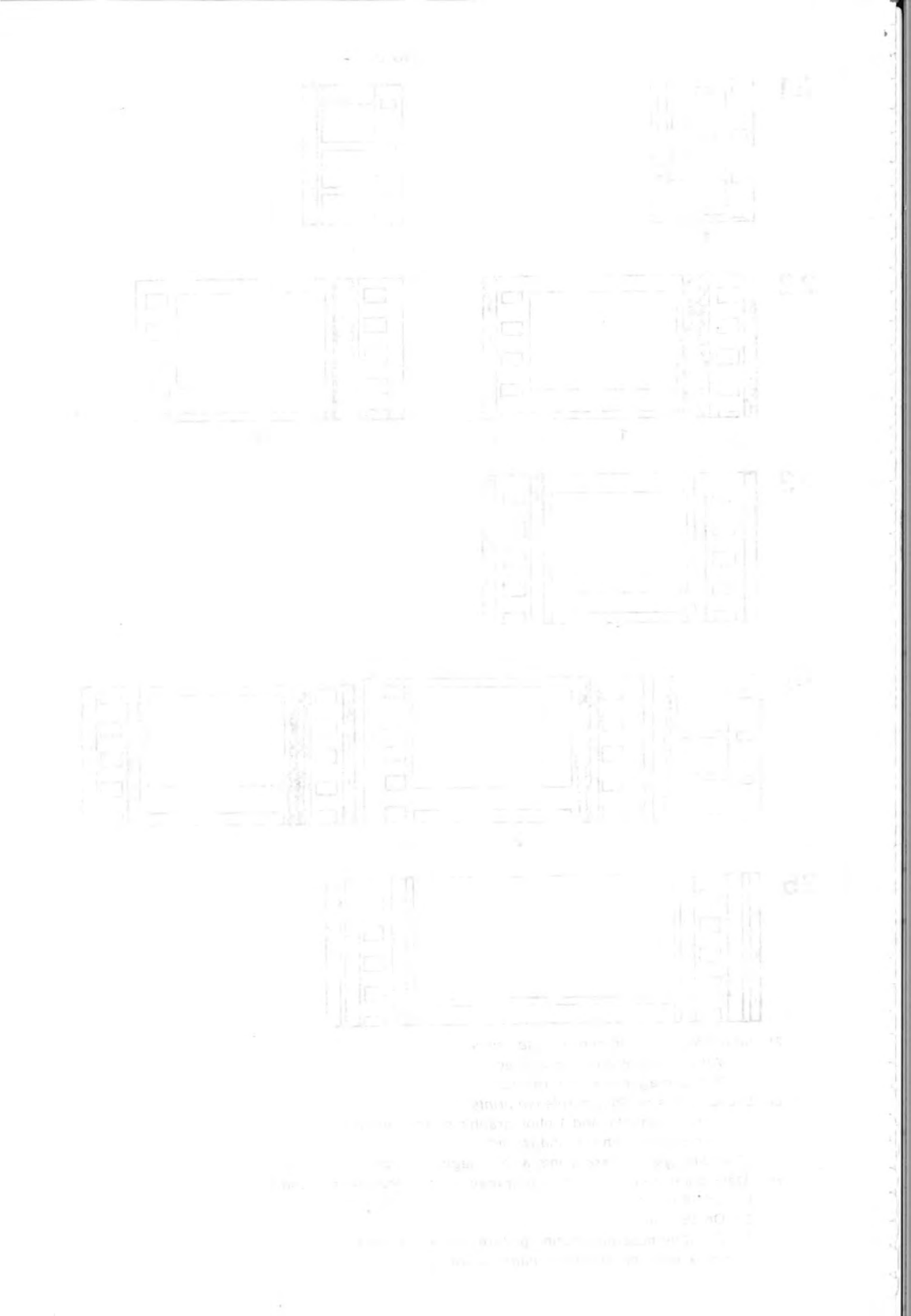
21 *Sound tracks on 16 mm release prints.*
- 1 With a photographic sound record.
- 2 With a magnetic sound record.

22 *Sound tracks on 35 mm release prints.*
- *1* With 2 magnetic and 1 photographic sound records.
- 2 With photographic sound record.

23 *'Cinemascope' release prints with 4 magnetic tracks.*

24 *'Madoptikal' release prints with a magnetic-photographic sound record.*
- 1 On 16 mm film.
- 2 On 35 mm film.
- 3 On 'Cinemascope' motion picture film with 4 tracks.

25 *70 mm release prints with 6 magnetic tracks.*



8.2.4 Checking and release printing of sound tracks

Checking of sound records includes assessments of technical condition and sound quality. In the first case, films are checked for technical defects, such as emulsion peeling, presence of mould, degradation of the base, raised perforations and bad splices. The shrinkage is measured and leaders are repaired. If necessary, the defects are eliminated by restoration.

In monitoring, the general characteristic of the sound is determined, namely, average sound level, frequency balance, intelligibility of the dialogue, music quality (clarity, tone colour, wow and flutter), and excessive noise and distortion.

In release printing of sound records, the sound quality must correspond exactly to that of the master tape (e.g., same tone colour, absence of excessive noise and distortions). It is essential to ensure image and sound synchronization. Lost frames may be replaced to restore synchronization of dialogue. Film materials are synchronized on special editing tables.

As late as the 1940s, tracks on release prints were made by duplication from positives, which considerably reduced the sound quality of the tracks thus obtained. Film archives still sometimes use this method. A more efficient method is re-recording from optical sound tracks onto a negative film followed by contact printing. The final sound quality of the print is a result of successful re-recording and correct sound track duplication.

8.3 Preservation of sound recordings

The possibility of further usage of sound records is the only criterion for the evaluation of their state in long storage. Their quality is mainly affected by temperature and relative humidity (destruction of a film or tape layer and changes in its geometrical dimensions) and various operational effects resulting in mechanical defects and noisiness. To preserve a sound record as long as possible, it is necessary to keep certain requirements for their checking and preparation for storage, provide the appropriate temperature and relative humidity in places of storage, restore their physico-mechanical properties and sound quality.

This is also true for sound film recording made by original methods, e.g., by recorders on a film, phonograph cylinders, or discs, by push-pull recording on the same medium etc.

8.3.1 Requirements for the preparation and storage of sound tracks

Films with sound tracks which are to be stored should be wound with uniform tension, and the lateral surfaces of the roll must be smooth otherwise the edges can be damaged.

A sound record should be kept in a special can. It is recommended to enclose the reel in polyethylene bags to protect the record from dust provided that it is not a nitrate film. Cans are normally stored in racks.

Upon removal from storage, the cans must be acclimatized (see 5.3.2.4).

Recording and periodic inspection of records must be made in clean premises. The records must be protected from exposure to direct sunlight to avoid their overdrying and curling.

Magnetic tracks should be stored in cans of steel to protect the record from the effect of external magnetic fields. If metal racks are used, their contours must be closed for protection from external magnetic fields (refer 11.2.2).

8.3.2 Recommendations for the storage of optical sound records and film materials with optical sound tracks are the same as for film pictures:

Nitrate film,	black-and-white:	- not higher than +6° C;
	colour:	- not higher than -5° C.
Safety film,	black-and-white:	- not higher than +12° C;
	colour:	- not higher than -5° C.

Relative humidity must be kept at 40 to 50% for black-and-white film, and for colour film 20 to 30%.

Magnetic tracks should be stored at a maximum temperature of +12° C and relative humidity of 50 to 60% (i.e. at the same climatic conditions as black-and-white triacetate films), with air conditioning and a positive pressure of 0.2 atmosphere above normal. That means it is better to separate picture and sound before storing preprint material for colour films with sound tracks. Records made on discs and phonograph cylinders must be packed in such a way as to protect them from dust and moisture. They are normally put into cartons; discs being packed into airtight polyethylene/aluminium bags. The cartons are placed on racks in a vertical position. It is advisable to store them at 20-22° C and a relative humidity of 50-60% (i.e., a normal climate in working rooms).

The correct observance of these requirements for storage will preserve sound tracks for many years.

8.4 Repair and restoration of sound tracks

Repair and restoration is carried out on sound tracks which have suffered physical damage, deterioration because of bad storage conditions, or other loss of sound quality as compared with the original. The procedures include manual repair, chemical treatment, reprinting of positives from negatives, and re-recording positives with unsatisfactory sound quality onto magnetic film while employing devices for improving sound quality.

8.4.1 Repairs

Manual repair includes removal of traces of cement, repair of patches and broken perforations, removal of dirt, retouching of the film, and checking of synchronization with the picture. With magnetic tracks, adhesive tape splices are remade, perforation damage is repaired and synchronization with the picture is obtained.

The necessity for any chemico-mechanical treatment of optical tracks is determined depending upon the nature of any defects found. This may include ultrasonic cleaning, polishing, etc. The methods of treatment do not differ from those used for picture film.

Long-term storage and utilization can result in an accumulation of dust and particles from the magnetic coating on the surfaces of magnetic films. This can result in poor contact between the sound track and the playback head which causes loss of sound quality and scratching of the magnetic coating. Therefore it is necessary to remove these defects before the film is used.

A sound negative which does not require the above procedure can be used for photographic printing of the sound positive. If the negative has suffered considerable wear, wet printing is recommended.

8.4.2 Restoration

8.4.2.1 The conditions for printing sound positives are determined in the following way. On a sound negative, sections containing speech with sibilants ("s", "ch", etc.) are selected. A series of positives at a range of different densities is printed from these sections. Then the prints are monitored to determine the optimum print density, which ensures the maximum cancellation for non-linear distortions in variable-area records and the optimum output of variable-density records. The minimum and maximum densities of positive silver and dye-plus-silver tracks are 0.8 and 2.5 respectively. Then the entire sound record is printed under the recommended conditions.

The positive thus obtained is listened to for determining sound quality. Such defects as non-uniform sound signals, high level of additional noise and unintelligibility of cues can appear. These defects can be eliminated without discernible distortions in tone quality by means of using noise suppression filters and manual control of level in re-recording. The magnetic record thus produced is used for obtaining a sound negative with a density close to that selected as giving greatest cancellation.

8.4.2.2 When re-recording sound from phonograph cylinders, discs etc. onto magnetic tape it is necessary to obtain a true record of the original recording. At a later stage, e.g. when making a duplicate sound negative, it is possible to restore and improve the sound quality.

A re-recorded sound record can be made from the master by applying effective devices to eliminate hissing, clicks and so on with no audible alteration in timbre. As masters, such materials can be stored as wax discs, phonograph cylinders as well as discs or cylinders made of special plastic. Both lateral and vertical types of records can be encountered. Recording speeds can be different; grooves can start from the centre of the discs or from the periphery.

Therefore a reproducing device (a player) should provide the possibility of choosing the required rotation speed of the master and of tracing correct orientation of the pick-up cartridges. For tracing vertical records, stereophonic pick-up cartridges are used, followed by mixing signals into one channel. It is also necessary to have a set of reproducing stylus tips of different thickness and shape. This will make it possible to avoid (within some limits) the appearance of additional noise induced by re-recording due to high sensitivity of modern pick-ups. To read out signals from the first (negative) masters, specific pick-ups, such as Stanton ones (USA), can be recommended. Before the re-recording, the original material must be cleaned to remove dust.

The problem of making the new sound records synchronous with the picture image should be solved at the stage of preparation for re-recording. For this purpose the original motion picture projection speed should be known and a number of discs or other material necessary for synchronous reproduction with one film roll defined. The speed should be the same for the motion picture projector, recording device applied for re-recording, and reproducing device (player) used for the synchronous playback of the new sound record with the picture image. In the motion picture projector, this can be achieved by using a motor with variable speed. In recording and playback devices this can be done by a change in the power mains frequency or in capstan diameter.

Stroboscopic markers on the turntable platter or tachometer pulses can be used to derive neopilot tone on SMPTE time code.

PART II

MAGNETIC RECORDINGS

Chapter 9

THE HISTORICAL DEVELOPMENT OF MAGNETIC TAPE RECORDING OF MOVING IMAGES AND SOUND

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9.1 Introduction

9.1.1 Magnetic recording appeared at the end of the nineteenth century together with several other important inventions in the field of communications, such as the phonograph, motion pictures, and the telephone, which have had a great influence on the shape of modern everyday life. The driving force behind the construction of the earliest sound recorders was the rapid development of one of these other inventions, namely the telephone. Inventors in many places were striving to record telephone conversations simply, quickly and without the necessity of additional signal processing. This also motivated the development of the phonograph (see reference 18.1). Additionally there was a technological connection since the active components of the original telephone, the microphone and the speaker, were the only means available at that time of transforming sound into an electrical signal and then back again to sound.

9.1.2 There was no concurrent need for development of a method of image retention, largely because still photography already existed and developmental studies were being done on the problem of recording motion. These techniques were scientifically and technically feasible at the time, and image recording by other than photographic means is technically many times more complicated. Alongside the scientific and technical base that had emerged in the course of the nineteenth century there were favourable economic conditions for industrial development.

9.1.3 The opportunity arose for a group of talented technicians to realize an age-old dream by creating a method of storing sounds. However, the path to a practical process and its implementation in the industrial production of a commercially profitable instrument was neither simple nor straightforward.

9.2 First steps

9.2.1 In 1837, the Frenchman Paul Janet accomplished some exciting scientific work on the possibility of transversely magnetizing a wire. However, his view of the physical nature of the effect ruled out the possibility of any practical application. Thus, the technical prehistory of magnetic recording begins in the 1870s with an entry in the

laboratory notebook of Edison's assistant, Sumner B Tainter. This report was published as a patent application four years later. Tainter's method would strike us as bizarre today. He combined a mechanical recording procedure, whereby recording was accomplished by varying the width of a uniformly magnetized surface, and play-back involving magnetic sensing of the surface area. Nevertheless, this was the first basic conception of how an electromagnetic transformation could be used in audio recording. Tainter suggested employing a metal plate as the recording medium in his patent, but there is no evidence that it was ever developed (refer reference 18.2).

9.2.2 The work of the American Oberlin Smith had by 1888 reached the point where it approximated present-day forms of magnetic recording. Although it is probable that Smith also was not able to implement his ideas, as evidenced by the somewhat melancholy conclusion of his article, the formulation of his ideas is surprisingly exact and valid when considered in the light of modern developments. Smith's investigations were first motivated by the necessity of recording telephone conversations, but his consideration of the problem went further. Above all, he was the first to suggest using a tape as the record carrier. In this, he had come to an excellent understanding of the recording process (reference 18.3):

> "If the undulating current leaves the telephone by means of the spool then, so to speak, a series of small magnets can be formed on the tape, so grouped as to alternately strengthen and weaken the magnetism. Their real length depends on the speed at which they move, however, their relative length is determined by the relative wavelengths and their relative intensities from the relative amplitudes of these waves. A possible construction might be a cotton, silk, or similar tape, in between the fibres of which carbide steel powder, perhaps in the form of small pieces of thin steel wire, have been sprinkled. Each small particle could, of course, form a complete magnet."

9.2.3 Besides this method, Smith suggested various other types of carrier, for example, where the magnetic medium would be dispersed in a non-magnetic disc. In conclusion he stated (reference 18.3):

> "The cited cotton tape appears better than all the other possibilities because of its cheapness, simplicity and flexibility. The Lord's Prayer can be recorded on several feet of tape or wire, and a young girl receiving a small cotton spool from her loved one will feel neglected if the letter isn't at least 200 feet long."

9.2.4 We have considered Oberlin Smith's observations in some detail, not only to better understand the novelty and completeness of his ideas, but also to better comprehend his conclusions. Although the need for a simple and ready-to-use recording medium was clearly felt, the solution of the problem still remained far away (reference 18.3):

"The author has not fully dealt with this thought; he has only considered it in writing. He has no time, let alone a well-equipped laboratory, in order to find a logical conclusion to his thoughts, be he successful or unsuccessful. He publishes them in the hope that one of the many experimenters currently working in this field discovers something sound and useful in them. Should this be the case, he will undoubtedly reap commensurate recognition for his work on this problem. Alternatively, should these proposals turn out to be worthless they will nonetheless have served a useful purpose, for proof that something **cannot** be done is often a guide as to how it **could** be done."

9.2.5 The first person to cross the border of prehistory was the Dane Valdemar Poulsen who, in 1900, after his first experiments in 1893, and patent registration in 1898, displayed his "Telegrafon" at the World's Fair in Paris. This was the first industrially produced magnetic audio recording instrument. He used neither a cotton nor a silk tape, but a steel wire wound onto a drum, so that the device outwardly reminded one of a phonograph. The Telegrafon, as may be gathered from its name, perpetuated the tradition that these instruments were to be used for recording telephone calls, or alternatively as dictaphones.

9.2.6 The use of magnetic recording for entertainment purposes was not thought of at that time, although the mechanical phonograph cylinders or gramophone discs had already been adapted for this purpose. The technology of magnetic recording did not allow for such an application. The Telegrafon operated without an amplifier, the microphone and earpiece being directly coupled to the magnetic head. In spite of this, the Telegrafon was enthusiastically received, as evidenced by a large number of articles in the technical journals and in the popular press of the day.

9.3 The non-magnetic base and the magnetizable layer

9.3.1 The years that followed brought a series of technical improvements such as: 1) in 1902, direct current pre-magnetization, which greatly improved the quality of recording by reducing distortion of the recorded sound; 2) in 1903, disc recording; and 3) in 1918, alternating current erasure which significantly improving the effectiveness with which previous recordings could be erased. In 1921, the first patent was issued for high-frequency pre-magnetization, which, although practically achieved twenty years later, was an example of the progress in technical understanding that was a precondition for further development. Proposals for new applications appeared; for example in 1915, a suggestion for a synchronous motion picture sound system.

9.3.2 During this period, metal was used as the recording base, either in the form of wire or flat tape. Especially in the case of metal tape, this required very bulky equipment, and in view of the high transport speeds of tape, recording reels of appreciable size and weight. Smith's

proposal of a light, flexible tape seemed to have been forgotten.

9.3.3 Only in a footnote to a short article by A Nasarischwily in 1920 was it acknowledged that it was still necessary to reduce the amount of recording medium required, as well as to improve its working properties:

> "The possibility exists of depositing a nickel coating on a paper base with the aid of electro-deposition. In this case, the paper may be cut out in the same way as a telegraph tape."

9.3.4 Today it is difficult to judge if this was the inspiration, or if the Dresden engineer Fritz Pfleumer had already independently begun to consider the idea of bonding particles that could be magnetized onto a non-magnetic base. All that we can be sure of is that his patent, issued in 1929, is the starting point for the history of magnetic tapes, although it has been referred to as "more of a pudding recipe than a technical specification".

9.3.5 Pfleumer attempted to realize the forty-year-old dream of combining small magnetic particles with a non-magnetic base. At first he also thought of using a paper base. However, Pfleumer's limited means held out little hope for reaching a practical solution which would transform his concept into a commercially viable product. The resources of one individual were insufficient for this. Therefore, it was a stroke of good luck for magnetic recording that, as early as 1932, a collaboration between Pfleumer and AEG had begun with the aim of developing a tape recording device, the "Magnetophon".

9.3.6 There is only a short distance between AEG and BASF/IG Farben factory in Ludwigshafen, where work commenced on the development of a magnetizable tape that could be produced in commercial quantities.

9.4 Paper tapes for broadcast

9.4.1 The rapid development at the beginning of the 1930s was not rooted in the interests of scientific research, but in more practical grounds. The broadcasting companies were just completing their first decade of operation. After the first experimental transmissions they had switched over to regularly scheduled professional programs and therefore had a pressing need for an economical and easy-to-use recording technique. The problem had not been satisfactorily solved by wax phonograph records, the voluminous Blattnerphone steel tape recorder, or other instruments.

9.4.2 First and foremost, it was necessary to discover a new and more suitable recording medium. At first, carbonyl iron supplied for the cores of Puppin coils proved useful. The available machinery at BASF/IG Farben for painting and varnishing was used in the coating process for the production of a "magnetic varnish". Positive results were quickly achieved under the direction of Dr Gauss and in July 1934

production was started on a 6.5 mm wide tape designed for recording at a speed of 1 m/s. In that same year a new magnetic material, magnetite (Fe_3O_4), was introduced and successfully tested.

9.4.3 Whereas the first tapes were grey and, as can readily be seen from old samples, could oxidize or rust because of their chemical composition, the new tapes were black and chemically stable. The recording capabilities of the tape had been significantly improved. One disadvantage that was encountered was the difficulty of erasing previous recordings because of the considerably higher coercivity of the new tape.

9.4.4 In general, the paper-based tape had a very short lifetime. Tapes that had been subject to mechanical stress during the transport process showed signs of extreme wear. For all practical purposes, the original tapes cannot be used today, fifty years after their introduction, because they fall to pieces. The only possibility of conserving the sound is to transfer the content of the old tapes onto a new base in a painstaking procedure.

9.5 Acetate base, new magnetic materials and mass tapes

9.5.1 Because of the poor durability of paper tape, it was not long before cellulose acetate was used as the base material. It was formed by pouring a solution of cellulose acetate onto an endless metal belt, in the same manner as the bases for still and motion picture films were made. This process was a logical development as another branch of the IG Farben company, Agfa Gevaert, located in Wolfen, specialized in the preparation of cinematographic materials and had both the necessary machinery and expertise to manufacture such audio tape in industrial quantities, which it did from 1943.

9.5.2 The new system, the Magnetophon and magnetic tape, was originally scheduled to be displayed at the 1934 Radio Exhibition. However, this decision had to be rescinded at the last moment because capstan motor problems had arisen which could have cast doubt upon the reliability of the new process. By 1935, when the Magnetophon was demonstrated to the public in Berlin, there were no longer any obstacles, and thus a new era for sound recording, if not for signal recording in general, was opened.

9.5.3 In November 1936, the new medium confirmed its usefulness when it was used to record an extensive musical production, a concert of the London Symphony Orchestra under the direction of Sir Thomas Beecham, at the BASF Auditorium in Ludwigshafen. From this point in time, it was not long before magnetic tapes were generally used for radio transcription.

9.5.4 This development was not, however, adopted in other countries. In the United States, steel wire came into even more extensive use as a recording medium, though its functional and quality limitations virtually ruled out its

use for anything but dictaphones. In other countries people continued to use the old robust installations.

9.5.5 A stimulus to the development of magnetic tape recording was the preparations for war, and the realization that magnetic recording could also play its part. It was no coincidence that new types of military tape recorders ("Tonschreibers") were developed and became standard pieces of equipment.

9.5.6 In the field of tapes, this new stage became apparent through the research effort undertaken to further improve recording qualities. In 1935, this led to the production of the "C" series of tapes, which were coloured dark grey. "C" stood for "Cellite" which was the BASF/IG Farben trade name for cellulose acetate. The C-type tape was introduced in Berlin in 1935 and became the standard of the broadcast industry for a long time.

9.5.7 Its dominant position was not even threatened in 1943 by the production of the type "L" or so-called "mass tapes". Historically, their introduction marked an important stage of development, if short-lived, due to the fact that the magnetic particles were randomly deposited in the polyvinyl base.

9.5.8 Although the preparation of cellulose acetate films had been mastered for cinematographic purposes, it became obvious, when the base thickness was significantly reduced below that used for films, that the material had important limitations. Apart from the relatively low tensile strength, particularly under dynamic strain, which led to the tearing of the tape while in operation, the reaction of the base to changes in humidity and temperature was especially troublesome as this affected not only the strength, but the geometry of the tape. The tape shrank as it dried, the edges curled, and the flexibility decreased. This also implied a limited archival utility, even where relatively stringent climatic conditions were maintained.

9.5.9 Thus, the introduction in 1943 of a new type of tape of a classic construction, i.e., with a non-magnetic base on which was bonded a magnetizable recording layer, may be regarded as a step forward. Here the base was polyvinyl chloride. Even if this material did not completely solve all problems, it represented a certain improvement over acetate, especially with regard to the dynamic characteristics of the tape.

9.6 Postwar progress in the development of magnetic materials

9.6.1 After the war, the world quickly learned of the progress that had been made in Germany. The devastated European economy, however, had little chance of achieving further progress either technically or in the manufacturing process where a complicated nexus of problems surrounded the production of magnetic tapes.

9.6.2 Industries in the United States quickly recognized the decisive advantages of a flexible tape and almost immediately switched over from metal wire to tape with an oxide coating. As early as 1946, they had also developed important modifications of the recording medium.

9.6.3 Whereas, the cubic crystals of ferric oxide had been distributed on the tape without an intrinsic directional orientation, the new oxide coating, although of the same composition, was characterized by the use of long, needle-like crystals that were directionally orientated. It was possible to significantly improve the magnetic properties of the tape when the crystals in the recording coating were aligned in a uniform direction during manufacture by an external magnetic field. Tapes so produced exhibited remarkably excellent and uniform properties along their longitudinal axis. This improvement was mainly a result of an increase in the coercivity of the tape by roughly a factor of two as compared with the earlier ferric oxide tapes. It is not without interest to note that this new advanced oxide coating was originally deposited on a paper base.

9.6.4 The most important consequence of the introduction of this new magnetic material was the possibility of using it to decrease the recording speed from the original 76.2 cm/sec (30"/sec), first to 38.1 cm/sec (15"/sec), then further to 19.05 cm/sec (7.5"/sec), and finally to 9.53 cm/sec (3.75"/sec). This radical reduction of the tape transport speed without sacrificing the quality of the recorded sound, opened the way to a vast new area of non-professional applications.

9.6.5 During this period, European manufacturers did not have the opportunity to experiment with new types of coatings that could be magnetized. They attempted therefore, to achieve similar results, primarily an increase in coercivity, by other means. One of the solutions, embodied in a new generation of tapes, was to dope the classical cubic ferric oxide with the addition of cobalt ions to the crystal lattice. These tapes, introduced in Europe in 1950, had excellent properties and were practically the equivalent of the tapes which used the needle-shaped crystals, yet, they also had some distinct disadvantages. Specifically, they were not heat proof and the quality of the recordings deteriorated with the passage of time. Some of their properties, for example copy absorption, depended strongly on external environmental conditions during manufacture and during storage. Nevertheless, they also made possible the transition to slower transport speeds and thus facilitated a quick spread of magnetic tape recording into practically all fields of human activity.

9.6.6 A few years later, the European manufacturers also switched to the needle-like, directionally oriented crystals for the oxide coating that, in contrast, provided an excellent stability for sound recordings. This substantial improvement in coatings prompted an intensive search for superior base materials. It is interesting that in terms of

historical development, improvements in magnetic coatings alternated with improvements in base materials.

9.7 Thinner base

9.7.1 The most important requirements were greater strength of the tape to allow a reduction in the necessary base thickness, and thus a reduction in the space necessary to store the recordings, a better dynamic behaviour during transport of the tape through the machine (flexibility, resistance to tearing, etc.), and finally a durability of the tape with reference to external climatic conditions, in particular humidity.

9.7.2 Towards the end of the 1950s such a material was produced. This was polyethylene terephthalate (polyester). Again, the original impetus came from the United States where the new base appeared under the trade name "Mylar", but the material very quickly spread into general use. A direct consequence of its introduction was the construction of new thinner tapes suitable for use at very low speed (4.76 cm/sec; 1 7/8"/sec).

9.7.3 The various types of tape used during this period were differentiated by their function, the specifications being geared to their different uses. From the archival viewpoint, from this time on, one can consider the actual recordings as well as the materials on which they are stored, as being very stable.

9.8 Magnetic stereo sound on moving images

The rapid increase in the quality of recorded sound, as well as in other specific properties of the magnetic recording process, made it possible to realize the forty-year-old concept of using magnetic recording for synchronous sound in motion pictures. Moreover this was accomplished in two different ways. For primary sound recording during film production, a magnetic film was utilized with a magnetic coating distributed over the entire surface of the usual 16 or 35 mm perforated base. After the processing of release prints in photographic laboratories, a narrow stripe of magnetic coating was bonded to the film in the position usually occupied by the optical sound track, adjacent to the perforations. The sound was then recorded on this magnetic stripe. The possibility of placing several narrow tracks on the film allowed the introduction of stereo sound. Especially in connection with widescreen projection, this provided a new stimulus, albeit only a transitory one, for film production. This development also encouraged an effort to significantly improve optical sound recording methods; an effort which has been particularly successful in recent years.

9.9 Tape cassettes

9.9.1 The start of the sixties also marked the final transition from empiricism to goal-directed scientific studies of new possibilities, as well as in the search for

new applications. With the applications in mind, the most important event was the introduction of the tape cassette in 1963. This resulted in a further spread of magnetic recording technology into the most common daily activities, and it significantly extended the user community to include those without any technical training or skills. The successful elimination of complicated tape manipulations stimulated similar developments in related fields such as cinematography, photography, etc.

9.10 New magnetic oxide creates incompatible systems

9.10.1 Research in recording materials is trying to meet a need for further increases in recording capacity; i.e., the possibility of further reducing tape size while maintaining, or even improving, recording characteristics.

9.10.2 Theoretical studies indicated that one such possibility would be to further increase the coercivity of the magnetic material. There were, however, at least two obstacles that made this difficult to achieve. On the one hand, a completely new material that can readily be magnetized had to be discovered and, on the other hand, the introduction of such a material would constitute a real threat to the compatibility of existing recording systems, because the new tape could not be used on the present recording equipment. The search for a new recording medium was successful, however, when, in the second half of the sixties, a new magnetic oxide, chromium dioxide, was developed, with a coercivity that can be up to 50% higher than ferric oxide. With the introduction of this oxide, magnetic tapes again changed colour; this time from brown to silver black.

9.10.3 Technically the first problem was solved, but the second hurdle, incompatibility, remained. The new tape required a different head alignment, different pre-magnetization, as well as another form of distortion correction. Consequently this led to the introduction of dual systems, with tape recorders becoming more complicated to operate. Because of this, it took almost ten years before the new tapes were used widely. This was not the case for video recording where, practically speaking, there was no standard to replace and where, therefore, the chromium oxide tapes soon reached a position of dominance. We will deal with this later in the section devoted to video recording.

9.10.4 The complicated system of patents that protected the chromium dioxide manufacturing process led to a repetition of the situation pertaining in the early fifties. To avoid the patents, new ways were sought to achieve the same effect, namely an increase in coercivity, by fundamentally different methods. The solution (cobalt doping) followed the same pattern with foreign cobalt ions being introduced into the crystal lattice of ferric oxide. The big advantage was that the new tapes were much more stable than tapes made 20 years earlier.

9.11 Magnetic video recording for television use

9.11.1 Due to technical and economic factors, the development of magnetic video recording came much later than audio recording. The public demand for moving images was initially well served by film, which, in addition, facilitated a world-wide and relatively economical distribution system in a period when no other such possibility existed. The properties of film and the uncomplicated projection equipment met all of the requirements of the period.

9.11.2 The demand for a new recording medium was due to the rapid development of television after the Second World War. In television, the signal was generated and transmitted as an electronic signal. In contrast, film represented an unnecessary intermediate step for television, and this prompted comparison with audio tape recording and the possibility of doing the same with images. A direct application of audio recording methods was not possible because of the widely different characteristics of the signals, especially in relation to the frequency requirements of the video signal, which is much greater than that for audio, and could not be met by the audio recorders then available.

9.11.3 A second important stimulus was the necessity of compensating for time zone differences in large countries such as the United States. This had already created problems in the synchronous transmission of programs over the entire country. The need for a technology that was adaptable to the nature of the processed television signal had become most urgent. The added benefits of being able to prepare television programs well in advance of the broadcast date and then to transmit them without difficulty, as well as being able to edit them up to the moment of broadcast, were extraordinarily attractive.

9.11.4 The short wavelength limit for recording was set by the physical characteristics of the magnetic coating and by straightforward logic; this implied a tape transport speed of several metres per second for video work. We have already mentioned that the new generation of audio tapes employing needle-like magnetic crystals had appeared in the first years after the war. They were responsible for a rapid decrease in the short wavelength limit of recording signals. Thus the pre-conditions were met for work on many systems (Crosby, RCA) that generally solved the problem of video recording by using a very high transport speed, moving the tape over stationary heads as in classical audio procedures. Although by the early fifties it had become possible to record moving images on conventional sound recorders, the disadvantages of this longitudinal recording system (the enormous amounts of recording tape required, head abrasion and limited recording capacity of a reel) caused these fixed-head types of video recorders to decline in potential importance. Meanwhile, work that had been started by the Ampex Corporation in California appeared to hold much more promise. Their technique utilized four rotating heads to transversely

position a narrow recording track. This radically reduced the transport speed, although it also had the consequence of increasing the width of the tape to 50.8 mm (2 inches).

9.11.5 For the first experiments, an audio tape with paper base was adequate. The only change was that the manufacturer 3M had to cut it to a width of 50.8 mm (2 inches). Towards the end of 1952 and at the beginning of 1953, the tape manufacturers switched to a more suitable acetate film. In this case, however, the coating abrasion as well as the signal to noise response were not good enough. It was only in 1954, that the first samples were made on a polyester base. The producers were seeking optimal results and therefore ordered laterally oriented tapes from several manufacturers (Reeves, 3M, Audio Devices). Finally in 1956, at the National Association of Radio and Television Broadcasters' Exhibition, a recording system with four transversely rotating heads and a 50.8 mm (2 inch) wide tape was demonstrated. This was to be the only system accepted for professional video recording for over twenty years.

9.11.6 Video recording tape does not differ in principle from audio tape. It has a coating that can be readily magnetized and bonded to a non-magnetic base. Its magnetic layer is composed of microscopic ferromagnetic crystals. The main difference is the mechanical properties of the tape that, in comparison with audio tape, is subjected to much greater strain because of the high speed (40 m/s), and because the recording heads press against it at a relatively high pressure. This demands extraordinarily high adhesive strength between the coating and the base, and high resistance to abrasion, etc. The tape must be sufficiently pliable and flexible. Because of the transverse position of the recording heads and tracks, the tape must also be transversely oriented magnetically as opposed to an audio recording tape which is longitudinally oriented.

9.11.7 Video recording technology stabilized for a long period. A "model change" was only necessary after ten years, in 1966, when a new type of tape was developed for wide band recording of colour signals. Experience in the manufacture of professional video recording tape, especially with regard to its durability, influenced the manufacture in the early sixties, of video tape for amateur recorders with slower transport speeds and tilted instead of vertically rotating heads (the "helical scan" formats). By this time, tape manufacture had spread to many countries in Europe and, most importantly, to Japan where the production of audio recording tape had reached a very large volume.

9.12 Further developments

9.12.1 The development of video recording was a condensed version of the development of audio recording. Here too, after the primary problems had been solved, a precondition for wider use turned out to be the placement of the tape in a cassette that, on the one hand, prevented damage and, on the other hand, greatly simplified handling.

9.12.2 Work is continually in progress in the search for new recording materials. As in the case of audio tapes, there has been renewed investigation of ferric oxide, although modified in various ways such as double-layered coatings.

9.12.3 It is only an apparent paradox that further reductions in the thickness of the oxide coating to 2 µ at a higher level of development will permit a return to the original recording principle, namely recording with a tape moving at a higher speed, now only 3 m/s, past a stationary head.

9.12.4 During the years of development, magnetic tapes for video and audio recording have experienced a rapid perfecting of their physical properties. The versatility of tape ensures that it can equally well be used for the recording and storage of digital signals, which may be the basis for audio and moving image recording in the future. Tape technology has now achieved stability. Isolated developmental changes in recent years have solved small problems. The degree of maturity that magnetic tape recording has achieved is evidenced by the fact that it has now become the subject of serious archival study.

9.13 In summary

This brief survey of the history of magnetic tapes is intended to outline the characteristics of the various stages of development and to act as an orientation for archivists in the identification and classification of the tapes that they have in their custody or will acquire.

Chapter 10

THE BASIC PRINCIPLES OF MAGNETIC TAPE RECORDING

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10.1 The fundamental problems of audio and video recording

The fundamental principle behind magnetic tape recording is the transformation of an electrical signal which varies in time into a spatially distributed magnetic structure. Playback, of is the reverse process. The actual recording must be preceded by conversion of the sound or images into electrical signals with the aid of the appropriate acousto-electronic transducer (a microphone) or opticoelectronic transducer (a television camera). This process is sketched in Figure 10.1. Because the information contents of audio and visual signals are so different, the electronic specifications which the appropriate recording instruments must meet differ by orders of magnitude. Therefore two relatively disparate technologies have evolved which differ from each other not only quantitatively, but more importantly, require fundamentally different transport mechanisms and signal processing electronics. This will be elaborated on in the following discussion of the basic concepts of recording.

Suppose that a sinusoidally oscillating signal

$$\sin 2\pi ft$$

of a certain frequency (f) is to be recorded. An approximately linear transformation between the time and position coordinates is maintained by the constant relative velocity (v) between the recording medium and the magnetic head. The exciting oscillation imposes an equivalent sinusoidal variation upon the recording medium through a linear superposition which varies spatially along the direction of the motion (x) as

$$\sin 2\pi x/\lambda$$

where the wavelength (λ) is the distance between two consecutive positive or negative maxima. The relation

Eq. 10.1 $$v = \lambda/f$$

is obtained. Thus, the higher the limiting frequency (f_{max}) the greater the relative velocity (v) between tape and head must be, because the smallest recordable wavelength (λ_{min}) is a constant, fixed by the tape transport speed

Eq. 10.2 $$\lambda_{min} = f_{max}/v$$

If the reproduced signal is to be at the same frequency as that recorded, then the identical transport speed must be chosen. For this reason magnetic tape recorder transport speeds are internationally standardized. The running speed of magnetic cinematographic sound units depends on the number of frames per second of the particular camera and projector units being used. For video techniques international agreement exists only for studio recorders and video cassette recorder (VCR) systems.

10.1.1 Frequency modulated recording

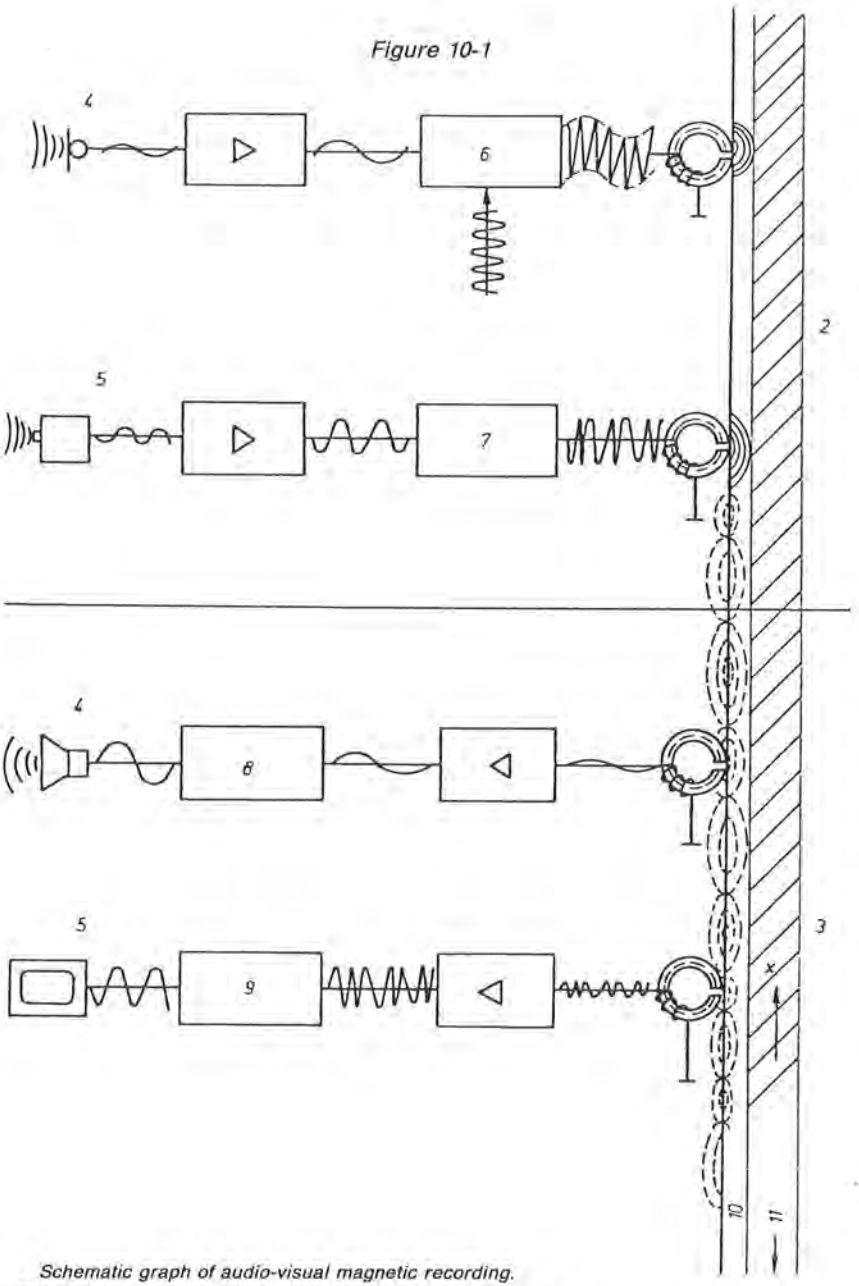
The low frequency limit (f_{min}) critically influences the basic design of the recorder. In Section 10.6 of this chapter, it will be shown that the magnetic tape recording process is based on the law of magnetic induction. This means that a direct current (DC), or constant, signal cannot be scanned. For video recording, a DC superposition is required where the contrast remains constant across a horizontal scanning line. Thus the information contained in the image must be modulated upon a carrier oscillation as is illustrated in Figure 10.1. In this case a special frequency modulation bandwidth compression technique, residual side band modulation is used. For frequency modulated (FM) signals, the picture content is determined entirely by variations in frequency. Therefore, according to Equation 10.1, even relatively small variations in speed will lead to noticeable image distortion. As noted, the transport system must be capable of maintaining an extremely uniform running speed.

If frequency modulation is to be used, a very high frequency limit is required. This means that the transport velocity must be increased by a factor of more than 100 over that which is necessary for sound recorders. In audio instruments the time-to-position transformation is handled during both recording and playback by the passage of the recording medium past the fixed heads. Due to the requirements necessary for video recording this would be possible only in certain exceptional cases. Hence, the rapidly rotating magnetic head mechanism was developed. Here the magnetic tape is run at normal audio recording speed past a set of heads that rotate perpendicularly or at some angle to the direction of transport. The rapidly rotating heavy drum on which the heads are mounted, ensures that any deviations from a uniform angular velocity will be small.

10.1.2 Direct recording

Audio recording is done directly, that is without frequency modulation. This is possible because human hearing is sensitive only to audio frequencies greater than approximately 20 Hz. The reproduction of lower frequencies is not necessary. If one considers the physical principles behind the two different recording technologies, audio recording might be thought to be the more complicated in

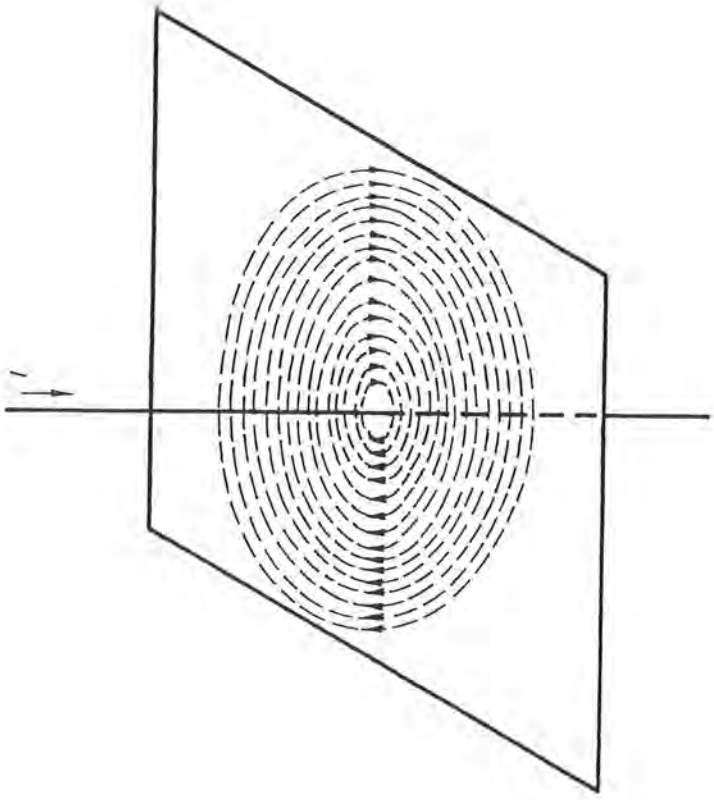
Figure 10-1



Schematic graph of audio-visual magnetic recording.

2 Recording.
3 Reproduction.
4 Sound channel.
5 Picture channel.
6 Recording electronics.
7 FM - Modulator.
8 Reproduction equalizer.
9 FM - Demodulator.
10 Magnetic layer.
11 Support.

Figure 10-3



Magnetic field of a straight current carrying conductor.

some respects. The recording of sound involves not only acquiring information about frequency, or pitch, but one must also record the amplitude, that is the loudness of the signal. If the amplitudes of the fundamental and overtone frequencies are not truly reproduced, one speaks of linear distortion. This shows itself as a reduction in the quality of reproduction. However, during the recording process the fundamental frequency may acquire new overtones. Such nonlinear distortion can change the entire colour tone of a performance. It is extremely disturbing, especially when it gives rise to difference and combination tones. Nonlinear distortion always results when the functional relationship between the input and output signals is not a straight line, but rather some curve. When this is the case the output does not vary proportionally with the input, but is reproduced in a distorted form. An example of such a nonlinear characteristic is the hysteresis curve shown in Figure 10.3. The elimination of this effect is a major problem in audio recording. On the other hand video techniques are, practically speaking, insensitive to this type of distortion.

The measure of nonlinear distortion is the distortion factor. The quadratic distortion coefficient (k_2) is the ratio of the root mean square (RMS) amplitude of the second harmonic ($\tilde{a}_2$) to the RMS amplitude of the integrated signal ($\tilde{a}$):

Eq. 10.3 $$k_2 = \tilde{a}_2/\tilde{a}$$

In a similar manner the cubic distortion coefficient (k_3) equals

Eq. 10.4 $$k_3 = \tilde{a}_3/\tilde{a}$$

Asymmetric distortion as represented by k_2 can be eliminated for the most part by Hf-premagnetization (bias), as discussed in section 10.4.

One of the most important factors in the evaluation of acousto-electric transducers is the ratio of the loudest sound that can be reproduced with minimal nonlinear distortion to the background noise of the system. The ratio of the acoustic pressure exerted by the loudest and softest sounds in a work is called the dynamic range and is given as the logarithmic quantity

Eq. 10.5 $$D = 20 \log_{10} P_{max}/P_{min} \quad \text{(in dB)}$$

Since the greatest dynamic range achievable by an orchestra is about 60 dB, roughly the same value is required of a tape recorder.

10.1.3 Digital recording (Pulse code modulation) (PCM)

The newer demands of the user in respect of higher dynamic range and lower distortion, as well as greater signal processing capability, exceed the capacity of classical recording methods.

The introduction of pulse-code modulation (PCM) brings within reach all the quality parameters required of a modern signal recorder. The principle is illustrated in Figure 10.2.

The incoming analog signal is converted into binary information of a constant bit rate by an analog-digital converter (ADC). For optimal recording of this digital (source-coded) signal, it must be adapted to the characteristics of the recording channel (channel-coded). Thus, a series-parallel converter supplies the necessary parallel channels for subsequent error correction coding and recording coding, before the data current is fed to a multi-track magnetic head.

During reproduction of the signal, the head signals are amplified, equalized, digitalized and decoded, error correction information is generated and the data pulses transformed in the parallel-series converter into one-bit serial data current. If necessary - as in audio-visual recording without digital reprocessing - the original analog form is restored with a digital-analog converter (DAC).

PCM-recording has a number of significant advantages over conventional recording of audio and visual signals:

a) higher signal-to-noise ratio;

b) better quality of multiple generation copies;

c) reduction in the influence of jitter or timebase errors;

d) reduction of crosstalk;

e) greater amplitude precision;

f) wider dynamic range;

g) lower signal distortion; and

for audio recording only:

h) improved compatibility by reason of:

* azimuth adjustments become less critical

* mechanical guidance and the speed of tape need not to be so critical.

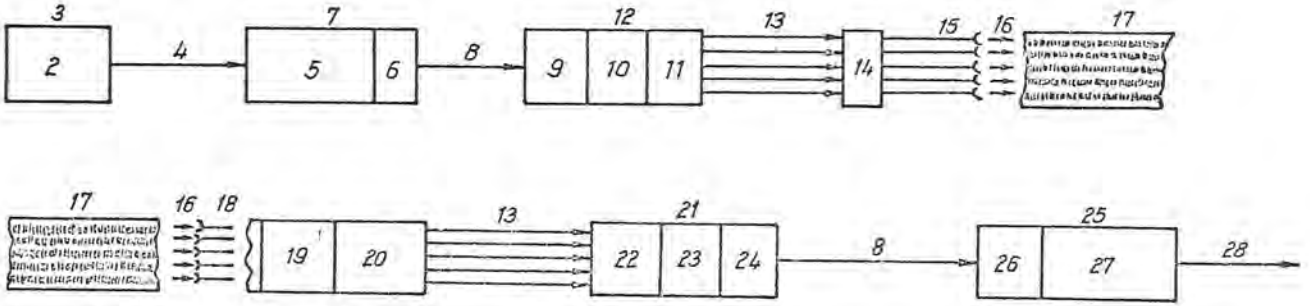
On the other hand it has the following disadvantages in particular:

i) increased costs;

j) increased complexity.

The state of technology in this field is advancing rapidly.

Figure 10-2



Schematic graph of digital magnetic recording.

2 Video or sound pick up.
3 Qualog source.
4 Qualog signal.
5 Qualog to digital converter.
6 Data compressing.
7 Source encoding.
8 Binary data.
9 Serial to parallel converter.
10 Error detecting and correcting coder.
11 Write encoder.
12 Channel encoding.
13 Channel data.
14 Write amplifiers.
15 Write current.
16 Magnetic heads.
17 Magnetic tape.
18 Read voltage.
19 Read amplifiers.
20 Filter.
21 Channel decoding.
22 Decoder.
23 Error detecting and correcting.
24 Parallel to serial converter.
25 Source decoding.
26 Data compression.
27 Digital to analog converter.
28 Qualog output.

10.1.4 Principles of operation for a tape recorder

Until now we have concentrated on the differences between audio and video recording. If one looks at the actual physical construction of the recording medium and its interaction with the magnetic head assemblies, including the attendant attenuation and distortion mechanisms, then the two techniques (audio and video) may be properly treated as one. Their basic form, especially the way the magnetic heads and tapes function, is identical, or at least very similar. In each case an electric current flows through the windings of the recording head, producing a fringing field, i.e., the recording field, in the gap between the arms of the head's iron core. The characteristic form of this electric current is optimized to fit the requirements of the situation by the recording electronics. When a magnetizable film is passed through the fringing field it will be magnetized, and after leaving the field will retain a certain fixed remanent of the magnetization imposed by the variation of the current. If a tape containing such information is later run through the air gap of an iron core belonging to the playback head, then the magnetic flux originating in the imposed magnetic structure penetrates the iron core, inducing a playback voltage in the windings about the core. The playback electronics recover the original signal from the transformed waveforms stored on the tape and feed it to loudspeakers. An example of such a transformation is frequency modulation.

10.2 Basic magnetic processes

10.2.1 Magnetic fields

A current-carrying conductor produces a magnetic field in the space surrounding it just as a permanent magnet does. The magnetic field strength H can be easily calculated for simple geometric cases. For example the field outside of a thin straight conductor carrying a current (I) is,

Eq. 10.6 $$H = I/2\pi r$$

where r is the distance from the centre of the wire. The field strength increases linearly with the exciting current (I) and is reciprocal to the distance from the conductor.

For a cylindrically wound coil the current (I) follows the same path in each winding and thus each winding produces the same magnetic field (see Figure 10.3).

Therefore, the field strength which is a superimposition of that from each winding, depends linearly on the number (n) of turns in the coil. For a coil whose length is much greater than its diameter, the field strength in the centre of the coil is constant.

The field is directly proportional to the number of Ampère-turns (I·n) and inversely proportional to the length of the spool (l).

Eq. 10.7 $$H = I \cdot n/l$$

The unit of field strength (H) is given in Ampère/metre (A/m). The conversion factor from the customary unit of Oersteds, which belongs to the formerly used CGS system, is

$$1 \text{ Oe} = 10^3/4\pi \text{ A/m}$$

For example the strength of the earth's magnetic field is about 0.4 A/cm. Using Equation 10.7, we can calculate the current necessary to achieve this field strength in a 0.12 m long coil with 15 windings. This is just

$$I = H \cdot l/n = 320 \text{ mA}$$

The quantity ($I \cdot n$), which is also called the "magnetomotive force", is closely related to the existence of closed paths of magnetic flux. Magnetic flux (ϕ) is defined as the quotient of the magnetomotive force ($I \cdot n$) and the magnetic resistance of the circuit (R_m) by Ohm's law for magnetic circuits,

Eq. 10.8 $$\phi = I \cdot n/R_m$$

Units of flux are the Weber (Wb), the volt-second (Vs) or the previously valid maxwell (M).

$$1 \text{ Wb} = 1 \text{ Vs} = 10^8 \text{ M}$$

$$10^{-6} \text{ Wb} = 1 \mu\text{Vs} \quad \text{(microvoltsecond)}$$

$$10^{-12} \text{ Wb} = 1 \text{ pVs} \quad \text{(picovoltsecond)}$$

The magnetic flux per unit area is the flux density (B),

Eq. 10.9 $$B = \phi/S$$

written in units of teslas (T) with

$$1 \text{ T} = 1 \text{ Wb/m}^2 = 1 \text{ Vs/m}^2 = 10^4 \text{ G}$$

The old CGS unit, the gauss (G), is no longer valid.

In air, the relationship

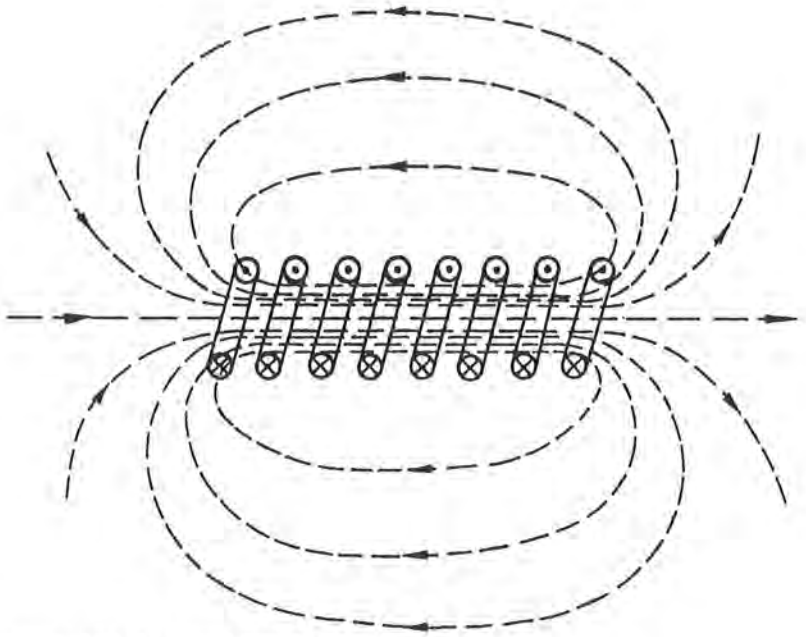
Eq. 10.10 $$\underline{B} = \mu_o \underline{H}$$ ($\underline{B}$ means vector B)

between the flux density and the field strength holds. The proportionality constant (μ_o) is the permeability, that is the magnetic conductivity, of air. It has the value

$$\mu_o = 4\pi \cdot 10^7 \text{ Vs/Am}$$

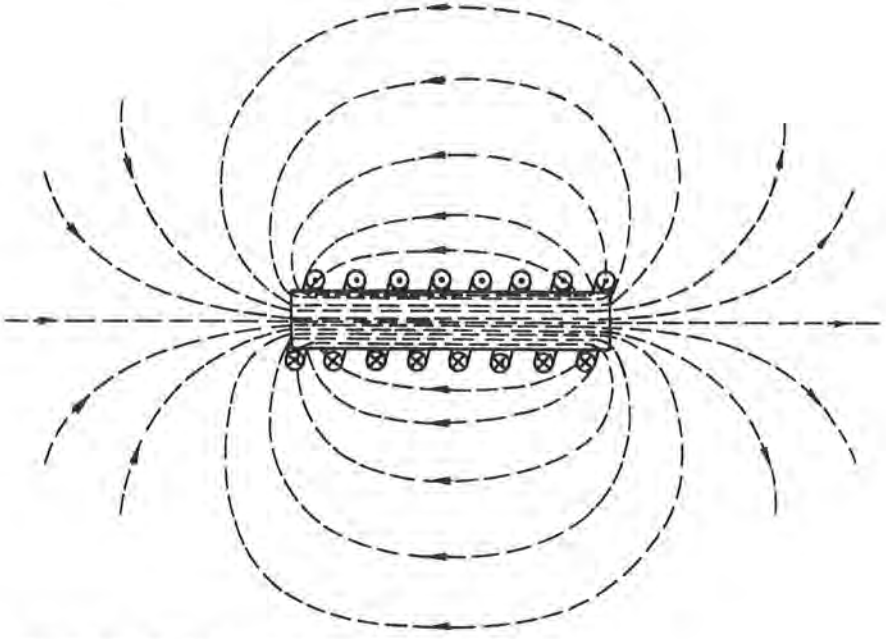
Using Equations 10.9 and 10.10, one can calculate the magnetic flux from the field strength. For example, let us consider the interior of the coil whose field equals that of the earth (40 A/m). If this coil has a cross-sectional area (S) of 2 cm^2 , then the magnetic flux is

Figure 10-4



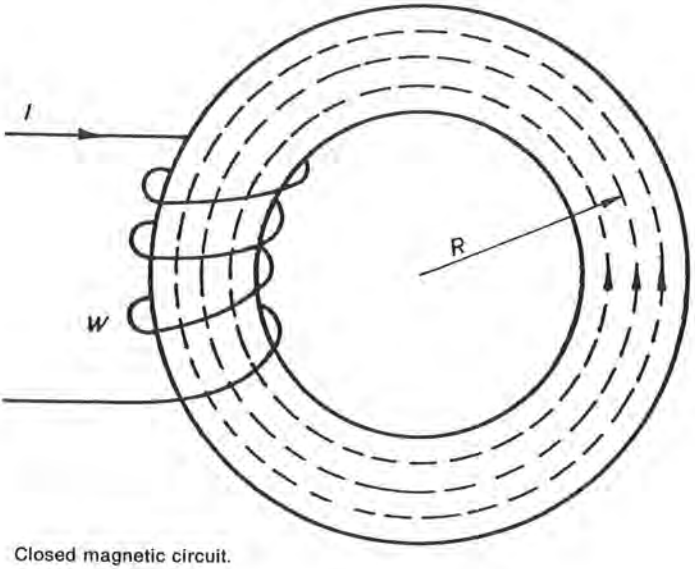
Magnetic field of a current-carrying coil.

Figure 10-5



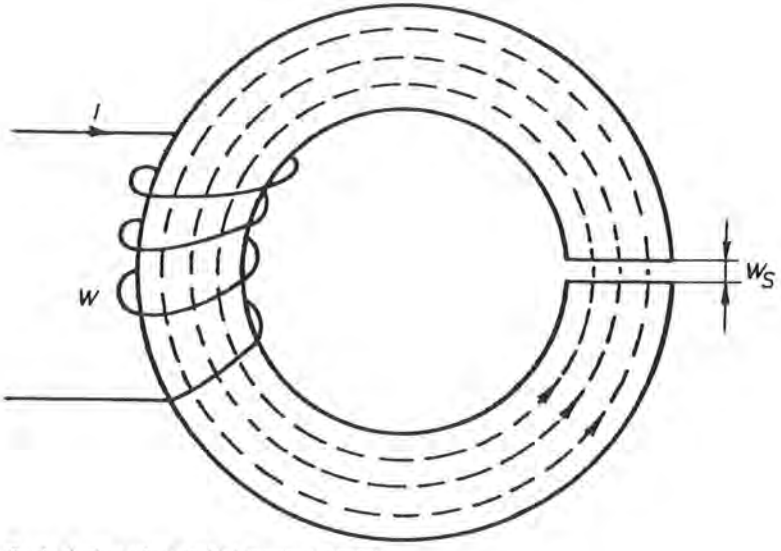
Magnetic field of a coil having an iron core.

Figure 10-6



Closed magnetic circuit.

Figure 10-7



Basic design of a toroidal magnetic head.

$$\phi = \mu_o \cdot H \cdot S = 0.01 \ \mu Vs$$

By comparison the average field strength at the pole of a bar magnet is roughly 10^6 A/m. If the pole pieces were 2 x 3 cm, then they carry a magnetic flux of 750 Vs.

10.2.2 Magnetic circuits

The flux density inside a piece of magnetic material exposed to a field of strength (H) is increased above that in air by the magnetic polarizability of the material.

Eq. 10.11 $$\underline{B} = \mu_o(\underline{H} + \underline{M})$$

Eq. 10.12 $$\underline{M} = \underline{J}/\mu_o$$

The polarizability $\underline{J}$ and the magnetization $\underline{M} = \underline{J}/\mu_o$ of the material depend on the applied field strength and the previous history of the particular piece. The factor is called the relative permeability. For air and other non-ferromagnetic materials, $\mu_r \sim 1$.

If a piece of ferromagnetic material, such as soft iron is placed inside a current carrying coil, a basic electromagnet is formed. The field of such an electromagnet is generally described as an open magnetic circuit. Figure 10.5 illustrates this. It is worthwhile noting that the fringing field of such a magnet is identical to that of the bar magnet shown in Figure 10.4.

In contrast to an open magnetic circuit, which is not completely contained within the highly permeable medium, the magnetic field of a closed magnetic circuit runs completely within the permeable medium, for all practical purposes. An example of this is the toroidal ring of Figure 10.6. It has a mean radius (r) and a coil containing a number (n) of turns, through which a current (I) flows, is wound upon it. The field strength within the magnetic material is

Eq. 10.13 $$H = I \cdot n/2\pi r$$

where the flux density (B) is: $B = \mu_r \mu_u H$.

If a second coil, which we will call the induction coil, is wound upon this ring, then one has constructed a primitive transformer. If, on the other hand, there is an air gap in the ring shown in Figure 10.6, which the magnetic flux must cross, and therefore a fringing field is created, then one has made an open magnetic circuit once more. The force of interaction of the fringing field with a bar magnet or a piece of magnetizable material can be used to construct a very primitive loudspeaker. If the magnetizing effect of the field is used, then one has a basic magnetic recording head. For an air gap of a certain width (w_g), the field strength within the gap to a first approximation is,

Eq. 10.14 $$H = I \cdot n/w_g$$

This is illustrated in Figure 10.7. For comparison, the

field strength in the air gap of a loudspeaker amounts to a value between 5×10^5 and 1×10^6 A/m, while for recording heads it lies between 5×10^4 and 5×10^5 A/m.

10.2.3 Magnetic heads

The purpose of a recording head is to produce a magnetic field proportional to the current (I_v) flowing through the number (n) of coil windings. The working gap (w_g) and the head mirror are so made that the fringing field is concentrated in as narrow a space as possible. This allows the field to fall off as sharply as possible at the back end of the gap so that the shortest wavelength signals may be recorded. To achieve this it is important to have a precisely formed gap edge, the width (w_s) being less important. The gap must be at least large enough to permit the realization of a magnetic field strength (H_v) at the point where the tape passes through. The calculation of H_v is based on Ohm's law of the magnetic circuit (Equation 10.8). If the magnetic resistance of the circuit is divided into the core reluctance (R_f) and the gap reluctance ($R_g = w_g/\mu_o S$), then the gap field strength (H_v),

Eq. 10.15 $$H_v = (n \cdot I_v / w_g) \delta_g$$

and

Eq. 10.16 $$\delta_g = R_g / (R_g + R_f)$$

where δ_g is the efficiency of the recording head.

In view of Equations 10.14-10.16, the pole area (A), or for a given mirror width, the gap depth (d_g ; see Figure 10.8) must be as small as technically possible. Typically, gap depths are 0.2 mm for mu-metal, 0.1 mm for alfenol and 0.05 mm for modern ferrite materials.

The optimum gap field strength (H_{vo}) for recording with a particular magnetic tape is reached at an optimum recording current

Eq. 10.17 $$I_{vo} = (w_g / n \cdot \delta_g) H_{vo}$$

for a specific head.

Depending on the saturating field strength for the core material used, the maximum possible field in the gap ranges from 3×10^5 A/m for ferrite to 6×10^5 A/m for permalloy, mu-metal, alfenol, etc.

The width of the gap is usually fixed by a gap insert constructed of beryllium bronze. The insert prevents the introduction of abrasive particles into the gap. Modern ferrite heads use a glass insert. Typical gap widths for recording heads lie in the range between 2 and 12 μ, depending on the particular application. Playback, or combination heads for both recording and playback, such as are universally found in video apparatus, need the narrowest possible gap to ensure efficient operation. Therefore,

Figure 10-8

Construction of a magnetic head with metal core.

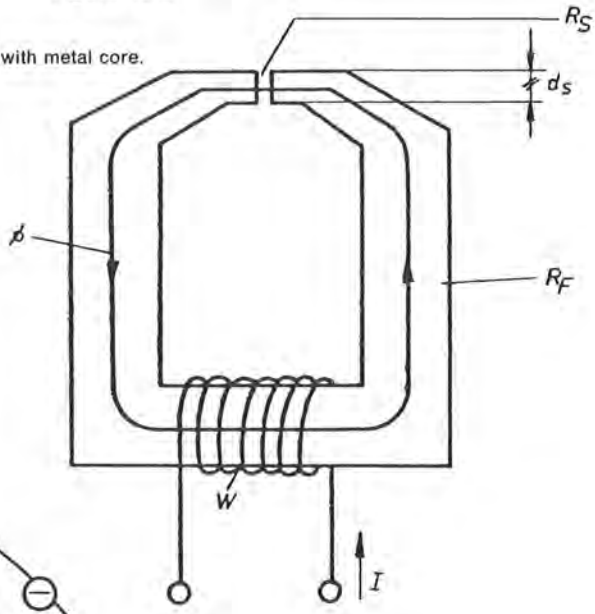
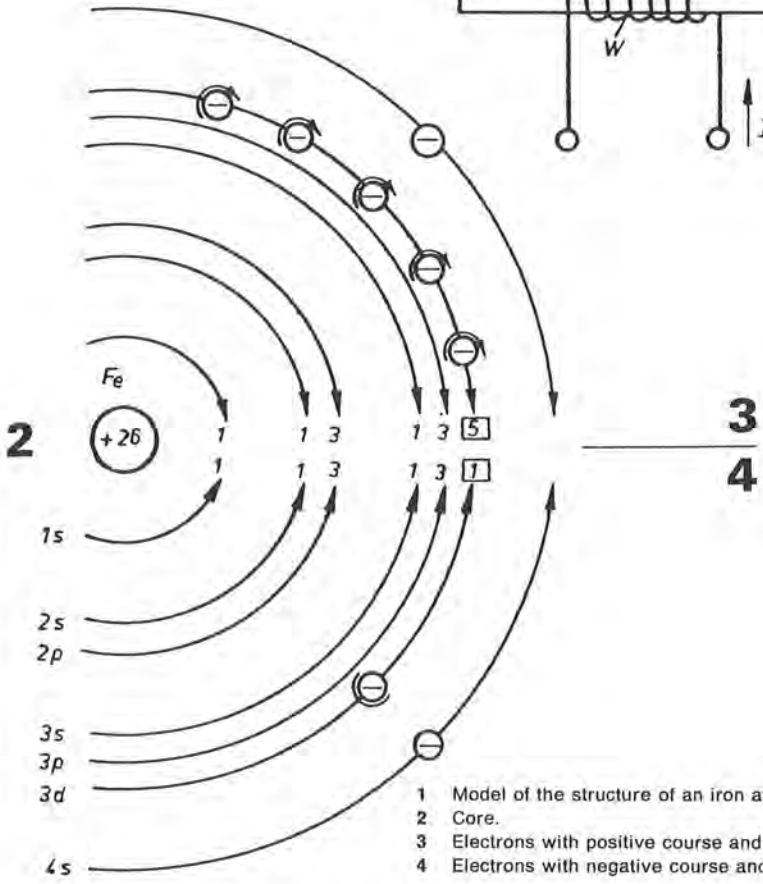


Figure 10-9



1 Model of the structure of an iron atom.
2 Core.
3 Electrons with positive course and spin direction.
4 Electrons with negative course and spin direction.

again depending on the specific application, they have gaps that range from 0.5 to 6 μ. Erasing heads, because of their mode of operation, must have a larger gap of between 50 and 300 μ.

In order to ensure the most linear frequency response possible, the core material of the head should have the smallest possible eddy current and hysteresis losses. (See Section 10.3.3 for a more complete discussion). Magnetically soft materials such as permalloy, mu-metal, alferile and ferrite exhibit small hysteresis losses. If the core is built up of laminated sheets, then, as is explained in Section 10.3.3, the eddy current losses will be minimized. Ferrite, because of its high electrical resistance has very small eddy current losses, and therefore ferrite cores will display outstanding frequency response characteristics. Thus they can be used to record even the highest frequencies necessary for video storage work.

10.3 Basic magnetism

10.3.1 Ferromagnetism

The basic cause of magnetism is the existence of a permanent magnetic moment in the atoms of several elements. For example the moments of the elements iron, cobalt and nickel result from a net electron spin. On the other hand the net angular momentum of the electrons moving in relation to the fixed nucleus contributes strongly to the magnetic moments of several of the rare earth elements. Those electrons responsible for the magnetic properties of the iron group and its alloys belong to the 3d atomic shell, while for the rare earths they belong to the 4s shell.

Figure 10.9 represents the orbital structure of an iron atom with the electrons, and their spin quantum numbers being represented by arrows. The outer 4s shell electrons are the source of free conductors in the solid, or crystal phase, as is typically the case for metals. The inner 1s to 3p shells are filled, and thus have the same number of electrons with positive as with negative spin, so that the net magnetic moments of these electrons compensate each other. On the other hand, there are five electrons in the 3d shell with positive spin and only one with negative spin. Because of spin interaction, all of the axes of rotation will lie parallel to each other. The sum of the spin moments is thus non-zero. Under these conditions the atom acts as a small permanent magnet.

As is represented in Figure 10.9.1, where the total spin vector is represented by $\underline{s}$, the force exerted by the field will be directed through the atom, and antiparallel to the resultant spin.

The potential field of the atom interacts with its neighbours and aligns the atoms parallel to each other. A great number of atoms can so combine, to build a magnetically aligned domain, each atom being within the

minimum distance from its nearest neighbours as allowed by the crystal structure of the solid. These groupings are called Weiss zones, after the discoverer of the phenomenon. The formation of such domains is a precondition for ferromagnetism.

In a powder, such as γ-Fe_2O_3 used in magnetic tapes, the size of the domain is usually identical with the size of the particles. The small crystals each contain about 10^{18} molecules. In a continuum (i.e., a solid) a magnetic structure forms spontaneously, consisting of differently oriented Weiss domains. Each domain, being 100% aligned, is completely saturated, even when the solid considered as a whole has no net magnetization. This is a result of the random statistical distribution of the vector magnetic moments of the domains. Each region is said to be spontaneously magnetized. At the border between neighbouring domains aligned along different axes, complex structures develop. These are called Bloch walls in honour of their discoverer.

10.3.2 Macroscopic magnetization processes

The magnetic structure and also the macroscopic magnetic state of a ferromagnet can be altered through the influence of an external field in two ways:

a) increasing the volume of those domains aligned parallel to the field at the expense of the others; and

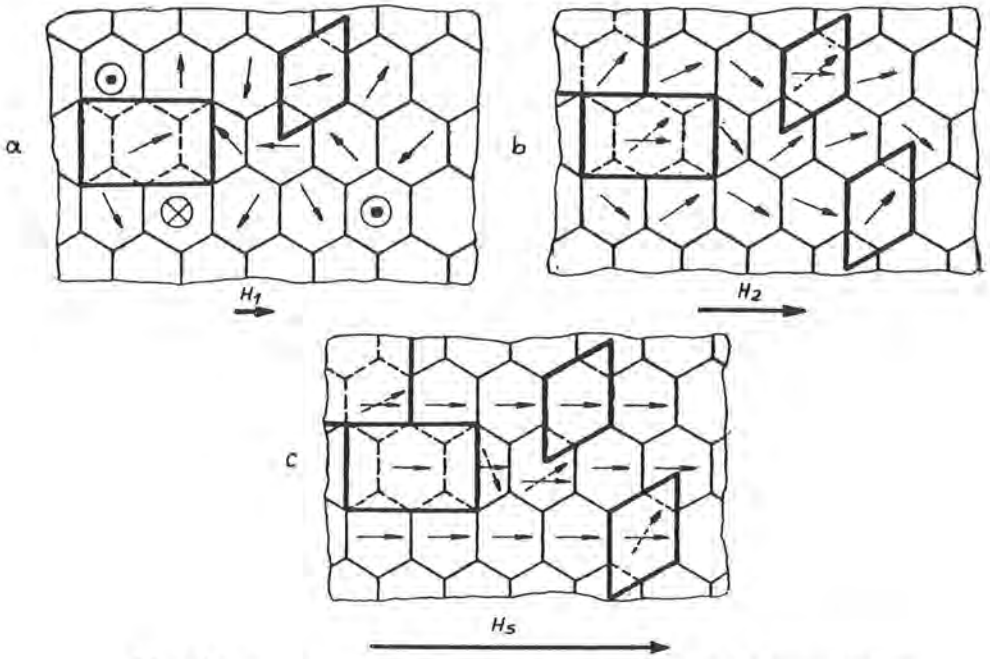
b) altering the direction of magnetization of a domain(s) by rotation.

Figure 10.10 illustrates how, even a weak field (H_1) will cause magnetic domains aligned parallel to the field to expand. Because the total volume of these domains is increased at the expense of other domains the net magnetization of the material (M_1) will be non-zero. This is shown in Figure 10.11 where M(H) is plotted as a function of H. If the magnetic field is turned off or removed the Bloch rolls will return to their original positions, as shown by the dotted lines in Figure 10.1 and the macroscopic magnetization will disappear. This process is reversible.

If a stronger field (H_2) is applied, as is shown in Figures 10.10 and 10.11, besides causing a further shifting of the rolls sudden jumps in the orientation of the magnetic vectors of some of the domains will occur. These are called Barkhausen jumps. The field strength necessary for such jumps can, in principle, be different for each domain, or for every magnetic particle in a discontinuous layer. In practice several Weiss domains, or single crystals slip into a preferred orientation parallel to the field at the same time.

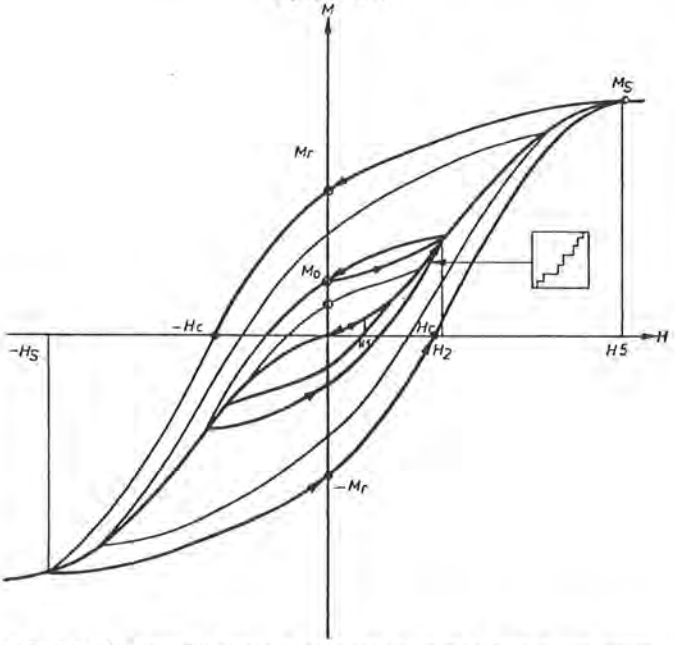
In permanent magnets or information storage media most of the domains remain in their new orientation if the external field is removed: the change is irreversible. Only a few relax and adopt a more energetically stable orientation in

Figure 10-10



Effect of an external magnetic field on the state of magnetization of a ferro-magnetism
Dotted line: field free (remanent) state.

Figure 10-11



Hysteresis curves of a magnetic material, enlarged view with Barkhausen jumps.

the absence of the magnetic field. This is represented by the light lines in Figure 10.2. Therefore the remaining, or so-called remanent magnetization (M_o) will be somewhat smaller than M_2, as can be seen in Figure 10.11. For equipment and materials used to contain magnetic flux this remainder is undesirable. Examples of such devices include guiding plates, transformer sheets, and magnetic heads. In such cases it is essential that the functional dependence of the magnetization (M) on the field strength (H) should be chiefly determined through reversible processes.

If the field is again raised to H_2, the dependence of M on H is somewhat different from when the field was removed. This is due to what may be thought of as the inertia of the domains. However the magnetization reached at H_2 will be about the same as before. Figure 10.11 shows this closed loop. One says that inside the loop the material is magnetically stable.

When the external field is increased further the magnetization vectors of the domains will align themselves more closely to the field direction (Figure 10.3). The net magnetization thus increases slowly until it reaches the saturation value (M_s). This is identical with the spontaneous magnetization of the continuum. For a powdered sample it is reduced by the bulk packing factor.

Clearly this state in which all the domains are aligned can only be maintained in the presence of the saturating field (H_s), which exerts a strong force on the domains. If the field is removed some of the domains will rotate into a more energetically favourable orientation as shown by the dotted lines in Figure 10.3. Thus, when the field is removed, the material will shift its magnetization to the saturated remanent value (M_r) (see Figure 10.11).

10.3.3 Hysteresis in ferromagnetic materials

The path that the total magnetization follows, from the unmagnetized, field free state, up to saturation is called the "virgin" curve (see Figure 10.11).

The slope of this curve near the origin is

Eq. 10.18
$$\lim_{\substack{H\to 0\\ M\to 0}} \frac{dM}{dH} = \mu_i$$

where μ_i is the initial permeability.

In the upper section of the virgin curve one reaches the maximum permeability

Eq. 10.19
$$\mu_{max} = \frac{B}{\mu_o H}\bigg|_{max} = 1 + \frac{M}{H}\bigg|_{max}$$

The value of μ_{max} is the ratio of the increase of magnetic induction (B) in a ferromagnetic material over its value in air.

The phenomenon described in Section 10.3.2, i.e., the fact that a larger total magnetization results when the field decreases to zero after having reached H_2 than was measured upon the initial increase from zero to H_2 is known as hysteresis. Hysteresis is basic to magnetic information storage.

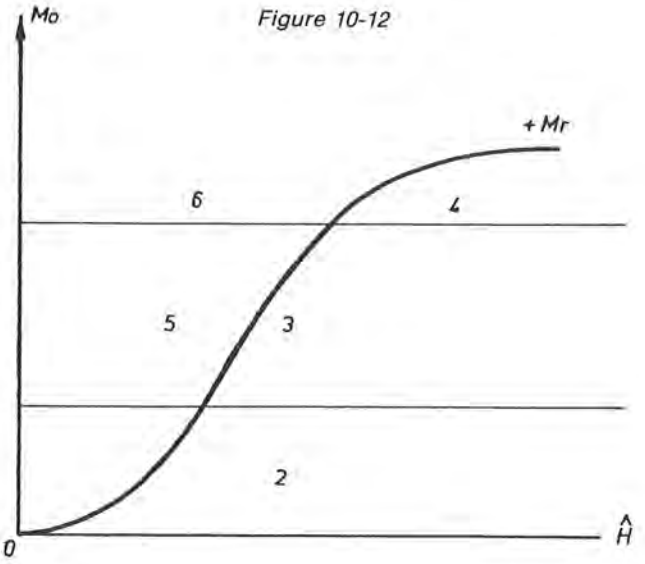
Let us continue to sketch the path of the hysteresis curve for antiparallel fields starting from the saturation remanence (M_r). As the field becomes more negative, the total magnetization continues to decrease. What occurs is quite similar to that described in Section 10.3.2. The negative field strength resulting in complete erasure, that is a completely demagnetized state, is called the coercivity field (H_c). Depending on the type of material, H_c will lie between 1 A/m and about 1×10^5 A/m. Media with H_c higher than 10^3 A/m are called magnetically hard, while those with H_c less than 10^3 A/m are called magnetically soft. Magnetic tape recording requires hard materials with H_c higher than 2×10^4 A/m. The higher H_c is for a particular material, the more stable the information-containing structures recorded in it will be against the influence of distorting external fields.

If the field intensity is decreased to the negative saturating field strength ($- H_s$) and then increased to the positive saturating field strength ($+ H_s$), then M(H) will follow the limiting hysteresis loop which can be seen to be a symmetric, reproducible closed loop.

If the magnetization cycle is not carried to saturation, one of the inner hysteresis loops is followed. In every case the tips of the loops lie on the virgin curve (see Figure 10.11). Accordingly, the value of the remanence (M_o) is always less than the saturation value (M_r). Thus it is possible to order the magnetization and field intensities used to store information; if one plots the remanence (M_o) against the maximum field (H) leading to it, then the remanence curve of the magnetic material is obtained. This is shown in Figure 10.12. It may be thought of as the operating characteristic for magnetic storage. The largest signal intensity is obtained when the curve is driven into saturation. On the other hand, recording with low distortion must be done in the linear region.

Permeability depends not only on the material but also on any heat treatment during manufacturing. The properties for highly permeable materials at maximum levels are reached only with the aid of a complicated heat treatment process, where the temperature is maintained at 1000° C for several hours, followed by a slow cooling. Subsequent forming or machining can cause heating and thus lead to a reversion of the crystal structure to an earlier form and lessen the permeability. This cannot be avoided in the fabrication of magnetic heads and leads to a reduction in the starting

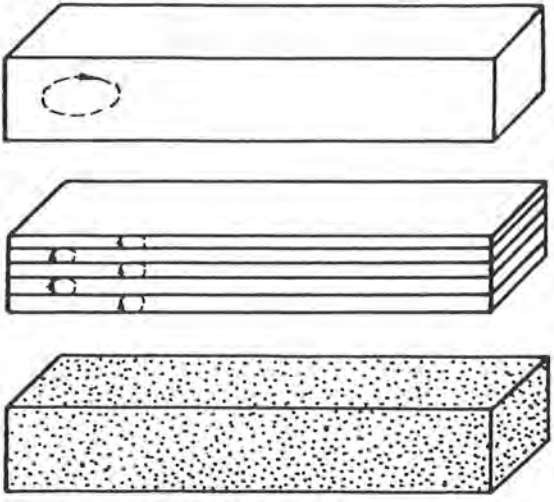
Figure 10-12



Remanent curve (constructed from fig. 11) and ranges of utilization.

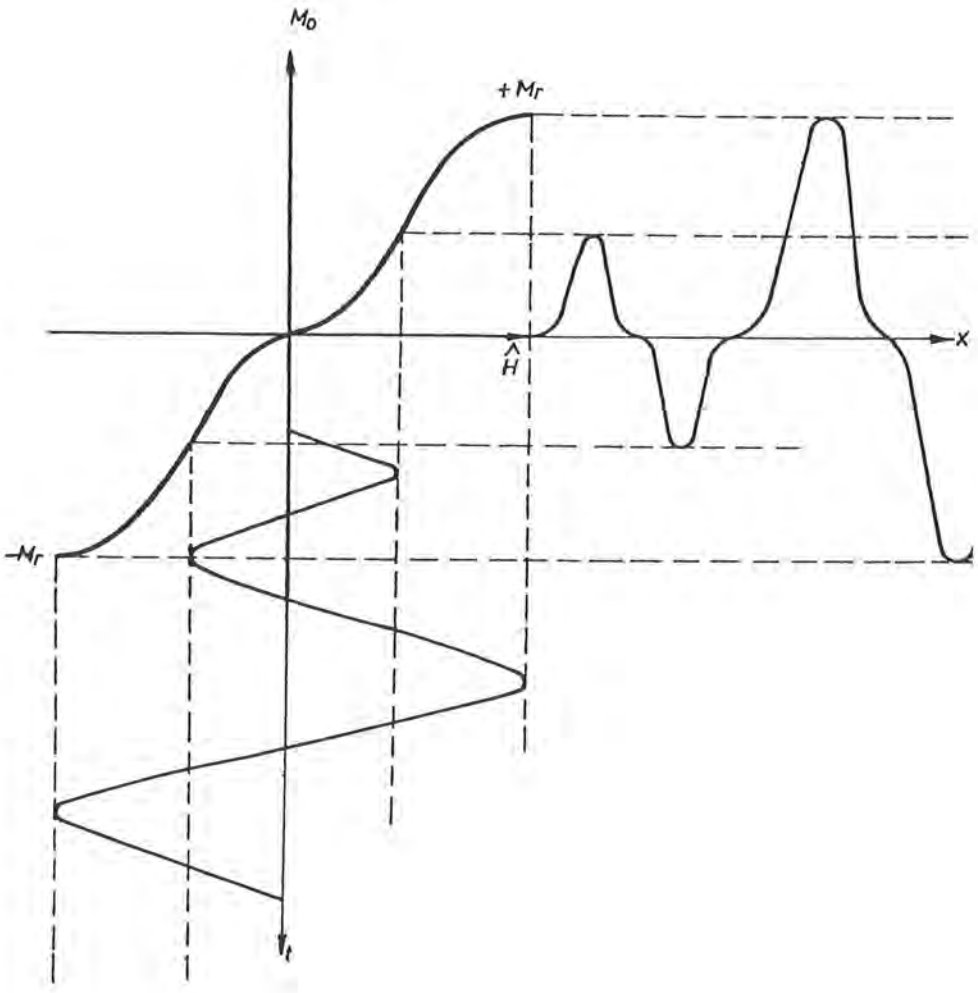
2 Not useable for storage.
3 Direct recording of sound storage (with bias).
4 FM-video recording and digital video and sound recording.
5 Linear region.
6 Saturation region.

Figure 10-13



Formation and prevention of eddy currents in differently divided core material

Figure 10-14



Nonlinear signal storage in FM picture recording.

permeability of mu-metal to 5000. Especially for mu-metal and alfenol the constant drag of the tape across the head mirror causes the surface to be work hardened, and this leads to a further reduction in the permeability.

When magnetic substances are placed in an alternating field they pass through one of the hysteresis loops once during each cycle. The work that must be done to remagnetize the piece against the hysteresis loss is proportional to the frequency and the area enclosed by the hysteresis curve. The energy is mostly transformed into heat and lost. Thus, in AC applications such as magnetic heads, transformers and transducers, magnetic materials whose hysteresis loops enclose the smallest possible area are used. Usually this means materials that have a small critical field.

The sum of the hysteresis and eddy current losses is called the iron loss. The eddy current losses, partially in the form of heat which must be dissipated, is a power loss rooted in the self-induction of circular electrical currents inside the conducting material. According to the induction law

Eq. 10.20 $$U = - d\phi/dt$$

and Ohm's law

Eq. 10.21 $$I = U/R$$

eddy-current losses will increase with increasing frequency and magnetic field strength and decreasing electrical resistance. The possibility of forming eddy currents is reduced when, instead of solid cores, thin sheets, or better yet, iron powder held together with a binder, or sintered metal powders such as ferrite are used.

10.4 Recording

10.4.1 Video recording (without premagnetization)

Frequency modulation (FM) techniques used for video recording operate in the nonlinear region of the characteristic curve (Figure 10.12) where the storage medium is driven to saturation. In a sense this is quite close to being a digital or pulsed storage method. Figure 10.14 illustrates the difference between the expected outputs for medium and high input levels. The latter reaches the saturation region. If the entire content of the stored image can be recovered from the variation in pulse frequency then the strange distortion of the signal shape plays no role. In this case other types of distortion dominate. They include imperfections in the tape, head phase error and transport speed fluctuations. All must be electronically compensated.

10.4.2 Audio recording

10.4.2.1 DC premagnetization (bias)

By superimposing a DC current, which produces a constant magnetic field, upon the audio frequency signal current, the working point will be shifted to the central, linear section of the remanence curve. Figure 10.15 shows how a sinusoidal low-frequency audio oscillation results in an almost sinusoidal response in the remanence.

A steeper characteristic is obtained when the recording is made on a tape that has been previously saturated by passage through a strong constant field, rather than on an erased, or remanence free tape. This may be accomplished with a permanent erasing magnet, so that, as can be seen from Figure 10.16, the remanence curve starts at the saturated value (M_r) rather than at zero.

A great deal of tape noise results when DC magnetic biasing is used because of structural deficiencies in the tape which cause local variations in the slope of the remanence curve. This is not only annoying during pauses, but can be heard on top of the recorded audio signal. The DC biasing method had been in common use, but it could only achieve a signal-to-noise ratio of 30 dB and a harmonic distortion factor of 5%, both of which do not come close to satisfying modern requirements. However the method is still used in cheap audio recorders because of the low level of technology needed to manufacture it.

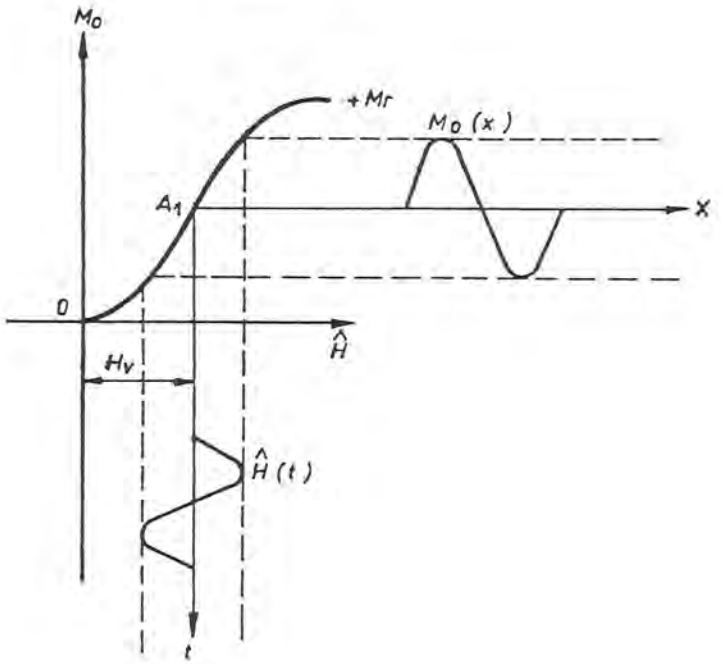
10.4.2.2 Hf-premagnetization (bias)

Hf-premagnetization involves the additive superimposition of a high frequency current (50 to 200 kHz) upon the audio recording signal. The premagnetization field strength (H_p) is chosen to be large enough that the operating point $A1^p$ lies in the middle of the remanence curve's linear region (see Figure 10.17). Therefore the extrema of the mixed waveform follow the Lf-audio oscillations. This signal is linearly transformed into magnetization patterns on the tape. This is perhaps an illustrative, though certainly very simplified, explanation of how a linear transfer characteristic is achieved by Hf-premagnetization. In reality the Hf structure of the oscillations is not recorded as they destructively interfere with each other in the negative field gradient of the gap. The remaining structure in the remanence depends only on the audio frequency envelope as is shown by the heavy line ($I_r(x)$) in Figure 10.16. Consequently the audio frequency spectrum can be stored almost without interference. The instantaneous value of the remanence can be calculated from the envelope, according to Camra's simplified quasi-static theory, as

Eq. 10.22 $$M_o = (M_1 + M_2)/2$$

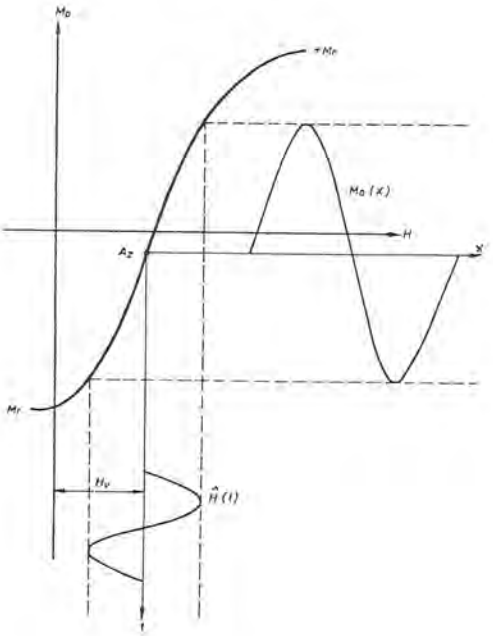
The linearized characteristic is obtained from Equation 10.22. As seen in Figure 10.17 it results from the addition of the two remanence curves, as derived from that shown in

Figure 10-15



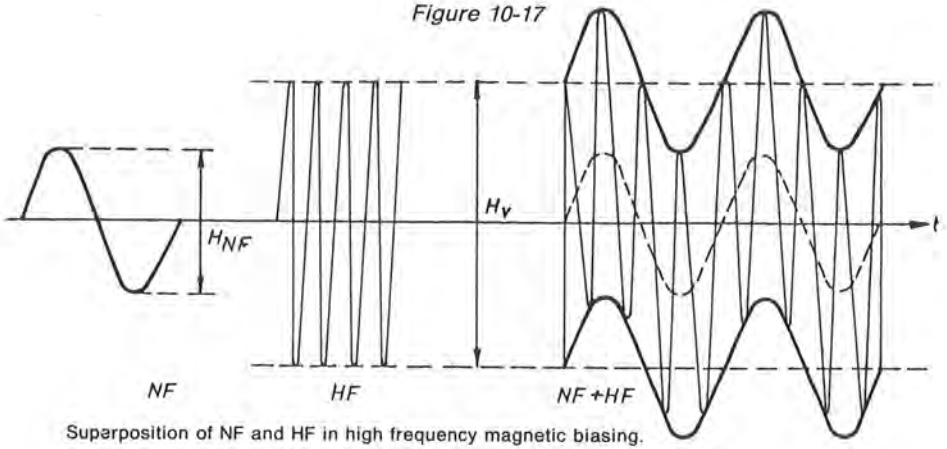
Signal storage with D.C. premagnetization.

Figure 10-16



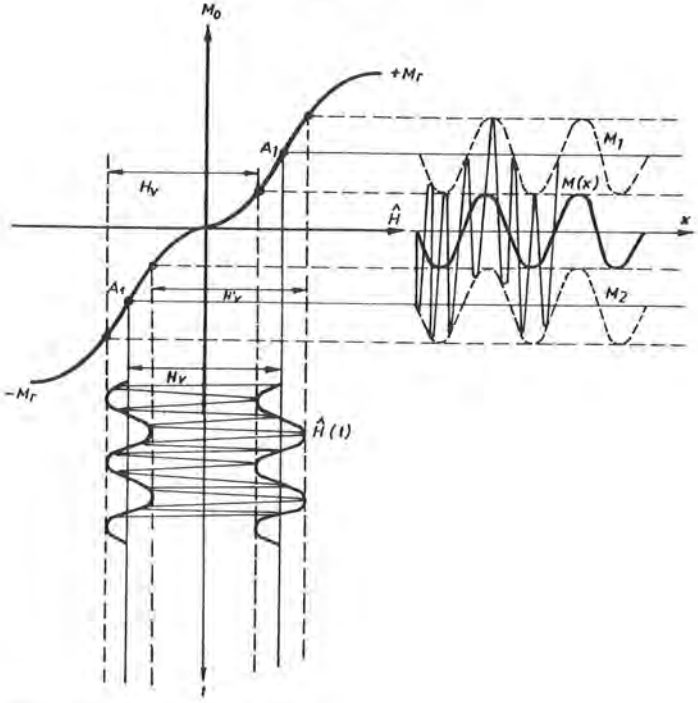
D.C. premagnetization from the state of saturation.

Figure 10-17



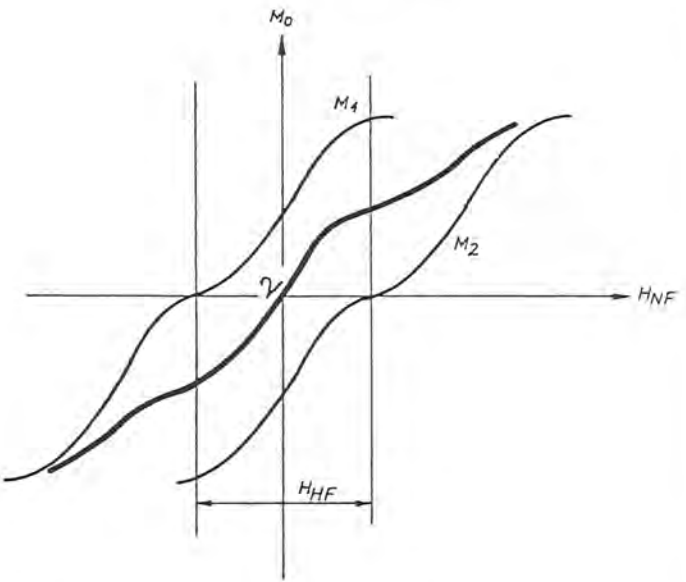
Superposition of NF and HF in high frequency magnetic biasing.

Figure 10-18



Signal storage with HF magnetic biasing.

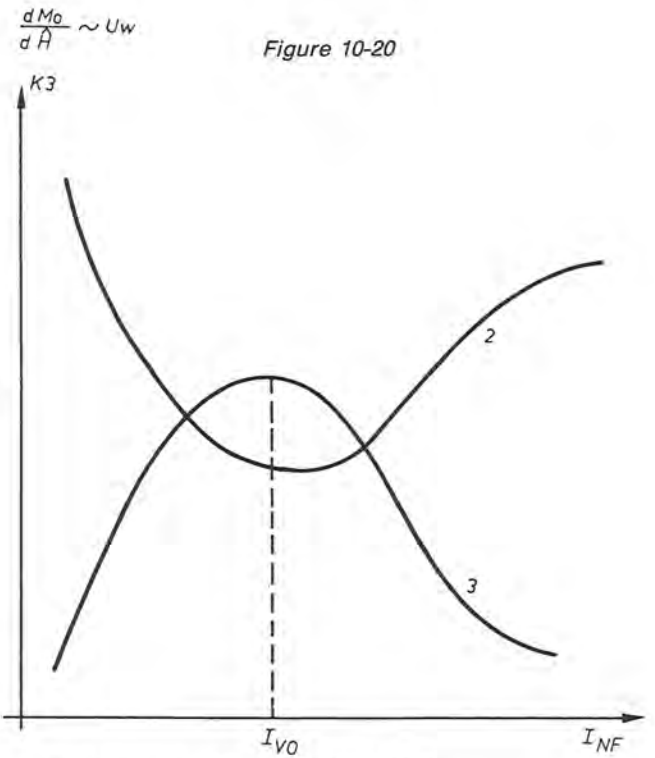
Figure 10-19



Construction of the dynamic characteristic

2 Dynamic characteristic.

Figure 10-20



Playback voltage U and distorsion factor K_3 as functions of the biasing current I_v

2 Distorsion factor K_3.

3 Voltage Uw.

Figure 10.12 which are separated from each other by H_p. One notices that, depending on the modulation depth, the operating characteristic does not deviate from a straight line near the origin. This holds only when the maxima of the Hf field roughly coincide with the operating point A1. It is easy to verify that the linear region is shrunk when the Hf field is smaller than optimum. The curve also becomes very nonlinear if the premagnetization is too large. Thus, it is vital to optimally adjust the biasing current to match the hysteresis parameters of the tape and recording heads in use.

Besides linearity, one is interested in the slope of the operating characteristic. Maximum slope means maximum tape sensitivity. In Figure 10.20 the slope, in the form of the derivative dM_o/dH , of the operating characteristic, is plotted against the premagnetization current (I_p). This function is measured experimentally from the playback voltage (U_p) under conditions of small signal amplitude and long recorded wavelengths. One may observe that a well defined maximum exists for the slope and therefore the tape's sensitivity. The particular premagnetization biasing current required to reach this maximum is denoted as I_{po}, and is an important operating parameter of a given tape-head combination. It can be seen that at I_{po} , not only is the sensitivity of the tape at a maximum, but to a first approximation the best linearity and greatest modulation depth may be reached. The second curve in Figure 10.20 represents the symmetric nonlinear distortion as measured by the harmonic distortion factor (k_3). Only older varieties of tape, that are not much in use today, display a clear minimum in the distortion factor. Modern tapes have a relatively large region in which the distortion factor is a minimum. The functional dependence of the playback voltage also depends on the tape variety. Older tapes have a relatively sharp maximum, while for modern tapes the peak is less well defined.

Hf-premagnetization is superior to constant current premagnetization not only because of the greater modulation depth that it is capable of achieving, but also because of its higher dynamic range which is a result of the Hf field's erasing effect. This dramatically reduces the noise during quiet spaces in the recording.

So as to most effectively generate the 50 to 200 kHz Hf field necessary for Hf-premagnetization the inductance and capacitance of the head winding are chosen to make the circuit resonant at the working frequency. This is usually done by adjusting the number of turns. By choosing such a high premagnetization frequency the audio frequency range is adequately separated from the resonance frequency.

10.5 Erasure

Before a new recording can be made on a magnetic tape the old one must be erased. The depth of erasure must exceed the dynamic range of the recording which could be 60 dB. This is accomplished by exposing the tape to a magnetic

field high enough to saturate it. Afterwards one will trace out new paths on the hysteresis curve since the previous magnetic history of the tape has been erased. If, as in Figure 10.21, the erasure is done with a constant field, the saturation remanence (M_r) is left on the tape. If an AC field is used for erasure, then the saturation remanence which appears at the start of the process will disappear with the repeated change of field direction if the field magnitude is slowly reduced to zero (see Figure 10.22).

The simplest erasing procedure is done with the erasing coil. This is a rod shaped laminated core of generator sheets, wound with several hundred turns of thick copper wire. The coil is connected to an AC power source and the high current passing through it produces a strong alternating field. One can bring an entire roll of tape into the near field of the coil and then slowly remove it. From the standpoint of the tape this effectively looks like a slow decay of the erasing field. The magnetization plotted as a function of the field for this process is shown in Figure 10.22, where one passes through constantly smaller hysteresis loops until zero remanence is reached.

A modern version of the erasing coil is a device in which the decaying AC field is generated by the coupling of a charged capacitor with the exciting coil to form a damped oscillator. With this device several reels may be simultaneously erased. Video tapes, which are recorded on rotating head machines, are erased in this manner. For fixed head configurations the usual method is to erase directly on the transport, using a special erasing head sitting in front of the recording head. It consists of a toroidal core with an air gap, preferably built of a ceramic material, ferrite, that has extremely low eddy-current losses.

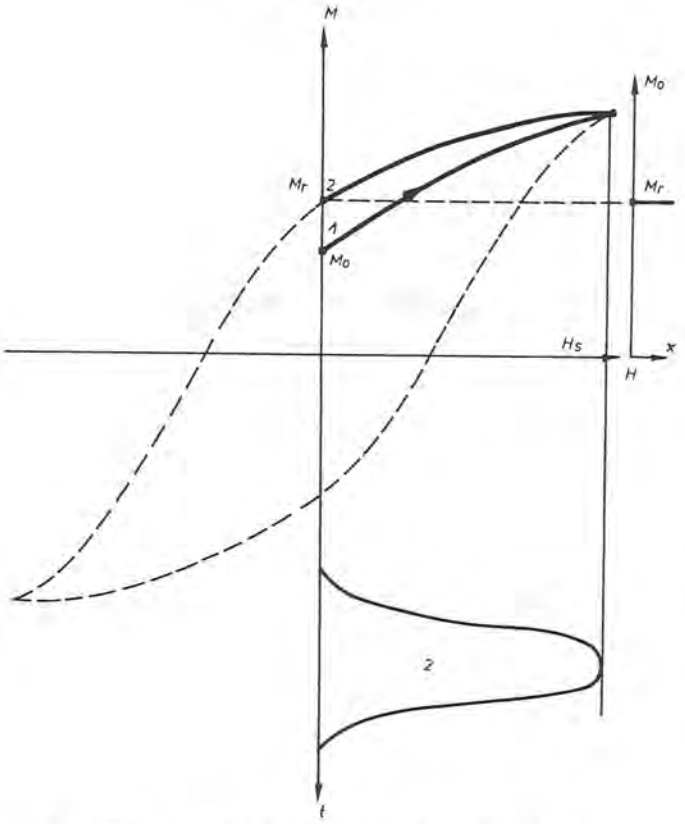
A high frequency current, greater than 50 kHz, rather than the line frequency is used for erasure, to ensure that the field direction reverses polarity several times during the tape's passage through the decaying field in the gap. Thus the exciting field behaves as shown in Figure 10.22. In order to maximize the number of remagnetization cycles during passage of the tape from the middle of the gap to its edge, the erasing head is made with a gap of up to 0.3 mm. Erasing heads that have ferrite cores generally have two gaps of about 50 u placed back to back. In this way the attenuation from erasing can be improved when compared to that of wider heads constructed of mu-metal.

From the above, one may conclude that Hf-premagnetization during recording can partially erase an old recording. This can be used for mixing with home recorders. One uses the "trick" button, which turns off the erasing head, and overwrites a new signal, which has the normal audio response, upon the somewhat damped old recording.

10.6 Magnetization of the tape

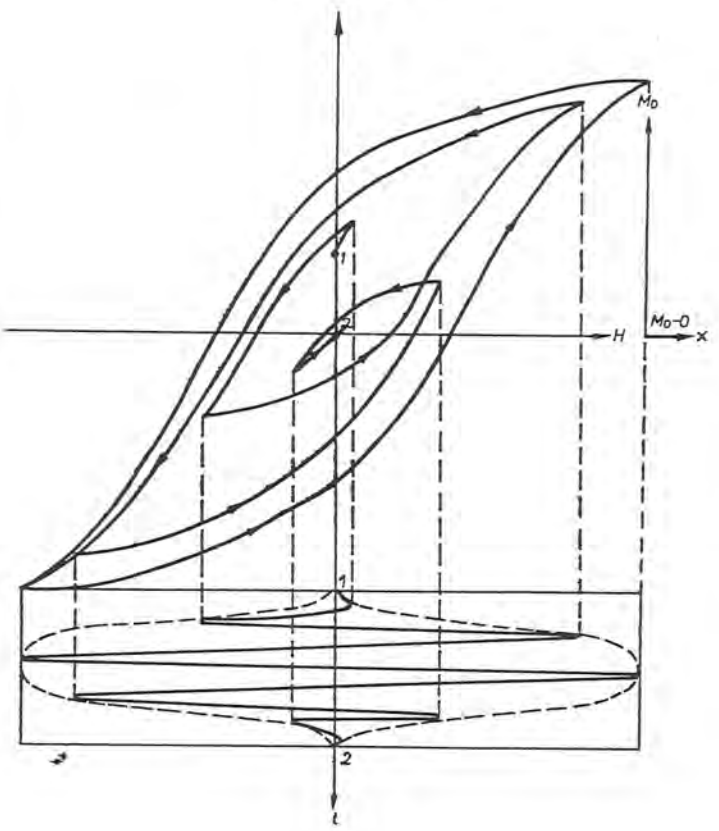
To understand the tape storage process it is necessary to

Figure 10-21



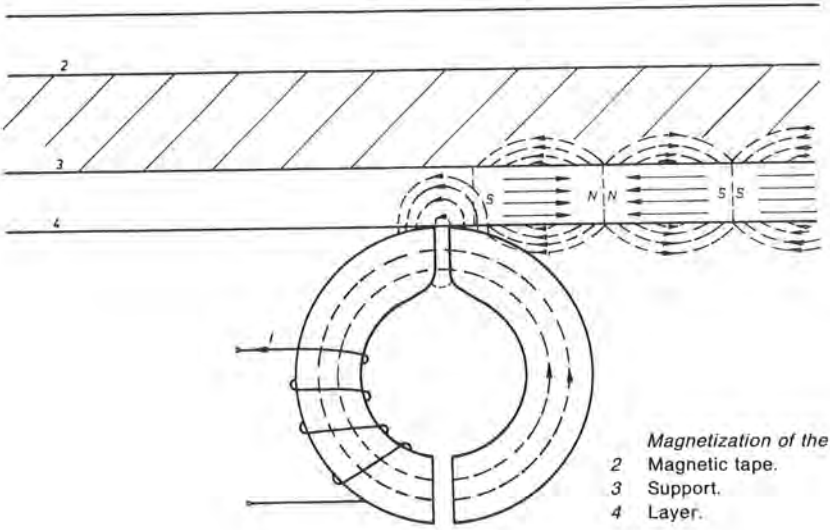
Field strength curve and erasing process for d.c. field erasure.
2 Erasure field e.g. field-distribution in the gap of an erasure head.

Figure 10-2



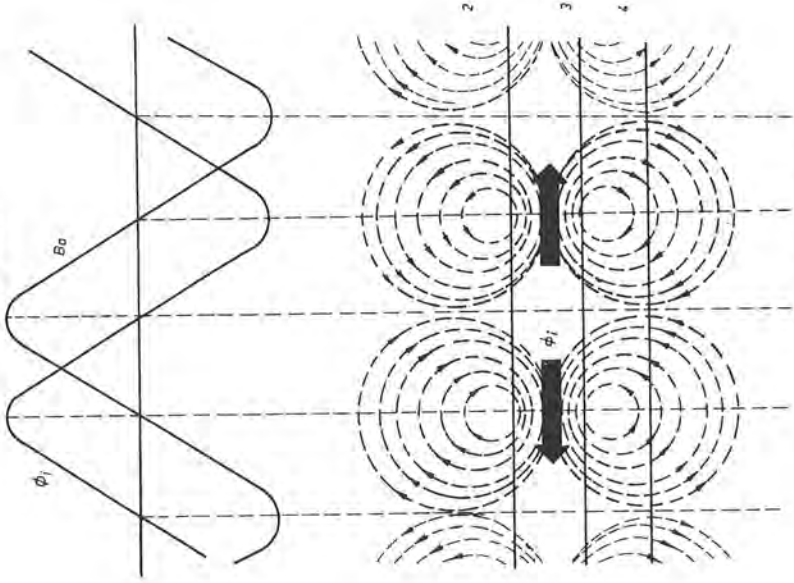
Field strength curve and erasing process for alternating field erasure.

Figure 10-23



Magnetization of the tape.
2 Magnetic tape.
3 Support.
4 Layer.

Figure 10-24



Internal and external tape flux.
2 Upper side of the layer.
3 Layer.
4 Lower side of the layer (support).

talk about the state of magnetization of the magnetic coating after it leaves the recording head. In view of how magnetic structures are created, as discussed in 10.3.2, a patterned magnetic remanent structure of varying polarity will be left on the tape after it passes through the exciting recording head. This will lie mostly along the longitudinal axis of the tape and can be schematically represented as a chain of small magnets with touching north and south poles (see Figure 10.23).

Every magnet produces a field with closed magnetic lines of flux. The path of the flux passes through the magnet's interior from pole to pole, and returns outside the magnet, again from pole to pole. For a sinusoidal excitation, Figure 10.24 shows the course of the internal tape flux (ϕ_i) and the flux density (B_e) occurring at the surface of the tape. The external flux of the structure formed by a recording on the tape can be made visible to the eye by dusting a suspension of finely powdered iron over it. Clumps of magnetic particles will build up where the external flux density (B_e) is greatest, and even the smallest wavelengths can be seen under a microscope. Today so-called tape viewers with which the recorded magnetic tracks can be seen, are commercially available.

In accordance with theory the smaller the recorded wavelength, or in other words the shorter the elementary magnet, the stronger its self-demagnetizing field. This results in an auto-demagnetization which manifests itself as a wavelength-dependent decrease in the tape's flux. A rough approximation of the auto-demagnetization attenuation (D_e) for short wavelengths (λ) is

Eq. 10.23 $$D_e = (H_c/M_o)/(\lambda/d)$$

where d is the coating thickness. The product $M_o \cdot d$ is called the magnetic moment and is directly proportional to the demagnetizing field. On the other hand H_c is the force opposing the demagnetizing action of the field. This means that the upward extension of the reproducible frequency range or a reduction of the transport speed necessary for recording shorter wavelengths is only possible for tapes with both the thinnest possible magnetic coating and a high coercivity field. A consequence of this, among others, is the appearance of cassette tapes with very thin coatings, made with chromium dioxide or other highly coercive materials.

10.7 Print-through effect

If a tape with a magnetic structure, such as is shown in Figure 10.24, is wound on a reel (see Figure 10.25) adjacent turns may influence each other. While we have assumed until now that magnetic particles can only be influenced by an external field, we must now take account of how the magnetization vector can change under the influence of heat. Heat will cause a small oscillation of these vectors which may lead to a shift in the equilibrium distribution under the influence of weak external fields, as long as they are

present for long periods of time. Some magnetic domains can flip irreversibly in the direction of the disturbing field. In particular this effect will make itself noticed at those points where a weakly magnetized region comes under the influence of a strong field (see Figure 10.24) produced by the adjacent tape winding. When the strong field is removed as the tape is unwound, those domains which have been reversibly displaced, will return to their original position, while the irreversibly rotated ones will not. This is the cause of the print-through effect. It increases with a rise in the ambient temperature and varies logarithmically with the exposure time. Since every strong disturbance has two nearest neighbours, one differentiates in practice between pre-echoes and after-echoes, as shown in Figure 10.25. If the influence of one source extends through several layers, several echoes will result, but the amplitude of the effect will decrease with distance, or in other words the print-through attenuation will increase. The print-through effect is wavelength dependent. Its maximum lies between 100 to 400 μ, depending on the thickness of the tape. This corresponds at high transport speeds to frequencies between 1 and 2 kHz. According to Fletcher's hearing sensitivity curve, human ears are very sensitive in this range. At lower transport speeds the maximum distorted frequency, and thus the extent to which the print-through effect may be noticed, decreases proportionally with the speed.

A substantial reinforcement of the print-through effect occurs whenever the reel of tape is exposed to stray external oscillatory fields. This may be turned around and used to duplicate magnetic tapes by placing a fresh tape in contact with a master and exposing them to a high frequency field. Satisfactory results are achieved when the master tape has a higher coercivity than the copy tape.

10.8 Playback

Figure 10.26 illustrates how the playback process works. Since the magnetic resistance of an iron core, through which the tape is run, is much smaller than that of the air gap, the external flux (ϕ_e) belonging to the tape will tend not to go through the gap, but will rather be guided into the playback head. As the core is wound with n turns, the magnetic flux (ϕ_e), changing synchronously with the audio-frequency or modulated video signal, will induce a playback voltage (U_p),

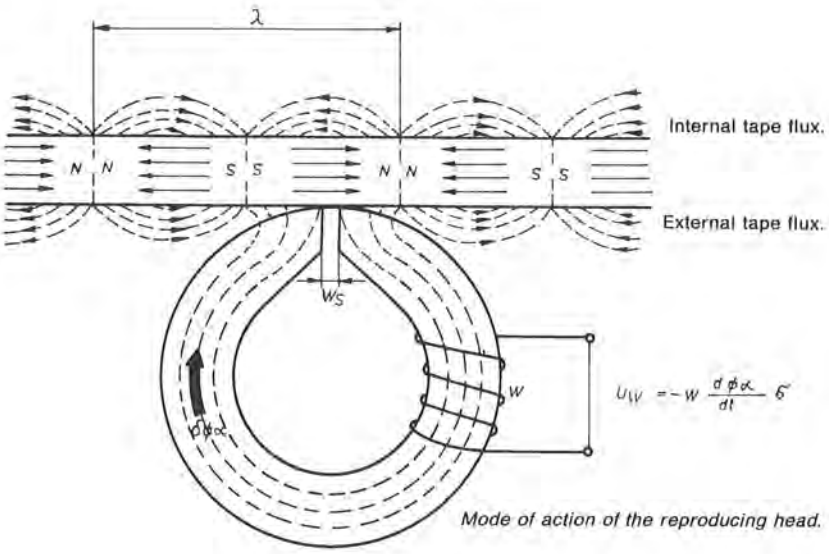
Eq. 10.24 $$U_p = -n\delta d\phi_e/dt$$

(δ) is the magnetic head efficiency which is effectively the percentage of external tape flux (ϕ_e), which actually passes into the iron core. It is identical with the δ_g of Equation 10.16.

The external tape flux from recording a sinusoidal signal can be written as

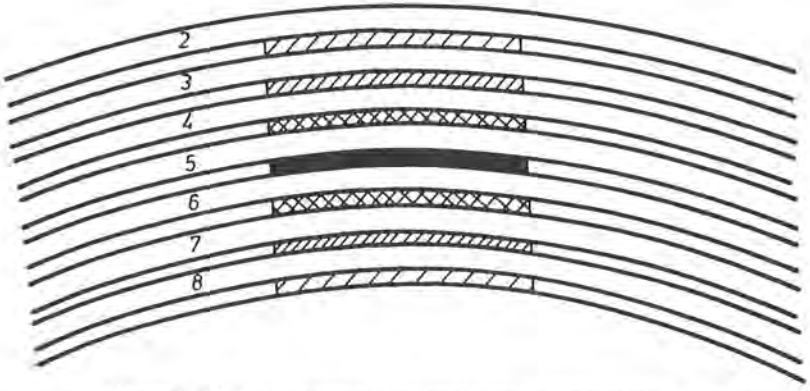
Eq. 10.25 $$\phi_e(x) = \phi_o \sin(2\pi/\lambda)x$$

Figure 10-26



Mode of action of the reproducing head.

Figure 10-25



Situation with the occurence of the print-through effect in the tape reel.
Printing attenuation after 24 hour storage at 20°.

2 3. Pre-echo — 65 dB.
3 2. Pre-echo — 61 dB.
4 1. Pre-echo — 56 dB.
5 Original signal — 0 dB.
6 1. Post-echo — 58 dB.
7 2. Post-echo — 63 dB.
8 3. Post-echo — 67 dB.

and setting x equal to $v_o t$

Eq. 10.26 $$\phi_e(t) = \phi_o \sin(2\pi v/\lambda)t$$

Since f is v/λ

Eq. 10.27 $$\phi_e(t) = \phi_o \sin 2\pi ft$$

Which may be combined with Equation 10.24 to yield

Eq. 10.28 $$U_p(t) = -n\delta(2\pi v/\lambda)\phi_o \cos(2\pi v/\lambda)t$$

or

Eq. 10.29 $$U_p(t) = -n\delta 2\pi f \phi_o \cos 2\pi ft$$

It follows from Equation 10.28 that for a given recorded signal with (λ) constant, the reproduced voltage will be directly proportional to the transport velocity (v). From Equation 10.29 it can be seen that the playback voltage increases with the frequency (f). The linear dependence of U_p on f is called the omega response because $2\pi f = \omega$ (see Figure 10.3.1).

However, U_p is linear only at lower frequencies. The higher the frequency (or the shorter the wavelength) the more apparent frequency-dependent eddy-current losses, and wavelength-dependent self-demagnetization become. In addition, there are wavelength-dependent losses, which occur only during playback, because only a part of the external magnetic flux of the tape is transferred into the magnetic core.

10.8.1 Gap attenuation

In general Equation 10.24 is valid only for wavelengths that are large compared to the gap width (w_g) of the playback head. If the wavelength is of the same order as the gap width, then the external flux of the tape can no longer be totally accommodated within the air gap, but is short circuited in the air. The excluded portion does not contribute to the playback voltage. The calculation of this "gap attenuation" is done by using the gap function derived from optical cinematographic sound systems. This yields a calculated attenuation of

Eq. 10.30 $$D_g = (\sin(\pi w_g/\lambda)/(\pi w_g/\lambda)$$

Figure 10.27 makes it clear that D_g has a zero at $\lambda = w_g$ where the playback voltage is also nil. This sharply limits the reproduction bandwidth. More detailed calculations show that the effective magnetic gap width, which actually determines the position of the zero, is not identical to the geometric gap width. The deviation is about +12%, so that 1.12 times the geometric value should be used in Equation 10.30 for w_g.

It is evident that the smallest possible gap width should be used to reproduce the widest possible frequency range, and

that this is especially important for video work. However, it is worth noting that playback head gaps must also be narrowed when slower tape transport speeds are used. Considering today's available technology and requirements, modern gap widths lie between 1.5 and 6 μ for audio heads and 0.5 and 1.5 μ for video heads.

10.8.2 Distance attenuation

A further attenuating influence on the reproduction of short wavelength signals is imperfect contact between the head mirror and the magnetic film of the tape. This "distance" attenuation (D_d) is related to the effective tape-head distance (a) by the exponential function

Eq. 10.31 $$D_d = e^{-2\pi a/\lambda}$$

or expressing it as a logarithmic quantity

Eq. 10.31a $$20 \lg D_d = -55\text{dB}(a/\lambda)$$

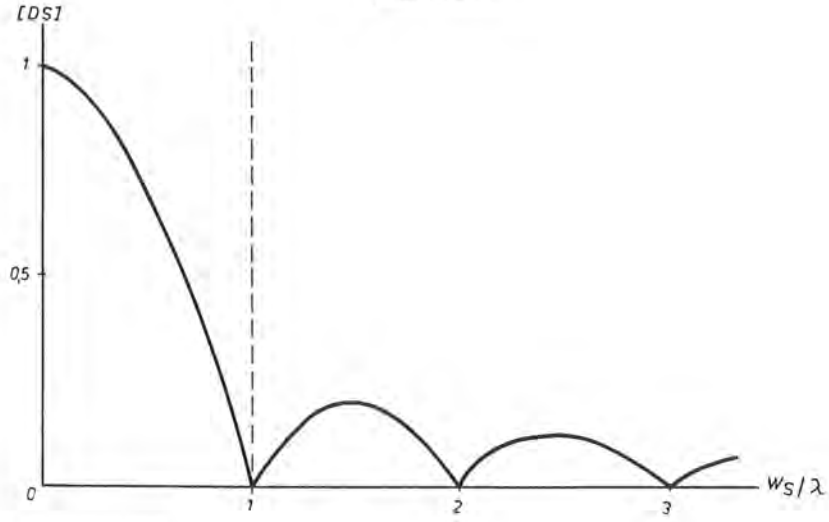
This is the most sensitive and inevitable of all causes of attenuation in magnetic tape technology. Only a few tenths of a micrometre roughness on the surface of the tape or head, or the presence of a thin, but not especially permeable, layer of similar thickness on the working head mirror can severely attenuate the playback signal at short wavelengths. If, in addition, there are some small number of uneven spots on the tape, or dust particles stuck to it by static electrical attraction, a sudden break in the playback level, called dropout, will result from the invisible and scarcely measurable lifting of the tape from the head. Also if the edges of the tape are wavy because of an asymmetric stretching of the tape, giving it a sabre shape, the way in which the transport mechanism applies tension to the tape will lead to a further lifting. Loss of contact between tape and head can also be the result of the tape coating or base becoming brittle, or increasingly rigid, in the sense of inflexible.

For completeness it should be noticed that variation in the separation during recording can also cause linear, and even non-linear distortion, because the optimal Hf-premagnetization current (I_{VO}) is set for only one particular tape head separation (a). The probability of drop-outs will be increased if the Hf-premagnetization current is too low. The maintenance of excellent surface quality, as well as elasticity, flexibility and evenness of the magnetic coating and supporting base, as well as protection of the reel of tape from exposure to dust are the necessary prerequisites for achieving quality reproduction.

10.8.3 Thickness losses

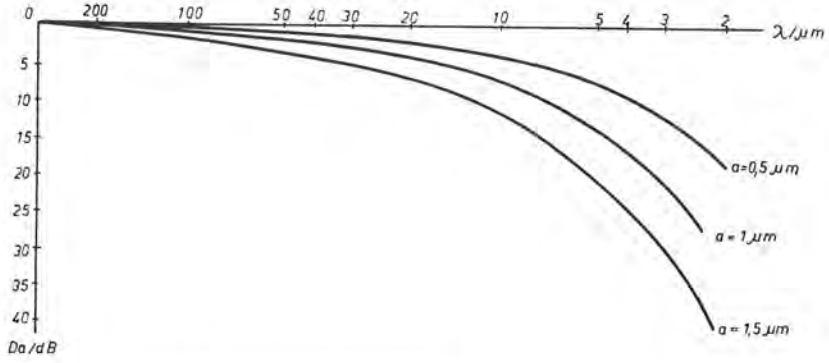
Regarding the reduction of the thickness of the coating, invariably a compromise has to be looked for. On the one hand the remanent flux increases proportionally to the thickness of the coating. It is however, obvious that the field of magnetized tape regions expands ever more slightly

Figure 10-27



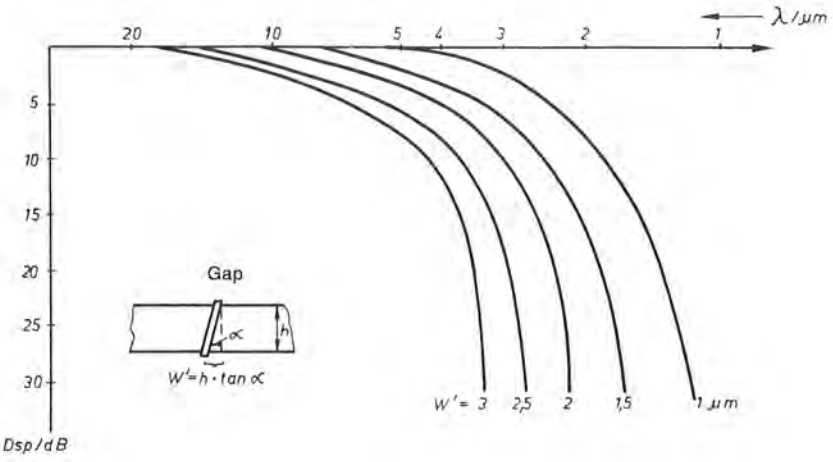
Gap function [D_S].

Figure 10-28



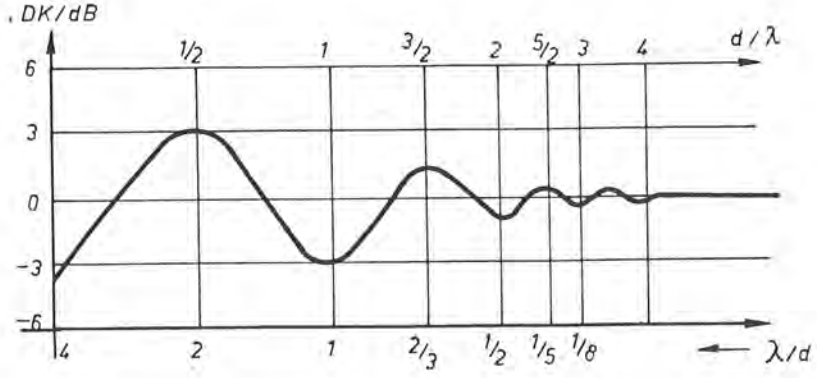
Space loss function D_a and thickness loss function D_d.

Figure 10-29



Skew attenuation D_{sp}.

Figure 10-30



Head mirror attenuation d D_K.

with decreasing wavelength, and that thereby part of the flux lines from the interior of the tape does not all reach the surface. The thickness of the coating therefore plays an important role in this.

The flux declines with decreasing wavelength and with increasing thickness of the coating. Figure 10.28 shows the reduction of the thickness of the coating which depends on the wavelength, for three different emulsion thicknesses. For the storing of short waves, only the region close to the upper surface of the coating has significance. The frequency response of the tape flux is thus compensated by a lesser thickness of the coating.

That is why the objective of the efforts being made at present in the development of magnetic tapes is the production of thinner coating. It must be understood, however, that coatings which are too thin can lead to a lower signal noise ratio, and in audio tapes can diminish the dynamic range of low frequencies.

10.8.4 Gap skew attenuation (azimuth)

Displacement of the position of the gap from the vertical position, as shown in Figure 10.29, gives rise to a further wavelength dependent attenuation of the playback voltage. The calculated gap-angle function is

Eq. 10.32 $$D_{gs} = (\sin\pi w'/\lambda)/(\pi w'/\lambda)$$

where $w' = h \cdot \tan\alpha$ is the projection of the gap on the edge of the tape as shown in Figure 10.29, h the track width and α the angle of inclination between the gap and the vertical. One should observe that the gap angle function has extreme values at higher orders, as does the similar function graphed in Figure 10.27. Therefore it is necessary when adjusting the gap, to take care that the central and major peak is reached.

10.8.5 Head mirror attenuation

All of the wavelength dependent loss processes that we have talked about so far increase with decreasing wavelength. However the reproduction of very large wavelength signals (or low frequencies) is also subject to limitations, when the recorded wavelength is of the order of the head dimensions. Here, the mirror edges begin to act as a second gap edge pair, separated by a distance (b). This causes subtraction or addition of lines of flux. Figure 10.30 shows the resulting ripple, with minima at $b = N \cdot \lambda$ and maxima at $b = N \cdot \lambda/2$, (N = 1,2,3 etc).

The ripple increases as N decreases and reaches its highest value when N = 1 or at $b = \lambda/2$. A further increase in wavelength results in a rapid decrease of the output voltage. At this point all of the magnetic field lines emanating from the tape cannot pass into the iron core. The mirror length must be at least equal to half the wavelength of the lowest frequency. This is generally an easy

condition to satisfy, so that the wavelength dependent attenuation in the lower part of the frequency range can be kept small.

10.8.6 Playback frequency response

If the most important quantities affecting the playback voltage are combined (Equations 10.28-10.32), the following result is found for the maximum value,

$$\text{Eq. 10.33} \quad U_p = n\delta \frac{2\pi v}{\Phi_o} \frac{\sin \frac{\pi w_g}{\lambda}}{\frac{\pi w_g}{\lambda}} e^{-\frac{2\pi a}{\lambda}} \frac{\sin \frac{\pi w'}{\lambda}}{\frac{\pi w'}{\lambda}} \cos \frac{2\pi v}{\lambda} t$$

or, in terms of the frequency of the signal

$$\text{Eq. 10.34} \quad U_p = n\delta\, 2\pi f\, \Phi_0 \frac{\sin \frac{\pi w_g}{v_f}}{\frac{\pi w_g}{v_f}} e^{-\frac{2\pi a}{v_f}} \frac{\sin \frac{\pi w'}{v_f}}{\frac{\pi w'}{v_f}} \cos 2\pi f t$$

From this one can calculate response curves for various tape speeds as functions of the frequency (f), using the relationship $v = \lambda/f$. The curves rise to a maximum, and then drop off sharply with increasing frequency (see Figure 10.31). The lower the tape speed, the lower the frequency at which this happens. For example if $v = 9.5$ cm/sec the response drops off at frequencies above 5 kHz for older tapes and magnetic heads. Besides wavelength-dependent losses, frequency-dependent losses also exist, due to eddy currents in the magnetic heads. The amount of attenuation that they cause depends on the frequency and the composition of the magnetic heads, including any laminations.

10.8.7 Frequency response equalization

The frequency response of a typical magnetic tape system, as shown in Figure 10.31, deviates considerably from the ideal linear response of an acoustical reproduction system. Therefore it is necessary to linearize the frequency response by using electronic signal processing methods. Such a procedure is sketched in Figure 10.1.

The frequency response of the recording amplifier (see Figure 10.32a) is designed to amplify high frequency signals to the same extent that the magnetization loss processes attenuate the tape's response during recording. This is called pre-equalization. Similarly the playback amplifier (see Figure 10.32c) produces an equalization that linearizes the playback voltage response. The equalized frequency response is thus the mirror image of that shown in Figure 10.32b. Thus, as can be seen in Figure 10.32c, a linear frequency response characteristic is obtained for the magnetic tape unit, considered as a whole.

Figure 10-31

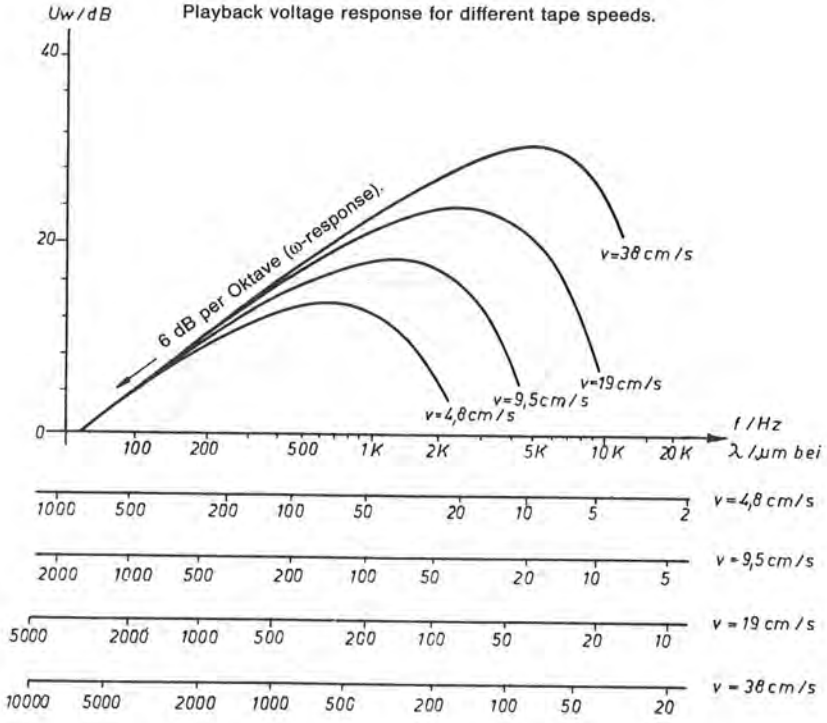
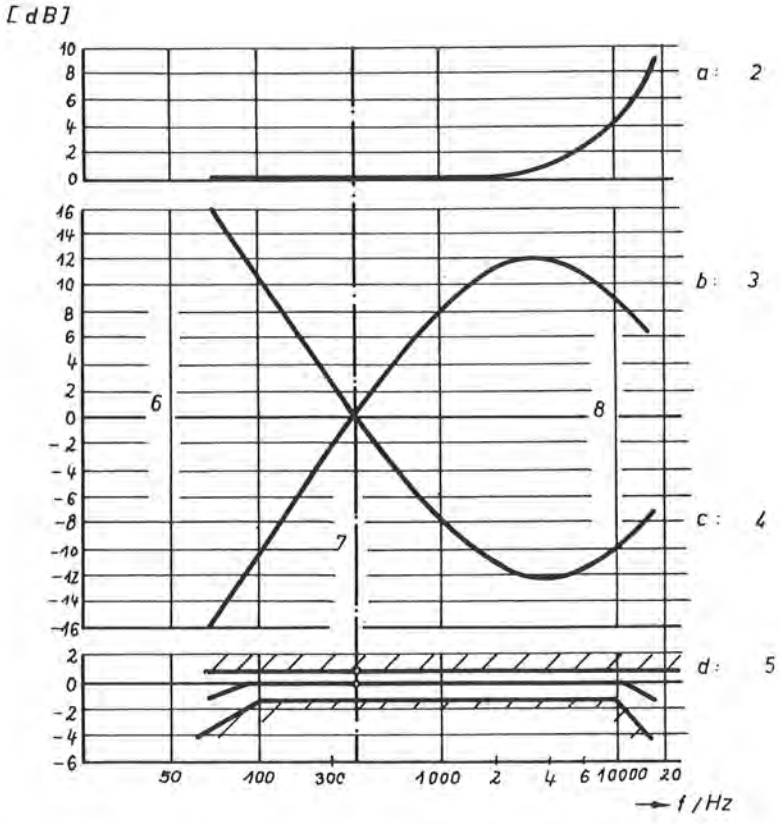

Uw / dB
Playback voltage response for different tape speeds.
40
20
0
6 dB per Oktave (ω-response).
v=38 cm/s
v=19 cm/s
v=9,5 cm/s
v=4,8 cm/s
f / Hz
λ / µm bei
100
200
500
1K
2K
5K
10K
20K
1000
500
200
100
50
20
10
5
2
v=4,8 cm/s
2000
1000
500
200
100
50
20
10
5
v=9,5 cm/s
5000
2000
1000
500
200
100
50
20
10
v=19 cm/s
10000
5000
2000
1000
500
200
100
50
20
v=38 cm/s

Figure 10-32

Frequency responses of the recording current, the playback voltage equalization, and the playback.



2 Pre-emphasis of the recording current.
3 Original playback frequency response.
4 Playback equalization.
5 Equalized frequency response with tolerance limits according to IEC standard.

10.9. Noise

10.9.1 Background noise

The ferromagnetic particles embedded in the binder of the magnetic coating are each elementary magnetic domains which, in the absence of an external field, have their own spontaneous magnetization due to the spin interaction of the several atoms. Due to the uneven distribution of size, shape and magnetic properties among the particles, microscopic fringing fields of different intensity and direction exist at the tape's surface. These fields are the source of the random background noise, present during playback of a virgin tape. The smaller the particle size and the more uniform their dispersal, the lower the background noise will be. Low noise tapes are made in this way.

The average disturbing flux (Φ_{df}) is proportional to the root of the product of coating thickness (d), multiplied by the track width (h),

Eq. 10.35 $$\Phi_{df} \sim \sqrt{d \cdot h}$$

because the energy of the distorting field is proportional to the mean number of magnetic particles on the film. The background noise is about 60 dB below the maximum signal level. Since the signal is proportional to $d \cdot h$, the signal-to-noise ratio is reciprocal to $\sqrt{d \cdot h}$.

10.9.2 DC field noise

The finite fluctuations in, and anisotropic distribution of, particle aggregations, in addition to surface unevenness and variations in the coating thickness result in statistical variations of the remanent magnetization and flux, in the presence of a DC, or constant, magnetic field. This is the cause of the DC field noise.

We differentiate between

a) the direct action of the field on the tape, and

b) superimposition effects caused by Hf-premagnetization.

A source of the first type of interference is the tape guiding elements,in so far as they are constructed of ferrous materials. Just as the magnetic heads, they may acquire a remanent magnetization, and therefore emit a stray field, after being exposed to an external magnetic field. Touching the tape with a magnetized tool, or bringing it near an electromagnet may also cause DC field noise.

Among all the types of magnetic heads, the recording head is especially prone to the risk of acquiring a residual remanence. This can come about through switching surges or the application of extremely asymmetric signals. The core material of the head, in contrast to the tape, must be made of an especially soft magnetic material, with the smallest

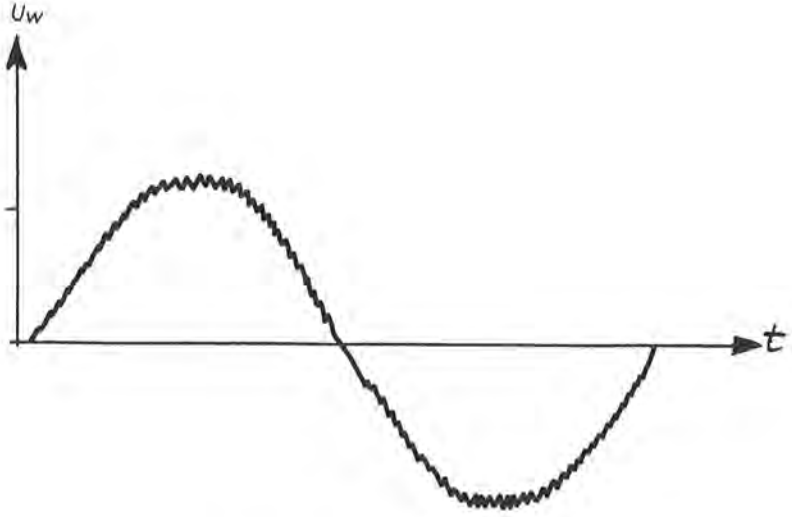
remanence possible. The higher the remanence, the greater and more disturbing the resulting DC field noise on tapes recorded with those heads will be, because the heads will have some remanence when the exciting field is zero. This effect can be reduced by building a special backwards shearing gap into the recording head to prevent the appearance of a high field inside the core. When the magnetic film is saturated, as happens in DC erasure, DC field noise is also seen. Therefore AC field erasure is used almost exclusively. The AC erasure technique also leaves no net macroscopic orientation of the magnetic coating even when the particles and their remanences are unevenly distributed.

10.9.3 Modulation noise

The major part of the modulation noise comes about during recording because of variations in contact between the tape and the head. This involves continuous minor variations in the effective field strength of the magnetic coating, and hence the remanent magnetization.

Variations in the coating thickness and an irregular distribution of the particles have the same effect. As the amplitude of fluctuations depends on the useful signal level and is roughly proportional to it, one speaks of a multiplicative noise, or modulation noise (see Figure 10.33). It shows itself as a whizzing sound. The signal-to-noise ratio for the modulation noise is about 50 dB.

Figure 10-33



Modulation noise as a function of the signal.

Chapter 11

GUIDELINES FOR THE CONSERVATION OF MAGNETIC TAPE RECORDINGS

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11.1 The structure of magnetic tapes

The tapes used in the magnetic recording of sounds or moving images consist of a base and a coating that can be magnetized. The two layers are firmly and permanently bound together by superficially melting the base material into an intermediate adhesive layer, or with a suitable adhesive material in the coating.

The first successful recordings were made on steel wire in 1900 by Poulsen. Thus the voice of Emperor Franz Joseph is preserved today on steel wire in the Technical Museum of Vienna. Later on, steel tapes were used in such devices as Blattner's audio player, and many such machines may be seen in museums.

11.1.1 Base materials

The archivist may find significant clues as to the age of a tape by examination of the base material. The earliest tapes had either a paper base or the same type of acetyl cellulose (AC) base that is found in modern safety film. After 1945, some manufacturers returned to paper as a base for magnetic recordings. Shortly after the Second World War, polyvinyl chloride (PVC) was introduced as a base material.

Today, AC bases are used for perforated magnetic film, while polyester (PE) bases are found both in perforated magnetic film and, almost exclusively in all unperforated tapes. The tendency is toward a greater use of the PE base because it has some truly outstanding qualities. It is less sensitive to humidity and heat and is practically immune to attack by fungi and bacteria; these properties make it very suitable for long term storage. To be sure, the magnetic coating must contain a fungicide in order to prevent organic growth. The resistance to tearing at the edges of PE bases, and thus the confidence it inspires in using it, is appreciably higher than with AC bases, where the smallest edge defect can easily lead to a break when the tape is subjected to a jerky stress such as occurs during the starting and stopping of the tape transport. More care is required when playing AC tapes in order to prevent damage.

Ironically, on the introduction of PE base tapes, this disadvantage in the use of AC base tapes was considered to

be an advantage. When an equipment failure occurred the AC base tape would break without stretching, due to its low tearing resistance, while the PE base tapes would stretch without tearing. The AC base tapes recording could be repaired with a splice, while the PE base tape was permanently defective.

In recent years the tensile strength of PE base tape has been substantially improved by prestretching (see 11.1.1.3b).

11.1.1.2 Coefficients of expansion

The coefficient of thermal expansion ($\Delta L/L$), i.e., the variation in length (ΔL) per unit length (L) for a 1° C rise in temperature is

$$2 \times 10 = 0.00002 \text{ for PE}$$

and $$6 \times 10 = 0.00006 \text{ for AC,}$$

that is, three times the expansion of PE.

The coefficient of expansion under exposure to moisture ($\Delta L/L$) for a 1% rise in the relative humidity is

$$1 \times 10 \quad \text{for PE, and}$$

$$15 \times 10 \quad \text{for AC,}$$

that is, 15 times that of PE.

These are average values. The value for a specific tape depends on the specific chemical composition of the base and the thickness of the tape. In combination, this determines the maximum permissible winding tension. Exceeding this tension leads to stretching the tape and serious damage of the recording.

11.1.1.3 Tape varieties

At the current time, the following materials are used as tape bases:

a) PE tapes: Polyester which is slightly stretched, but only along the longitudinal axis. When this tape is subject to a stress greater than the allowable winding tension, it can stretch up to double its length and will at the same time roll up into a thread. All recordings on such a distorted tape are lost.

b) Stretched PE tapes (prestretched or tensilized) are made of polyester which has been prestretched to double its original size in both the longitudinal and transverse directions. This increases the tensile strength by a factor of three, while the per cent elongation before breaking is reduced to 20 or 30%. When subject to excessive stress, these tapes will stretch, and thus the recordings on them will be lost. The temperature at which the polyester

becomes soft (the softening point) lies between 200° and 220° C.

c) AC tapes: Tapes manufactured with an AC base almost always break under the slightest overtensioning before they stretch. This is due to the universally present microscopic edge defects caused by the cutting process. These tapes are rarely produced today. The softening point is approximately 180° C. Pre-stretching of AC tapes is not possible.

d) PVC tapes: Like PE tapes, these tapes are not sensitive to moisture. However, the softening point is as low as 60-70° C. At temperatures above 60° C they lose their mechanical strength, and geometric deformation can occur. The edge tear resistance is comparable with that of PE. The tensile strength may be increased by prestretching.

e) PVC mass tapes: These tapes were produced in the past for a brief period of time. They consisted of a PVC base in which the iron oxide particles were homogeneously distributed. These tapes could be used only at the high transport speed of 76 cm/sec, and could not keep up with the technical progress that was achieved with tapes consisting of a base with a magnetic coating on the surface, and their production ceased.

11.1.1.3.2 Perforated tapes (magnetic film)

a) AC magnetic film: Which behaves like AC tape, but because of greater thickness (about 120 μ) is resistant to stretching and is therefore still in wide use.

b) PE magnetic film: Generally this film is only weakly prestretched along the longitudinal axis. The base has a thickness of only about 75 μ, giving the film a desirably greater flexibility and longer playing time for the same size reels. Thus less space is needed to store them.

11.1.1.3.3 Identification of the base material

The following characteristics may be used to identify the composition of tapes. The tests should be carried out on short lengths taken from the tapes:

a) AC tapes can be easily torn from an edge.

b) PVC and PE tapes are very tough and can only be torn with great difficulty from an edge.

To distinguish between PVC and PE tapes, immerse the sample piece into boiling water. PVC will be completely deformed, PE remains unaffected.

To distinguish between PE tapes that are not prestretched or only slightly prestretched and those that are strongly prestretched, place the sample under tension until it breaks. The first type will stretch to double its length; the second, depending on the actual degree of prestretching, will elongate only 20 or 30% and will require a much greater

force to break.

11.1.2 The magnetic coating

11.1.2.1 Structure

The magnetic coating consists of a mixture of binding agents (varnish) and particles of compounds that can readily be magnetized, such as iron oxide, chromium dioxide, or metal powders.

11.1.2.2 The binding agents

The binding agents are special organic varnishes which serve to embed and hold the magnetic particles on the base. Generally soluble thermoplastic varnishes are used. The softening point of the physically dried varnish is under 100° C. However, polymerized multi-component varnishes are frequently employed.

After polymerization, such coatings are distinguished by chemical stability and high mechanical resistance, especially to abrasion. The softening point of these polymerized coatings lies above 200° C. They are mainly used for video tapes. Polymerized coatings can be identified by trying to wipe the coating off with a cloth soaked in a solvent, such as acetone or acetic ester.

11.1.2.3 The magnetic particles

In the early stages in the development of magnetic tape, cubic iron crystals were used. Initially they were about 0.5 μ on each side; later this was reduced to 0.1 μ, and the coercivity was raised by doping the crystals with cobalt. Today, almost without exception, the magnetic particles are needle-like crystals of γ-iron oxide, magnetite, or chromium dioxide, all grown to lengths of between 0.3 and 1 μ in a chemical process. The length-to-thickness ratio is about 10:1. In order to improve the magnetic properties of the tapes, the particles are aligned in the direction of the recording track (longitudinally for audio tapes and transversely for 2 inch video tapes) by a strong external magnetic field, while the coating is still a liquid. Although some background noise is inevitably present, the amount is influenced by the average length of the particles and the statistical distribution of their sizes. Shorter and more uniform needles, known as low noise particles, reduce the amount of noise. The volume that they occupy in the dried coating (volume filling factor) should be as high as possible. For oriented tapes, the factor usually ranges between 30 and 40%, but can reach 46%.

11.1.2.4 Iron oxide

Iron oxide in the magnetic coating exhibits a coercivity of 300-400 Oe (24 to 32 kA/m). It is chemically stable, that is, it does not react to changes in the atmosphere, and tapes using iron oxide are therefore especially suitable for long term archival storage.

In order to increase the coercive force above 500 Oe (40 kA/m), iron oxides are doped with cobalt. Experience gained over the course of years with earlier versions of such "high energy tapes" showed that they were unstable to a limited degree, at short wavelengths (high frequencies) when subjected to mechanical stress. The specific cause was the sharp mechanical bending of the tape guides. This effect is particularly noticeable when the tape is frequently played; the level loss is mostly at high frequencies. Level loss due to time and temperature were not observed. Recent cobalt tapes do not have this pressure demagnetization problem.

11.1.2.5 Chromium dioxide

Chromium dioxide tapes, because of their high coercivity of 450 to 500 Oe (36-40 kA/m), have proven very valuable for recording very short wavelengths, as is needed for video and compact cassette recorders. The needles are especially uniform without any branches (dendrites), and this makes them very easy to align and thus they may be very tightly packed. The volume filling factor for chromium dioxide may rise as high as 46%. This increases the magnetic flux per unit area over the cross section of the magnetic film, i.e., the residual induction is increased.

The Curie temperature, being the temperature at which the ferromagnetic properties of the medium vanish, is about 120° C for chromium dioxide, which is low in comparison to the roughly 300° C Curie temperature of iron oxide. This opens the possibility of copying recordings from iron oxide tapes onto chromium dioxide tapes by heating them in a contact copying process. To accomplish this the chromium dioxide tape is heated to 120° C, thus being fully erased, and brought into contact with the iron oxide magnetic film of the master. During the cooling process the signal is copied. PE bases and polymerized coatings can take the brief heating without sustaining any damage. With long term storage in mind, it should be remembered that chromium dioxide tapes will be completely erased by heating them to temperatures above 120° C.

Chromium dioxide has not been used for video tapes since 1981. The use of cobalt is now universal.

11.2 Major problems of conservation

11.2.1 General introduction

The object of conservation is to preserve the recorded audio and video information so that it may be recovered without any loss of quality at any future time. Therefore we shall only consider those effects to which the tapes are subject during storage or transport that can affect the quality of reproductions.

For long term storage one should only use blank virgin tapes without any splices, and the tapes should be of a type whose physical properties have been studied for many years and

which are known to offer the smallest risk of deterioration due to ageing. An example of such a tape presently available is doubly stretched PE tape with a dulled back surface to improve its properties for winding.

If tape recordings are acquired that have been made on other base materials (see 11.1.1.3.2), then it is recommended that these be re-recorded onto PE tapes before ageing impairs the quality of reproduction or destroys the record completely.

11.2.1.1 Identification data for tape recordings

The following data are the most important in identifying any magnetic recording and should form part of the written record that is retained with the tape:

a) Recording data, such as title, date and running time.

b) Recording system: transport speed, playback equalization (time constant in sec), maximum recording level (in nWb/m), recording frequency range.

Additionally for multi-track recording: position and number of the tracks, whether it is a mono-, stereo-, or quad-recording, whether it was done with or without Dolby or any other system of noise suppression.

c) Type of tape: base material, studio or amateur work, length, whether it is a long double or triple tape, for small cassettes whether it uses iron oxide, chromium dioxide or multilayer magnetic films although this is usually printed on the cassette.

d) Level and frequency response. At the start of a tape it is advantageous to place a recording of a 1 kHz signal at the maximum level used in the recording and a high frequency signal between 10 and 14 kHz. This aids in adjusting the gap position, the frequency response of the playback system, and can be used to set the playback time constant, enabling one to obtain the flattest possible frequency response.

11.2.1.2 Standardization of playback characteristics

In studios the playback channel standardization has remained unchanged for twenty years. In home units the standard has changed many times in the same period, but one may identify the applicable norm from the date of the recording.

In relation to video both the 2-inch quadruplex tape and 1-inch tape (in two formats) are in use by broadcasters. At the semi-professional level, video cassettes such as the 3/4-inch Sony U-matic are widely used, and for home use the 1/2-inch video cassette (VHS and Betamax) are manufactured by the thousands. These systems are not compatible; recordings made on one system cannot be played on the other. In general, recordings made on reel to reel equipment by one manufacturer are not interchangeable with tape reels made on equipment by another manufacturer even though the tape size is the same.

11.2.1.3 Recommendations for archives

a) Master tapes must be protected. As a matter of principle it is urgently recommended that no originals, whether of video or audio recordings, be used for reference. Only copies should be used, because continual use may result in mechanical defects and a consequent loss in quality.

b) Archival tapes should have no splices. One should be cautioned against splicing archival tapes because the adhesive may be squeezed out by the pressure due to winding, thus gluing together adjacent turns. The consequences of this can be damage to the tape through stretching, tearing, or a failure of the dried-out splice during high speed rewinding. If tapes are supplied to the archive with splices, then they should be re-recorded as soon as possible on fresh tapes without any splices. The adhesive may dry out or become hard which will lead to the splice lifting off the head when it is passing through the playback gap, causing an audible disturbance.

c) Reels of archival tapes should be smoothly wound. Tapes should be stored only if the reels are wound so that no windings protrude, or there are steps in the reel, because this can lead to deformation during storage. Tapes whose backs have been dulled wind better, especially during fast rewind, and should therefore be preferred. A more perfect wind is normally obtained on the take up reel during normal playback. The tapes should therefore be stored after a play through, without rewinding, and only rewound just before use the next time. If it is necessary to store tapes with splices, they should be checked for durability before each use.

d) Dust protection. It is recommended that for dust protection tapes be stored in polyethylene bags, or magnetic film in metal cans, after they have been exposed to atmosphere conditions in the vault for two days.

In the following section we shall consider those factors which affect the reproduction quality of the tapes during storage. On the one hand there are magnetic influences which do not affect the coating or the base. These include stray magnetic fields, time and temperature dependent effects such as the decay of the remanence, and the print-through effect. On the other hand there are mechanical influences, which produce changes to the dimensions and structure of the coating and the base, thereby affecting the quality of reproduction with the passage of time. These changes can be accelerated by changes in temperature or humidity in the storage area.

11.2.2 Stray magnetic and electro-magnetic fields

One of the distinguishing characteristics of all magnetic recordings is that they cannot be permanently fixed; a complete erasure can result from the action of an external magnetic field. The stability of the recorded information against the influence of stray fields depends on the

magnetic properties of the tape and the conditions under which the recording was made. Generally speaking the maximum stray field strength should never exceed 400 A/m (about 50 Oe).

Although a weak field at that level will not even cause a partial erasure, it will result in an increase of the print-through effect, especially if it is generated by an alternating current.

Noticeable erasure begins to occur as field strengths exceed the tape's coercivity of about 24 kA/m (300 Oe). A field of over 80 kA/m (1000 Oe) will completely erase any recording.

One must, therefore, do everything possible to ensure that such stray fields are not generated in the immediate vicinity of the tapes. Sources of great potential danger include open magnetic circuits such as permanent bar or horseshoe magnets, electro-magnets like those used in junk yards or as mounting magnets in industrial processes, and high-current-carrying conductors, for example those leading to ground from lightning rods. The danger should not be overestimated, however, since beyond a short distance the stray field will no longer be effective. Even the largest motors and generators have, for the most part, only closed magnetic circuits, where the fringing fields in the air gap between stator and rotor are purposely kept to a minimum as they cause losses and thus decrease the electrical efficiency. Every tape recorder has one or more motors, and very often there are strong loudspeaker magnets in the immediate vicinity, but these have no effect at all on tape recordings.

Erasing coils, which are very common, are among the most effective sources of stray magnetic fields. These are AC electromagnets with a large space between the poles, so that there is a significantly large stray field in front of and between them. However, beyond a distance of 2 metres these coils will no longer have any detrimental effect on the recording.

It might be expected that tapes in transit, outside the archives vaults, might be in special danger from fields generated in public transportation systems. Detailed investigations, however, have failed to find any evidence of this. Small magnetic tape reels, a few centimeters in diameter, on which a calibrated signal had been recorded with a well defined signal level, were glued directly to the interference source under investigation and subjected to normal operating conditions. Systems investigated included: electric truck cables, starting cables for aircraft and their motors, aircraft baggage compartments, baggage wagons on electric trains, trams, large generators in power stations, lightning strikes against aircraft (with the tape cemented against the skin of the plane), and powerful radar antennas with the pulsed beam immediately in front of the horn antenna.

The signal levels of the tapes were measured before and

after use. No measurable erasure level was detected.

It has frequently been proposed that tapes should be transported in expensive, highly permeable, iron containers. In view of these experiments it would appear that this is not necessary. Moreover, the containers would be useless because at field intensities high enough to cause erasure they themselves would be saturated and thus eliminating their shielding effect.

11.2.3 Deterioration during storage

11.2.3.1 Magnetic instability

It is well known that permanent magnets lose some of their remanent magnetization in the course of time.

This loss is accelerated by:

a) heat;

b) vibration; and

c) opening and closing the magnetic circuit. This can be done, for example, by removing and replacing the armature of a horseshoe magnet.

Physically each of these makes the auto-demagnetizing field of the poles more effective and leads to some of the less stable domains flipping over. In order to prevent this loss of remanent magnetization, permanent magnets intended for use in measuring instruments are artificially aged by superimposing an alternating field over the constant one during magnetization. This "fixes" all of the unstable domains. Magnets treated in this manner will be very stable against loss due to ageing.

The same holds true for magnetic recordings. They consist of small permanent magnets whose length equals half of the recorded wavelength. For audio recordings a strong high frequency alternating field is almost always superimposed (Hf-premagnetization), so that the recorded information will be completely stable for all practical purposes. Tapes recorded at a defined level i.e. reference tapes, show no measurable amplitude loss after twenty years.

The situation is different for video recordings. It is done without Hf-premagnetization and thus will be unstable initially. When the tape is repeatedly played, the amplitude will rapidly decrease by about 10 or 20% but will then remain constant. Since such recordings are frequency modulated, and hence the signal is defined by the positions of the nodes, this attenuation is of no importance.

In the print-through effect, the echo signals are also produced without the stabilizing influence of an alternating field, and will thus be very unstable (see Section 11.2.6).

11.2.3.2 Chemical instability

Iron oxides are very stable chemically; they do not shift to a nonmagnetic phase under the influence of the ambient atmosphere or lose any remanent magnetization. Their recording level remains constant.

Chromium dioxide reacts with atmospheric oxygen, changing over to a non-magnetic phase and the crystals therefore have to be protected by a coating that more or less prevents level losses due to ageing. It is still not known exactly what this loss will be over time. There is a similar lack of information about the stability of metal powders.

11.2.3.3 Mechanical instability

Depending on the number of plays, cobalt-doped iron oxide, the coating for the so-called high-energy tapes, shows a wavelength-dependent level loss, which can be as high as 6 dB, or half of the original amplitude. One can reach the limiting value of this loss by pulling the tape over a sharp edge. Bending stresses can also cause a maximal loss of this type where the magnetostriction leads to demagnetization, as discussed in relation to vibrations in Section 11.2.3.1. Signals recorded without Hf-premagnetization, such as echoes of FM signals, show a similar behaviour, even if recorded on iron oxide or chromium dioxide magnetic films.

As stated in Section 11.1.2.4, recent cobalt tapes do not have problems concerning pressure demagnetization.

11.2.4 Plasticizer losses

Cellulose acetate (AC) and polyester (PE) are the two materials of choice as bases for both perforated and unperforated magnetic tapes. For AC tapes containing plasticizers the same environmental storage conditions are required as for the storage of black-and-white cinematograph film. PE tapes and perforated PE films also contain plasticizers, and therefore the same effects due to plasticizer loss occur with them, but at a far less critical level. The experience of the past fifteen years indicates that changes in temperature and humidity have relatively little influence on plasticizer loss in such tapes during storage.

11.2.5 Background noise

The noise remaining on a tape when erased using Hf-current, and then premagnetized without the imposition of an exciting signal, is called the background noise because no information is present. This operational background noise is, generally speaking, higher than that on similar tapes erased with an erasing coil. It gets worse if the Hf-current has an asymmetric form with phase-shifter second harmonics, or when the recording or playback heads have any residual magnetization. Therefore the heads should be carefully demagnetized. The actual source of the background

noise is the oxide particles within the magnetic coating. They represent isolated, spontaneously magnetized domains, each acting as a small magnetic needle. They do not lose their magnetism but only change polarities. In the erased state the polarities are statistically distributed and in saturation the poles all point in the same direction. In the erased, randomly distributed phase, they induce low voltage transients in the playback head, which manifest themselves as the background noise.

11.2.5.1 Low noise oxide

Among other things the amount of background noise depends on the size of the oxide particles. Therefore special tapes have been developed for high fidelity recordings, the low noise tapes, which have excellent recording and playback properties because of the extraordinarily short length of the oxide needles (only about 0.3 μ instead of 1 μ) and the homogeneity of the distribution.

At the present moment, however, there are still some disadvantages. For instance it is more difficult to attach the magnetic film to a PE base. Moreover, print through (see Section 11.2.6) is 4 to 10 dB higher than for normal tapes.

Therefore low noise tapes currently on the market are not especially suitable for long term storage. Recent improvements in these properties, however, are making low noise tapes as durable as normal tapes.

11.2.5.2 Constant (DC) field noise
(Caused by a remanence in the magnetic heads)

If the reproduction head of the playback unit has any remanent magnetization, the background noise will increase. Two situations can occur: for low head magnetization, the additional noise disappears after the head has been demagnetized and tapes that have been played on the unit are not adversely affected. If the head remanence is too large then the length of tape or tapes that have already been played have a permanently higher noise level and the information on them is tainted forever.

Careful demagnetization of all parts that touch the tape is a necessary precondition for prevention of damage when playing archival tapes.

11.2.6 Print-through effect

11.2.6.1 General introduction

By print through one means the undesirable duplication of recorded signals on a reel of tape transmitted from one turn of the wind to several adjacent windings. The print-through signal will be detected as disturbing, low volume, pre- and post-echoes.

The strength of the print through depends on:

a) the thickness of the base and the total thickness of the tape;

b) the recorded wavelength;

c) the signal strength and the duration during which the magnetic field acts;

d) the ambient temperature;

e) stabilization of the echo signals by changes in the temperature at which the tape is stored;

f) any measures taken to reduce the echo signals.

The ratio of signal to print-through echo level is constant for any particular tape, which has been recorded at a defined level from 1 to 4. This is called the print-through attenuation, abbreviated KD after the German word "Kopierdaempfung", given in units of dB and has a constant value for any specific type of tape. For a studio tape recording of a 1 kHz signal made at a transport speed of 38 cm/sec, with an equivalent wavelength of 380 μ, and stored 24 hours at 20° C, the print-through attenuation will be 56 dB, or about 0.16% of the signal level, a value that most broadcasters can tolerate.

The print-through effect has two phases. A measurable, if not audible echo is an immediate result upon contact between adjacent tape windings. The second phase is the long term storage effect, with the amount of echo increasing as the logarithm of the storage time. Every doubling of the duration increases the echo by the same constant, small amount. The first part corresponds to the expected normal magnetization effect. The occurrence of the second time-dependent part falls into the category of a magnetic after-effect, whose explanation is not completely understood.

11.2.6.2 Contact copying

High temperature increases the effects of both print-through processes. By using an especially suitable oxide, such as chromium dioxide, and exposing it to a high temperature of about 100 to 120° C, the print-through effect may be increased to the point that good duplicates of original tapes can be produced by contact printing.

11.2.6.3 Curie temperature

The above mentioned possibility depends on the low Curie temperature of 120° C of chromium dioxide, at which, even upon exposure for the shortest time, the recording will be completely and immediately erased, while the PE base and magnetic coating are not damaged. In the temperature range up to 80° C, the amount of print through in chromium dioxide tapes is the same as that seen in iron oxide, whose Curie point is above 300° C, a temperature at which the base and

coating are destroyed by scorching.

11.2.6.4 Wavelength dependence

The print-through effect is wavelength dependent, having a maximum which is contingent on the total thickness of the tape; at low transport speeds the maximum shifts to a frequency range where the human ear is less sensitive, and thus it is less audible. This explains why print through is no problem for the extremely thin cassette tapes, whose thickness is only 20% of that of studio tapes and which have a transport speed of 4.76 cm/sec.

Video tapes show no ill effects from print through, because they are recorded at short wavelengths, however, due to the thinness of the tape and depending on the transport speed required by the system, the sound track will be more or less susceptible to print through. The 2-inch tapes used in quadruplex transverse video recorders represent the worst case.

11.2.6.5 Echo signal instability

Every recording made without the stabilizing influence of high frequency pre-magnetization is extremely unstable and after repeated play, due to bending stresses imposed at the tape guides, the sound level will decrease to less than half its original value (-6 dB). In the same way weak alternating fields reduce an unstabilized recording by a factor of 2 to 4 (6 to 12 dB), whereas, they have hardly any effect on tapes that have been recorded at exactly the same level but stabilized with Hf-premagnetization. The printed echoes, created as they are without this stabilizing influence of alternating field, or temperature cycling, must also be unstable.

11.2.6.6 Measures for reducing print-through

This instability may be used to reduce the effects of print-through by repeatedly rewinding the archival tapes before playing or reproducing them. Here the mechanical bending stresses tend to demagnetize the echoes.

A more effective reduction can be made with so-called echo erasing heads. The recording head may be used for this by feeding a small high frequency current to it, where the amplitude is so adjusted that a high frequency signal above 14 kHz for example, will be erased by perhaps only 1 dB, an amount that cannot be heard. Depending on storage conditions such as duration, temperature and temperature cycling, the echo signals will be reduced by a factor of 2 to 4 (6-12 dB), and in most cases will then be inaudible.

The partial erasure of the useful signal happens only once, in the first pass through the echo erasing head; repeated treatment after further storage does not cause further erasure, provided that the low Hf-premagnetization current is not increased.

11.2.7 Variation in the geometrical dimension of tapes

1.2.7.1 Elongation

In contrast to metals, all plastics flow under tensile or compressive stress to one degree or another. This occurs even in the elastic region, depending on the duration of the stress and the temperature.

Magnetic tapes are generally subject only to stretching, the amount of which can vary, especially during fast rewind. These variations in tensile stress cause varying amounts of elongation within the reel, which may be frozen in during storage, and thereafter give rise to disturbing variations in the pitch of the recording. AC and PE, both prestretched and non-prestretched tapes have vastly different reactions to stretching. Prestretched PE tapes have proven to be the most resistant to stretching, AC tapes come next, and then the non-prestretched PE tapes.

As was previously explained in Section 11.2.1.3c, tapes should be stored without rewinding because the reel has then been wound at slow speed, and above all at a constant tape tension.

11.2.7.2 Shrinkage

Shrinkage, of length or width, presents no essential problem in the conservation of PE and PVC tapes. Reproduction of these tapes is not influenced by shrinkage.

The situation is different for AC tapes and magnetic film; these shrink just as triacetate film does, especially through drying out (see Section 1.1.2). Whereas a certain amount of shrinkage can be compensated for in movie film, shrinkage in AC tapes leads to disturbing pitch variations and fluctuations that cannot be corrected.

The amount of shrinkage in magnetic films can be measured as the distance between the perforations, while non-perforated tapes can only be measured by monitoring the recording and noting the pitch variations that occur as flutter.

11.2.8 Adhesion of magnetic tapes

PE magnetic tapes do not stick together, even after long storage, unless the manufacturer has made a mistake that has resulted in some chemical decomposition. Even water does not affect the recording quality of the PE tapes. Only attack by fungi and bacteria can impair the magnetic coating and thus the quality of reproduction possible.

Tape windings of other tapes can, however, adhere to one another. This may happen if the tapes are very smooth, that is tapes whose backs have not been matted. The adhesion is due to the blocking effect, which arises when the smooth surfaces of the tape lie on top of one another without an intervening pillow of air. For the most part this adhesion of magnetic tapes may be overcome by the tension applied

during recording and playback. Electrostatic charging can also cause adhesion.

Refer to Section 11.2.1.3b for information about the risk introduced by adhesive splices during long term storage from leakage of the glue causing adjacent windings to stick together.

11.2.9 Electrostatic charging

At low ambient humidity electrostatic charging may result from the rubbing of the tape against the tape guides and the magnetic heads, or while the tape is unwinding from the reel. This may cause a disturbance by inducing an audible interfering voltage that sounds like a click when there is a static discharge at the playback head. This noise does not affect the information stored on the archival tape, but the clicks are recorded on any copy being produced at the time and will be heard when it is played.

Tapes that have been charged up attract dust particles, which are then wound into the reel and are embedded in the film by the pressure between the windings, and will adhere firmly to the tape thereafter. These foreign bodies cause level dropouts, resulting in audible defects in audio tapes or light flashes on video tapes.

Friction at the tape guides and magnetic heads is unavoidable. Thus the only possibility is to remove the charge as quickly as possible by playing the tape in a humid environment and using grounded (earthed) metal spools. In obstinate cases, an ionized radiation source placed before the playback heads will help.

A general remedy is provided by antistatic agents, such as carbon black, incorporated into the film or applied as a dull matted finish, to increase the electrical conductivity of the tape.

11.2.9.1 Testing methods

One can test the charging capacity of a tape by rubbing it with a dry cloth and then holding it over an ashtray. If no ash is attracted then the conductivity is high enough to eliminate the disturbing discharge clicks. Another test is to bring the rubbed tape near a wall. If it is attracted and held, then the conductivity is not sufficient.

Chargeable tapes generally wind poorly during fast rewind, because the Coulombic repulsion lifts the tape off the reel causing overshooting.

11.2.10 Winding speed

As a matter of principle, tapes intended for long term conservation must never be rewound at high speeds. Preferably the tape should not even be rewound before storage. If this strategy is followed, the following benefits will accrue:

a) the reel will always be wound under uniform tension;

b) overshot windings and their resulting side bulges are avoided;

c) splices which have failed, or have become defective during storage may be detected when the tape is rewound before playback;

d) rewinding before playback and a subsequent 24 hours of storage reduces the print-through effect.

11.2.11 Recommendations concerning storage conditions

Temperature and humidity are the external influences that affect magnetic tapes during storage.

11.2.11.1 Vault types

It is foreseen that three types of vault will be provided for film storage, the climatic conditions of which will be adapted to the requirements of the various motion picture film base materials:

a) Nitrate film: maximum +5° C and 60% RH.

b) Acetate film (b&w): maximum +12° C and 60% RH.

c) Acetate film (colour): maximum -5° C and 30% RH.

11.2.11.2 Temperature

According to the manufacturer's specifications magnetic tapes can be stored at room temperature without risk. A reduction in temperature, however, will considerably improve the longevity of the tapes in store. It is therefore recommended that archives with air-conditioned vaults suited to the needs of cinematograph film store their magnetic recordings in the vaults used for triacetate film, at a temperature ranging from +6° to a maximum of +12° C.

Archives presently lacking such air cooled vaults should store the magnetic tapes at a room temperature between +18° and +22° C if possible. Constant environmental conditions are preferable to fluctuations outside the standards recommended, and the temperature alone should be controlled as in many office buildings, if that is the only storage space available.

For safety reasons it should be emphasized that magnetic recordings should never be stored in nitrate film vaults.

11.2.11.3 Humidity

The humidity should correspond to that specified for acetate film, or a maximum of 60% RH. An increase in the humidity above this point can result in fungal infestation of the polyester tapes which will rapidly spread. It is understood that constant humidity can only be maintained by an air

conditioning system. In order to prevent the drying out and stiffening of AC films and AC tapes, it is recommended that the relative humidity be maintained above 50%.

When separate picture and sound track of a black-and-white cinematograph film are held in an archive they should be stored in the same acetate vault.

In the case of colour films there is no reason why the picture and the magnetic sound tracks should not be stored together in the same vault at a maximum temperature of -5° C.

Chapter 12

THE RESTORATION OF MAGNETIC RECORDINGS OF SOUND

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12.1 Introduction

Restoration is usually understood as the process of returning something to its original state. The original character of the record must be preserved as faithfully as possible. Higher technological standards and the different tastes of a modern audience can be incorporated when duplicate records are produced.

12.2 Chief recording factors

In order to meet the above standards, it is necessary to reproduce, or if possible to improve on, the following key recording factors: frequency range, signal-to-noise ratio, and synchronization.

All of these factors can be impaired through external mechanical, electrical, thermal or magnetic influences. Over and above this, there is considerable possibility for error during subsequent reproduction due to changes in standardized norms and procedures which occur in the course of time. Therefore detailed technical documentation for each recording is an important prerequisite for successful archival storage.

12.3 The most important sources of error

12.3.1 Frequency response

12.3.1.1 Technical deficiencies in older tapes

During the course of development of audio tapes over four decades, the frequency range has been expanded relative to the speed at which the tape moves past the head. Such expansions, made possible primarily through improvements in the quality of the recording material, were originally possible only at medium and low levels, but have recently been extended to higher amplitudes. This has allowed audio recording to keep pace with the increasing requirements of contemporary music recording across the entire dynamic range.

12.3.1.2 The results of changing technical standards

Due to the poor dynamics of older tapes in the higher frequencies, and especially at slower tape speeds,

equalization was mainly associated with the reproducing channel. Only during the development of better tapes was it decided to arrange the equalization in another manner by the introduction of altered equalization time-constants. Recordings with different equalizations cannot be reproduced over standard playback channels without some sacrifice of equality. During playback with correct equalization, the older standard tapes are comparatively noisier than newer recordings because, as has already been indicated, the reproducing channel must have much higher amplification, with resulting higher noise.

The following table sets out some equalization functions. A minus sign indicates the required accentuation in playback.

Table 12.1

f/Hz	35 µs	50 µs	70 µs	100 µs	90 µs	120 µs	140µs	380µs
31.5	+0.2	+0.4	+0.75	+1.45	+1.2	+1.95	+2.5	+5.45
40	+0.2	+0.4	+0.75	+1.45	+1.2	+1.95	+2.5	+4.1
63	+0.2	+0.4	+0.75	+1.45	+0.2	+1.95	+2.5	+2.0
125	+0.2	+0.4	+0.75	+1.4	+1.2	+1.9	+2.45	+0.65
250	+0.2	+0.4	+0.7	+1.3	+1.15	+1.8	+2.3	+0.15
500	+0.15	+0.3	+0.55	+1.0	+0.65	+1.35	+1.75	+0.05
1000	0	0	0	0	0	0	0	0
2000	-0.55	-1.0	-1.7	-2.65	-2.35	-3.2	-3.65	0
4000	-2.3	-3.7	-5.4	-7.2	-6.65	-8.1	-8.8	0
6300	-4.4	-6.5	-8.6	-10.8	-10.2	-11.8	-12.5	0
8000	-5.9	-8.2	-10.5	-12.7	-12.1	-13.8	-14.5	0
10000	-7.5	-9.95	-12.3	-14.6	-14.0	-15.7	-16.4	0
12500	-9.1	-11.7	-14.2	-16.5	-15.9	-17.6	-18.5	0
14000	-10.0	-12.7	-15.1	-17.5	-16.8	-18.6	-19.3	0
16000	-11.1	-13.5	-16.2	-18.7	-18.0	-9.8	-20.5	0

Since 333 or 315 Hz was often used as the crossover frequency, especially at low transport speeds, the second table lists an equalization function with a reference frequency of 315 Hz.

Apart from the listed functions there are several others, rarely used. Most of these can be correlated to one of the listed functions with only slight errors.

Table 12.2

f/Hz	90 µs	100 µs	120 µs	140 µs	200µs	3180µs	1590µs
31.5	+0.15	+0.2	+0.25	+0.35	+0.4	+5.35	+10.0
40	+0.15	+0.2	+0.25	+0.35	+0.4	+4.0	+8.35
63	+0.15	+0.2	+0.25	+0.35	+0.4	+2.05	+5.1
125	+0.15	+0.15	+0.25	+0.3	+0.3	+0.55	+1.8
250	+0.1	+0.1	+0.1	+0.15	+0.2	+0.05	+0.3
333	0	0	0	0	0	0	0
500	-0.2	-0.2	-0.3	-0.4	-1.0	-0.05	0
1000	-1.05	-1.25	-1.7	-2.1	-3.5	-0.1	-0.3
2000	-3.4	-3.9	-4.9	-5.75	-8.1	-0.1	-0.3
4000	-7.7	-8.45	-9.75	-11.0	-14.4	-0.1	-0.3
6300	-11.3	-12.0	-13.4	-14.7	-17.4	-0.1	-0.3
8000	-13.2	-13.9	-15.4	-16.7	-19.7	-0.1	-0.3
10000	-15.1	-15.9	-7.3	-18.6	-21.7	-0.1	-0.3
12500	-7.0	-17.8	-19.2	-20.7	-23.6	-0.1	-0.3
14000	-17.9	-18.7	-20.2	-21.5	-24.5	-0.1	-0.3
16000	-19.1	-9.9	-21.4	-22.7	-25.7	-0.1	-0.3

These tables show what changes must be made in equalization, if the function used for the original recording is known, as well as showing how the function deviates from that available for playback on a particular machine.

12.3.1.3 Storage defects

Storage defects can show themselves in many forms. If proper storage conditions are maintained, changes in frequency response should seldom occur. Nevertheless a few remarks on this topic may be appropriate.

Stability in long-term storage depends then on the immediate environment, and on the nature of the tape material itself. For example, modern tapes on a polyester base are substantially more stable than the tapes produced in the fifties and sixties. However, it must be remembered that the magnetic properties of all tapes react differently to the physical properties given such factors as temperature changes. The standards for environmental controls in tape

storage vaults are usually set by the manufacturers taking into account only the mechanical properties of the tape.

Tapes can be damaged, for example, when exposed to the influence of a strong, external magnetic field (static hum), or if the tapes have been stored in a very dusty room. Defects can also result from mechanical injuries or through changes in the physical properties of the base caused by poor environmental conditions and/or poor handling. Tapes can become excessively dry, lose their flexibility, and develop sharp creases due to bending under those conditions. Problems can also occur when tapes are stored under proper conditions. Examples of such phenomena include print-through, and changes in the structure of certain early tapes over long periods of time, changes which may appear in a very short time under poor storage conditions. Changes in the physical properties of the tape make themselves known through measurable defects such as loss in the frequency response when the tape loses flexibility, and the tape to head contact no longer meets the specification, or as increased noise due to the same cause, or as the appearance of dropouts due to dirty tapes, or as phase errors, excessive noise, curling of the edges of seriously damaged tapes and so on. The identification of these defects and their cause is not always clear or easy to determine. Even errors in synchronization can be traced to defects caused by ageing.

Fundamentally, errors in frequency response can no longer be described quantitatively because the tapes in use today and the recording process by which they are made respond in a different way to the same source of interference. Objective comparisons between what should be and what actually is, are not possible unless a standard guide leader is attached to the tape, as is the case in international exchange of stereophonic recording tapes. Consequently subjective evaluation is the only possible approach in most cases, and this is dependent to a great extent on such external conditions as the state of the monitoring equipment, the monitoring room, the listening habits of the technician involved, etc. Defects in frequency response that result from storage are therefore hardly ever susceptible of proof.

12.3.1.4 Defects caused by the technical equipment

Apart from those sources of error listed under 12.3.1.1 and 12.3.1.2, errors in the frequency response may be introduced through deviations between the standards (as measured from reference tapes) used to adjust the recording equipment versus those used to adjust the reproduction equipment. Depending on the tape speed and the gap width, significant errors are possible. For example, if a track that is 6.25 mm wide passing through the gap of a playback head at a speed of 19.05 cm/sec is subjected to a deviation of 6 minutes in the angle that will lead to a serious attenuation of 5.5 dB at 10 KHz.

12.3.1.5 Possible ways of eliminating errors

In order to restore old recordings, it is recommended as a

matter of principle that the original should first be copied and that the necessary corrections be done on the copy.

The reproduction equipment should have an adjustable playback head which can be subjectively orientated to obtain the maximum playback amplitude, or in the case of a stereophonic tape, adjusted with the aid of a goniometer to minimize the phase difference between the two channels. For recordings with a test leader one can use the test signal to adjust the equipment. When the optimal adjustment of the playback head has been made, a subjective evaluation should be carried out to assess whether the reproduction meets the desired technical specifications. If sufficient documentation is available, the equalization of the recording and the reproduction equipment should be compared and if necessary corrected. The necessary equalization values may be obtained from Tables 12.1 and 12.2.

Subjective correction is possible, but it carries the risk that the acoustic peculiarities of a particular orchestra or concert hall will be eliminated (corrected away) because it does not conform to the technician's "standards". If carried to extremes the historic value and, to some extent, the archival value of the recording will be lost.

Any improvement in one area, moreover, results in a worsening of others, such as noise or distortion, that can lead to a greater total distortion of the sound than was caused by the original deficiency. In making any correction, the overall sound of the reproduction should always be the decisive factor.

12.3.2 Signal-to-noise ratio

12.3.2.1 Technical problems of older recordings

Recordings of music and speech were originally accompanied by a multitude of undesired interference effects which, in part, originated in or were picked up through the microphone, or from the recording equipment itself. While signal-to-noise ratios of 40 dB were once considered to be very good, today it is routine to demand values over 60 dB in studio work. Background noise, once recorded, cannot be removed unless its frequency distribution is concentrated at the edges of the spectrum of the reproduction. In such a case, the noise may be filtered out without impairing the actual recording. It is also possible to remove parasitic recordings (over-dubs) made on the same tape, but under different recording conditions.

12.3.2.2 The influence of technical standards

As we have seen in section 12.3.1.2, very high noise levels, as compared to those in present-day recordings, can be generated as a result of inappropriate equalization. Under normal circumstances, once the recording is made, nothing can be done to improve this situation.

12.3.2.3 Correction of errors

It is very difficult to correct defects such as those described in Section 12.3.2.1. Filters are only useful when the noise is concentrated at a few discrete frequencies, and even then these frequencies cannot be in the middle of the frequency range of the recording. The use of even very narrow-band filters will still cause the loss of some part of the signal. The situation is different, however, with cecordings distorted by hum, or very high frequency noise. With the aid of suitable high and low pass filters, most of the interference may be eliminated without disturbing the actual recording. For normal speech, one can set a cutoff above 6 KHz and below 125 Hz without running the risk of damaging the recording.

In limited circumstances, such measures can be applied to the recording of music, particularly when one recalls that the frequency range of early recordings was much narrower than that in present use. The reproduction of the entire spectral range that is the standard today will deliver no additional information and only add noise. A precise understanding of the conditions in which the original was made is important. Knowledge of the character of the recorded music is also important; the instrumentation, the structure of the score, etc. can give hints about how filters can possibly be used to reduce the noise. In general, the chances of success are slim and become even slimmer when dealing with defects that originate from problems with technical standards, because here any correction of an error, which causes amplitude attenuation, will result in other types of distortion. Because amplifiers in use today normally generate less noise than earlier types, it must also be remembered that the quality of the original tape, such as it was at the time of recording, has probably not decreased, but will only be perceived as such because present-day standards are so much higher.

The use of compressors and expanders to minimize a previously existing interference is not worthwhile, because of the principle on which such instruments function. There are, however, other techniques that take advantage of the different ways that sound is emitted from musical instruments in loud or soft passages.

Dynamic noise filters depend on the fact that, at low amplitudes, higher frequencies above a certain limit are attenuated so that the portion of the high frequency noise, which is audible at lower levels, will appear to be considerably weaker. Circuits of this type were introduced by the industry in connection with cassette sets in which tape noise was a considerable factor in the overall quality of the reproduction. Since measures such as this can be employed while making the copy, they do not affect the original tapes, and such techniques may be applied to any normal recording with good prospects for success.

Defects that result from inadequate storage must be dealt with in terms of their causes and/or symptoms. Parasitical

recordings, of which the so-called print-through echoes are the best known, are generally less stable than the useful recording, because they have been made without the reinforcing effect of a biasing field. Under the worst conditions, however, particularly as a result of radical shifts in temperature, stabilization can occur. As long as this stabilization has not occurred, the print-through signal may be attenuated by two techniques.

a) The first is to subject the tape to mechanical stress. Such stress can be induced by simply rewinding the tape repeatedly, or by playing the tape. In this way an improvement of a few dB may be achieved.

b) The second is by using special erasing devices that have been in wide use by radio stations. In this technique, it is important that a large enough field is present to eliminate the parasitical recording, but still too weak to affect the useful recording. If the echo-erasing head is placed so it radiates from the back side of the tape, with the field running through the tape, it is possible to achieve an attenuation of the signal of as much as 10 dB.

Another technique, but less successful, is the use of a normal erasing head, again on the reverse side of the tape. Here the attenuation of the useful recording is of the order of one or two dB.

The effects described here are dependant upon many factors, such as the type of tape, the tape recording conditions, the storage time and conditions, etc. The actual recording is more sensitive if it has been made using a small premagnetization field. The application of echo-erasing machines must be undertaken with caution.

Tapes made at low recording speed are less endangered by the print-through effect because the intensity depends on frequency. The worst problems appear at recording speeds of more than 38.1 cm/sec.

Mechanical defects resulting from dust can be eliminated by various cleaning processes. In general, the use of a piece of felt for cleaning will suffice, but it should be used only when necessary and even then, the adhesion of the magnetic coating to the base should be checked. For some tapes, this adhesion decreases with time, and the danger exists of removing the magnetic coating itself along with the dust. In severe cases, a vacuum cleaning device can be mounted on the head carrier, in front of the head, so that the tape is cleaned before contact, and arranged so that the tape path is not affected and the playback channel is neither electrically charged nor magnetically influenced. There are also industrial cleaners, wet and dry, that were originally developed for computer tape in data processing.

Defects in the magnetic coating are generally not repairable and point to the mechanical instability of the entire tape. The only solution is to copy the tape with the least

possible drag on the tape, avoiding any unnecessary strain on the coating. The same procedure applies for defects in the base. In some cases, damaged edges can be supported by a self-adhesive tape backing. The playback of wavy or crumpled tapes can be improved by increasing the tension on the tape as it passes the head, or by increasing the drag on the tape. In the case of recordings of music, if certain parts of the tape can no longer be restored, it may be acceptable to splice in a replacement piece, true to the recording of another performance of the same piece which is true to the style and technical character of the original.

Very old tapes have pronounced wow and flutter problems. These defects are often caused by the recording technique, but can also be due to alterations in the tape materials during storage. Under normal circumstances these cannot be corrected, but in some cases a small increase in the tension, or on the pressure of the rubber rollers, can improve the quality of the copy. Such measures can only be applied experimentally, and it is assumed that the available equipment can be adjusted as required, and that the tapes can withstand the pressure.

12.3.3 Required playback facilities for restoration work

Playback facilities must meet the requirements noted in the previous sections. In addition to the capacity to run at all the tape speeds required, with the speed control adjustable to correct for any variations that may be encountered, the equipment should include the following:

a. an adjustable equalization amplifier that can handle all possible standard equalizations;

b. adjustable filters to limit the frequency range;

c. high and low pass filters with variable limiting frequencies and fall off;

d. a dynamic noise limiter;

e. echo erasing equipment;

f. the possibility of adjusting the tape transport for tension, rubber roller pressure, head adjustments and track position;

g. amplitude and phase error measuring instruments;

h. standard monitoring equipment;

i. comparison recordings for subjective evaluations.

12.4 Restoration of magnetic video recordings

Magnetic video recordings are produced by a variety of different processes. The equipment and recording materials used in television studios have been standardized to a large extent, but the incompatibility of recordings produced for

home consumption is a serious problem. As far as present day recording equipment is concerned, the manufacturers have attempted to incorporate devices (e.g., dropout compensators) to correct recording defects. The pace of development has been very rapid in recent years with the result that new equipment and new types of tape have been introduced in rapid succession.

Many of the problems associated with the archival storage of videotape and video cassettes are discussed in the chapter entitled "Guidelines for the conservation of magnetic tape recordings". In addition, many of the suggestions in this chapter on the restoration of audio tape apply to videotape with regard to mechanical defects. The physical properties of the base and the coatings are roughly similar, and the recommended storage conditions and handling procedures are the same.

PART III

TRANSFER OF THE SYSTEMS AND NEW MEDIA

Chapter 13

THE TRANSFER OF CINEMA FILM ONTO THE MAGNETIC RECORDING SYSTEM

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13.1 In preceding chapters cinematographic film and magnetic tapes have been described as storage material for archival use. Although the two systems are based on entirely different physical characteristics, they are used for the same purpose (i.e. information and entertainment). Transfer of cinema film to magnetic tape and vice versa was considered necessary for practical reasons. This process proved to be difficult at first, but it has meanwhile become everyday routine television practice, and is easily carried out by means of telecine machines.

However, a film picture which has been transferred to tape does not preserve its original quality. 35 mm film material has a resolving power of approximately 1700 lines, whereas television (TV) pictures of the NTSC or SECAM/PAL systems have a vertical resolution of only 525 lines or 625 lines respectively. The resolution is mainly a function of the system bandwidth which is normally 5.0-5.5 MHz; (1 MHz equals approximately 80 lines of resolution). Using the present standards, the result is a loss in image quality of the 35 mm film image, even after retransfer. The fact is often used as an argument by archivists against the transfer of their film material on to tape.

It appears to be rather doubtful, whether this difference, which exists in mathematical terms, can be distinguished by a normal human eye. Electronic moving images of a resolution of more than 1100 lines have been projected in public on a large screen.

Let us therefore continue this chapter with a discussion of this issue.

13.2 Image quality specifications

The storage of motion picture images on mechanical, magnetic or photographic media may be used only if it is certain that the images transferred onto these media and then reconstructed, will have the same quality as that obtained by projection of a print of the film.

At present both ordinary TV and cinema audiences, together with a large number of experts in this field, think that the projected image by classic optico-mechanical means of a

release print on a cinema screen is much better than that projected on a TV screen by electronic means. The film buff came to this conclusion by comparing the home-TV image (greatly deteriorated by its broadcasting over the ether, by the low performance of the TV set, by the improper setting of the same device, and by the conditions of viewing) with that which can be seen on the cinema screen, where the projection is made by means of professional projection equipment operated by specially trained people. The experts came to the above conclusion as they took into consideration the parameters of film characteristics (the resolving power expressed in lines per millimetre), or the video signals' frequency range expressed in MHz.

It is obvious that the image would be better when projected from 35 mm prints, because it is well known that the TV standards are 525 lines in the USA and 625 lines in Europe. We would reach the same conclusion if we took into consideration only the mathematical criteria, comparing the specific frequency range of the 35 mm colour film (14-16 MHz) with that of the TV systems (5 MHz). So the result is that on 35 mm negative we can record more information than we could record on magnetic tape containing 525 lines per image.

When referring to the capacity for recording fine details, one must consider the recording capacity of the system as a whole, and not only that of the original film material. At the same time we must analyse the quality of such information. It is well known that the accuracy with which the film itself records details diminishes as the details get finer; also that the cinematographic process implies some technological steps starting with photography and ending with the screening, and these in their turn contribute individually to the diminishing of the system capacity to record fine details. On screening one can ascertain that as details become finer and finer their image on film will be fainter with reduced contrasts of brightness, which render them, in the end, less perceptible. They can no longer stand out against the other scene elements, being blurred by the film fog and grain.

This process, which is already noticeable in the image negative, is even worse in the print. The projection reduces the fine details which are then perceived less, or not at all by the audience.

The TV image shows good clarity of contours, good sharpness in the highest frequency range. If one takes into consideration the capacity of the eye to perceive, one can establish that its best visual acuity lies exactly in the field where both the cinema and television projections operate.

These are reasons to assume that, from a qualitative point of view (clarity, brightness and colour tone reproduction, background noise, fogging and grain), the images obtained from a cinema screen and from a TV one (when they are watched in equivalent distance conditions) may seem comparable.

Furthermore we should say that the equipment and technologies, which would be used if video-electronic techniques were applied to film preservation, would have high quality characteristics. The image quality is improved in the following ways:

a) the image transferred from film is not picked up from the screen of a common kinescope tube (as does the spectator's eye), but from special kinescopes;

b) some of the transfer systems of the electronic image on the film do not use the kinescope tube as intermediate image support;

c) the image transfer may be performed at a frequency lower than the standard (therefore not in real time), the subsequent film projection on the screen being performed at standard frequency;

d) one may use special TV standards with an increased number of lines (1100 lines systems are tested at present).

The electronic image also has the advantage that the TV signal can be processed by electronic methods in order to reduce the background noise to a minimum. We have the possibility of energetically prestressing the high frequencies in the video range (i.e "to enhance" the image by means of an increase in the contrast of fine details), there are a lot of ways to correct the colour balance and saturation, methods to erase the TV lines so these are not perceptible on the screen. By the assimilation of digital techniques, memorizing and computing techniques, the possibilities for the processing of video signals may be improved and adapted to the transfer of motion picture films having different sensitometric characteristics.

13.3 Preservation and transfer

The practical utilization of some of these techniques by archives is still in the future.

13.3.1 The aspects of media development which have most significance as far as archival storage technique is concerned are:

a) long-term durability;

b) increase in the information storage density;

c) relative freedom from maintenance;

d) simplification of the air-conditioning requirements.

13.3.2 In particular these conditions can be satisfied by recording media which largely dispense with the following:

a) dyes;

b) photographic emulsion (however, a magnetic coating in an organic binder is used);

c) multi-layer systems.

These requirements are almost met by magnetic tape and the optico-electronic system base for reproduction on a TV monitor or large-screen projection. There are, however, still some unsolved problems concerning the introduction and standardization of these techniques which stem from the number of makes on offer and the short life of some of these systems.

13.4 The principle of producing video-frequency electrical signals

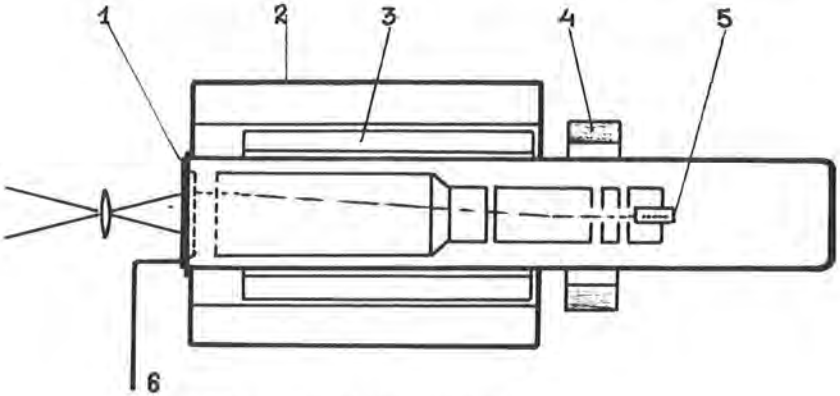
13.4.1 Camera scanners and telecines

The transformation of a two-dimensional image into a one-dimensional signal takes place either in a television camera or in a special telecine apparatus. The image is transformed either by a television camera employing a pick-up tube, by a photo-multiplier, or a camera using a charge-coupled device (CCD). In each case light produces electrical impulses using the photo-electric effect in semiconductive material. In the pick-up tube the image is conveyed optically by a lens onto a photo-electric conductive layer on the face of the camera tube. The reverse side of the layer is scanned line by line and electrically charged by an electron beam in a vacuum. When light falls on the photo-electric conductive layer, the layer's inner resistance is reduced at this point. The electrons thereby released form a charge pattern. The electron beam scans the layer and reads the resistance values corresponding to the light variations. The currents thereby produced, again varying according to the light differences, are converted by the camera tube into an electrical signal. Figure 13.1 illustrates schematically the coils which deflect and focus the electron beam. Present-day video cameras can operate from a light sensitivity (minimum level of illumination) of 2 up to 40 lux for black-and-white, and of 10-20 lux for colour. This is roughly comparable with a film sensitivity of 39 DIN (6400 ASA) at 2 lux and 29 DIN (ca. 700 ASA) at 40 lux.

Pick-up tubes with a screen or signal-plate diameter of 1 inch conform to the highest quality requirements. Various types of pick-up tubes are distinguished by the chemical composition of the photo-layer and the way it reacts. In the Vidicon the screen is coated with antimony trisulphide, while in the Plumbicon, which offers the best picture quality and is used professionally, lead oxide is used.

High-grade colour cameras employ three of the tubes which have been described. The incoming light is divided by dichroic reflectors (beamsplitters) into the three spectral bands, red, green and blue. One tube is assigned to each colour. The colour camera therefore produces three colour-value signals, corresponding to the three colours, which are then recombined into a coded colour signal (see Figure 13.2).

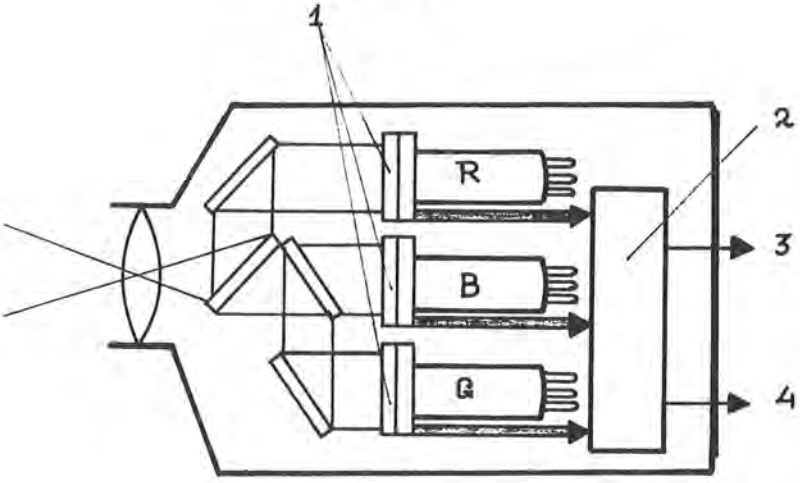
Figure 13-1



The lay-out of a Vidicon-type camera tube.

1 Recording plate semiconductor photolayer.
2 Focussing coil.
3 Deflecting coil.
4 Alignment coils or magnets (beam alignment).
5 Beam emission system, with cathode, control electrode and anode.
6 Signal.

Figure 13-2



The three-tube camera.

1 Colour filters (red-green-blue).
2 Matrix.
3 Luminence signal.
4 Colour signal.

13.4.2 An alternative to the camera tube is the CCD Camera. This has the advantage of great longevity, high reliability and little sensitivity to shock, and it does not require a high voltage. The core of the camera is the CCD sensor, a matrix of light-sensitive solid state switching circuits on the basis of charge-coupled metallic oxide semiconductor (MOS) structures. In modifying the normal CCD computer store, photons are used here for the purpose of image scanning to produce the carrier. In principle, as with the tube camera, the analogous picture signals are represented by electrical charges of varying magnitude and are read line by line via a shift-register.

13.4.3 The regime of image scanning is standardized. Essentially the NTSC standard applies in USA, Canada and Japan whereas SECAM/PAL is used in most Western countries. They are distinguished by picture scanning frequencies (either 60 or 50 fields per second) and line rate (525 or 625 lines per picture). A scanning pattern as shown in Figure 13.3, leading to two overlapping fields (half-pictures), is a uniform feature. This avoids visible flicker. Scanning takes place point by point, line by line, from left to right, omitting alternate lines each time. This technique is known as "interlaced" scan. Picture scanning and picture reproduction must be fully synchronized with one another and are therefore controlled by a common control pulse which allocates the corresponding point of the picture at any time. Extensive synchronization measures are necessary in addition. In both the line blanking intervals and between fields there are synchronization and reference signals, which permit synchronizing and level adjustment in the picture receiver.

Generally the video signal has three main components:

a) the synchronization signal;

b) the black-and-white (luminance) signal;

c) the colour (chrominance) signal.

These signals are available from the output of a camera scanner, a telecine machine, a character generator or other originating devices.

The simplest method of transferring film to video is to project the film directly into the lens of the video camera. Synchronization between picture transport and television scanning in such a camera scanner is achieved by a film projector equipped with a synchronous motor and a video camera likewise controlled by the network frequency. Flickering is avoided by using a rotating disc shutter in the projector. The dark intervals during projection are not a problem as they are bridged by the afterglow of the camera tube's photo-layer.

13.4.4 A better quality method of film transfer is held to be flying-spot scanning. The film is transported at

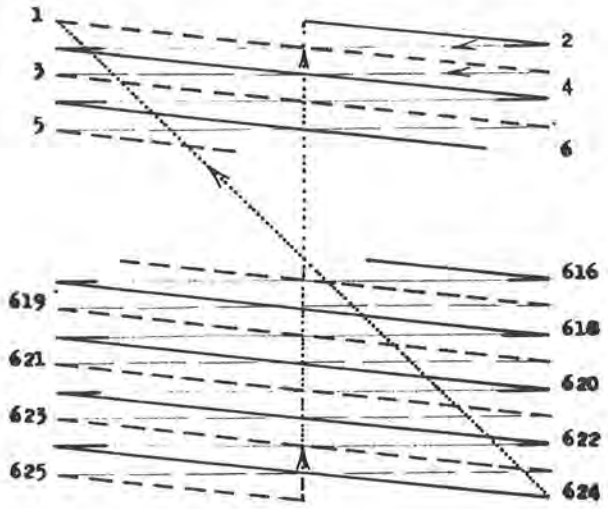
constant speed and scanned line by line by a small spot of light. Deflected in the form of a raster, the light spot of a cathode ray tube (CRT), which in principle is of the same construction as a television tube, can serve as a light source. Its distinguishing feature is the phosphor deposited on the plane glass face of the CRT which has minimal afterglow. The light beam, modulated in brightness and colour by the transparency and colour of the film is conveyed via dichroic reflectors (beamsplitters) to three electric photocells, which convert the light beams of the three primary colours into electrical voltage signals. The light path is shown in Figure 13.4.

The greatest problem with flying-spot scanning is the short time left for transporting the film after the picture has been scanned. Both actions must be fully synchronized. A 16 mm film can be pulled down very quickly using a pneumatic system, but not 35 mm film. For this, special scanners have been developed, in which the film is transported continuously and scanned via a highly precise system of optics (one for each field). The vertical movement of the scanning beam is contrary to the film movement and so scans a field line by line in a direction opposite to film motion. Then it jumps forward to catch up with the picture which has already moved on by one field, and scans the second field. Then it jumps back to the next picture and so on. Such vertical steering of the light beam may be effected both electrically, by deflecting the electron beam in the vacuum tube, and mechanically, by deflecting the light beam with a tracking deflecting mirror. The film perforations serve as an aid to re-registering for the tracking, as well as means of correcting for shrinkage.

13.4.5 Figure 13.5 shows the modern concept of a digital CCD telecine. The picture information, after colour separation in a prism system, is read by CCD sensors line by line while the film is simultaneously transported. It is then digitally processed and produced as a standard video output. This machine offers among other things, automatic and manual colour correction.

13.4.6 All machines for film-to-video transfer permit some electronic correction of the film's contrast and colour in a very broad region which is one reason why this method has become popular in television broadcasting. Practically all longer films are transferred onto videotape, with appropriate correction, before transmission. A further advantage of prior transfer to tape is the elimination of the risk of film breakage during transmission. Positive and negative films of various gauges can be transferred onto video formats of various standards, with continuous film transport at normal speeds, in slow motion, accelerated motion and freeze-frame. Moreover, the transfer of film onto video offers the possibility of electronic correction while copying. In this way, some corrections can be achieved which are not possible by photography.

Figure 13-3

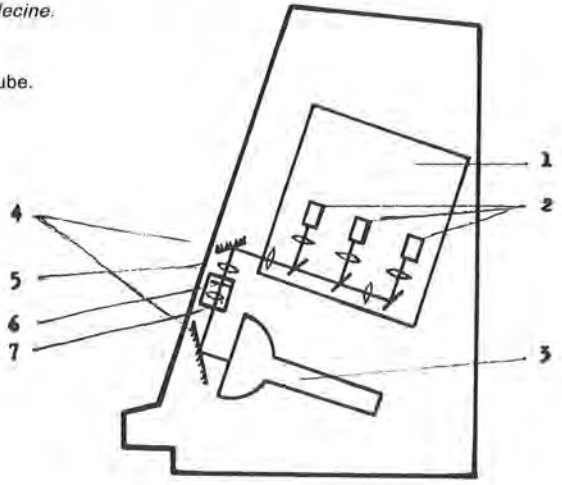


Interlaced scan method (CCIR standard).

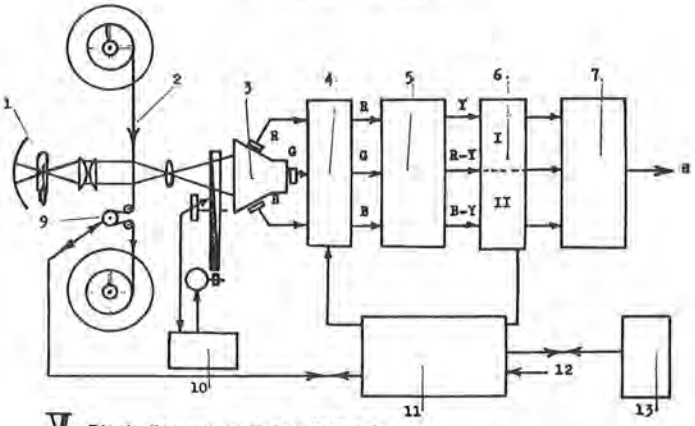
Figure 13-4

Beam path of a flying spot telecine.

1 Photocell unit.
2 3 photocells.
3 Flying spot cathode ray tube.
4 Mirrors.
5 Condenser lens.
6 Film plane.
7 Objective lens.

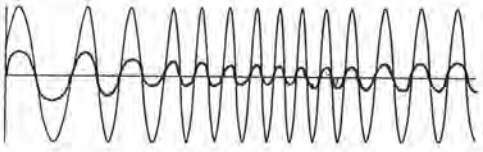


Figures 13-5/6/7

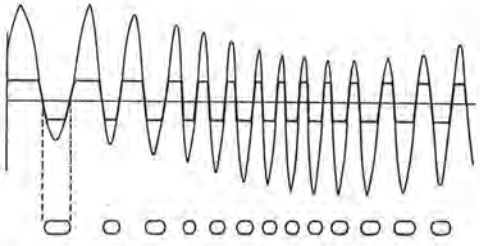


V Block diagram of digital CCD telecine.

1. Lamp.
2. Film.
3. CCD unit.
4. Scanner with clockdriver amplifer fixed pattern correction.
5. Processor I Matrix
   White level
   Black level
   Gamma.
6. Frame store Field I
   Field II.
7. Processor II Contour correction
   Colour correction
   Encoder.
8. Video signal.
9. Capstan.
10. Light control.
11. Micro computer — Drive mechanism control — Frame store control.
12. Synchronizing pulses.
13. Film timer.



VI Schematic representation of wave pattern in videotape recording.



VII Schematic representation of signal pattern in the videodisc.

13.5 Storage of the picture content

13.5.1 On magnetic tape

The incoming electrical signals after suitable adaptation (modulation) are converted into a recording current which creates a magnetic field in the recording head and a permanent magnetization structure in the magnetic tape (see Figure 13.6 and Chapter 10).

An important practical consideration is the type of tape machine on which the video information is to be transferred. In general, a machine of high studio quality will be chosen; for many purposes a lower quality copy can be supplied from this (see Table 13.1).

Table 13.1

Video recorder quality levels (examples)

a) wide-band broadcast: 2 inch helical (e.g. IVC), 2 inch quad, e.g., Ampex, 1 inch BCN, 1 inch C-format;

b) medium-band broadcast: 3/4 inch high-band U-matic, M-format, Betacam, Quartercam;

c) high semiprofessional industrial quality: 1 inch IVC (obsolete), 3/4 inch low-band U-matic;

d) low semiprofessional quality: 1/2 inch VHS, 1/2 inch Betamax, 1/2 inch J format, Video 8 mm;

e) high amateur quality: 1/2 inch VHS, 1/2 inch Betamax, Video 8 mm;

f) low amateur quality: 1/4 inch Akai, 1/2 inch J-format.

13.5.2 On video disc

The signal which arrives from the telecine or from the magnetic tape controls a light modulator which regulates the intensity of a laser beam. This exposes the photo lacquer of the rotating master disc. After development the former electrical signal is retained as a mechanical profile, as shown in Figure 13.7.

Reproduction is carried out from the artificial impressions by transmitted or reflected light, or by capacitive scanning. In each case an electrical video signal is once again produced (see Figure 13.8).

13.6 Large-screen video projection

13.6.1 Apart from the normal television sets and video monitors, there are large-screen video projectors available for presentations to a larger audience. One group of relatively cheap machines, offering low-quality presentation with screen areas of up to 5 m^2, operates by front

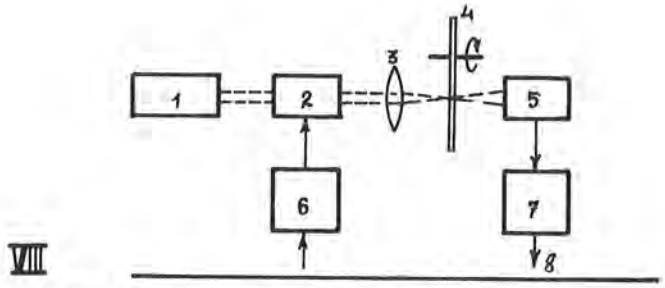
projection of the picture content onto a special screen with the aid of three electron beam tubes (see Figure 13.9).

13.6.2 An example of a high-performance, high-quality method is the Eidophor system, in which the light beams from a high-intensity lamp are deflected, (i.e., dispersed and projected) across a control layer formed of oil. The oil layer lies on a concave mirror onto which an electron beam, modulated by the picture content, is directed. The concave mirror and the beam system are housed in a vacuum chamber. The oil layer is the system's actual picture carrier. The surface of the oil layer is distorted by the varying electrical charges which result from the impact of the electron beam, and a relief image is formed corresponding to the brightness distribution in the television image. The light from a xenon lamp, directed onto the oil layer by condenser lenses and a mirror bar system, is deflected through this relief image and projected as a large picture on the screen via a reflecting optical system.

Colour projection works with three projection systems for the primary colours, red, green, and blue. High luminance density and brilliance of the projected image is obtained by using a high-performance light source separate from the information system. The light beam is modulated by the oil layer relief and hence by the television picture. The light performance is so high that this process can also be used in only partially darkened rooms (at least 6 m x 8 m). In fully darkened rooms a maximum projection surface of 13 m x 18 m is possible. A number of different object lenses permits projection distances of between two and ten times the screen width. The projection angle is adjustable in the vertical by between plus 10° and minus 20°, and the keystone distortion thereby produced may be compensated for by electronic means.

The contrast ratio is 60 dB and a resolution capacity of up to 1029 television lines is possible. The image geometry is more exact than 0.5% of the picture height, colour registration is initially within 1% of the picture height. Realignment becomes necessary with time.

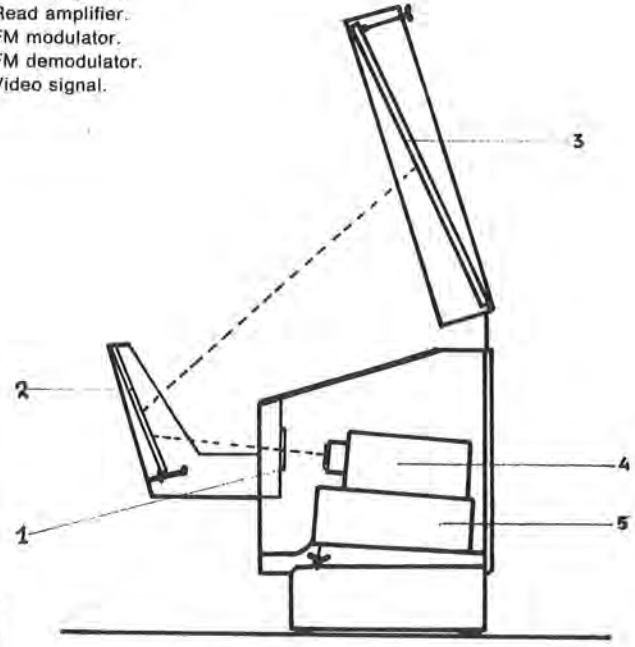
Figures 13-8 and 9



VIII

Block diagram of videodisc recording and playback.

1. Laser.
2. Light modulator.
3. Object lens.
4. Recording disc.
5. Read amplifier.
6. FM modulator.
7. FM demodulator.
8. Video signal.



IX

Principle of large screen video projection.

1. Lenses.
2. Mirror.
3. Projection screen.
4. Projector.
5. Television receiver.

Chapter 14

NEW RECORDING MATERIALS AND NEW TECHNOLOGIES

By Alexandru Marin, Romania Film, Bucharest, Romania

14.1 New technologies

As the examination of cinematographic film in earlier chapters indicates, the film now used in the motion picture industry is not an ideal medium for preserving the image because of its lack of permanent stability. The colour image in films is far more difficult to preserve than black-and-white film and the methods used to extend the storage life (very low temperatures, colour separations on black-and-white films, etc.) are very costly and difficult to apply from a technological point of view.

At the present time, motion picture film and video tape are not the only audio-visual media available. New technologies enable us to transfer classic films or tapes to new media which might be more permanent and do not involve high preservation costs.

There are two steps in the application of these new recording materials to moving image archives: the first step consists of transferring the existing moving images to the selected media for storage; the second is to retransfer to film or video tape for exhibition purposes. The second step may not be necessary as new technologies of exhibition no doubt will be developed.

Progress in the development of audio-visual technologies over the past twenty years is illustrated by the utilization of new methods of recording on mechanic, photographic and magnetic devices.

The following three examples are chosen from a far greater number of new developments, many of them being replaced by new advances, or withdrawn for commercial reasons. The three examples represent three different approaches to the problem, but only one of them promises real progress in the archival storage of moving images and recorded sound - the video disc.

14.1.1 Magnetic method

14.1.1.1 Principle of method

The video frequency electric signals picked up from a TV camera, or from a telecine (film-to-tape transfer) machine, or from a TV set, or from another device replaying a

previously recorded image are recorded on a magnetic medium. This method is based on recording media which have the property to be strongly magnetized under the influence of magnetic fields and to keep the remanent magnetic induction. The magnetic recording of the image uses erasing, recording, and playback heads, similar to those used in the field of sound recording. But the video frequency signals have a wide range (2.5-6 MHz), so it is necessary to have a much higher relative speed between the heads and the tape than in sound recording systems. There are two methods of image magnetic recording and playback: with transversal tracks and oblique (helical) tracks.

Transversal track recording is designed for professional use, especially in TV studios, owing to its very good characteristics.

The video frequency electric signal is picked up by the windings of four magnetic recording heads, mounted on a rotary disc (which rotates 250 times per second). One after another, each head alternatively scans the moving magnetic tape, performing remanent magnetic inductions on parallel tracks across the tape. Alongside the transversal tracks made by the video signal, on longitudinal tracks are; the audio track, the recording of a control signal for synchronization, and the recording of a work indication signal (CUE). Each transversal track has a width of 26 mm and a length of 46 mm; it contains 15.025 TV lines of recording. The magnetic tapes are 50.8 mm (2 inches) in width and move at a speed of 397 mm/s both for recording and replay. The heads move in relation to the tape at a speed of 40 m/s.

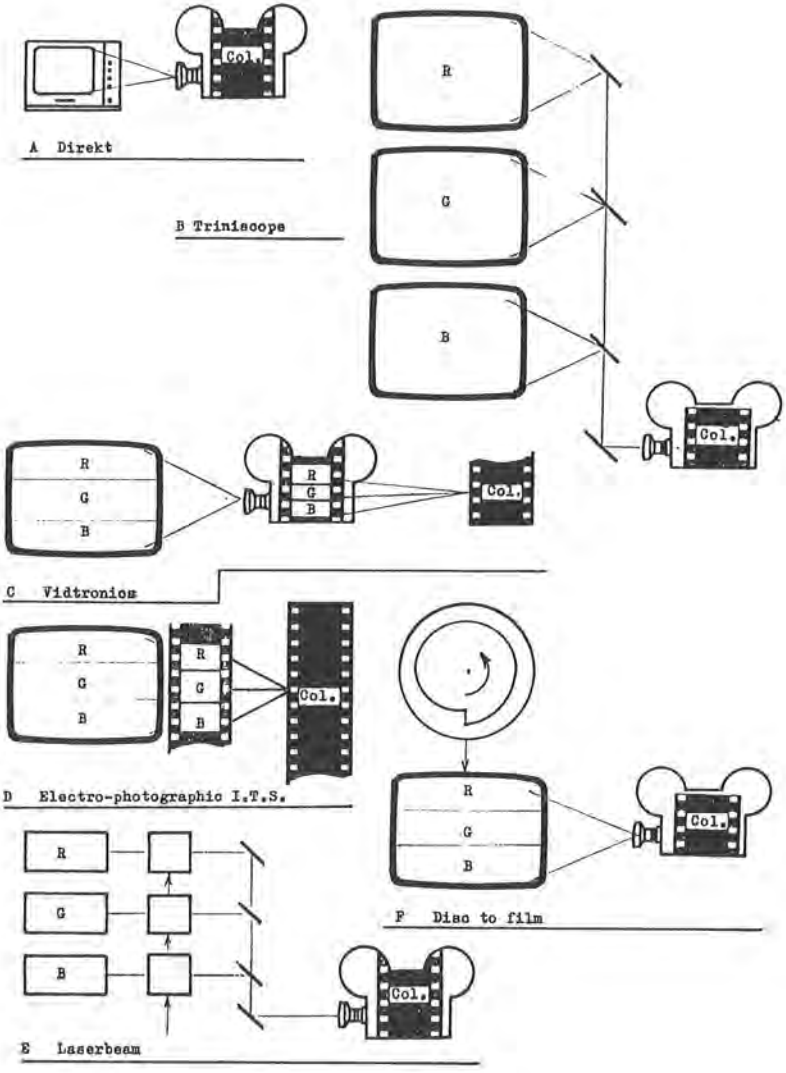
When replaying the image from the magnetic tape, the remanent magnetization on the transversal or oblique tape tracks induce electromotive forces in the winding of the replay heads which are rotating exactly like the recording heads during the recording process. (In fact the recording heads and replay heads are the same). The signals carried by the control track establish the correct position of the magnetic heads on the recorded tracks. At the same time the sound recorded on the audio track of the tape is replayed.

Quadruplex video recordings of this tape are of high quality. There is virtually no difference between the image sent from a TV camera straight to the screen of a kinescope tube and the image reproduced on the same screen from a tape on which the same video signals were previously recorded.

14.1.1.2 Magnetic tape as a storage medium

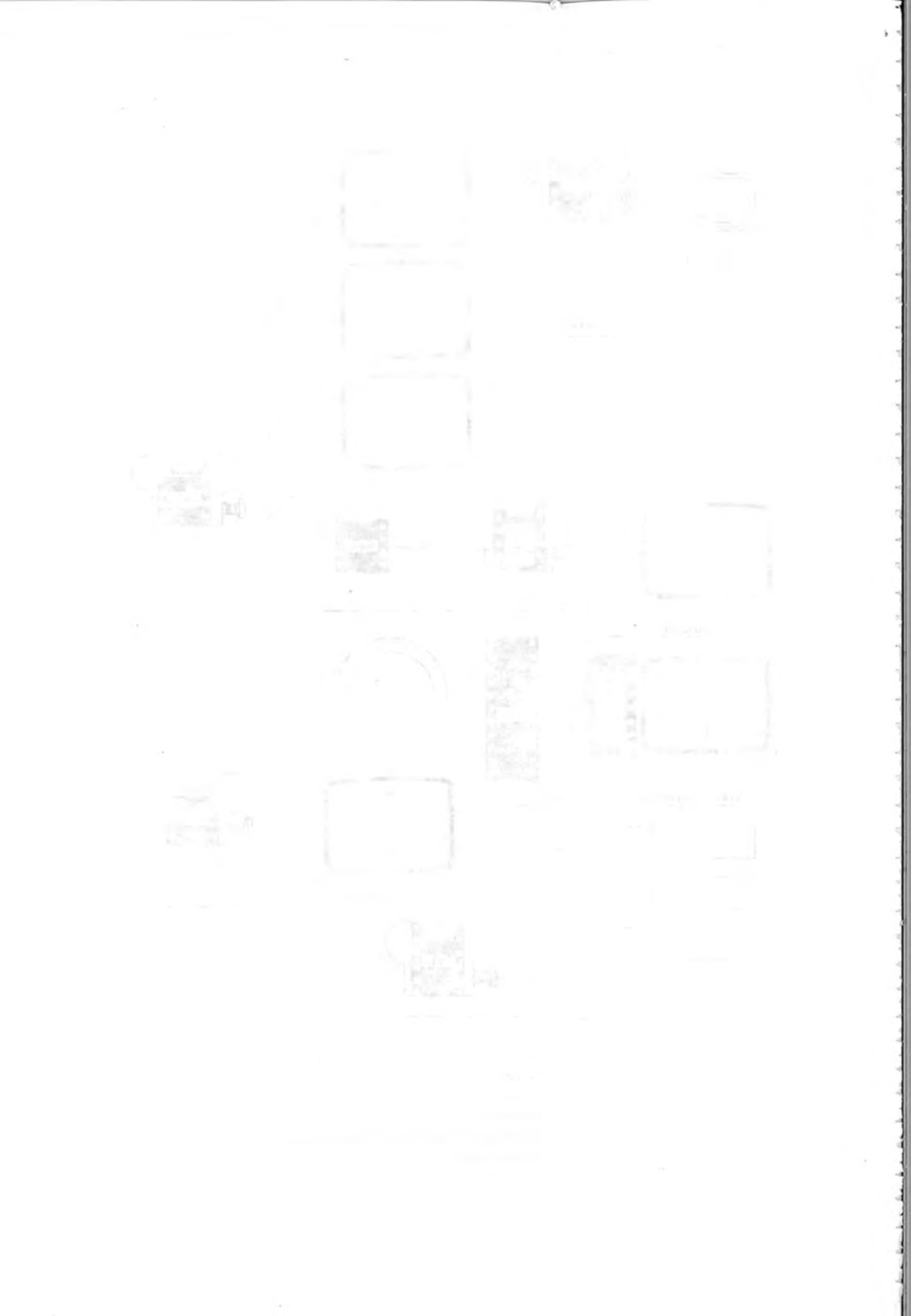
Experiments indicate that the magnetic image is reasonably stable over time, due to the frequency modulation of the video frequency signal. The subsequent decrease in the remanent magnetism amplitude does not significantly alter the image stability. Nevertheless, video recording experiments on magnetic tape are only 20-25 years old, and it is not possible to conclude that the recording is permanent. It is interesting to cite the inquiry made among

Figure 14



Schematic diagrams of the most important transfer methods.

A. Direct.
B. Triniscope.
C. Vidtronics.
D. I.T.S. electro-photographic method.
E. Laser beam.
F. Disc to film.



members of the European Broadcasting Union (EBU) in 1973; an inquiry with relation to the stability of video recordings made in 1959. Most of the respondents stored the tapes at 15°to 27° C and 40 to 60% relative humidity, i.e., the conditions recommended by the manufacturers. The tape recordings made in 1959-1960 were examined in 1973 and they were found in good or reasonable condition, with the quality judged as good as when the recording was made. Many of the broadcasters reported that the present quality was even superior to the original due to the improved equipment for reproduction. Video recordings on magnetic tape appear to be more reliable than was first believed given the nature of the magnetic recording material.

We know, therefore, that magnetic recordings stored in environmental conditions like those recommended for black-and-white acetate film have lasted for at least 15 years, and there is no reason to believe that they will not last much longer because the image degradation process is very gradual.

14.1.2 Electrophotographic method

14.1.2.1 Principles of method

Silver halides, contained in film emulsions, are also sensitive to the impact of electrons bombarding the surface of the film. It is possible, therefore, to obtain a photographic image from an electronic one by placing a black-and-white film in the way of an electron beam (instead of the kinescope screen phosphor). Because a very thin electron beam (a few micrometres in diameter) and very fine grain films (virtually 400 lines/mm) are used, the results are images that are very sharp. A very high vacuum must be maintained inside the recording device.

Projection of the electron photograph type of image is either on television or by transfer to motion picture film.

14.1.2.2 Aspects of long-term preservation

The electron photograph recording method permits a recording of great density, much greater than that in cinema film, and has stability with regard to time roughly that of black-and-white film. For long-term preservation of colour films, however, it is necessary to make black-and-white separations before the electron photograph method can be applied.

14.1.3 Hologram method

14.1.3.1 Principles of method

Light radiations, given off by the surrounding objects, are waves that reach different space points at a given time with certain intensities but also with certain phases. In photographs and motion picture film, the image is the result of light radiations given off by the filmed objects, so the resulting image will be two-dimensional and the audience will see on the screen an image without relief.

Photographic and motion picture holograms allow both the intensity and the phase information of light radiations to be recorded upon the photosensitive emulsion. Projecting an image made by holographic methods results in a three dimensional image of the filmed objects both from the point of view of its brightness and of its relief.

Holography uses coherent (refer footnote no. 1), monochromatic light sources, for example lasers, to light the objects being recorded. Two beams of light emitted by the laser arrive at the photosensitive surface: (cinema film, photographic plate) one which is reflected by the filmed or photographed object (object beam) and another which comes directly from the laser (reference beam). Because both of them are coherent light beams, they will interfere on the photosensitive emulsion so that we will obtain more or less bright areas as dots, lines or strips depending upon the amplitudes and phase difference between object wave and reference wave, these in turn being determined by the brightness of different points on the object. The photosensitive emulsion of the plate will correspondingly be impressed. After processing, a black-and-white pattern of the light waves reaching the plate will be obtained. This is the so-called hologram.

In order to reconstruct the object image, a laser sends through the hologram a monochromatic and coherent light of the same wavelength as that used for recording. The hologram, constituting a diffraction (refer footnote no. 2) network, will yield a pair of first-rate diffraction waves. These will create a virtual image of the object (which can be seen) and a real image symmetrically placed.

The recording of extremely fine photographic patterns for the subsequent object image reproduction calls for high resolution photographic emulsions (2,000 lines/mm).

The holographic method also requires perfect immobility of the object and recording device during the recording of the hologram.

14.1.3.2 Aspects of long-term preservation of holograms

The holographic image has some interesting characteristics for archival storage:

a) it shows an excellent image when replayed;

Footnotes:

1) The coherent waves have the same wavelength and a constant phase difference in time.

2) The phenomenon of light travelling behind the obstacles is called diffraction. A diffraction network is an optical device made by opaque and transparent spaces alternatively.

b) little mechanical damages like scratches, dirt, spots, etc. do not harm the quality of the image,

c) great density of the recordings, greater than that for any other recording material, saves storage space.

Black-and-white film used in holograms is no more stable, however, than that used for cinema film. This means it should be stored in environmentally controlled conditions.

14.1.4 The video disc

14.1.4.1 Introduction

Image recording and replay on or from a disc medium use television technology. A video disc contains in fact both audio and visual information. The audio-visual programme is picked up from a TV camera, or a video tape recorder, or a telecine machine as a series of electric signals which are brought to the recording device input. This device will print on the master disc surface "traces" which are encoded video and audio information. The track carrying these recorded signals is spiral in form, like that of the audio disc. This master disc will serve to manufacture the reference discs. Television sets equipped with special players will decode the "traces" printed on the disc and translate them into sounds and images.

The television raster odd lines are the first on the helical disc track, and after them (not interlaced as in kinescope recordings) appear all the even lines. During the playback of the disc each image line is arranged in sequence, according to television standards, and the reconstructed image may be viewed on a standard television screen. In most disc systems each television frame (i.e., each field pair) corresponds to a disc rotation. This allows special effects (freeze frame, fast motion, slow motion) and also allows a disc-to-film transfer.

14.1.4.2 Optical video disc

If a coherent light beam hits a narrow slit in an opaque plate, a part of the beam, as a result of diffraction changes its direction, being dissipated. This phenomenon is more obvious when the light beam hits a small depression (pit) made in a transparent plate or when it hits a reflecting surface with a tiny depression. If the size of the depression is a little smaller than that at the light beam, the light dissipation owing to diffraction is converted into a decrease in the intensity of the incident beam in its initial direction. If a photodetector is placed in the path of the diffracted light beam, it will detect the intensity decrease, and will convert it into an alternate electric signal.

In essence, optical disc recordings are made as follows: the video signal (the colour and luminance components) is combined with the audio signal resulting in an electric signal of which peaks are clipped; the resulting signal

modulates the laser light; the laser traces audio and visual information on a photosensitive layer coated on a rotating glass disc. After the development of the photosensitive layer, tiny oblong depressions will appear along a helical path. They have equal depths and widths, but the distances separating them are variable depending upon the characteristics of the recorded signal. A nickel pressing mould is made from the master disc by electrogalvanic means, and commercial release discs or reference copies can be made by pressing copies from the nickel disc, as in the music recording industry.

Optical discs made by MCA-Philips are rigid discs with a base of polyvinyl. A reflecting metallic layer covered by a transparent protective layer is coated on their surface.

They have the following characteristics:

a) a diameter of 300 mm;

b) a playing time of 30 minutes colour image and sound on each side (45,000 images per side);

c) one disc rotation corresponds to a TV image;

d) a speed of 1,500 revolutions per minute for 25 frames per second (50 Hz main power frequency); 1,800 rotations per minute for 30 frames per second (60 Hz main power frequency);

e) a helical track pitch of 2 μ;

f) a depression width of 0.7 μ, a depth of 0.1 μ, and a length of 0.6-0.4 μ.

The player unit for the Philips discs uses a helium-neon laser of 1 mW, the light of which passes through an optical system and is focused on the disc surface as a spot of about one micron in diameter. The laser light which scans the helical track will be reflected towards the optical reading system by the reflecting layer between two depressions; most of the light, spread by the diffraction, does not return towards the lens. Modulated according to the recorded signal, the reflected light reaches a detecting photodiode which converts its variations into electrical signal variations. An electronic scheme picks up the signals from the detecting photodiode, extracts the image and sound information, processes them and then sends them to the screen and the loudspeaker of a TV set. A special control unit maintains the playback light beam on the disc in a correct position above the helical track.

The discs made by Thompson-CSF are plastic optical discs, transparent, flexible, and their characteristics are as follows:

aa) a diameter of 301 mm and a thickness of 0.15 mm;

bb) a length of the recorded audio-visual programme of

30 minutes per side;

cc) one disc revolution corresponds to a TV frame;

dd) a speed of 1,500 rpm for 25 frames per second (50 Hz main frequency); 1,600 rpm for 30 frames per second (60 Hz main frequency)

ee) a number of images as high as 45,000 on one side (SECAM standard) and 54,000 (NTSC standard).

Playback on the Thompson discs is achieved by passing a light beam through the disc. The beam is modulated by the depressions in the disc and these variations are detected by a photoelectric device. This detector transforms the variations in the intensity of the light as reflected from the recorded signal into electrical signals which are picked up by an electronic system and converted into image and sound on the TV set to which the disc player is connected. During the disc playback, control systems maintain the correct position of the light beam relative to the helical track on the disc.

14.1.4.3 Video disc as storage medium

Although the video disc is just emerging from the laboratories it has already demonstrated some special properties that may be suitable for archival work.

The structure of optical discs would appear to have some distinct advantages for long-term storage:

a) the matrix or master, consisting of a mixture of chromium and nickel can theoretically be conserved without any special environmental controls for more than 1000 years; the suitability for long-time preservation is therefore determined by time the playback unit will be in existence;

b) the density of the recorded signals use almost 95% of the storage capacity of a disc; more than 50 times more audio-visual information may be stored in a vault using discs than when using 35 mm films;

c) the disc appears by design to be relatively impervious to tropical temperatures, or extremes of humidity and light;

d) the disc can be structured so that it does not require environmental controls even in tropical climates, and the matrix can be stored in a normal office environment as long as it is protected against dust and mechanical damage.

As there is no mechanical wear in playing the disc it would appear to be an excellent medium for archival storage of moving images and recorded sound if the image quality had been better.

Optical discs, moreover, demand the appropriate technical equipment for the transfer of audio-visual signals now on cinema film or magnetic tape to the video disc, and trained

personnel to operate the equipment. That is, of course, expensive. This cost should be balanced against the current costs of storage, because the disc holds the promise that archives will be able one day to function without special vaults and environmental controls.

14.2 Transfer methods from one medium to another

14.2.1 Film to new media transfer

14.2.1.1 Film and tape transfers to disc

Transfers from film to tape and from tape to disc are now commonly carried out in the industry and therefore archivists can call on the experience of specialist and specialized laboratories for assistance in transfer operations. The technology is not beyond the capacity of advanced archives to acquire and operate themselves.

The emerging technologies can also be improved in order to make them meet the demands of long-term storage, and this will probably increase as these technologies are assimilated by film archives (i.e., colour correction, signal-to-noise ratio corrections, the adoption of special TV standards with a line system that approaches 35 mm, etc.).

14.2.1.2 Film and tape transfers to holograms

For film image transfer by holographic means, colour separations are used, but unlike the traditional system, the three colour separations are transferred to a single frame, on the surface of which they will be overlayed. The cinematographic image transfer to a special black-and-white film is made by a holographic printing device. The reference wave and the object wave (of which the latter passes through the colour film to be printed on the black-and-white film) are generated by a red light laser, a green light laser and a blue light laser, and are brought together by a system of three mirrors. After processing, the black-and-white holographic film will contain on its surface the three colour separations overlayed.

The chief advantages of this technology are as follows:

a) any change in the dimension of the black-and-white film on which the three colour separations are printed does not affect the ability to reproduce the colour image;

b) the film volume in storage is only one third that required for traditional three colour separations;

c) by controlling the variations in the light intensity of the three lasers, the necessary corrections to the colour characteristics of the image during printing can easily be achieved.

14.2.2 Tape-to-film transfers

Being a very complex and expensive technology, tape-to-film

transfers are being used less and less. However, television broadcasters use them for national and international film exchanges (because motion picture film is the only medium still standardized all over the world), for programme production, and for their conservation in archives. In the film industry tape to film transfers are made for the purpose of film production (work prints) and film release (release prints).

14.2.2.1 Tape-to-film transfers by filming the television screen

Between the recording and playback systems specific to television and those specific to motion picture there are the following differences:

a) television relies on discrete recording and playback of the image by interlaced frame scanning, while motion picture relies on simultaneous recording and playback using the entire frame surface, the film being moved past the recording device by a pull-down system;

b) the time to pass from one frame to another is shorter in a television camera than in a motion picture camera (1.3 milliseconds for 525 lines standard and 1.6 milliseconds for 625 lines standard in comparison with 15-20 milliseconds for motion picture);

c) television image frequencies are different from those of motion picture images.

The differences between the two systems have the following negative consequences on the transfer of tape to film:

aa) the appearance on the positive print of a horizontal stripe which moves in a vertical direction during projection;

bb) bad image quality as a result of the long pull-down time of ordinary motion picture cameras which do not allow all of the image television lines to be recorded on the film;

cc) image quality that is affected by the poor characteristics of the kinescope picture tubes, and by the incompatibility that exists between their phosphores and film colourants.

To eliminate or to at least control the loss in image quality in such transfers the following operations are possible:

aaa) the operating television frequencies and those of motion picture camera are equalized and the respective equipment can be synchronized; (if the television system runs at 25 frames per second, the camera should also operate at 25 frames per second; if the television system operates at a 30 frames per second standard, the camera can operate at 24 frames per second with each 5th half frame of the

television image being discarded);

bbb) motion picture cameras with very short pull-down times can be used to minimize the differences;

ccc) the kinescope picture tubes can be equipped with small deflection angles (small screens);

ddd) electronic corrections can be made directly to the image signals in order to adapt them to the sensitometric and chromatic characteristics of the camera films in use, and to balance them from a chromatic point of view.

14.2.2.2 The Trinoscope method

Transfer by this method is achieved by means of three black-and-white kinescope picture tubes with high definition (800-1,000 lines). On the screens of the tubes are reproduced in black and white the corresponding images of the fundamental colour signals (blue, green, red) received by separate electronic circuits from the video tape recorder on which the tape is being played. A coloured filter is placed before each tube corresponding to the colour of the signal received by the tube. The resulting light beams are recombined through an optical system and focused on the camera film. In order to use cine cameras with longer exposure times than 1.3 or 1.6 milliseconds, recent models of the Trinoscope method include a memory system called "frame store". The video signals supplied by the video tape player are digitized and stored in this "frame store" before being transferred. This stored data may be called for in 1, 2, ..., 625 lines succession, and not in the interlaced succession of an ordinary television raster. The television image will no longer be composed of two fields with a 1.6 milliseconds time interval between them (an odd lines field and an even lines field), but by a single one containing all the lines. So the time between two television frames is now increased to 8 milliseconds. The motion picture camera can now film the entire television image at 25 frames per second, with a pull-down time of 5 milliseconds. In this way the mechanical strain on the film will be decreased, and the image will be of a better quality.

14.2.2.3 The Vidtronics method

In this method, the result is achieved through the use of the three colour separations (blue, green and red) which form a colour image, the separations being recorded on three fine grain 35 mm black-and-white negatives. The motion picture camera records the separations one by one from the black-and-white kinescope screen to which they are relayed successively by a video tape unit. An electronic filter at every exposure allows only one fundamental colour signal to pass and be transferred to the film during the exposure time. A very high resolution kinescope and a motion picture camera with 5 milliseconds pull-down time are used. Colour prints can be manufactured from the three colour separations by means of colour reversal internegative; or by the Technicolor method.

14.2.2.4 The electrophotographic method

The image transfer is achieved in two steps. The first is the recording on a 16 mm black-and-white film of three frame successive groups, each of them corresponding to the three colour signals (blue, green and red) of the images transferred from the tape. The printing is made by means of an electronic beam in an electrophotographic recording unit on a 16 mm fine grain film (the resolution of the resulting image is 1,000 television lines after processing). The 16 mm film (the master film, therefore) is made on a special step printer and a colour internegative is derived from it. Each frame of the internegative is exposed three times through a disc filter provided with three colour sections. The film is rotating so that each of its three colour sections will be in front of the printing light when the corresponding colour separation is transferred. The movement of the 16 mm master film containing the colour separations, the colour raw stock, the rotating movement of the disc filters, and of the shutter disc are all synchronized. The above method called "Electron Beam Recorder" was designed and engineered by Mincom Division of 3M.

The recorder described above can also be used for the transfer of colour films to be stored on a black-and-white film by the colour separation method, and then to be retransferred to a colour film when necessary.

The method also provides the possibility of efficiently correcting the transferred image to improve the quality of the picture.

14.2.2.5 The laser method

The monochromatic beams sent by three lasers (argon laser for blue and green colours and helium-neon laser for the red colour) are supplied to three beam modulators where they are modulated by a signal corresponding to the video signal being transferred. Carrying the video signal, the three beams are brought together in a single beam by a group of three dichroic mirrors. The resulting beam is focused on colour film stock after being reflected by two moving mirrors and passing through an optical system.

Transfers by means of the above equipment (designed by CBS Laboratories for the CBS Network) yield a very good colour image using 8, 16 and 35 mm films. The electronic signals can also be enhanced and adapted to the chromatic characteristics of the colour film.

14.2.3 Video disc to film transfer

In most of the video disc recording and playback systems, one disc rotation corresponds to one television frame. The sensor of the playback device can read the track section corresponding to the same rotation continuously (so a freeze frame is possible). It is also possible to locate any place on the surface of the disc in order to carry out this

operation.

It is possible, therefore, to do frame-by-frame printing of the image from the disc, with the frames in sequence, by means of equipment consisting of a disc player, a black-and-white television set, a disc equipped with filters (red, blue and green) and a film camera. Each frame it is read successively four times during transfer. First the black-and-white television set receives signals corresponding to the red separation of the image. The beam passing through the black-and-white image, also passes through the red filter in the filter disc which is synchronized to the video disc, and then reaches the colour film in the camera. The scanning head on the player is then automatically reset in the start position in order to read the same track section. This time the blue separation is transferred; then the green separation is transferred. At the fourth step no image is transferred. During this phase the film in the cine camera is pulled down in order to expose a new frame. The exposure time for each separation in a 25 frames per second television system is 40 milliseconds, and the film pull-down time is also 40 milliseconds. These time intervals are long enough to allow the use of an ordinary cine camera operating in a frame-by-frame mode.

14.2.4 Reconstruction of the motion picture image from the holographic image

It is possible to reconstruct the motion picture image from the holographic image as described in 14.2.1.2. The hologram is illuminated by three laser beams (blue, green, red) to build up one frame on colour film stock. The process is obviously slow but the film can be completely restored.

14.3 Possibilities for the use of the new technologies in motion picture conservation

Is it possible to apply the new technologies in their original form or in an adapted form, to a practical programme of film conservation? To answer that question several factors must be considered.

14.3.1 One is the characteristics of the new technologies in relation to requirements for the long-term conservation of motion picture film.

In all of the systems noted, the information to be registered is introduced as electronic or optical signals and not as images. The image is encoded in the form of variations in the magnetic, photographic or mechanical impulses used to transmit the information.

Some of the technologies described use as a storage medium metals or plastics with a high resistance to the potentially hazardous elements in the environment, and that argues in favour of their potential utility as a storage medium.

As can be seen from examining the summary description of the

new technologies none of them use the colour couplings or dye transfers in recording colour. They use a mechanic, magnetic or photographic encoding of colour information, so that it may be assumed that the chromatic characteristics will be maintained in long-term storage.

Both the recording and the play back procedures have as an intermediary stage a video electronic process, and this process allows corrections of the image characteristics in an operative and more efficient way than in traditional film technology. The corrections may be carried out both when the images are transferred on the new media and when the images are reconstructed in order to be projected on a screen.

Table 14.1

Recording medium	Relative density of stored information
Black-and-white film	1
Colour film	2.5
Magnetic tape	10
Electrophotographic recording	250
Holographic recording	1700

All the above systems allow the recording of a much greater quantity of information than traditional film systems, and this may be a very great advantage that outweighs the cost and complexity of the technology involved. The use of media with large capacities for image recording obviously leads to a corresponding decrease in the volume of storage space required.

14.3.2 Image quality specifications

The storage of motion picture images on mechanic, magnetic or photographic media which are not yet used in the film industry can be justified only if you can obtain a quality comparable to the original film when projecting the reconstructed image on the screen.

At present both ordinary television and motion picture viewers, and a large number of the experts in this field believe that the image projected by traditional opticomechanic means of a motion picture on the screen of a cinema theatre is far superior to that projected on a television screen by electronic means. The ordinary viewer arrives at this conclusion by simply comparing the home television image (highly impaired by the means of broadcasting, the poor performance of the average television set, the improper setting for viewing in the home, and by the ambient viewing conditions) with that seen in the

theatres where the projection is by means of professional projection equipment operated by people specially trained for this purpose. The experts arrive at the same conclusion by taking into consideration the digital index of film characteristics as the resolution power expressed in lines per millimetre, or the video signals frequency range that they can record as expressed in MHz.

Last but not least, there are the characteristics of the human eye which should be taken into consideration in judging image quality, because the human eye is still the main decoder of both the television and the motion picture image.

It is obvious that the picture quality of a 35 mm image is superior to that of a TV image. This is because the television standards are only 525 lines in the USA and 625 lines in Europe. The same conclusion is reached if the specific frequency range of 35 mm colour film (14-16 MHz) is compared with standard television systems. It is also true that a 35 mm negative frame can record 16 times the amount of information that can be recorded on a 50.8 mm (2 inch) magnetic tape in the 525 lines per frame standard.

The electronic image has the advantage that the television signal can be processed by electronic methods in order to minimize background noise. There is the possibility of energetically prestressing the high frequencies in the video range (i.e., "to enhance" the image) and there are a number of operative ways to correct colour balance and colour saturation, as well as methods to erase the television raster structure lines so that these are not perceptible on the screen. By adapting digital techniques from computer technology there may be additional possibilities for the enhancement of video signals.

14.3.3 Conclusions

There is sufficient potential in the new technologies to foresee their eventual adoption and/or adaptation in moving image conservation.

At present the following premises should be studied:

a) magnetic tape may be considered a satisfactory medium for the medium-term storage of motion picture images that must be transferred because they are in danger of deterioration;

b) video discs appear to be the most promising medium for the long-term storage of moving images.

The potential of the new technologies in solving some of the problems encountered in moving image conservation should be explored collectively through the work of FIAF (in close consultation with the International Federation of Television Archives (FIAT)) until firm recommendations can be made, and the new media tested under archival operating conditions.

PART IV

TECHNICAL PRACTICES OF AUDIO-VISUAL ARCHIVES

Chapter 15

STORAGE BUILDINGS

By Herbert Volkmann, Former Director
of the State Film Archive of the German Democratic Republic

15.1 Position

15.1.1 General principles

Buildings for the permanent storage of all types of film should be sited away from big cities or industrial areas for the following reasons:

a) wherever coal or oil is burned in large quantities the air contains hydrogen sulphide, sulphur dioxide and possibly other acid compounds, which eventually damage the film;

b) in cities or regions which have a great deal of traffic, there is considerable danger of pollution by dust. Unless the ventilation plant of the storage buildings is equipped with expensive dust filters, scratches can be made on the film by particles of dust during inspection or exhibition;

c) for nitrate film, in particular, siting in densely populated areas is prohibited by the abnormal fire risk.

Ideal conditions for the building of film stores are to be found away from large cities and industrial centres, in woods, on dry ground with a low subterranean water level, and not in the vicinity of large lakes or marshes. In such situations there is no danger of the films suffering damage from a high proportion of acid in the air. The pollution from dust is low, and it can be diminished further by cultivation of the surroundings, for example by laying down lawns. The woods give natural shade to the buildings, and there are no dwellings in the immediate neighbourhood to be endangered. A good choice of site is particularly important when it is not immediately possible to establish ideal storage conditions.

To prevent everything from being lost for ever in the case of a catastrophe, no two copies of the same film should ever be stored in the same vault.

15.1.2 Legal requirements

For the building of nitrate film stores most countries have legal requirements stipulating the minimum distance from inhabited buildings. As a result of experience gained from the big film fires of the last forty years, it has been

realized that these legally prescribed distances are too small. Most of these regulations were made several decades ago at a time when nitrate film was not yet old enough for the increasing danger of ageing film to be properly appreciated. Experience has shown that during some big film fires burning reels of film have been hurled for distances of more than 22 metres, so that the whole region within this radius must be regarded as dangerous in the event of an accident.

Nitrate film should not be stored near residential areas, factories, airports or other industrial plant.

15.2 Design of storage buildings

At present there are as many types of film stores as there are archives, partly because in the past only a few archives could construct new storage facilities; partly because climatic conditions vary considerably from one country to another, and not least because of financial limitations.

In building a film store, it is possible to achieve the goal of storing under optimum conditions in different ways. There are three different types of store in use, as follows:

a) at ground level, equipped with air conditioning plant (e.g., Gosfilmofond, Moscow; National Film Archive, London (new vaults));

b) underground, with air conditioning plant (State Film Archive of the German Democratic Republic, Berlin);

c) at ground level, built with thermal insulation but without air conditioning (National Film Archive, London (old vaults)).

15.2.1 Ground level store with automatic air-conditioning plant

Gosfilmofond has developed four types of store: one for nitrate film, one for acetate film, one for exceptionally precious films, and one for colour film. All types are built at ground level on a foundation of stone and concrete. The outer walls of the black-and-white film vaults are 78 cm thick, made of hollow brick, and the interior walls are 38 cm thick. The ceiling consists of flat slabs of reinforced concrete with an insulation of foam concrete, and the roof is covered with three layers of rubbery material sealed with asphalt. All the storage buildings have automatic air conditioning plants.

One nitrate film store holds 70 tons of film, distributed among 28 vaults containing 1000 reels each (2.5 tons). Each group of three vaults has a common corridor with a door to the outside. All doors are fireproof and all vaults are fitted with pressure vents. The climatic conditions maintained in the store are:

Temperature: 6° C ± 2° C (43° F ± 3° F); relative humidity: 55-65%; 30% fresh air. The films are stored on steel racks with hardwood shelves.

One acetate film store has a capacity of 100 tons in two storage compartments of 20,000 reels each (50 tons).

The entrance to the storage compartments has an air-lock. the climatic conditions maintained are:

Temperature: 12° C ± 2° C (54° F ± 3° F); relative humidity: 55-65%. The films are stored on steel racks.

The store for particularly precious films has a capacity of 51 tons (20,400 reels). Each reel is stored in its own fireproof compartment, closed with a flap, and each compartment has a pressure vent opening into a channel which leads to the outside air. The climatic conditions are:

Temperature: 0° C (32° F): relative humidity: 55-65%; 30% fresh air.

15.2.2 Underground store with automatic air-conditioning plant

In former times the State Film Archive of the German Democratic Republic in Berlin had old ground-level stores with a controlled temperature of 6° C ± 2° C. The storage buildings of 1967 have, in addition to a non-airconditioned store for distribution films, two types of underground stores for nitrate film and acetate film. The outer and inner walls are of brickwork with heat insulation. The ceiling and roof consist of reinforced concrete and a layer of insulation material.

The nitrate film stores have a capacity of 100 tons each, distributed among 40 vaults each holding 2.5 tons (1,000 reels). All vaults have fireproof doors to a central corridor and pressure-operated vents to the outside air. The climatic conditions maintained are:

Temperature: 6° C ± 2° C; relative humidity: 50-60%. Ten films are stored in each fireproof cabinet which is ventilated.

The acetate black-and-white film stores have a capacity of 300 tons each, distributed between 6 fireproof compartments each of 50 tons capacity (20,000 reels). The staircase, lift and air-conditioning plant are in the centre of the store and at each end are emergency exits (as in the nitrate store). The films are stored on open steel racks. The storage conditions are:

Temperature: 12° C ± 2° C; relative humidity: 60% ± 5%.

In 1981 an underground deep-freeze store for colour films was completed. It has a capacity of 800 tons (320,000 cans). The outer walls are of reinforced concrete and incorporate heat insulation. The conditions maintained in

it are; temperature -7° C; relative humidity 25%.

15.2.3 Ground level store with thermal insulation

The National Film Archive in London has developed and built for its nitrate film a type of store which can be recommended to all those who cannot immediately install an air conditioning plant. Each storage building has a capacity of 28 tons distributed between 28 vaults of 1 ton (500 reels) each. The outer walls are 40 cm (16 inches) thick, and have the following composition:

brickwork	11.25 cm (4 1/2")
hollow space	5 cm (2")
brickwork	11.25 cm (4 1/2")
glass wool	2.5 cm (1")
thermal insulting block	10 cm (4")

The roof is made of reinforced concrete, 15 cm (6") thick. In this brick building are housed the 28 vaults, in two rows of 14 vaults each, back to back, but surrounded by an air passage. Between the vault ceiling and the roof of the outer brick building there is also an air space with an outlet for warm air. The corridors have automatic electric heating, which comes into operation in the winter when the temperature falls below 13° C (55° F). All the vaults have pressure-operated vents in the roof. The National Film Archive states that this form of building makes it possible to keep the internal temperature of the vaults at about 13° C (55° F), except in the case of extreme outside temperatures.

In the sixties the National Film Archive built stores for acetate film with large storage compartments and an automatic air conditioning plant (T=13° C; RH=55%) for black-and-white safety films.

15.2.4 Insulation and air conditioning

The harmful effect upon permanently stored film of dampness and high temperature makes it impossible to stress too greatly that insulation from ground moisture, prevention of the penetration of summer warmth, and protection against excessive atmospheric moisture are the most important elements to consider in the construction of a film store. If, for economic reasons, new storage buildings (whether for nitrate or acetate film) cannot be provided with an air-conditioning plant immediately, it is urgently recommended that its future installation should be envisaged by making provision in the building for the necessary openings, channels etc., so that the plant can eventually be incorporated without any rebuilding. Such channels and openings must be rendered fireproof until the automatic fireproof flaps of the air-conditioning installation are built in.

In tropic zones the long term preservation of cinema films cannot be guaranteed without air conditioning.

15.3 Storage buildings for nitrate film

15.3.1 Capacity of nitrate vaults

The capacity of a nitrate film store will depend upon the safety measures which have been taken to prevent a fire starting within the store or spreading to it. The most important safety measure is to lower the temperature to such an extent that spontaneous ignition is, to the best of our knowledge, made impossible. For various reasons it is accepted that the optimum storage temperature lies under 0° C (32° F) (we recommend 5° C, 60-50% relative humidity). With the film cooled to this extent, and given ample fire precautions, relatively large stores with a capacity of 100 tons or more can be built. But it is necessary to stress that in this case the possibility remains of a conflagration, causing total destruction and danger to the surroundings. When nitrate film is stored without air conditioning, it is essential that the vaults are kept as small as possible and have very effective heat insulation.

The capacity of the vaults (i.e. the fireproof units in which generally 500 or 1000 cans of nitrate film are stored) is of great importance in limiting the scale of a fire. The regulations in England do not allow more than 500 cans each holding 1000 feet (305 m) of nitrate film to be stored in any one vault; in several other countries the storage of 1000 cans is permitted. If 1000 cans are stacked along the two long walls to a height of 2.4 m, this requires a vault some 3.4 m long, 2.7 m high and 2 m wide. No more than 1000 cans should be stored in one vault. If the vault is made longer, there must be an emergency exit in the rear, which makes air conditioning more difficult.

15.3.2 Racks, partitions and compartments

There are several ways of storing the cans. The most simple method is to put them on open (i.e., non-compartmentalized) shelves (made of steel, wood, concrete, etc.). In the event of fire, the whole contents of the vault will be lost.

A second method is to store them in compartments open at the front, each holding one or two cans, and made of fireproof materials to a thickness of at least 1 cm. It is considered in the USA that such a construction, aided by an automatic sprinkler installation, will ensure that any outbreak of fire is confined to one compartment. We have some doubts. At least the opposite row may be endangered.

Thirdly, one to ten cans can be stored in enclosed steel boxes, the box being fire resistant, insulated against external heat, and capable of ventilation. The room also needs to have a pressure flap opening to the outside. If automatic sprinklers are employed then it is possible to limit the fire to a small unit.

15.3.3 Air conditioning and ventilation

Under 15.3.1. reference has been made to the artificial air

conditioning of nitrate film stores and to the desired optima. The optimum values are: max, temperature 6° C; relative humidity 50-60%; 25% supply of fresh air. This low temperature is necessary not only for reasons of safety but primarily to impede the rate of disintegration.

If the quantity of nitrate gas given off from a 300 m reel of old nitrate film at 0° C is reckoned as one unit, then this quantity at 5° C will be 2 units, and at 10° C it will be 4, at 15° C it will be 8, and at 20° C it will be 16 units. In other words, at 20° C, 16 times as much nitrogen dioxide is formed as at 0° C. This becomes all the more important when it is remembered that gases develop within closed cans which allow comparatively little ventilation. Three little holes (2 mm diameter each) should be punched in the bottom of the can to permit the escape of the heavy nitrate gases. Low temperatures are extremely important for the preservation of nitrate film. When, for reasons of economy, it is not possible to install an air conditioning plant, an attempt should be made to approximate the optimum conditions as nearly as possible by other means (see 15.2.3.)

15.3.4 Fire prevention

The structural and climatic conditions for preventing the outbreak and spread of a conflagration have already been dealt with in preceding sections so that it remains only to deal with specific fire prevention measures.

15.3.4.1 Pressure vents

The most important of these is the pressure-operated blast vent which releases the pressure of the very rapidly developing gases of combustion into the open air, and thereby prevents an explosion. In rooms where nitrate films are stored a pressure-relief opening is necessary. The flap which normally closes the opening should move very easily (particular care must be taken against rusting) and it should open automatically under a force of 6 kg.

The hinges should be placed so that the flap opens downward by its own weight and not so that it opens sideways or even has to be lifted up. The opening can be placed in the roof or in the top of the wall, and it should lead to the open air by means of a channel which has a cross-sectional area equal to that of the opening itself. Fixed windows or panes of glass are not sufficient, since the breaking of a glass pane requires a far greater force than that which should be able to open the flap.

15.3.4.2 Sprinkler installations

As has already been stated, the fire of burning reels of nitrate film cannot be extinguished. Therefore the only purpose of installing sprinklers is to confine the fire to its place of origin. Usually water is used, not for the purpose of extinguishing but for the purpose of cooling. For a vault holding 1000 cans, 8 sprinkler nozzles are sufficient for moistening the walls. The installation comes into

operation when a predetermined room temperature has been reached (usually 60-90° C).

When the sprinklers have been in action, all the cans in the vaults concerned must be wiped dry and inspected to discover whether any water has penetrated them. Besides water sprinklers, carbon dioxide installations can be used. Carbon dioxide has no value for extinguishing burning film, but it prevents the formation of flame. It has the advantage that it does not damage the film with which it comes into contact, but on the other hand it has the very great disadvantage that it is a poisonous gas which can be fatal.

Stores in which carbon dioxide sprinklers are used must be evacuated, in case of fire, within a few minutes. In view of this, water sprinklers are preferable, although they are very imperfect for their purpose.

To protect the surroundings in the event of a conflagration, hand fire extinguishers should be ready for use in the immediate vicinity of the origin of the fire. They should also be installed in corridors, near the doors of the vaults, on staircases, at exits and in all the work rooms. The hand fire extinguishers are generally filled with carbon dioxide or a fire-extinguishing foam. The foam will spoil any film with which it comes into contact, but it has the over-riding advantage that it may prevent the fire spreading.

15.3.4.3 Doors

Vault doors and all other doors in nitrate film stores should be made of fireproof material. Usually they consist of steel outer layers, filled with asbestos cement (the two steel layers should not touch each other) or of steel with an underlayer of asbestos and hardwood. All doors must open outwards. The vaults should not have a direct exit to the open air (see 15.3.1.).

15.3.4.4 Emergency exits

All larger stores with an internal entrance should have emergency exits which can open directly to the outside in case of necessity. Emergency exits should never be locked on the inside and it should always be possible to open them by a slight pressure on the latch. There is no need for them to open from outside except in case of emergency.

15.4 Storage buildings for acetate film and magnetic tapes

Whereas the design of nitrate stores is greatly influenced by fire prevention requirements, this is not the case with acetate stores. Acetate film presents no greater fire hazard than ordinary paper, so the fire precautions need be no more elaborate than those which are observed in large libraries. Magnetic tapes may also stored in these vaults.

15.4.1 Storage units

In the construction of storage buildings for acetate film there is no need for the storage units to be small and quite large rooms can be used. This should always be taken into account when new buildings are being considered because it is a much more economical form of construction than small vaults. Nevertheless, limits should be observed in order to avoid very large losses in the event of a fire. As was made clear in 15.1, copies of the same film should be stored in separate vaults.

15.4.2 Partitioning against fire

As a safeguard against accidental outbreaks of fire, very large stores (those with a capacity of 100 tons or more) should be subdivided into smaller sections separated by fire-resistant partitions. There is no standard size for such sections. The largest built up to the present have had a capacity of 50 tons (20,000 cans). Given adequate safety measures, there is no objection to storing acetate film in buildings of more than one storey.

Acetate film can be stored on open racks for which, in general, steel is recommended.

15.4.3 Air conditioning

Air conditioning is as important for acetate films as for nitrate, despite the absence of any danger of disintegration. Because acetate film has potentially a much longer life, it has to be treated more carefully in order to preserve the properties which give it greater durability. Moreover, acetate film has the same emulsion as nitrate film and therefore the control of moisture and temperature, which is necessary for the emulsion of nitrate film, is just as necessary for acetate. In general it can be said that for the storage of acetate film there is no need for such low temperatures as for nitrate film, but a cool store is better than a warm one. A maximum temperature of 12° C and a maximum relative humidity of 60% are recommended.

It has to be remembered that acetate film has the same emulsion as nitrate film and the base gives off acetic acid in small quantities, and the plasticiser also evaporates; it would therefore appear to be advisable to use low temperatures here also in order to inhibit these chemical reactions.

Since no injurious gases have to be disposed of, air conditioning with circulating air, and a low percentage of fresh air (about 8%), is sufficient.

15.5 Storage buildings for colour films

15.5.1 Vaults and the level of the ground water table

The preservation of the colour picture in films needs temperatures below zero (Celsius) and a low percentage of

relative humidity (see chapter 4).

Whether it is preferable to construct vaults below or above ground level depends upon the level of the ground water table.

15.5.2 Insulation

If you decide to build up underground vaults for deep frozen storage, the outer walls and the bottom should consist of about 40 cm waterproof reinforced concrete. The insulation inside this block depends on the highest external summer temperature.

At almost all film vaults built in recent years, in which air conditioning was inbuilt, it was found that the insulation was not adequate to eliminate the fluctuations of temperature due to seasonal temperature variations. Walls, floors, ceilings and air conditioning ducts have to be well insulated against such variations. Therefore it has to be urgently recommended that greater rather than lesser insulation be used and especially it should be noted that a large roof absorbs a great deal of heat from solar radiation and therefore must be protected by, for example, a white-painted over-roof which at its highest point allows the escape of circulating warmed air.

All entrances must be shielded by sufficient air locks so that warmer outer air cannot penetrate the deep-cooled stores.

15.5.3 In order to establish additional shielding against heat exchange, one can build above the actual vaults e.g. rooms for the storage of documents which will have air conditioning with the air escaping from the vaults with higher temperature and humidity. In any case it must be assured that the temperature in the film vaults will remain constantly in the range fixed.

15.5.4 One problem that needs attention is the prevention of frost damage to the foundations and side walls of vaults built below ground level. If the vault is air-conditioned to -5° C through -7° C not only the film but also the whole building with all its equipment will be brought in the course of several months to -7° C. This has the consequence that the surrounding soil may freeze up to a certain distance from the building and thus there will arise serious dangers. Such frozen soil may thaw in the higher external temperature of the summer months. Since water increases in volume when it freezes (biggest extension at $+4^{\circ}$ C), the water in the soil surrounding the building can create such pressure upon the foundations and walls, as to cause serious damage or even total destruction.

This must be countered by appropriate insulation of the endangered parts of the vault, preventing the influence of cold from the surrounding soil. From these matters of deep freezing and strong insulation it is shown that the building of colour film vaults is not cheap. But we have always

realized that as science stands today, the preservation of precious audio-visual material necessitates considerable expense.

15.6 Other requirements

15.6.1 Films not to leave the store

There is more to film preservation than the provision of suitable storage buildings. The film has to be rewound, examined, renovated and eventually copied. If possible, it should not leave the repository for all this work. Naturally the allocation of space must depend upon the size of the archive, its financial position, and its technical facilities. Film work rooms should not be in the same building as nitrate film stores, since this would increase the danger of fire.

15.6.2 Card indexes

Finally, each film store requires the following:

a) a technical card index, giving all necessary data and the results of all tests carried out on each film; and

b) a storage card index, indicating where any given film may be found at any time.

Chapter 16

THE NATURE AND FUNCTION OF EQUIPMENT USED BY FILM ARCHIVES FOR FILM HANDLING AND PERMANENT PRESERVATION

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6.1 Introduction

If motion pictures are to be preserved over lengthy periods they must be stored under the best possible conditions, tested regularly and, if necessary, copied or technically restored. Each of these processes - examination, testing, restoration and storage, as well as printing and projection - involves passing of film through machines.

Film as a mass medium is the product of a highly developed technology.

As far as possible, audio-visual archives employ the technologies used by the respective mass media, but for examination and restoration in particular certain special types of equipment are needed.

Such pieces of equipment are manufactured either as single items or in small numbers, and the costs are correspondingly high. They do, however, offer considerable advantages. What follows is a description not of particular makes but of the various types of equipment and what they do. Which items an individual archive decides to acquire and use will depend on the money and space it has at its disposal.

The order in which the various types are described in this chapter is not an indication of their relative importance. We will begin with those items which audio-visual archives are sure to need in their everyday work. As most archives regrettably do not have their own printing laboratory, we will leave until the end the equipment which this would require.

The necessary work has to be carried out, however, if not at the archive then elsewhere, such as at a film processing laboratory.

This chapter does not set out to describe every process or piece of equipment which may have been used through the years. Similarly, to mention all the various makes would go beyond the scope of the present work. The authors' intention is to deal with representative types of equipment which are suitable for archival use.

16.2 Accessories

All of this equipment belongs on the film examiner's actual workbench, namely the single-way winding table, or on a shelf fixed over the table at a convenient height.

16.2.1 Gloves

Gloves of a soft white material (nonfraying cotton) should be available for use on occasions when it may be necessary to touch the surfaces of the film; since grease or harmful acids from the skin can soil or damage the emulsion. Do not allow gloves to become soaked with perspiration.

16.2.2 Scissors

Scissors are needed for repairing perforations or for preparing splices.

16.2.3 Brush

A soft brush is sometimes sufficient to remove particles of dust.

16.2.4 Scraping knife

Scraping knives are needed to remove the emulsion and any protective layer when preparing splices or repairing perforations.

16.2.5 Splicers

Splicers are needed for making or renewing splices. A bottle of film cement as well should be found on the workbench. The quantity of cement used needs to be just right, since excess will spread beyond the join and spoil the adjacent picture.

There is a need to make splices by hand when repairing film which is very shrunk or in which the frame line is not in the standard position.

16.2.6 Shrinkage gauge

The degree of shrinkage is measured exactly with a shrinkage gauge.

16.2.7 Chinagraph pencils

Chinagraph pencils should be on hand for marking film.

16.2.8 Magnifier

A ground-glass screen, illuminated from below, and a magnifying glass are needed to inspect film. The screen and light source are built-in to the winding table for convenience.

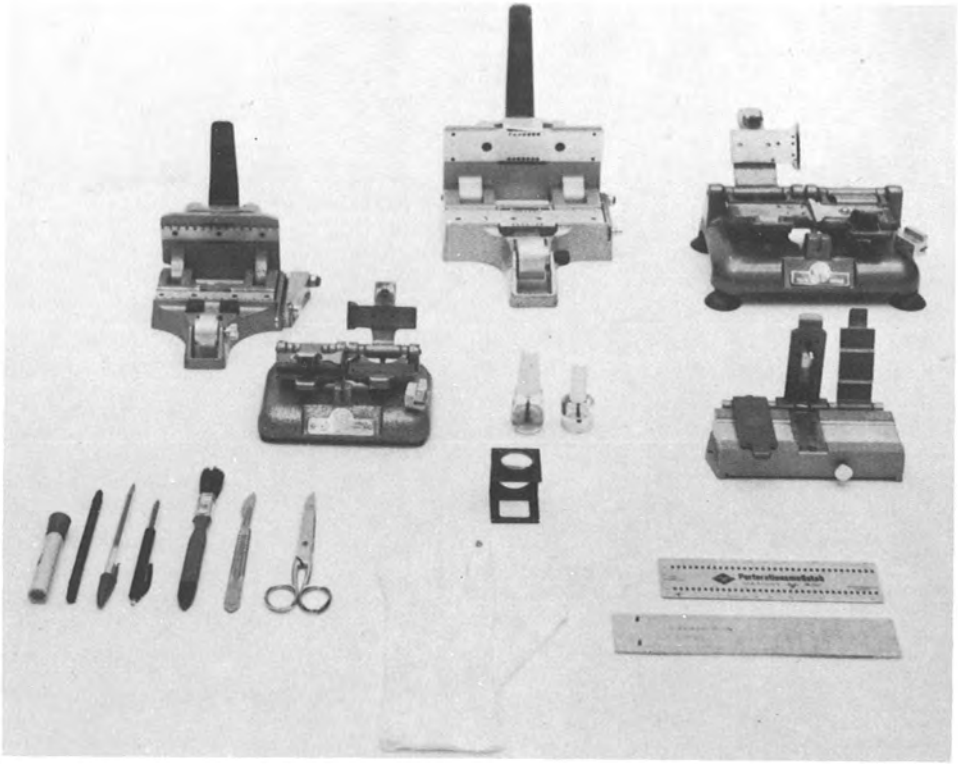


Figure 16-1 Accessories.



Figure 16-2 Single-way Hand-winding Tabel.

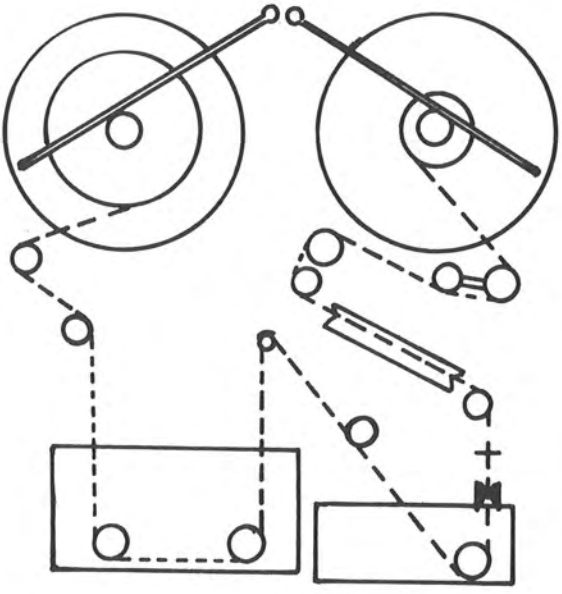


Figure 16-3 Ultrasonic. Cleaning. Machine.

16.2.9 Footage counter

A footage or metre counter, which should be built-in to the table, performs the important task of measuring the film's length.

16.2.10 Film rule

A film rule should be let in to the work surface of the hand winding table as well. Precisely engraved on the rule are the dimensions of the perforations and their distances from one another.

16.2.11 Film bin

When working with film it may be found necessary to unwind considerable lengths into a film bin. The bin consists of a frame which holds a bag made of lint-free fabric.

16.3 Equipment used for winding, cleaning and repairing

16.3.1 Single-way hand-winding table (See Figure 16.2)

The two-plate horizontal hand-winding table is the most important device used for the initial examination of the film and its condition. On the left and right sides of the table are horizontal winding plates for 300 metre or 600 metre reels, which are manually driven by means of a handle. The feed and take-up spindles of the plates should be able to accommodate different gauges, projection spools and cores.

The film is wound through by hand to allow a technical inspection to be made. At the same time dirt can be removed and any damage to the perforations determined. In the printing laboratory a similar table may be used for grading.

Lightly clinging dust can be removed by manual cleaning. The film is drawn slowly through a folded cloth made of soft velvet. Moistening the cloth with a solvent increases the cleaning effect. In this case the speed of winding will depend on the rate at which the solvent evaporates, as the film must be dry before it can be wound in. The freons are especially well suited as solvents because of their low toxicity. They are non-inflammable. Carbon tetrachloride is highly toxic and its use is prohibited in some countries and certainly is not to be recommended. Trichloroethylene is still used, but is also somewhat toxic.

The preferred cleaning solvent is trichloroethane which is as effective a solvent as trichloroethylene and is the least toxic of the common chlorinated solvents. Trichloroethane is also known as methylchloroform.

Solvents for cleaning film	Risk to user
a. n-Butyl chloride	low
b. Carbon tetrachloride	high
c. Cyclohexane	low
d. Cyclopentane	low
e. Freon 113	low
f. Heptane	low
g. Hexane	low
h. Methylcyclohexane	low
i. 1,1,1-Trichloroethane	low
j. Trichloroethylene	high
k. 2,2,4-Trimethylpentane	low

The cleaning is done on an ordinary hand-winding table, which must have an extractor system to protect the operator from exposure to the toxic vapours given off by the solvents.

Film with a strong electrostatic charge attracts dust particles from the air. To prevent this the film can be wiped dry on the winding table using an anti-static cloth.

Machines which move the film in a dry state past velvet rollers, or which are designed to remove dust particles by means of high speed air currents, are not guaranteed to clean properly, and there is always the danger of damaging the film.

16.3.2 Motorized single-way winding table

The motorized single way winding table performs the same function as the hand-winding table. Its speed is continuously variable and makes the film examiner's work easier. The rewinding speed of the film material should be adapted to the respective cycle of work and mechanical state of the film.

16.3.3 Motorized film cleaning machines

Special machines have been developed which clean the film with solvents. The film runs through a tank containing the cleaning fluid (see 16.3.1). Outside the tank it is then cleaned mechanically by means of rotating brushes, velvet-covered washing rollers etc.

Another machine works on the principle of high-pressure spray cleaners, the liquid being sprayed onto the film at a determined pressure, thereby loosening and removing the dirt particles.

Apart from the solvents mentioned in 16.3.1 aqueous solutions with synthetic detergents may be used as cleaning agents in special machines. This is possible in small developing machines as well.

16.3.4 Ultrasonic cleaning machines

In recent years ultrasonic cleaning has proved itself the most effective method of cleaning film material. This

process depends on the principle of liquid cavitation. If intensive sound waves are produced in a liquid, myriads of tiny bubbles full of vaporized liquid are formed. These bubbles suspended in the liquid are not stable and collapse implosively, whereupon the stored-up energy is released in the form of shock waves. The force of the impact of the shock waves directly on the dirt particles produces the intensive cleaning action. This is followed by a rinse, by spraying for example, to remove the loosened dirt. The film then passes to the dryer, where it is dried with warm air. This method of cleaning is very gentle on the film. Suitable ultrasonic cleaning machines are available (see Figure 16.3).

16.3.5 Polishing equipment

Scratches on the base side of the film can be either polished or matted. Films can be polished by either the classical method or by the coating process.

Matting is rarely carried out, as afterwards it is scarcely possible to print the film optically (because of loss of light and strong reproduction of the rough surface of the base when printing by a directed beam of light). In case of severe base scratches it is possible to polish the base after first matting it.

16.3.5.1 Classical method of polishing (see Figure 16.4)

The base side of the film is drawn under tension over a polished glass roller which takes a mixture of, for example, acetone, ether and methanol from a supply trough. The polishing process is initiated by the softening and moistening of the base side in the solvent mixture. When the film is pressed very tightly against the polished glass roller the scratches are closed up. The film takes on the smooth surface structure of the roller. This method is not often used nowadays, but the relevant equipment is available.

16.3.5.2 Polishing by the coating process

Here the film base is treated on the picture width only, with the aid of a noncorroding metal roller which dips into a solvent. There is no direct contact between film and roller. The film's base side is moved past the roller at a distance of about 0.5 mm. The roller dips into a trough containing solvents, which are carried along by adhesion to make contact with the film. To ensure uniform coverage the roller moves at twice the speed of the film. In the drying cabinet the solvent is able to work on the film base and dry off (evaporate). The solvent does not operate as in the polishing process where the scratches are pressed together, but instead the refracting sharp edges of the scratches are rounded, so that refraction no longer takes place. The film is therefore practically unscratched for projection or printing purposes.

There are also devices which can apply protective lacquers

by the coating method to increase the film's abrasion resistance.

16.3.6 Machines for soaking the emulsion layer

Scratches on the emulsion side are best removed by causing the emulsion layer to swell. Small developing machines are suitable for this purpose if the first tanks are filled with alkaline baths for soaking the emulsion.

In the case of older films of which the nitrate base has suffered some de-composition, although there is nothing visible, soaking may wash the emulsion off altogether.

16.3.7 Complex machines

The great advantage of complex machines such as these is that by carrying out several processes simultaneously they save a great deal of time.

16.3.7.1 Multipurpose machines

There are machines for carrying out protective or repair work which allow several processes to be carried out with a single pass of the film; for example cleaning dirt from films, soaking the gelatin, polishing the base, applying a protective layer. If so desired, individual processes can be omitted.

16.3.7.2 Inspecting table

A combined film examining machine is available which can examine and clean the film at the same time. While the film is cleaned, its length and the number of splices are measured and the physical condition of the splices and perforations are indicated. Any deficiencies which are found are recorded on a concurrent paper band.

16.3.8 Viewing tables (See Figures 16.5 and 16.6)

16.3.8.1 Two-plate viewing table

With the help of a viewing table, it is possible to see the film picture on a screen or monitor and to hear the corresponding sound through a loudspeaker. On such a table the control of the picture and sound quality is more effective than on a rewinding table. A scanner provides the possibility of producing a positive picture from a negative picture. Using combined tables different film sizes can be assessed. By means of electronic scanning a negative can be shown on the screen directly in positive form.

16.3.8.2 Two-screen viewing table

Two-screen viewing tables on which two reels of film can run in parallel allow technical comparisons between negative and positive or between two prints of the same film. They are particularly useful as well for the task of re-editing old films in their correct sequence and of restoring them to

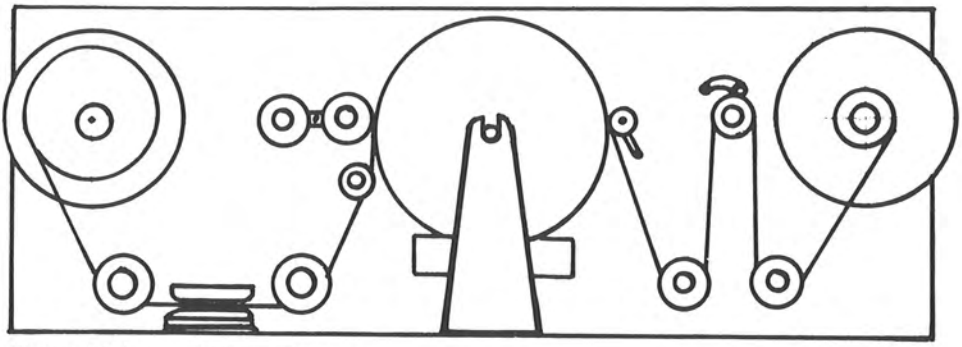
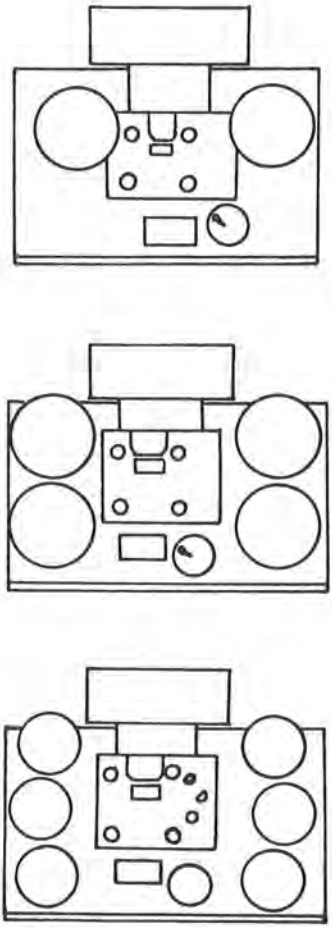


Figure 16-4 Polishing Machine
removing scratches of the base side.



Figure 16-5 Two plates viewing table.

Figure 16-6



Two-, four- and six plate viewing tables for archive work and laboratory.

their original length. An editing table for several film strips with either optical and magnetic sound is equally suited for synchronisation.

16.4 Equipment for measuring shrinkage

16.4.1 Shrinkage gauge

When working with old archival film it is very important to know first of all the degree of shrinkage. Any carelessness here can lead to irreparable damage. Shrinkage measuring rods, on which the degree of shrinkage is read off on a calibrated scale, are easy to handle, but the results are not very precise.

More exact measurements are obtained with a shrinkage gauge, in which the film is laid in a channel and positioned by two precisely defined perforations onto pins, one of which is movable and the other fixed. The movable pin is connected to a counter which shows the degree of shrinkage as an exact percentage (see Figure 16.7)

16.4.2 Optical instrument to determine the condition of perforations

An optical instrument used to determine the condition of the perforations has a ground-glass screen marked with measurements in the form of perforation holes. The length of film to be examined is placed in a channel between the objective and condenser lenses. The dimensions of the perforation holes must agree with the markings.

This device can be used to measure the sound track position as well (ground-glass screen with appropriate markings).

16.4.3 Measuring the sound track position

A measuring-plate with 0.1 mm subdivisions can be used to measure the sound track position.

16.4.4 Microscope

A microscope is useful for detailed examination of older film material which the archive intends to preserve. Early signs of damage such as fungus growth, the action of bacteria, minute perforation tears etc, which may prove catastrophic in the long-term if not countered, are more easily detected than with a magnifying glass.

If wafer-thin cuts (made diagonally to the longitudinal axis of the film reel) are observed under the microscope, it is possible to determine whether the layer adhesion is still intact.

Archives that have their own printing laboratory will find a microscope indispensable for measuring picture steadiness for the printer.

16.5 Transportation

Film reels are heavy (1 feature film weighs about 25 kilos), and therefore equipment is needed to move them anywhere. There is no specialized equipment but the usual methods of transport are sufficient or can be easily adapted for use in a film archive.

16.5.1 Transport in the film store (See Figure 16.8)

The most usual method is the sack barrow with rounded cross-bars to ensure that the film cans are securely housed. Hand trolleys are used as well. Some archives have special devices with drop sides which serve as small hoists. In large film stores one may come across conveying equipment (roller conveyors, conveyor belts), but they take up a lot of room.

16.5.2 Transport in the archive's grounds (See Figure 16.9)

Apart from sack barrows and hand trolleys, which can be used anywhere, large archives make use of electric or diesel trolleys whose loading surface should be the same height as the loading ramps at the film store and the loading surface of the transport van, so as to avoid heavy lifting. Beware of transporting magnetic recordings in vehicles with electric motors.

16.5.3 Vertical transport

Motorized ramps or lifts are a proven method of moving film from one level to another.

16.5.4 Transport outside the archive's premises

Vans are used to transport film outside the archive's premises. Fully enclosed box vans, insulated against heat as far as possible, should be used to protect the films from dust and direct sunlight. When the van is in motion the air stream can also be used as a means of cooling, but in this case dust filters must be installed behind the ventilator openings. Vans should never be left parked in full sunlight without refrigeration.

16.6 Storage equipment

16.6.1 Storage index

If the film collection is to be housed in orderly fashion, storage fixtures are required which allow the films to be clearly arranged according to the system in use (numbers, colours or symbols). There must be guaranteed ease of access, (i.e. it must be possible to remove any film from the store and to return it without difficulty). Every country has regulations governing the storage of nitrate film which we must comply with absolutely in our own interest.

Figure 16-8

Sack barrows.

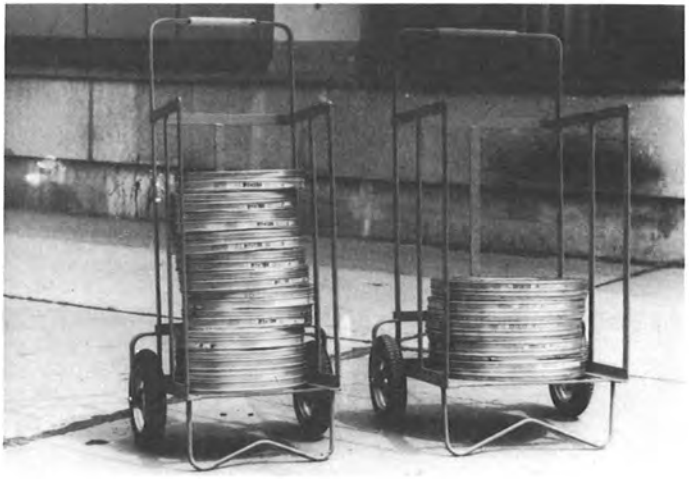


Figure 16-7

Shrinkage gauge.

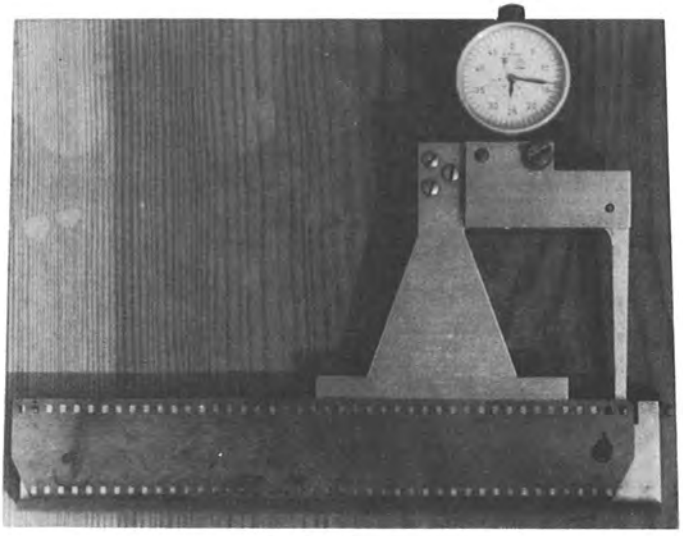




Figure 16-9 Electric trolley.



Figure 19-10 Shelves in a cold storage vault.
In the fore-ground two hand trolleys constructed for vertical transport with a special lift.

16.6.2 Film cans

Film cans made of metal or plastic should be used for long-term storage of film reels. Cardboard cartons are unsuitable for this purpose as they absorb moisture. Nitrate films must be stored exclusively in metal cans; storage in plastic containers can cause chemical damage. In the decomposition process of nitrate films heat is produced (exothermic chemical process). The dissipation of this heat is supported by using metal boxes. Acetate material can be stored in either metal or plastic cans except cans of chlorine plastics (e.g., PVC), which can damage films.

It is advisable to use standard format cans for 300 metre and 600 metre reels, to make more efficient use of the storage shelves.

16.6.3 Shelving (See Figures 16.10, 16.11 and 16.12)

Shelving made of metal or wood is recommended. The system chosen should offer flexibility of construction and a guaranteed future supply. For archival storage the cans are always laid horizontally, though for distribution prints and for films in temporary storage while they are worked on, vertical storage has the advantage of quicker access.

16.6.4 Mobile storage (See Figure 16.13)

Mobile storage offers more efficient use of floor space. In this system the shelving moves on a track, thereby dispensing with many of the corridors which would otherwise be necessary. This can double the capacity of a room. Operation is either by hand or by motor. Nitrate film must not be stored in this way as any fire would spread to catastrophic proportions. In any case, the small number of cans of nitrate film which the regulations allow to be stored in one room means that there is no point in installing a mobile storage system.

16.7 Air conditioning

16.7.1 General

It was established in Chapters 1 and 5 that the life of a film is prolonged by storage at constant levels of temperature and humidity. The storage values laid down by the Commission are to be found there.

Artificial air conditioning systems like this are very complicated for in certain cases (deep cold storage of colour film, for example) they affect the entire construction of the film store. We will not go into individual makes here. Ready-made refrigeration systems are rarely suitable, as they do not permit the optimal values to be reached.

16.7.2 Air conditioning for one room (See Figure 16.14)

Cabinet-type air conditioning units, installed in the room

itself, are suitable for use in smaller individual rooms. They have been used with some success.

16.7.3 Large air-conditioning system (See Figure 16.15)

Large systems are installed outside storage vaults, and consist of the following complexes:

- filtration of fresh air drawn in, and of the remaining recirculating air
- heating of the air (drying)
- cooling of the air to the pre-set temperature
- humidifying of the air to the desired level
- circulation of the air through the vaults to the outlet.

Such systems cannot be built by amateurs. They must be designed and installed by air conditioning engineers, working from the outset with the architects with regard to the air ducts, insulation, drains etc.

As a warning example, let us mention a case which happened some years ago. A large film archive took the welcome step of having a deep cold store constructed in its newly-built vaults. The architects concerned had up to then had no experience of cold store construction and the deep cold store was designed to operate at a temperature of -18° C (0° F). When the system was put into operation, condensation formed in the neighbouring vaults, and minor cracks appeared in the walls and ceiling of the deep cold store. Subsequently the refrigeration equipment was reset to provide a temperature of +5° C. The experience indicates that it is wise to separate completely cold stores from moderate temperature stores because of the difficulty of insulating the two from each other.

Archives should profit from experiences such as this.

16.7.4 Sealed film

It is more difficult to maintain a low humidity (approx. 20-25%) than to maintain a low temperature. The following technology can be used to overcome this difficulty:

Colour film materials are stored at a low air humidity in a room or cupboard for several days. If possible, the films should be rewound several times under these conditions. Then the film material is put into special foil bags and sealed up so that air has no access. The rooms where this sealed film material is stored only need a cooling system. There is no need to control the air humidity any longer as the film material stored in these rooms is air tight through the sealing process. Care should be taken that during the sealing process such low temperatures and humidities are chosen that when the film material is stored at a low temperature, the temperature does not fall below the dew



Figure 16-11

Shelves for archive use cans are stored horizontally.



Figure 16-12

Shelves for distribution storage (vertically).

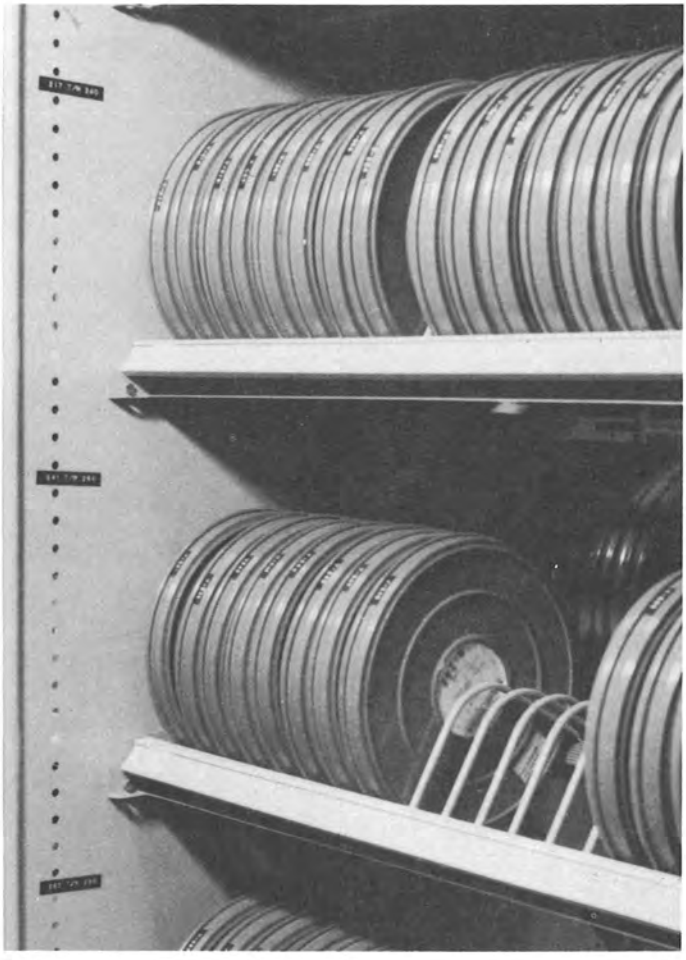
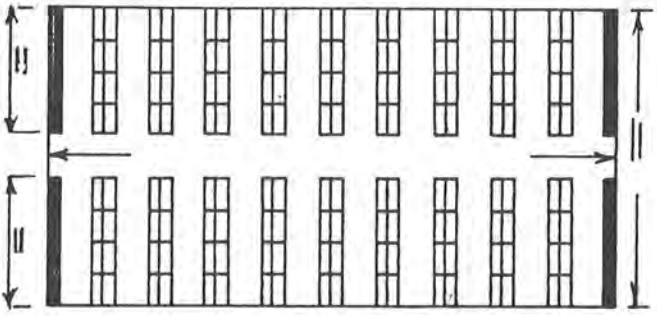


Figure 16-13



Fixed shelves.



Mobile shelves. Mobile storage.

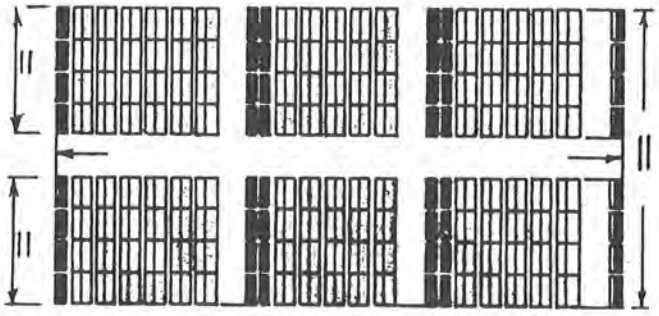
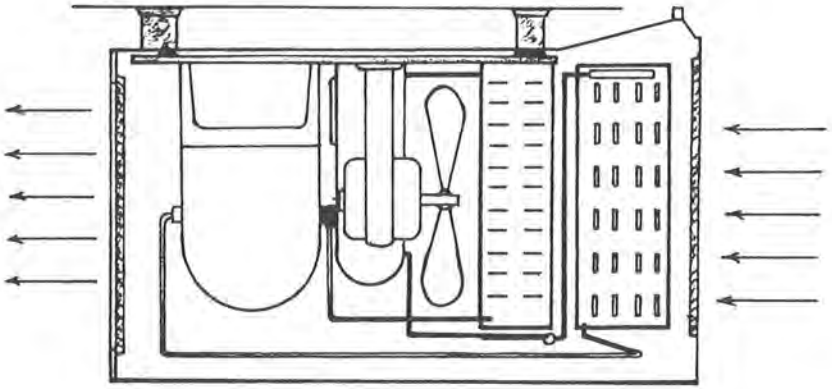


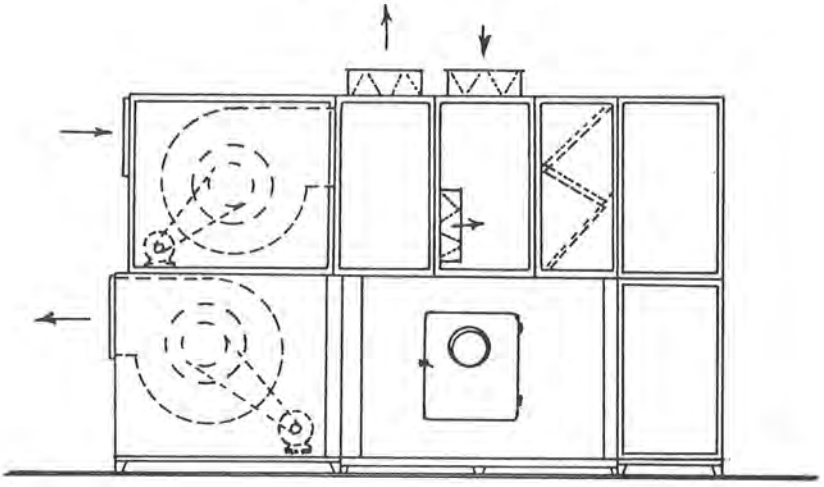
Figure 16-14



Cabinet-type airconditioning unit for one room.

Figure 16-15

Large airconditioning system.



point.

16.7.5 Acclimatization

Removing films from a refrigerated room, or putting them back, gives rise to another problem. There is a danger of condensation forming inside the film cans when they are taken out of the store. Films stored in wet cans in this way will be irretrievably lost. The cans must therefore be acclimatized beforehand. Natural acclimatization, whereby cans are left open in rooms where the temperature approximates to that of the store, may last for weeks or months. Accordingly the process of artificial acclimatization in acclimatization cabinets or chambers may be used. This system depends on the principle that when air is cooled the condensed water forms as ice on the cooling ribs (hence the relative humidity falls), while the ice melts and the humidity rises when the air is warmed.

Using such cabinets the State Film Archive of the GDR is able to bring 200 cans of 35 mm film to the desired levels of climate within 8 hours. The cabinets have been working perfectly for 15 years.

16.7.6 Thermohygrograph (See Figure 16.16)

Measuring instruments on which the levels of temperature and humidity reached can be read off, form part of any air conditioning system. As a precaution, constant readings must be taken from an independent source (e.g. by means of thermohygrographs). This apparatus registers the values with any variations over a period of 7 days on charts made of special paper laid over a drum, using recording ink. Specially treated hairs are used as measuring elements for humidity (with an accuracy of +2% RH), while for measuring temperature bimetallic strips accurate to 1° are used.

Occasionally one gets charts which show slight variations in the temperature section while the humidity recording shows a straight horizontal line. It is extremely rare that this is evidence of special stability of humidity: mostly it is a sign that the measuring hair has in the course of time absorbed too much water, thereby becoming slack and failing to measure. All that is needed is to dry the apparatus in a warm room for it to recover its accuracy.

16.8 Measuring equipment used in film processing

16.8.1 General principles

Only a few audio-visual archives have their own printing laboratory. This is a matter for regret, as the copying of old films, even when cleaned and repaired, calls for more patience and expertise than is to be found at the film industry's mass production printing laboratories. There are only a few laboratories anywhere in the world which are geared entirely or partially to printing old films. Large archives should have their own laboratory in any case, primarily as a means of duping films for preservation and

carrying out restoration.

The machines and apparatus needed by an audio-visual archive's printing laboratory are dealt with in the following sections. Of course, some items which have been described previously (sections 16.3 and 16.4) are required as well, such as cleaning and repair equipment and equipment for assessing the condition of the original (i.e. the film to be printed).

16.8.2 Grey scales

Grey scales are an important means of examining raw film stock and of controlling the process of developing at the laboratory. They consist of transparent material (film, glass, plastic, etc.), come in normal film widths, and are about 20 cm in length. Their grey tones have brightness values which vary either by steps of a standardized amount, or continuously, depending on the purpose for which they are to be used.

16.8.3 Sensitometer

The grey scale is placed with the raw film in the sensitometer and illuminated by a fixed printing light which is precisely defined as to intensity, exposure time and colour temperature. At the laboratory the exposed strips are then developed, fixed and dried in a small developing machine with standardized baths. They can also be clipped beforehand to exposed film tests or films, and developed with them.

The manufacturer's instructions must be followed exactly throughout the entire procedure. By evaluating the new copy of the grey scale one can assess whether the raw film stock meets the given optical specifications and maintain control over development during subsequent processing.

16.8.4 Densitometer

A densitometer is an optical instrument which allows one to measure exactly the optical densities of details of the sample to be printed and of new prints (grey-scales as well). The values so obtained are important for maintaining output of a constant quality during processing at the laboratory, and for assessing loss of density in recordings which are being preserved over a long period of time (see Figure 16.17).

Even those audio-visual archives which do not have their own printing laboratory should therefore acquire a colour densitometer with which to examine the densities of black-and-white and colour images. Loss of density during archival storage is nearly always the first sign of the destructive process.

16.8.5 Chemical laboratory

Any archive that has its own printing laboratory will need a chemical laboratory also where control of the developing

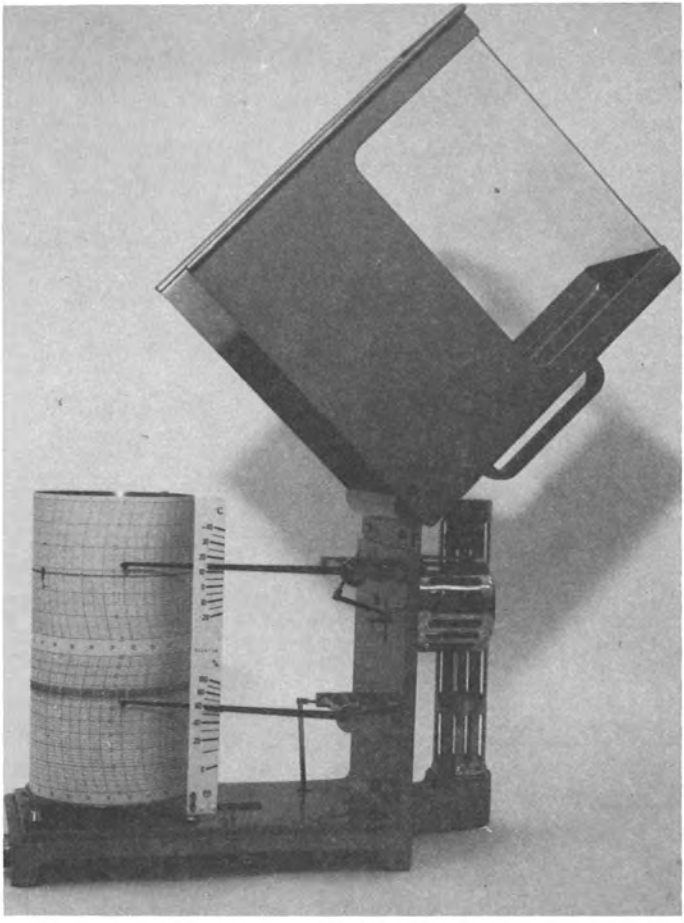


Figure 16-16 Thermo-hygrograph.

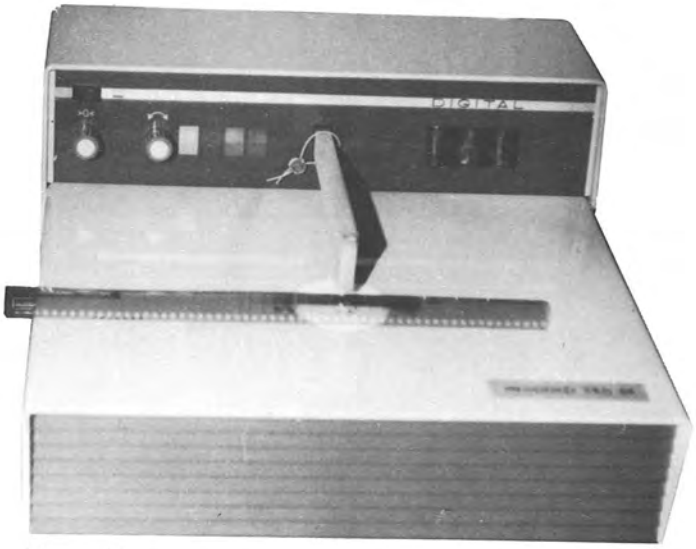
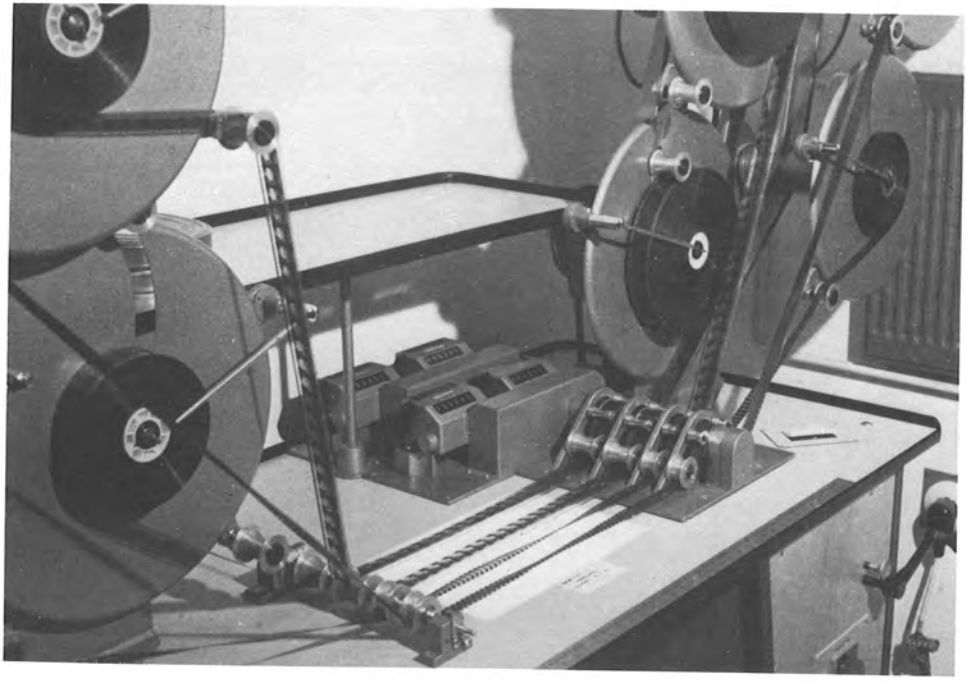


Figure 16-17 Densitometer.

Figure 16-18 Synchronizer Tables 16 and 35 mm.



baths etc. can be undertaken and the relevant analyses carried out. The methods of analysis must take into account the manufacturer's recommendations. The laboratory's basic equipment may need to be supplemented by special pieces of apparatus as required.

Those archives which do not have a printing laboratory only need a chemical laboratory if they carry out certain tests on a regular basis (e.g. measurement of colour density, nitrate/acetate test, artificial ageing test for nitrate, residual thiosulphate test etc.).

16.9 Synchroniser tables

16.9.1 Synchroniser table for two, three or four strips

Synchronizers are used for preparing film for printing, or for comparing films.

With a synchroniser table one can place negatives and positives to run in synchronism, position start marks on negatives, synchronize picture and sound and work with trial copies. The visible picture is only the size of the frame. The table cannot be switched from one gauge to another as required, although there are synchroniser tables available which will accept two 16 mm and two 35 mm reels (see Figure 16.18).

The table can be driven either by hand or motor, and can be switched in a continuous range from fast to slow, and to synchronous speed. Depending on the chosen setting, the sprockets which transport the film or maintain it in synchronism are connected either rigidly or freely to the drive shaft. Ground-glass screens, illuminated from below, footage or metre counters and loud speakers may be built-in.

16.9.2 Editing table

The film editor's most important tool is the editing table. It is a universal table which can be used for viewing, running film in synchronism and for editing. Most TV archives have one.

16.10 Grading

The purpose of grading is to determine density or colour variations in developed film material before it is printed, and to decide the printer lights accordingly.

16.10.1 Black-and-white grading

The aim is to obtain from the film to be printed a copy with consistent grey values, corresponding as far as possible to the unfaded original and agreeing with the cameraman's artistic intentions.

The film is unwound slowly over the illuminated panel on a hand winding table. Evaluation is always subjective, the grader deciding on the required printer light levels purely

on the basis of experience.

Several trial copies may be necessary before positive prints with satisfactory density balance can be produced. The process of correction is best carried out on a grading table equipped for synchronous work. The negative and positive are wound in synchronism on such a table with a screen illuminated from below, so that corrections can be transferred immediately from positive to negative and vice versa.

16.10.2 Colour grading

Preparing a colour film for printing involves colour modulation as well as control of the printer light intensity.

16.10.2.1 Classical method

Short lengths of positive are printed at various light settings, and developed. The judgement of further colour grading is then made.

16.10.2.2 Electronic colour grading

The use of a colour film analyser allows colour grading to be carried out more quickly and the subjective element to be eliminated to a large extent. The colour film is scanned electronically and the image displayed on a screen. By adjusting the controls of the red-green-blue channels, the grader can undertake the necessary corrections to arrive at the required colour balance for the scene in question. This dispenses with the need for numerous test prints.

16.10.3 Light control band

The estimated amount of light which the grader considers necessary for individual shots, in order to obtain a correctly balanced print, is transferred to light control bands.

16.10.3.1 Light control bands for black-and-white film

The perforated printing band in use consists of an opaque, perforated paper strip in which holes of varying diameter are punched at regular intervals (see Figure 16.19).

As the strip is moving along the light beam in the printer, the diameter of the successive holes, as determined by the grader, controls the amount of light from the printing lamp.

An older method which still continues to be used, consists of changing the intensity of the printing light by means of resistors which are connected to the circuit of the printing lamp. To achieve the change in intensity, a grading control band is used which allows 15 modifications.

The control band is perforated along both edges. By means of rectangular punchings which are staggered by one perforation step each, along the length of the band, and, depending on

the diameter of the hole in a transverse direction, an electrical resistor is connected to the circuit of the printing lamp in the switch box of the printer.

16.10.3.2 Subtractive printing of colour film

The subtractive printing process uses the light control band in the same way as the punched tape is used for black-and-white film.

Individual colour filters are stapled over the holes of the band in the succession: yellow, magenta, cyan and grey.

Another modification is to employ control bands with pockets for the filters. They consist of transparent material, perforated along one edge, with transparent pockets attached into which the aforementioned colour filter foils are slipped (see Figure 16.20).

16.10.3.3 Additive printing of colour film

The essence of additive printing is that the light from the printing lamp is divided, usually by dichroic filters into three beams, one red light, one green light, one blue light. The intensity of these three beams is separately controlled from scene to scene, thus adjusting both colour balance and overall density in the resulting copy.

The control is executed by a perforated paper strip having 8 rows of holes.

Rows 1-6 have colour information; row 7 has aperture information; row 8 has start and stop information.

These control bands are produced, duplicated and controlled by a system of devices (printers, duplicators and lasers); see Figure 16.20.

16.10.4 Printer light control

If the grader determines any necessary changes in the printer light, the change is indicated by means of an edge notch (approx. 1.3 mm deep and 37 mm long) on the film original. When the film subsequently passes through the printing machine, the notch activates a switch contact which advances the light control band electromechanically. The notches are prepared, and in some cases counted as well, by edge notch punches.

The cue-patch system of printer light changing has been developed for use with the new high speed continuous printers. In this system a suitable device applies the metallic foil cue-patches to the film. One advantage is that the patches may be removed again if any corrections are necessary.

Other methods of light changing are based on the counting of frames or perforations. This is known as "frame count cueing" (FCC).

16.11 Printing machines

16.11.1 General

Using established photographic duplication procedures, light-sensitive raw film is exposed in the printing machine to light rays which have passed through the original, (i.e. the film to be printed). This produces a latent image in the emulsion of the exposed raw film which becomes visible only when developed.

There are various sorts of printing machines; step printers, continuous printers, contact printers, optical printers, as well as specially designed ones. Generally they can be used both for colour and for black-and-white printing, provided that for colour there is provision for controlling the printer light in accordance with the image's intensity and colour composition. Light changing control can be by either the subtractive or additive methods as described in 16.10.3.2 and 16.10.3.3 above.

16.11.2 Contact step printer

The film to be printed and the raw film are moved in direct contact frame by frame past the printer's picture gate by means of claws. Exposure of the image at the printer gate takes place when the open part of the rotating shutter allows the printing light to pass through. During the claw stroke the shutter's dark sector blocks off the printer light. At the same time the swinging gate member is lifted away from the film path to avoid scratching the film. This type of printing does not alter the picture format. It can handle shrunken material, up to approx. 1.5%, if appropriate transport rollers are used and the claw's dimensions are suitable for the degree of shrinkage.

These machines are suitable for archival use, giving great picture sharpness and steadiness. The maximum speed is 1000 metres per hour (55 feet per minute), although there are machines of this type in use with far lower speeds, which is often an advantage with archival material.

16.11.3 Optical step printer

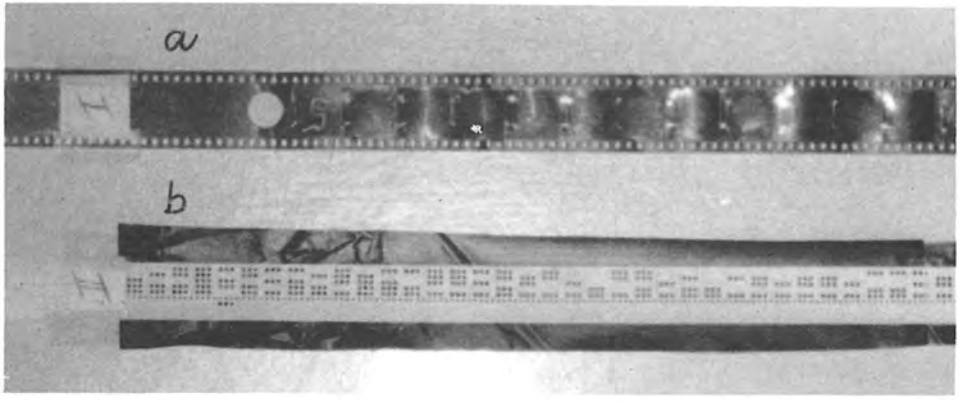
The original and the raw film are moved in opposite directions. Between them are object lenses which either alter the scale of the image or reproduce it 1:1, according to choice. Here too both the original and the raw film are moved by claws step by step past the picture gates (see Figure 16.21).

Because of its versatility this type of printer is very suitable for archival use. It permits reduction/enlargement printing to be carried out (e.g. 35 mm to 16 mm, 16 mm to 8 mm etc). With optical printers, moreover, it is possible to carry out anti-scratch printing (i.e. wet printing), by which new prints from scratched originals appear scratch free or nearly scratch free if the scratches are very deep. With this type of printer there exists also the possibility of



Figure 16-19 Light control band for b/w Film.

Figure 16-20 Light control band
for the grading of colour film.
a) Substractive grading.
b) Additive grading.



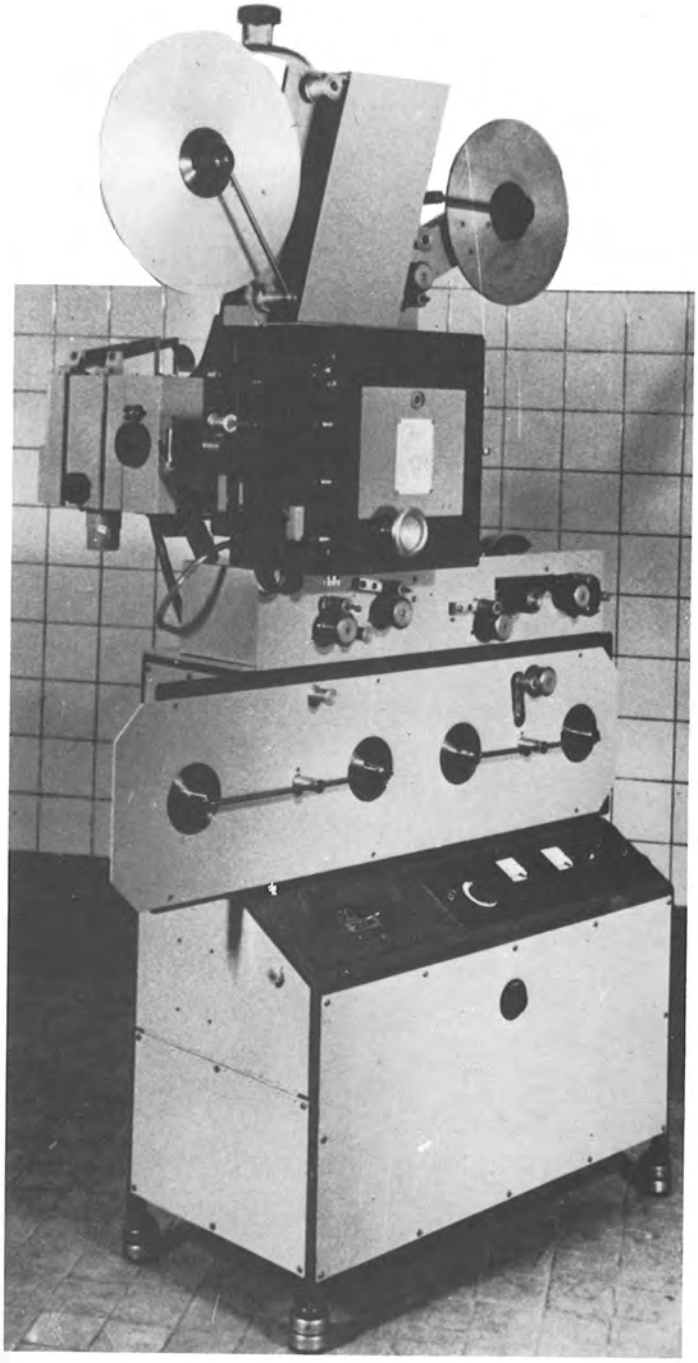


Figure 16-21

Optical step printer.



setting the claw stroke for the original differently from that for the raw film, thereby allowing badly shrunken film over 1.5% to be handled. Finally, by using an appropriate lens one can reduce the silent picture format to the normal present-day sound picture format without losing parts of the image.

All of these features are of great importance if old films are to be copied faithfully.

16.11.4 Continuous printers

They are designed for the rapid manufacture of large quantities of prints. They are used by the commercial film distributors.

Technically they are distinguished from step printers by the method of film transport. The films are moved past the exposure slit not by an intermittent claw stroke but by a high-precision sprocket which rotates continuously. The width of the exposure slit corresponds to the frame width, while its height is only a fraction of that of the frame. Feed and take-up is by way of normal film guide rollers. These machines may work at very high speeds (continuous contact printers at 7500 metres per hour (410 feet per minute)), and old films, which may already have perforation damage and splices, cannot stand up to the greater forces involved. Shrunken material can be handled only if the degree of shrinkage does not exceed about 0.8%.

As with step printers, there are contact machines and optical machines. While contact machines produce prints of the same format, continuous optical printers are used almost exclusively for reduction printing of sound tracks from 35 mm to 16 mm.

16.11.5 Special printers

The following are special printers:

- machines for producing colour separations on black and white film

- sub-title printing machines

- special effects printing machines

Their installation in an audio-visual archive can only be justified if their capacity can be used to the full.

16.11.5.1 Printer for producing colour separations

This may well be the case if the archive intends to preserve its colour films in the form of colour separations on black-and-white film. This is less of a problem than that of preserving colour films as such, but equally it is no more secure than preserving black-and-white films in general. It requires more storage space and, of course, a printer for bringing the three separations exactly together again.

16.11.5.2 Subtitle printing machines

An archive only needs a sub-title printer if a great many films are to be subtitled in a foreign language. As this is unlikely to be the case, it should prove cheaper to have any such films sub-titled at a foreign film laboratory.

16.11.5.3 Special effects printers

They are very versatile. They can do everything described in 16.11.3 (optical step printers) and more. They were designed for use in film production. Technically they consist for the most part of a projector and a film camera, which is mounted on an optical bench.

Their main interest as far as archives are concerned is that they can also produce prints from all the formats which are no longer conventional (e.g. 9.5 mm or 17 mm). These machines operate very slowly. Archives can scarcely make full use of all their capabilities (e.g., making dissolves). Their value for archival work is undoubted.

16.12 Developing machines

16.12.1 General

The latent image produced in the printer (or in the camera) becomes a visible film image by development and fixing in the developing machine.

Archives should choose sprocketless-drive machines so that films of different gauges can be processed on the one machine. When selecting a particular type of machine, one should bear in mind which processes are to be carried out in the archive's printing laboratory (whether simple printing, restorative printing etc.) and what sort of output will be required. At the same time one must take care to choose a type which offers a sufficient final washing capability at the intended output, as only film which has been thoroughly washed is suitable for archival storage.

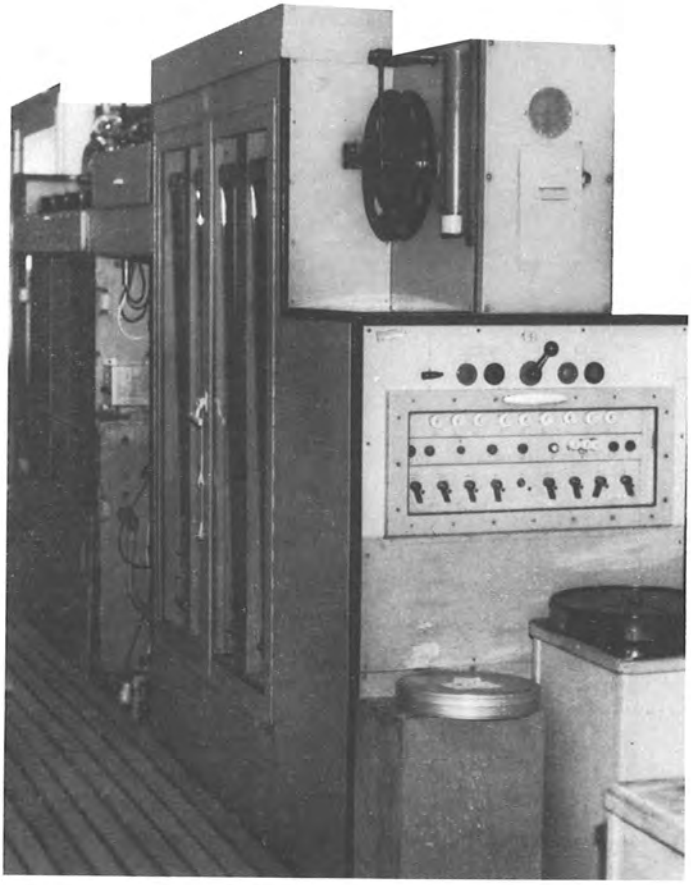
Developing machines can be divided into two categories: low output and high output.

16.12.2 Low output developing machines

They will process about 1000 metres of film per hour (55 feet per minute). They are of compact construction and are fitted out as complete operating units, comprising the developing machine itself, the supply reservoirs for the replenishment of the baths, a circulation and temperature control system for the baths, sound track redevelopment, and the drying cabinet. Apart from electrical supply, water supply and drainage, no further connections are required for this type of machine (see Figure 16.22).

Because developing machines handle only unused and hence undamaged film, there is no special risk. Nevertheless, low output machines are recommended for archival use, in so far

Figure 16-22 Low output developing machine.



as their output matches that of the step printing machines (16.11.3).

16.12.3 High output developing machines

In this category belong machines with outputs exceeding 1000 m/h for 35 mm film. They are considerably bigger than low output machines and consist of the following main elements:

- film magazine with feed
- wet part: tanks for the development and fixing baths, and for washing
- drying cabinet
- supplementary equipment for temperature control and for developer and fixer replenishment
- air conditioning for the drying cabinet
- sound track development.

Replenishment must be harmonized with the speed of the film's passage and with the film formats which are being developed. The replenishment supplies must be precisely adjustable.

An important element in the operation of all processing machines should be the recovery of silver from the fixing solution. This is not just for economic reasons but for ecological ones as well. Water pollution from printing laboratory waste is not inconsiderable. The limits placed on liquid waste disposal do admittedly vary greatly from country to country, but a tightening of controls can be expected in the foreseeable future.

16.13 Projectors

It is only natural that an audio-visual archive should have a projection room. Who would want to collect treasures and yet not be able to view or show them? Archives are intended to be used and are not an end in themselves. Viewing a film on an editing table or monitor is often insufficient.

All normal theatrical projectors can be used and are available for all usual present day formats. There are also dual-gauge machines available (e.g. 16 mm and 35 mm, or 35 mm and 70 mm).

Old silent films shot at speeds lower than 24 frames per second must be projected at the same speed today, otherwise even masterpieces can appear ridiculous. Some archives have speed regulators which allow any speed to be selected as desired (including 25 frames per second for television).

Double-headed projectors are required for simultaneous projection of separate picture and sound tracks. These are conventional machines supplemented by a special sound

mechanism, or which simply require additional drums on account of a special film guide.

Films intended for permanent preservation should never be used for projection, which should be confined to replaceable copies.

Chapter 17

MACHINES FOR THE RECORDING OF AUDIO AND VISUAL SIGNALS ON MAGNETIC TAPE

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In the course of their development the areas of both audio and visual signal storage have seen a wide variety of machines, and to describe them all would require a comprehensive reference work. This chapter will therefore confine itself to the basic types, which were always the foundation for specialized developments. However, special attention must be drawn to the fact that different systems are not compatible with one another, partly because of differing track placements or track dimensions, partly because of the electrical parameters which have been chosen. In view of the fact that system development is at present by no means finalized, it is prudent for archives to consider the fewest possible recording formats, so that later the material acquired may still be accessible at an acceptable cost. In such a case it is better to copy any materials which are on special formats onto more normal formats, rather than later have to keep a large number of machines operational.

17.1 Magnetic tape machines for the recording of audio signals

17.1.1 General principles

Essential to the understanding of magnetic tape recorders is their underlying operating principle which will be briefly explained here; a more detailed description will be found in Chapter 10.

The purpose of signal recording is to store a temporal event in a permanent form. In the case of magnetic signal recording, for example, visual or audio information is converted into magnetization running along the tape, a spatially dependent magnetization therefore, from which the original information can be reproduced.

The magnetic layer of the tape is so constructed that under the influence of magnetic fields its minute molecular magnets are re-orientated in a series of south and north poles dependent on a magnetic field, which in their turn exert a corresponding magnetic field in the immediate vicinity of the tape. The magnetic structure formed in this way is largely stable, i.e., it does not alter after the magnetizing force has been removed, unless subjected to excessive thermal, magnetic or mechanical influences.

The re-orientation of the molecular magnets of the tape under the influence of a magnetic field is known as recording, while the use of the magnetic fields of the tape to retrieve the original information is known as playback.

The recording field is produced by an electromagnetic transducer known as the recording head, while for playback a magnetoelectric transducer, the play head, is used. The signal current necessary for the recording head is provided by the recording amplifier, and the voltage induced in the play head provided by the play amplifier (see Figure 17.1).

The transformation of the time dependence of the signal to be recorded into a spatial dependence takes place with the aid of the tape transport, which moves the recording medium (the tape) past the recording head so that a different part of the tape is assigned to each instant of the signal. The more quickly the tape is moved past the head, the greater is the length for each unit of time. The following equation exists between the wavelength (λ) of a recorded signal, the tape transport velocity (v), and the signal frequency (f):

$$\lambda = v/f$$

A constant, defined speed is a prerequisite for exact reproduction of the signal frequencies.

17.1.2 Tape transport

The chief components of the tape transport are: the drive shaft (capstan), the rubber idler roller, feed and take-up spools, tape guides, control systems. All these components have relatively narrow tolerances, for example, permitted deviations in the capstan drive are measured in u. If these tolerances are exceeded then errors of speed will result.

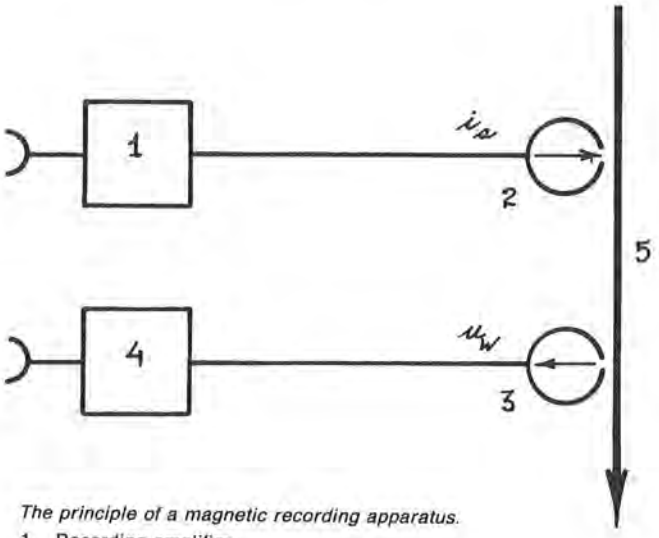
The principle of the drive is that the tape is transported by the capstan. The tape is pressed against the capstan with the aid of the rubber idler roller, so that it is moved by the capstan assembly (see Figure 17.2).

The velocity of the tape is approximately the circumferential speed of the capstan drive. The tape is fed from a spool (usually found on the left) which is braked either mechanically or electrically to keep the tape in tension and to dispense with tape guides. After passing between the capstan and the idler roller the tape is wound under tension onto the take-up spool with a smooth wind.

The tape tension is dependent on the machine and the tape, i.e., it is adapted to the type of tape intended for use with particular recorders, to provide correct head-to-tape contact.

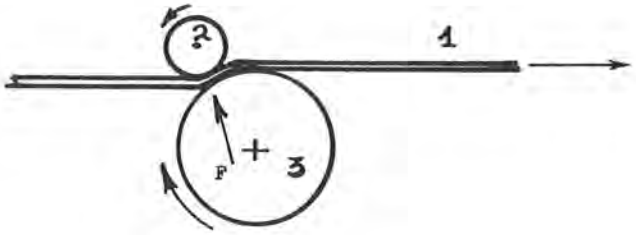
The choice of tape speed is based on the tape material used, the electro-acoustic requirements of the recorder, and operating costs. There is a loss of quality with lower tape speeds. The effective usefulness of the tapes themselves depends on their specifications, e.g., coating thickness.

Figures 17-1 and 2



The principle of a magnetic recording apparatus.

1. Recording amplifier.
2. Recording head.
3. Replay head.
4. Replay amplifier.
5. Magnetic tape.
6. i_a Signal current.
7. u_w Replay voltage.



Drive principle of rubber pinch roller.

1. Magnetic tape.
2. Drive shaft with peripheral speed V_u.
3. Rubber pinch roller pressing with force F.

In the final analysis the speed adopted for a particular machine represents a compromise between the specified values.

To make interchange of tapes easier the following tape speeds were internationally agreed; (ips = inches per second):

76.2 cm/sec (30 ips)
38.1 cm/sec (15 ips);
19.05 cm/sec (7.5 ips) ;
9.53 cm/sec (3.75 ips);
4.75 cm/sec (1.875 ips).

Other values for special applications can be encountered on odd occasions. In general, machines with the fastest tape speeds achieve the highest standards, but the necessary drive performance etc. involves expensive technology, and therefore machines with a speed of 76.2 cm/sec (30 ips) and nowadays 38.1 cm/sec (15 ips), for example, are nearly always reserved for professional use.

An essential criterion of the quality of audio tape transport mechanisms is the degree of wow and flutter, evaluated on a curve modelled on the sensitivity of the ear (evaluated pitch variations). Values of 0.4% are required for studio machines, while for domestic machines on which multiple copying to technical standards is not expected, substantially higher values are permitted. Above 3% though, one must expect a distinct impairment of quality.

The absolute value of the speed should be kept within a tolerance of $\pm$ 0.2%; values several times higher are permitted in domestic machines, though deviations of the order of one percent will prove unacceptable to a trained listener.

A smooth and uniform tape path is important. Tape weave and cupping etc. lead to variations in the frequency response characteristic, fluctuations in level and other effects. In slow-running machines the pressure required to maintain the necessary tape-to-head contact is produced by special pressure pads. On professional machines this is achieved by the tape tension, and the wrap of the tape round the head, which is approximately 10-15°. The quality of the surface polish of the head plays a significant role in this respect. Most machines have built-in controls to maintain constant tape pressure.

The functions of the machines are selected mostly by control keys, which in smaller machines carry out both mechanical and electrical functions (e.g., application of the rubber roller). With larger machines requiring greater power, the mechanical operations are carried out by key operated electromagnets. The functions are made up of a range of separate operations such as:

a) switching on and off of the motor;

b) applying and releasing the idler roller;

c) applying and releasing the brakes etc.

Depending on the machine, these separate operations must be co-ordinated with one another if tape damage such as stretching, twisting etc. is to be avoided.

The chassis of the transport mechanism must ensure long-term mechanical stability; machines with three motors are therefore built with ribbed mounting plates, smaller machines make do with simple cast plates or sheet metal constructions.

Audio cassette machines are now in widespread domestic use. They use a magnetic tape housed in a cassette, thereby simplifying considerably the frequently complicated process of loading the tape.

Cassettes do have one disadvantage, however, in that they possess additional guide elements and rubbing surfaces and can therefore have a strong effect on the overall running performance of the machine. Cassettes with extremely thin tapes, e.g., 90 or 120 minute cassettes, are extremely sensitive (easily damaged tape edges, sensitivity to stretching etc.) and are in no way to be recommended for archival use. Besides these compact cassettes there are special cassettes, e.g., endless loop cassettes, motif cassettes etc., which are similarly unsuitable for archival purposes. Moreover, it should be remembered that the material of which the cassette is made must be of long-term stability, otherwise deformations occur in the course of time which make such cassettes unusable (e.g., disposable cassettes which are intended for short-term use only).

17.1.3 Magnetic tape

The magnetic tape is not an intrinsic part of the machine, but as it is the actual recording medium it must be considered along with it. It consists of a mechanical support tape and a magnetic coating which during use faces towards the head. To obtain a recording which corresponds to the signal pattern it is necessary for the recording head current to be proportional to the signal and to have an auxiliary current which produces a bias field. Originally this was brought about by a direct current (DC) bias, but nowadays a high frequency current is used almost exclusively (Hf bias). Compared with DC bias, high frequency bias gives a superior tape performance with lower distortions and less tape noise. The strength of the bias current to be chosen at any time depends on the type of head and tape. Normally machines are overbiassed by 1 dB at midband to achieve the best modulation noise performance. With modern tapes, a flatness of the characteristic makes this difficult and current procedure usually is 3 dB over bias at 10 kHz. The international tendency within certain classes of recorder is towards compatible tapes, i.e., two types of tape whose bias requirements and recording sensitivity are about equal.

The wavelengths recorded on the tape may range from a few centimetres down to lengths measured in μ (1/1000 mm). If the wavelengths fall into the μ range, then the magnetization conditions become increasingly unfavourable (see Chapter 10). These conditions are allowed for by corresponding internationally agreed frequency-dependent magnetization characteristics.

As the wavelength depends on the tape speed, a special standard has been agreed for each tape speed. This is based on an analogy; i.e., the magnetization decrease shall be in the ratio of the impedance characteristic of a resistance/capacity (RC) parallel circuit, defined by a time constant (τ_2). With certain tape speeds a magnetization increase was agreed to improve technical parameters at low frequencies, expressed by a time constant (τ_2), which in this case corresponds to the impedance characteristic of an RC series circuit.

The usual values are as follows.

Tape speed v (cm/sec)	Professional machines τ_1(usec)	Domestic machines τ_1	τ_2(usec)
76.2	35		
38.1	35		
19.05	70	50	3180
9.53		90	3180
4.75		120	3180

Besides the frequency response of the tape, flux level, maximum tape flux (peak recording level), permissible distortions etc. are standardized, though these standards essentially relate to professional recordings.

17.1.4 Magnetic heads (See Figure 17.3)

Magnetic heads are used to create, reproduce or erase recordings. Their basic construction is always the same. A coil is wound around a ferromagnetic core (ring core or rectangular core) broken only by a working gap or additionally a secondary gap. If a current is applied to the coil a magnetic field is produced in and in front of the gap, in proportion to the intensity of the current flowing through the coil. Depending on the intensity and type of current in the head, recording or erasure can take place.

17.1.4.1 Ideally the recording head has a gap width of 6-8 μ. The coil must be laid out so that strengths of current are produced for the signal current and the necessary bias current (a few milliamps).

The subject is controversial. Narrow head gaps tend to give

a better frequency response but the depth of penetration into the tape oxide is very much less; therefore, the consistency of performance is degraded. With wide gaps, you get a better tape penetration and a more consistent modulation noise performance. The manufacturers fit narrow and wide gap heads respectively.

17.1.4.2 The erase head has a wide gap, often a double gap as well, to receive as many demagnetization cycles as possible during erasure and hence a high degree of erasure. The gap widths are of the order of 50-300 μ; the erase current strengths are 10-150 mA.

17.1.4.3 The play head operates in reverse manner from the recording head, i.e., the magnetic field of the tape recording enters the core across the gap, the magnetic flux induces a voltage in the head coil which is then passed on to the amplifier for further processing. In pure audio recording machines the play head gap widths range from 1-10 μ, according to tape speed and transmission range. If the wavelength to be reproduced is equal to the effective gap width (which is about 20% greater than the geometric gap width) then no magnetic flux is formed, as the same magnetic potential lies on both halves of the core. As a result no voltage is induced (the zero point of the so-called gap function or extinction frequency). Therefore, the gap must always be smaller than the shortest wavelength to be reproduced, expediently not more than half the size (see Figure 17.4).

17.1.4.4 Sometimes dual-purpose heads are manufactured (e.g., record/play heads) to permit machines to be produced economically.

The core material of the head must be low-loss and the surface wear-resistant to make economical amplifier design possible and to obtain long usage. The frequency response of the head and transmission factor are altered by wear of the head.

Heads must be aligned in the machine for height and azimuth, even slight misalignment leads to serious loss of quality (phase-and-amplitude frequency response alterations).

When more than one track is to be recorded on a single tape, the height of the head-stack is determined by the intended track widths and the width of the tape (see Figure 17.5).

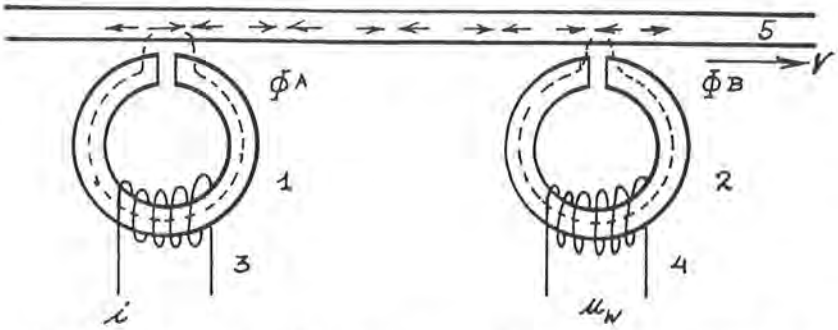
Similar standards exist for cassette machines.

Heads must be constructed so as to make full contact with the tracks, while at the same time leaving neighbouring tracks undisturbed; i.e., crosstalk must be negligible. The core dimensions often differ according to the function of the head.

17.1.5 Amplifiers

Depending on their individual functions a distinction is

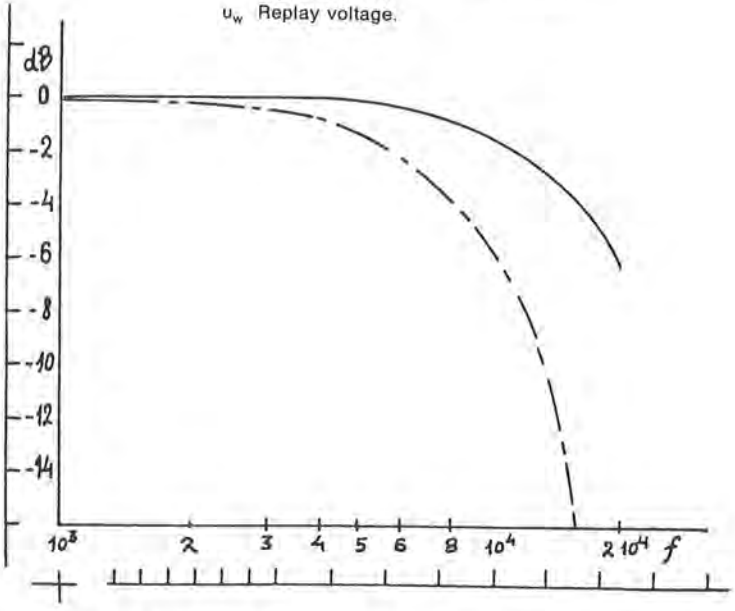
Figures 17-3 and 4



Simplified representation of the relationships at the recording and replay heads respectively.

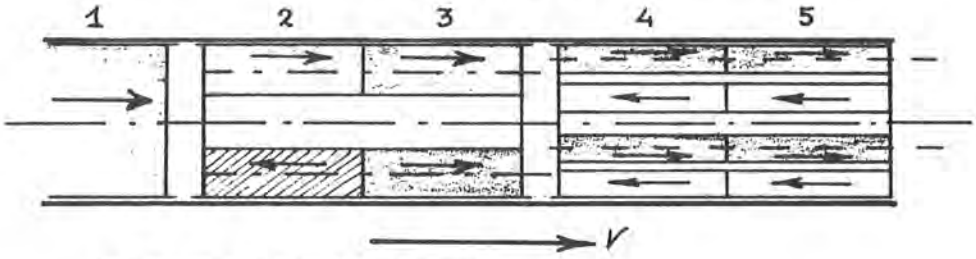
1. Recording head core.
2. Replay head core.
3. Recording head coil.
4. Replay head coil.
5. Magnetic tape.

V Tape speed.
ΦA Flux created in the recording head by i.
ΦB Magnetic flux scanned by the tape.
i Signal current.
u_w Replay voltage.



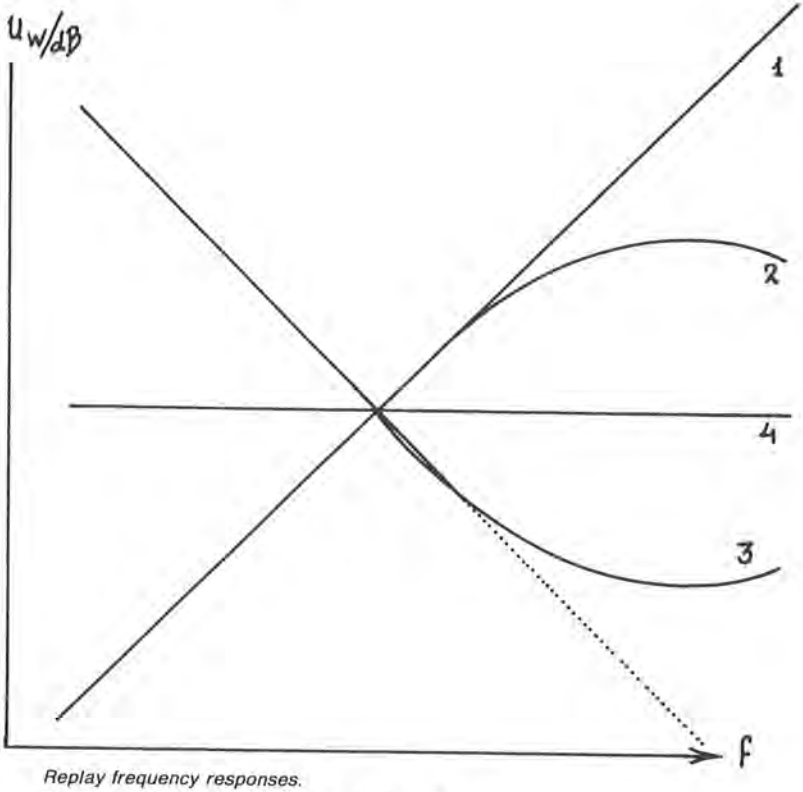
Losses of playback voltage as a result of the gap function and additional losses resulting from gap skew.

Figures 17-5 and 6



Track placement with reel-to-reel machines.

1. Full track.
2. 1/2 track monophonic.
3. 1/2 track stereophonic.
4. 1/4 track monophonic.
5. 1/4 track stereophonic.



Replay frequency responses.

1. So-called w-response of the replay head.
2. Replay head voltage taking into account losses present.
3. Mirror image amplifier frequency response.
4. Resulting frequency response.

made between recording amplifiers, play amplifiers, erase and bias generator.

17.1.5.1 The recording amplifier must produce from the input signal a current which is applied to the recording head. To achieve the standard magnetization characteristic a special modification of the frequency response is required (pre-equalization) to compensate for head and tape related losses; for the higher frequencies an increase in the head current is nearly always necessary. The adaption to the recording head must result in such a way that, if possible, the frequency dependence of the head resistance brings about no further frequency response problems: current matching is sought.

Moreover, the recording amplifier must not form, on the output side, a shunt for the bias current which is fed into the recording head parallel to the signal current. Accordingly the amplifier incorporates a high-frequency block in the form of a stopper circuit or low-pass filter, known as bias trap.

17.1.5.2 The erase and bias generator produces the high frequency erase or bias current. The high frequency (50-240 kHz) is necessary to avoid affecting the wanted signal, and to obtain sufficient demagnetization during erasure. The erase current is usually considerably greater than the bias current, because amongst other things a field must be created in front of the erase head. It must be greater than that produced by the recording, otherwise the erasure will be insufficient.

17.1.5.3 Push-pull amplifiers are often used to produce the best results with low distortion. Erase and bias currents should be separately adjustable. The erase head is frequently driven in a resonance circuit to achieve economy of performance. The symmetry of the bias wave form is important as this serves to eliminate steady field components which might cause noise.

17.1.5.4 The play amplifier is required to correct and to amplify the play head voltage. As this is an induced voltage, it rises with the frequency (so-called W response; see Figure 17.6, curve 1). Because of the standardized tape flux characteristic and unavoidable gap loss, eddy-current loss etc., a flux characteristic as represented by Curve 2 in Figure 17.6 is obtained in practice. The play amplifier must now possess a reverse frequency dependence of amplification to equalize the head voltage (see Figure 17.6, curve 3) and then a linear frequency response characteristic in the transmission range is obtained (see Figure 17.6, curve 4). As the voltage from the head is very small, amplifiers with extremely low hum and noise are required.

A worse unweighted signal-to-noise ratio occurs in machines with lower tape speeds because of higher gap losses, unfavourable correction conditions etc. This becomes yet more critical with split tracks and the poorer controllability of these tapes stemming from the use of a

thinner base. Compression and expansion processes, in which low levels on the recording side (quiet signal passages) are specially amplified, are used to correct this signal-to-noise ratio, often called dynamic range. During play, the amplification is decreased in proportion to the previous increase, and thereby interference noise is decreased as well (this is called 'companding'). There is a variety of suitable processes; signal-to-noise ratio improvements of up to 30 dB are claimed. In general the different processes are not compatible with each other and incorrect use can lead to a deterioration in other parameters (e.g., frequency response characteristic).

17.1.6 Machine accessories and necessary measuring devices

Machine accessories are mostly subject to specialized (professional) technologies or to particular fashionable viewpoints. They are of less fundamental importance and will not therefore be described here.

Certain measuring devices not normally used in conventional electro-acoustic measuring technique are required, however, if magnetic tape machines are to be maintained ready for use:

17.1.6.1 Reference tapes

For each tape speed there are reference tapes, generally laid down in national or multi-national standards, containing mostly the following recordings:

17.1.6.1.a Reference level recording

The amplification of the play channel is adjusted during play of the reference level.

17.1.6.1.b Gap adjustment section

It is important to record with the correct azimuth. The recording meant for gap adjustment is used to set the azimuth of the play head gap. Adjustment criteria include maximum output voltage or phase minimum of two stereo channels.

17.1.6.1.c Frequency response section

Recording of control frequencies corresponding to the standardized magnetization pattern. During replay of the frequency response section, the replay channel is set to the minimum possible deviation of frequency response from the reference frequency (e.g., 1000 Hz).

17.1.6.2 Speed control tapes

These tapes contain a recording of a known frequency at a precisely defined tape speed. By measuring the play frequency the actual speed of the play machine can be determined.

17.1.6.3 Stroboscope

A roller with stroboscopic divisions which can be mounted on the machine permits tape speed to be determined even without a speed control tape.

17.1.6.4 Tape tension measurer

With the aid of a tape tension measurer, tape tensions can be measured during normal operation and fast wind. Such measurements are important if one wishes to determine whether a machine is suitable, e.g., for triple tapes, old cellulose acetate or paper tapes.

17.1.6.5 Tape viewer

A tape viewer contains a suspension which can be magnetized, enclosed over a thin foil which, when placed against a magnetic tape (foil side to the tape emulsion), produces an image of the recording, so that track placements or track errors etc. can be recognised.

17.1.6.6 Cleaning of heads and components

It is not proper to use cleaning solvents which frequently attack not only particular metallic parts but plastic ones as well. Alcohol is normally safe to use. No cotton wool or woollen material generally may be used for cleaning purposes, as textile debris may penetrate to the bearings and adversely affect the running of the machine. Some companies offer special cleaning materials.

17.1.6.7 Demagnetizing coil and balancing tape

Studio machines, with their high interference voltage range, are especially sensitive to interfering magnetic fields, particularly if the heads themselves are magnetized by some influence or other. Disturbance effects are then produced as hiss, crackling in electronic editing etc.. One remedy is to demagnetize the heads with the aid of industrial demagnetization coils. The effectiveness of the demagnetization can be tested with the aid of a balancing tape. This tape contains bars of a special magnetic coating. If these bars are magnetized as they move past the head, they act like a series of rectangular impulses and induce an interference voltage which is distinctly audible and measurable. With the aid of this balancing tape the erase and bias currents can be so "balanced" that their constant magnetic field proportion is kept to a minimum and the interference voltage optimized.

17.1.7 Points to be considered when choosing suitable machines

The choice of machines depends primarily on what material a particular archive intends to store. Mostly it will be professional material which meets archival requirements in respect of quality and type. Archives should each establish guidelines for the acquisition of amateur material.

Documentation for such material should include tape speed, tape width and format, the number of tracks (track width), the tape material (standard play, long play, double play, triple play, cassettes, cellulose acetate, PVC, and polyester tape), limitation to particular companding processes, packaging (spool types, core types (NAB or European winding core), accompanying documentation, labelling etc.).

These guidelines can serve at the same time as the main criteria for the acquisition of suitable equipment. Magnetic sound equipment should in addition meet the following requirements:

a) It should consist of professional or semiprofessional machines.

b) Record and play channels should be separate, mostly recognizable by separate recording and play heads.

c) Record and play channels must be easy to align, i.e., the adjustment elements must be readily accessible.

d) The magnetic heads must be of long durability to ensure long-term stability of the equipment.

e) The play heads must be adjustable. The frequent practice nowadays of building machines with fixed heads makes them unsuitable for use in archives, as older recordings were often made with different angle positions.

f) It is expedient to have machines with interchangeable equalizations (e.g., the difference between European and American (NAB) standard).

g) The speed of the machine should be adjustable within defined limits (e.g., + 10% of the standard speed) in order to adapt to speed variations in older recordings.

h) The magnetic tape tension must be controlled. It is expedient to have machines which allow adjustment of the tape tension within defined limits.

i) All machines should have the same input and output voltage signal together with accurate metering so that they can be easily monitored, both in recording and play as well as in forward and reverse spooling.

j) The magnetic tape equipment is complemented by a standard monitoring assembly, as well as level and phase indicators and filters to modulate the frequency response in the restoration of older recordings. The use of built-in listening facilities for quality assessment is not to be recommended, as each loudspeaker or listening assembly has its own acoustic characteristics which may seriously impair evaluation.

17.2 Machines for recording visual signals

17.2.1 General principles

The recording of visual signals, more commonly known as video tape recording, differs from audio signal recording in the frequency range which has to be recorded and in the special processes which this involves, which are based on the same principles as those of audio signal storage.

The frequency range which has to be recorded include 0-6 MHz. Values of 0 Hz, i.e., DC values, cannot be recorded directly but require modulation processes, of which frequency modulation is generally used. The upper limit of 6 MHz presents difficulties also, as the longitudinal recording method usual in the audio signal field would require very great tape speeds, and hence tape lengths, to receive those wavelengths which were still recordable. To achieve the necessary high relative speed between the tape and the head without at the same time having to raise the transport speed of the tape accordingly, techniques involving rotating heads were developed, namely methods using longitudinally rotating heads (i.e., magnetization in the direction of the tape length), methods using helical scan (i.e., magnetization diagonal to the tape), and methods using transversely rotating heads (i.e., magnetization across the width of the tape on an axis parallel to the direction in which the tape travels; see Figure 17.7).

17.2.2 Transverse rotation (quadruplex) method

The oldest system is that of transverse scan using four magnetic heads. These four video heads are mounted on a drum which rotates at right angles to the direction in which the tape travels, i.e., the magnetic tracks so produced run nearly vertically from the top edge of the tape to the bottom edge. The tape speed is 38.1 cm/sec (15 ips), the relative head speed about 41 metres/sec (135 feet/sec), which permits an upper frequency limit of about 15 MHz to be achieved, leaving adequate room for storing the carrier frequency of the FM recording. Depending on where the carrier frequency lies, a distinction is made between high-band or low-band systems; professional machines for colour recording use the high-band standard.

For transverse scan recordings, each magnetic track has a time range of 16 television lines, which must be recomposed during reproduction. The tape-to-head contact must be exceptionally good and the tape as free of errors (drop-outs) as possible. Two-inch wide tape is used.

Errors in synchronization or of tape-to-head contact lead to obvious visual defects. To keep such errors to a minimum, a range of control and compensation methods are used. Nevertheless, considerable demands are placed on the precision of the individual elements. Permissible errors of timing lie in the range of nanoseconds. So as to keep to the timing requirements a separate edge control track is used, on which are recorded signals which during

reproduction are required to control the speed of the tape and the rotation of the head drum.

Also recorded longitudinally on the edge of the tape are two signal tracks, of which one serves to record the normal sound accompanying the picture, while the second is for recording an auxiliary signal, for cueing, editing purposes, additional commentary etc. Because of its narrower width, this track is not equivalent in quality to the first sound track. In the video recording machine one must therefore distinguish between the video signal path, the audio signal path and the control system as the essential group of functions.

Track placement, speed and other parameters are to a large extent internationally standardized, though regionally determined differences of standard (e.g., 50/60 Hz operation) have to be allowed for. The number of manufacturers is limited. When acquiring suitable equipment it is useful to base one's choice on which machines the archival material was originally recorded on. Only two manufacturers made 2-inch video tape machines and both have discontinued production.

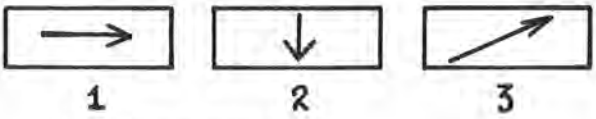
17.2.3 Helical scan method

In machines using the helical scan system, the tracks recorded on the tape lie at an angle of 3-6° to the axis of the length of the tape. The tape runs in the form of a helix around a highly polished two-part drum. Between the upper and lower parts of the drum is located a head which, depending on the system, one or two head sets are mounted (video erase head and video record/play head). There are two principal configurations for the angle of wrap of the head, the 360° wrap (alpha wrap) and the 180° wrap (omega wrap; see Figure 17.8).

With 360° wrap only one head set is needed which leaves a short information gap at the point where the head switches from the bottom edge of the tape to the top edge. With 180° wrap, two head sets are required. The tape speeds of helical scan machines range between 10 and 30 cm/sec, and the relative head-to-tape speeds between 16 and 25 m/sec. As in the transverse scan method, a control track is required to keep head and tape speed within the necessary tolerances. Helical scan machines come in widely differing variants, so the collection of archival material from each format is not advisable, as a particular machine would have to be acquired for each system.

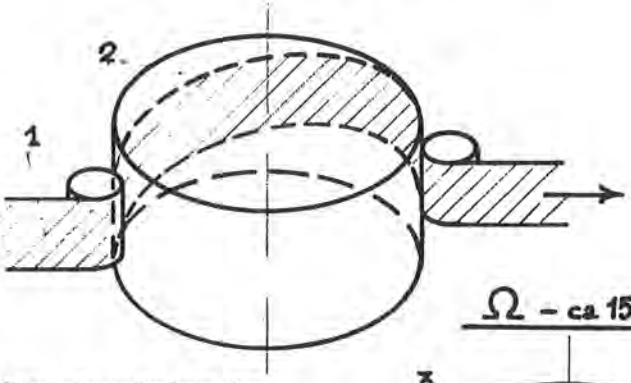
17.2.3.1 More advantageous features are offered by the video cassette recording (VCR) system, which is based upon agreement on standards by several firms. This gives a certain compatibility resulting from the uniform track format (see Figure 17.9). The VCR system uses the helical scan method and a two-head arrangement; the width of the tape is 12.7 mm (1/2 inch). A relative head-to-tape speed of 8.1 m/sec is obtained at a tape speed of 14.29 cm/sec. The video tracks are 130 µ in width and 57 µ apart. Along

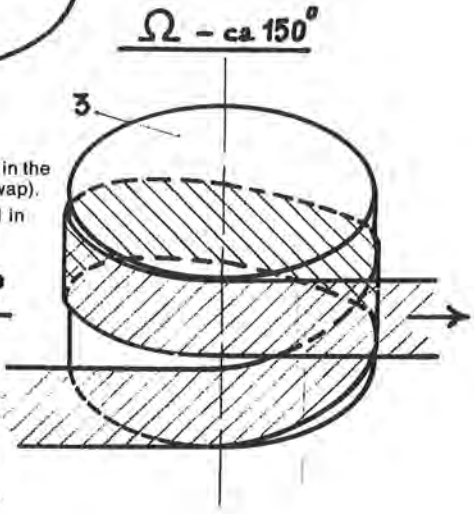
Figures 17-7/8/9



Magnetization directions.

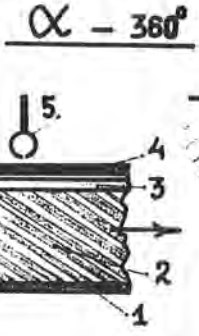
1. Longitudinal magnetization.
2. Transverse magnetization.
3. Oblique magnetization (Helical Scan).





Tape paths on the head drum.

1. Tape.
2. Head drum with two rotating heads in the middle of the drum 180° apart (Omega wap).
3. Head drum with one rotating head in the middle of the drum (Alpha wrap).



Track placement in the VCR system.

1. Sound track 1.
2. Video tracks.
3. Synchronizing track.
4. Sound track 2.
5. Sound head system.

the tape edges run two tracks 0.7 mm in width, the sound track lies next to a control track which is 0.3 mm wide. The sound recording follows after the actual video recording, the tape running past an appropriate head assembly. The VHS and Beta formats all cannot achieve broadcast standards of quality.

17.2.3.2 However, as a genuine alternative to transverse scan recording with 2-inch tape, several firms in the meantime developed 1-inch helical scan machines which have great compatibility within the system and the best possible technical data at justifiable operating costs.

The 1-inch recorders offer considerable technological options, such as slow motion, freeze-frame, time code recording etc. These machines have replaced the 4-head transverse scan recorders.

17.2.3.3 It is common practice to make use of companding to improve the sound signal in professional video recorders, except in the NTSC format. This is particularly necessary as the magnetic coating is orientated to favour the transverse video signal, placing limitations on longitudinal sound recording, or because the track widths available for sound signal recording are very narrow (e.g., 0.8 mm).

17.2.4 Points to be considered when choosing suitable machines

Even more than in the case of pure sound recording, archives must draw up definite criteria for the acquisition of material. Recordings originating from domestic machines should in general not be accepted, unless the material is of great value and unavailable in other formats. Therefore, one must go back to professional recordings with national variations of standard (OIRT, EBU, SMPTE) in mind.

Chapter 18

FILM STORAGE PROCEDURES

By Herbert Volkmann, Former Director
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Harold Brown, Former Head of the Technical Department
of the National Film Archive, London

18 Introduction

Cinematographic film and magnetic tape recordings are fundamentally different in their physical characteristics; neither the recording methods nor the equipment or the process compare with each other. The human eye can only distinguish mechanical damage in magnetic tapes; the quality of the recording can be judged by monitor replay only. As the preservation of magnetic recording has already been dealt with in Section 11.2, this chapter will discuss the treatment of cinematographic film prior to storage.

18.1 Preparation for storage

When it first arrives in the archive, every film must be inspected carefully before it is put into storage, in order to ascertain its condition.

18.1.1 First inspection

The first inspection is made on the winding table. The title on the can or on the delivery note is compared with the title on the leader. Then the film is slowly rewound and carefully inspected in order to determine whether any signs of disintegration are already visible, whether it has suffered any mechanical damage (scratches or tearing of the perforations), whether the joins are intact, and whether any chemicals are present in the emulsion. At the same time, the length of the film is measured.

In order to permit a thorough inspection, the winding through of the film should not be too fast (no faster than 600 m (2000 feet) per hour) to allow for adequate inspection and small repairs, for example, the securing of joins. This first inspection at the winding table is necessary to ascertain, in general terms, any damage to the film and particularly to the perforations, so as to determine what subsequent treatment may be necessary. At the same time, the shrinkage is measured by means of a shrinkage gauge (see 16.4.1.2).

18.1.2 Cleaning the film

If the film has not come straight from a laboratory, the next step is to have it chemically cleaned. If the condition of the perforations and the degree of shrinkage permit, the film can be cleaned mechanically. See 16.3.1 regarding chemicals and apparatus.

18.1.2.1 Cleaning by hand

If an archive has no cleaning machine, any necessary cleaning must be done by hand at a winding table using a pad of cotton velvet soaked in 1,1,1-trichloroethane. If the film is not wound slowly, it is possible to generate a static electric charge on the film which then attracts dust. It is therefore advocated, that after cleaning the film is passed through an antistatic cloth.

18.1.3 Distinguishing nitrate and acetate base

It is necessary to ascertain whether the film under examination is on nitrate or acetate base. This distinction, which has to be made in order to store the two types separately, must be determined in a way which leaves no room for any doubt as to the result.

18.1.3.1 Edge marks

One way to identify the film base is by edge marks. But the more often a film is duplicated or copied, the more difficult it becomes to identify the original edge marks because the edge marks of all the intermediate versions find their way cumulatively on to the final one. It is therefore advisable to rely upon edge marks only where no doubt can arise, and in all other cases to resort to one of the following tests.

18.1.3.2 Burning test

A burning test, other than one done on certain precisely prescribed apparatus, is unreliable and is also unsafe in nearly all locations. It is therefore not recommended.

18.1.3.3 Floating test

This test depends on the fact that the specific gravities of nitrate film and acetate film are different. When a piece of nitrate film is put into a container filled with trichloroethylene, it will sink. If the same is done with a piece of acetate film, it will float, because the specific gravity of trichloroethylene lies between that of nitrate film and that of acetate film. For this test, only very small pieces of film are required, punchings with a diameter of 1/2 cm, so that no significant damage to the film need be caused. It is essential to be aware that the whole of a reel is not necessarily on the same kind of base. For instance it is quite possible for a mainly acetate reel to have nitrate leaders, or for a mainly nitrate reel to have acetate leaders.

Trichloroethylene is toxic, and should only be used with great care. If a large number of films are to be tested, this work should be done in a separate room with adequate ventilation. If it is done only occasionally, it can be carried out in the examination room. A small quantity of trichloroethylene can be kept on the work table in a bottle with a ground glass stopper.

18.1.3.4 Methanol test

Nitrate film dissolves when it comes into contact with methanol, while acetate film is not affected. The result is immediately perceptible.

Methanol is poisonous, but the test can be carried out in the examination room. The liquid can be kept in small tightly-stoppered drop bottles.

18.1.3.5 Fluorescence test

A very simple and sure way of determining some Kodak acetate-based film is provided by the fluorescence test. Kodak has applied to some of its acetate films a very small amount of fluorescent chemical, which glows under an ultraviolet lamp. If a mixed reel of nitrate and this acetate film is viewed on edge under a suitable ultraviolet lamp in a partially darkened room, a vivid fluorescence is visible in the acetate parts of the reel, while the nitrate parts remain black.

18.1.3.6 Conclusion

In conclusion, both the chemical tests and the floating test are easy to apply and give reliable results. It is desirable to be equipped for two different methods of testing, since it is always possible that the first test may yield an indeterminate result.

18.1.4 The film stability test

When it has been ascertained that the film is on nitrate base, it is strongly recommended that it be subjected to a film stability test. During storage, film on nitrate base will deteriorate producing acidic substances which attack the gelatin emulsion. This deterioration, which is not only related to the age of the film, will eventually cause fading of the silver image and stickiness of the emulsion. In this condition the film cannot be duplicated and it is entirely lost.

In order to anticipate the onset of this condition at a stage while the film is still in good physical and optical condition and capable of duplication, a simple laboratory test has been devised. This is known as the Alizarin Red stability test.

18.1.4.1 Basis of the Alizarin Red stability test

A small punching of film of approximately 6 mm diameter and

weighing approximately 7 mg is placed at the bottom of a small glass tube fitted with a stopper around which is wrapped a test paper impregnated with Alizarin Red dye and moistened with glycerol and water. The tube is heated to a temperature of 134 C until the presence of acid vapour is detected by a change of colour of the lower edge of the paper. The colour of the indicator paper will change from pink to white or pale yellow. The result of the test is taken as the time in minutes required for the colour change to occur to about 3 mm of the bottom edge of the paper.

18.1.4.2 Description of apparatus

18.1.4.2.a Glass tube and stopper

The glass tube is closed at one end and is approximately 12 cm in length and 7.5 mm in internal diameter; it has a 2.0 mm thick wall. The stopper is approximately 4.0 cm in length and is of such a diameter (6.85-6.9 mm) that when covered with one thickness of test paper it makes a close sliding fit in the tube.

18.1.4.2.b Heating block

The tubes are placed in an electric, thermostat-controlled heating block; each tube being held in a hole in the block. The tubes need to be as close a fit as practicable; the depth of the holes to be such that the whole of the filter paper (see below) is visible above the surface of the block. (The NFA of England uses a Grant BT-3 block thermostat)

As the tests are normally carried out in the film storage building, any method of heating using an open flame, such as gas, cannot be used owing to the fire hazard.

18.1.4.2.c Test paper

A good quality filter paper is essential, since the presence of impurities makes it difficult for the observer to note the colour change accurately. (The NFA of England uses medium white filter paper made by Carlson Ford)

18.1.4.3 Preparation of test paper

One hundred milligrams (mg) of Alizarin Red powder are added to 2 millilitres (ml) of twice-normal ammonia, and after dissolving this is made up to 100 ml with distilled water. The solution is poured into a rectangular (ca. 25 x 30 cm) enamelled dish.

The paper is cut into sheets approximately 23 x 28 cm. Each sheet is then held by two corners and drawn through the solution leaving a strip about 1 cm wide along one of the short sides which is left dry for the purpose of handling. The sheets are then clipped onto a rack and left to dry overnight. An oven can be used to expedite drying. The object of thorough drying the sheets is to ensure the evaporation of all ammonia. After they are dry the sheets are then cut into pieces 22 x 38 mm.

When testing it is advisable to use freshly impregnated sheets, since if kept for a month or two the colour has a tendency to fade, thereby making the visual test more difficult to observe.

18.1.4.4 Testing method

Two small discs are punched out of the reel to be tested, one from either the beginning or end, and one from near the middle of the reel. Precautions to be taken when this is done are mentioned at 18.1.4.6. Each punching is placed in a separate test tube. A piece of test paper 22 x 38 mm is then carefully wrapped round the stopper in such a way that, when inserted into the tube, a snug fit is ensured. Trimming with scissors may be necessary. The paper is moistened with a mixture of 50% glycerol and 50% distilled water before being wrapped round the stopper.

After the test is complete the test papers and punchings are thrown away and each tube is thoroughly cleansed with a tightly fitting bottle brush. They are then rinsed and may be dried in the block heater. The stoppers are rinsed and left in the rack to dry.

18.1.4.5 The result of the test

The following action is taken on the result of the tests.

Reaction time	Action
Under 35 minutes: Unstable	Duplicate immediately
Between 35 - 60 minutes	Retest in 2 years
Over 60 minutes	Retest in 5 years

The re-test periods quoted above are based upon the experience of the National Film Archive of England, who has used this test for nearly 40 years. The lengths of the periods are based on the temperature of 13° C, at which their films are stored.

Archives who store their nitrate films at 7° C or lower will also be quite safe in working to these re-test period. However, they should investigate how much these test intervals could be prolonged.

Archives who store their films at higher temperatures or humidities, or whose storage conditions vary greatly will not necessarily be safe with these re-test periods and should retest at shorter intervals; at least until they have gained their own experience.

When readings of the two punchings do not closely agree, action should be taken according to the lower of the two readings.

18.1.4.6 Notes

18.1.4.6.a Method of sampling

When re-tests are made it is preferable to take the punchings from the same frames as those in the previous test. In order to find these positions rapidly they should be marked by small pieces of paper wound round the film. Care should be taken that each punching is obtained with minimal impairment of the intrinsic quality of the film. Suitable places are titles and the blank ends of fades, provided they are printed on the same raw stock as the rest of the reel. On no account must the punchings be taken at a splice, as an incorrect result will be obtained. In a multi-reel film, normally only the first reel is tested, since it is usual that all the reels have the same physical characteristics and have received the same treatment. This is not strictly accurate but unavoidable when many reels have to be tested. If in doubt, tests should be taken from more than one reel.

18.1.4.6.b Rack stand for test tubes

When a number of films are being tested it is preferable to use a rack stand holding the test tubes in pairs, with their respective stoppers. Each test tube is given a number which corresponds to a number on the heater and which is also noted down against the appropriate title on the list of films to be tested. As the punchings are very small it is essential to be methodical throughout the test, since it is very easy to mix the punchings. For this reason it is strongly recommended to place the punchings immediately into the test tube.

18.1.5 Tests for determining residual thiosulphate in developed films

Residual chemicals in the gelatin layer after processing should be removed (see 4.9.8, 5.2.3, and 5.2.4). We describe here three technologies for determining the presence of these residues, but they are complicated and very time-consuming.

18.1.5.1 Determining the presence of residual hypo by the SID process

30 cm^2 of exposed film, without sound track and perforations, is treated for 10 minutes at 25° C in a solution consisting of 10 ml 0.001 N-silver nitrate, 3 drops of glacial acetic acid and 40 ml of water. Potentiometric titration is carried out immediately after with 0.001 N-potassium iodide. From the consumption of 0.001 N-silver nitrate the quantity of thiosulphate is determined in µg thiosulphate per cm by taking into account the area of film used. A similarly prepared solution is titrated without the film as a blank test.

1 ml 0.001 N-$AgNO_3$ = 79.11 µg $Na_2S_2O_3$ = 56.2 µg $S_2O_3^{2-}$

18.1.5.2 Colorimetric determination of residual hypo

Elution solution:
20 g KBr + 1 g KH_2PO_4 dissolved to 1 litre.

Reduction solution:
3 g KBH_4 are dissolved in 100 ml 0.2 N-NaOH. In cold storage the solution is stable for at least a week.

$Fe_2(SO_4)_3$-reagent:
To 89 ml water are added 15 ml of concentrated H_2SO_4, and 3 g $Fe_2(SO_4)_3 \times H_2O$.

TSS-solution:
To 89 ml of water are added 15 ml of concentrated H_2SO_4 and 1 g N,N-diethyl-p-phenylenediamine. Should the solution be coloured, 5 g of activated carbon are added and, after shaking, filtered off. The solution should then be colourless.

0.1 N-thiosulphate solution

4% solution of $K_2Cr_2O_7$

To draw up the calibration curve, 25 ml 0.1 N-thiosulphate solution is made up to 500 ml in a graduated vessel and 5 ml of this solution made up to 250 ml in a graduated vessel. This solution contains 11.2 $\mu g\ S_2O_3^{2-}$/ml. 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 and 2.0 ml of the standard thiosulphate solution are advanced from a 10 ml burette and mixed with appropriate quantities of the elution solution from a 25 ml burette so that the total solution always amounts to 5 ml.

This solution is mixed in the test tube with 5 drops of boron hydride solution from the pipette. Then, as quickly as possible, a drop of the potassium dichromate solution, 10 drops of acetone, 5 drops of iron sulphate reagent and 10 drops of TSS solution are added; the test tube is tightly sealed with a plug, which should be on hand, and shaken for 30 seconds. The plug is removed briefly, and then the tube is plugged again and left standing for 15 minutes. In the spectral colorimeter the absorption of the developed dye at 670 nanometres (nm) is measured against an empty vessel. In setting up the calibration curve, the extinction is plotted over the number $\mu g\ S_2O_3^{2-}/cm^2$. (Example: 0.4 ml of standard thiosulphate solution are made up to 5 ml of test solution. It contains 0.4 x 11.2 = 4.48 $\mu g\ S_2O_3$. In the test 5 ml of solution are used, with which 10 cm^2 of film are elutriated. The measured extinction is therefore equal to 0.45 μg thiosulphate ion per cm^2 of film).

To determine the residual hypo content in the film, 10 cm of film (without perforations and sound track) are folded into a W-shape and fully immersed in a glass containing 5 ml of the elution solution. The film is left in the solution, which is shaken occasionally, for ten minutes. It is then removed and the test solution treated in the manner described above.

18.1.5.3 CD-process (chemical densitometric index)

The specimen to be examined, which if possible should have uniform density, is divided into two halves, one of which is immersed in an acidified silver nitrate solution (solution A). Any residual thiosulphate in the emulsion is transformed by the diffusing silver ions into insoluble dark silver sulphide. Following this the specimen is washed in a chloride solution (solution B), which changes surplus silver nitrate into insoluble silver chloride, which is removed by a fixing bath (solution C).

After washing and drying, the difference in density between the treated and untreated specimens is measured densitometrically. The difference is referred to as the CD index and serves as a measure of the residual hypo content.

The density differences are measured precisely to a hundredth part. However, where the residual hypo contents are negligible, such density differences are scarcely measurable and even more difficult to reproduce.

Solution A: 750 ml Water, 30 ml glacial acetic acid, 10 g silver nitrate; made up with water to 1000 ml.

Solution B: 750 ml Water, 5 g sodium chloride, 40 ml 25% ammonia; made up with water to 1000 ml.

Solution C: 750 ml Water, 15 g sodium sulphite (anhydrous), 45 g sodium thiosulphate; made up with water to 1000 ml.

18.1.6 Test notes and records

Careful notes must be made of all the tests to which a film has been subjected. The results of such tests, together with the date of entry and a record of any damage and imperfection, must be noted in the technical card index. The card index must be kept up to date with the results of any re-tests. The test notes should go to the archivist or his chief technician, so that he can decide if the film is to be treated (see Chapter 8), if it is to be immediately duplicated, or if it can go into storage.

18.1.7 Storage of film

Films destined for permanent preservation should be put into dry, clean, undamaged cans. The technical cards should not be put into the cans, but should be kept separately.

When there is a considerable difference between the temperatures of the workrooms and of the store (as will always be the case with storage under optimum conditions; see 15.2.2), the films will have to be left open in a cool room, free of dust, for several hours, to allow them to come into equilibrium with the storage conditions before being stored permanently.

18.2 How films should be stored

18.2.1 The film reel

For permanent storage, almost all archives keep their films in metal cans each of a capacity of 300 or 600 m (1000 or 2000 feet). It is absolutely essential to wind the films on to cores, and almost everywhere the usual commercial cores, made of plastic or stainless steel with a diameter of 5 cm (2 inches), are used.

18.2.2 Cans

For permanent storage, the film should be wound with the emulsion side outwards. Projection copies are purposely stored with the emulsion inwards.

To prevent the film being damaged by the formation of rust, and to avoid the periodic renewal of cans which this would involve, containers made of a non-corrosive material, such as stainless steel or plastic, are to be preferred. Compared with metal cans, cans made of plastic would have the following advantages:

a. they would be absolutely stainless;
b. they would be resistant to acids;
c. they could be manufactured in large quantities, without increased cost, in the most suitable form (for example, both with ventilation and with airtight seals, as necessary).
(Concerning storage of nitrate films in plastic cans, see 16.6.2).

Archives which have to use tin-plated iron cans should inspect them very carefully for rust, and at the least sign of this they must be changed immediately. Rust can make a film completely useless within a short time. Even to pack the films first in paper does not protect them since rust also affects paper.

It is not advisable to store film in cardboard cartons, particularly in a store without air conditioning, since the cardboard absorbs moisture and this endangers the film.

The cans used for permanent storage must be cleaned and dried. Archives use benzine for this purpose and have found that when tin cans are used in air-conditioned vaults no damage by rust has occurred over a period of ten years.

18.2.2.1 Cans for nitrate film

After all that has been said about the properties of nitrate film (see 1.2), it goes without saying that such film should never be stored in airtight cans. The cans should never be sealed with adhesive tape, and the ventilation must in no way be obstructed. It must always be possible for the nitrate gases, which are formed in the process of disintegration, to escape and be carried away by ventilation; otherwise the disintegration will be greatly accelerated (see 1.2.2).

18.2.2.2 Cans for acetate film

Airtight storage may be achieved by sealing the cans with adhesive tape, or by first placing the reels of film in plastic bags. Once more it should be stressed that a film can only be stored in an airtight condition when it is packed and kept at a steady temperature (see 1.3.2).

18.2.3 Camphor and oils

In the past it has been a frequent practice to put camphor in the cans of films being permanently stored, in order to preserve the flexibility of the film. Indeed, in several archives this is still done. The use of camphor dates back many decades, when copies were sometimes projected up to ten times a day. After two or three days, the film became very dry under the often repeated heat of the projector, so camphor was put in the can overnight, that is to say for a comparatively brief period, in order to restore the flexibility of the film. This was usually repeated after fifty projections.

So far it has not been established that there is any advantage in using camphor in permanent storage. However, the use of camphor is not to be advised. The same applies to the practice of depositing in the cans pieces of paper impregnated with liquids such as glycerol and eucalyptus oil. As long as there is no scientific proof of the beneficial effect of such measures, it is advisable not to use them.

18.2.4 Packing in paper

Many archives wrap their films in paper before storage as a protection against dust and rust. It is not a practice to be encouraged. Porous paper, particularly tissue paper, which presents little obstacle to ventilation, is apt to wear away very easily and in doing so to be itself a producer of dust instead of protecting the film against it. Although smooth paper (e.g. waxed paper) is much more durable, it impedes the ventilation. Only acetate films can be treated in this way. Here the same conditions apply as for packing in plastic bags (see 1.3.5.4). Paper does not give any protection against rust, because it is itself attacked by rust, which then penetrates to the film.

18.2.5 Horizontal storage on shelves

In permanent storage, the film reels must never be stored vertically, but always horizontally. If they are stored vertically, the whole weight of the reel rests upon the lower part of the film. If the film is approaching a stage when it is likely to become sticky, the layers in the lower part are pressed together so heavily that irreparable damage may result.

18.2.6 Complexity of the storage problem

It must be realized that the storage of film is a complex matter in which various factors have both beneficial and

adverse effects. It is impossible, for example, to separate the question of the airtight storage of acetate film from that of the air conditioning of the store, or the question of the preservation of nitrate film from that of ventilation. To achieve the best results in film preservation, all these factors have to be considered very carefully in relation to the existing climatic, technical and economic circumstances.

18.3 Surveillance of films during permanent storage

18.3.1 Films which are being stored permanently must be periodically inspected. In general, it may be said that this examination should take place every one or two years, but in the larger archives this is hardly possible. Consequently, a distinction must be made according to the age and condition of the films, which can be ascertained from the record cards.

Films for permanent storage must be examined in shorter or longer intervals (the longest interval reported is ten years). Such long periods are only permissible for new films being kept under very good storage conditions; with old negatives or positives they are dangerous. The interval for re-examining nitrate film is determined by the results of the film stability test (see 18.1.4), for acetate film by the results of examining the density with a densitometer.

18.3.2 Rewinding

The examination of a reel of film consists of rewinding the film on the winding table, and at the same time, during the first examination, cleaning it from dirt and dust. It is immaterial whether the film is wound by hand or electrically, but it is important that the winding is done sufficiently slowly to enable an adequate examination to be made (about 600 m (2000 feet) an hour; see 16.3.2).

Notes should be made of the results of each check. If no damage requires remedial treatment, the film should be immediately returned to the acclimatized store.

18.3.3 Checking for use

Films intended for permanent preservation should never be used for projection. If a negative is used for copying or a print for viewing, then it is essential that their technical conditions should be checked before and after use. The film stability test is not an automatic part of the examination, since it is applicable only to nitrate film. The films are only cleaned during examination when their condition makes it necessary. The same applies to all other measures.

18.3.4 Special recommendations regarding the storage of colour films are given in Chapters 5 and 6, storage of magnetic recordings is described in Chapter 11.

Chapter 19

STRUCTURE OF A TECHNICAL DEPARTMENT AND QUALIFICATION OF ITS STAFF MEMBERS

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We have tried in the previous chapters to make clear that in an audio-visual archive, a simple collecting activity is not the only concern. One can establish a film archive with enthusiasm (and which film archive has not been set up in this way?) but to build it up, to maintain it, to make a viable cultural entity out of it, to develop it into a modern audio-visual archive - for this, other elements besides enthusiasm are necessary. For this we need organizational abilities and very deep scientific and technical knowledge. For here we are concerned with the development of a new type of archive, geared to the scientific and technical possibilities of our age.

In the past, it did not look like that at all. Somewhere a film enthusiast began collecting and established a circle of film friends. The enthusiast did not use the collection commercially, but borrowed, built and exchanged, and slowly created a film archive.

That was the way in the past. However, today it starts in most cases with much more certainty, often with the support of governmental or municipal authorities. Nevertheless, there exist still today archives in which one person tries to do all the work with just a few members of staff - and this is, of course, not ideal. These archives are the nuclear cells.

However, there are also other, better-organized, film archives with hundreds of staff members which are recognised government cultural institutions or organizations subsidised by the government with a very high budget, and in which extensive organizational, scientific and technical work is being undertaken. Those archives can be seen as the objective for all.

Discussion of the qualifications required of members of staff of an audio-visual archive must be linked to those required for the large archives because these are the ideal to which we are aiming. What we describe below is the situation already in existence - we realize that tall trees do not grow up overnight: nobody starts big. We present a

target, but we know very well that if the financial means to support 100 people do not exist, then the functions must be distributed between fewer staff. We also realise that the number of staff does not only depend on the functions but also on the size of the collection of the archive.

19.1 In general we can arrange archives according to their size in three groups:

a) large modern archives

which have their own air-conditioned storage rooms, their own restoration and printing departments, in which a major part of the research work for the examination and restoration of film is being carried out, and where, to a certain extent, research work of a general nature is also being done;

b) medium-sized archives

which have a storage building of their own as well as a small examination and restoration department. In these archives, the collection, storage, examination and restoration work is carried out only to the extent that it cannot be undertaken by other institutions. For example, the usual printing work is carried out by other organizations on the instructions of the archive;

c) small archives

which have no department for carrying out technical work by themselves, and are compelled to ask other organizations to carry out all technical work for them.

It is up to the heads of the archives to work according to the instructions and suggestions that result from research in the technical field and to put these into effect as well as their finances allow.

Amongst these considerations, particularly, is the creation of common technical facilities in towns where several institutional or private archives exist, in order to utilize such technical facilities more fully and more economically.

We start our discussion with the concept of a large film archive with fully air-conditioned stores, with their own film examination and restoration groups for picture and sound, with their own printing workshops, their own film projection and repair workshops; in short, an archive with a big technical facility.

19.2 Structure of a large technical department

A large archive run by a director or a curator has a number of divisions, such as acquisition, cataloguing, documentation, access, preservation and technical services sections.

In this context, we are only interested in the preservation and technical services division, which is frequently called the main

technological department. This department attends to the preservation of the stock (nowadays mostly film and video tape), that is, the examination, restoration, regeneration and storage of it, with all the technical facility operation that goes with it.

The technical department can be broken down into eleven areas, namely, an overall management complex encompassing the whole technological division of ten departments:

a. Department for the examination of films
b. Restoration department
c. Department of sound technology
d. Printing work department
e. Laboratory control department
f. Film projection department
g. Department of energy resources and plant maintenance
h. Technological department
i. Buildings and construction department
j. Labour relations and safety department.

19.3 Tasks and qualifications

Under these headings let us now look at the tasks of the various special departments and the necessary qualifications for leading members of the staff:

19.3.1 Management

The head of this main department, who is often called Technical Director, Chief Engineer or Technical Head, has above all a co-ordinating role. The Technical Director is the Director's deputy in all technical matters. To this person report managers of the technical departments. The Head determines technological policy and the development prospects of his production base, employs engineers, controls the construction and developmental program, and watches workers' welfare. The Technical Director ensures the correct operation of the technological side of things, and plans plant modernization, making sure the archive receives relevant scientific and technological information. The Head is also responsible for the updating of his colleagues' qualifications.

Such extensive activity can only be carried out by an engineer with a technical university education. The engineer must have wide training and must also have professional experience, because the tasks include chemistry, physics, optics, the mechanics of film processing, machine construction, electrical engineering, air-conditioning techniques, and further tasks which arise from the special technical equipment of the archive.

19.3.2 Department for the examination of films

The head of this department undertakes the examination of all films, video tape and other audio-visual material for accessioning into the archive's collections. This department records the technical state of the material and

also fills out the accompanying technical documentation. It then has permanent control of the technical state of all audio-visual material in the care of the archive, determines checking periods, runs the technical recording department and decides upon further storage, restoration and reprinting. The head of this department also proposes destruction of material as necessary to the archive director. The department is responsible for the distribution of material, for checking it before it is printed, for sound recording and for restoration. Newly printed material is also controlled by this department.

The head of this department must be a chemical engineer. Likewise, the staff responsible under him for entry control and subsequent control of the collection should be chemical engineers. The actual work is carried out by group leaders who should be specialists in their craft or experts in printing work. Under them, there should be trained personnel.

19.3.3 Restoration department

Here the restoration of material will be carried out prior to prolonged storage according to established techniques. Restoration measures will be taken to repair damage. This is done by ultrasonic cleaning, washing, repair of splices and of perforations, polishing of the base, removal of scratches from the emulsion layer, removal of oil and dirt through cleaning, loosening of sticking windings, and eradication of fungus or bacterial infestations.

The head of this department should be a chemist with a university education, and the managers of the individual working groups should be chemical engineers with technical college educations.

All engineers coming newly from universities and technical colleges should first undertake lengthy on-the-job training to acquaint themselves with their work in these special spheres. The larger regeneration machines will require trained technicians or specialists. All other tasks can be carried out by printing experts or trained personnel.

19.3.4 Department of sound technology

Here optical and magnetic sound on films are examined and sound restoration is carried out by means of copying with special filters and noise reduction; the object being the reduction of extraneous noises. The sound is recorded on magnetic tape and special sound film stock. This department carries out tests with the sound films and determines the optimal conditions for the development and for the copying of material in order to produce optimal sound. In this respect, this department works in close co-operation with the restoration and printing departments. Where necessary, sound is added to silent films and indistinct parts of early sound films are re-recorded.

This department should be headed by a sound engineer with a technical university education who, if possible, should also

have training as a musician. He must have some expertise in electronics.

Under him there are sound specialists according to requirements. For the operation of the mixing desks, the amplifiers, the rectifiers and so on, personnel will be needed with special sound recording training or with technical training in electronics.

19.3.5 Printing department

Here the printing and processing of film stock material is carried out. Primarily the work undertaken is for the archive's technical requirements, including for the archive's cinemas, but orders may be taken from outside, from other archives and from organizations interested in copies of old films. The established practice is to reprint cellulose nitrate film onto safety film and to process optical sound negatives and positives according to set standards. Restoration is carried out using immersion copying methods and duplicating on special films (corrective copying). Chemical restoration is also carried out.

The laboratory works in close co-operation with the scientific department, the film examination department, the restoration department and the sound department.

The head of the department should be a chemical engineer with university education and many years' professional experience in duplication of film stocks.

The shift-leaders are chemical engineers, and there are a large number of special technicians who supervise the grading, the replenishment of the processing solutions, and the work at the printing and developing machines. The major part of this work is carried out by skilled printing operators, but some activities can also be carried out by persons trained in the archive.

19.3.6 Laboratory control department

Here all technical methods and parameters in all technical departments are checked, e.g., temperature and the composition of the developing and fixing solutions; likewise, the screen lighting, the constancy of the work of the printing machines, the quality of the film washing, the time for the carrying out of standardized measures etc. The raw film arriving in the archive is checked sensitometrically, and chemicals and solutions are analysed. Also, the hardness of the water is checked here.

The head of this department should be a university trained chemist under whom work assistants and other personnel who have been trained in the archive.

19.3.7 Film projection department

This department looks after all projection rooms in the archive, and it projects film material of all usual widths.

The department is equipped to show both combined prints and those with sound and picture on separate films, and it has facilities to project silent films at the speed at which they were shot.

The head of this department should be an engineer trained in film projection, and his colleagues should be trained film projectionists.

19.3.8 Department of energy resources and plant maintenance

This department is responsible for the supply of energy to the individual technical plants (electric energy, solid fuel, steam, gas, water and compressed air). It is responsible for the supervision of the control measuring instruments for all energy plants, the development of plans for optimum usage, and for detailed drawings and schedules for repairs. It is further responsible for the heating and cooling plants and the air-conditioning plant, all electrical installations, the repair workshop and the cleaning of the drains.

The head of the department must be an engineer with a university education, preferably with training in mechanics or electronics, but with wider knowledge than such training would provide and with professional experience in these fields.

Depending on the size of the archive and on its technical equipment, it is necessary to have special engineers and technicians for power, heating, steam installations and mechanical repairs. Each of the specialists should be responsible for the organization of a definite sector and should supervise the work of subordinates. The qualifications of the workers must correspond to the sophistication of the equipment available in the archive.

19.3.9 Technological department

This department is responsible for all technological processes. It establishes correct techniques whenever new plant, chemicals or film types are introduced. It is concerned with all questions of standardization. It makes recommendations for the introduction of new technological processes, carrying out the necessary calculations in close co-operation with the appropriate departments. It also helps to establish and eliminate causes for poor quality output in all technical departments. It investigates new methods of restoring and repairing films and looks for the development of new audio-visual media.

The department is run by a technologist with a university education. It is desirable if those working under this person can also be technologists with university education, as the entire rationale of the archive is largely dependent on the work of this department.

19.3.10 Buildings and construction department

This department organizes the carrying out and taking over of

building work (also building repairs) in the archive. It examines and controls the planning and costing documentation for building or reconstruction. It concludes agreements with contractors. It supervises building works, controls the building timetable, takes over the building works carried out, and controls the financing of them.

The head of this department should be a civil engineer with a university education. Under the head there should be one or two building technicians and investment experts.

19.3.11 Labour relations and safety department

This department is responsible for controls concerning adherence to the law, to instructions and rules, and the protection of standards of work. Newly arrived staff are instructed thoroughly and are subjected to regular training sessions in all departments. In close co-operation with the various departments, the sources of danger connected with the individual jobs are established and eliminated. The department participates in the investigation and analysis of the causes of lost working time and occupational diseases.

The head of this department should be an engineer with special training in worker protection or work safety. This person's colleagues are technicians who have corresponding education and training.

19.3.12 Of course, other structures are possible. This depends on the local conditions and it is not of great importance. But the qualifications of the members of staff are a decisive factor. Hurried decisions, techniques that are not sufficiently elaborated and examined, the employment of non-qualified and inadequately trained staff can have very serious consequences which will only be eliminated with the expenditure of much time and money.

The heads of small archives must not lose heart in the light of this "ideal". No archive has been founded on this technical level. It does exist, but it was necessary to fight for it for years and decades. We have described the structure as an example only.

19.4 Co-operation with other scientific institutions

From the remarks about the structure and staffing of technical facilities, it is quite clear how complicated and varied the organization of an ideal modern film archive is and what important obligations the staff have.

What we said above applies mainly for the archives which we still call film archives. It is, however, certain that in an increasing measure information sources other than optical films will be added. We have also discussed magnetic records, video discs, electronic storage and laser technology.

Whilst the development of new information sources is not up to the archives, the archives must work in close co-

operation with the institutions which are creative in these fields, and most importantly, also study the relevant literature from all over the world, so that they will be ready to start taking measures for the preservation of endangered material as soon as it begins to be mass-produced.

Co-operation with other scientific institutions must particularly apply to:

a) the maintenance of existing archives stocks;

b) new restoration methods;

c) the establishment of more durable information media;

d) the development of technology transfer from one information medium to another.

This co-operation must be undertaken not only by archivists, who are mainly technical laymen, but it will be necessary to have for this purpose academically educated engineers, chemists and physicists, who work in the archives and for whom it is easier to keep up contacts with their colleagues who are doing research work. One kind of collaboration which can promote the work of the archivist to a high degree is the request for scientific investigation of special topics. That need not always be costly; frequently, institutions and universities are prepared to set diploma tasks and suggest dissertation topics which are of importance to the archives.

Suggestions for tasks to be tackled by competent relevant institutions would include:

a) establishment of international, valid, exact definitions of the degree of destruction of colour in films;

b) further research into the regeneration of colour in film;

c) the creation, storage and regeneration of black-and-white separations of colour film materials;

d) investigate the possible conservation of colour films with the help of electronic techniques;

e) acknowledgement of new developments in the field of audio-visual information sources and of their utilization in the archives;

f) investigations into the storage, preservation and restoration of video tapes.

The questions raised here can be dealt with by any archive. They are raised, not in order to solve problems in the work of any one archive, but to suggest to the competent institutions that they concern themselves with them. The FIAF Preservation Commission will do its best to set a good example in this respect.

PART V

CHRONOLOGICAL SURVEY

Chapter 20

SYNOPTIC TABLE OF PRINCIPAL DISCOVERIES AND INVENTIONS MAKING POSSIBLE THE DEVELOPMENT OF RECORDING AND REPRODUCTION TECHNIQUES FOR MOVING IMAGES AND SOUND

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This table is not exhaustive. It simply aims to provide audio-visual archivists with the principal milestones which allow us to understand the development of audio-visual techniques and the impact of one discovery on another.

1515 Leonardo da **VINCI** describes the **"camera obscura"**; a pin-hole cut in a light-tight chamber allowing the inverted image of an illuminated shape to be projected on the inside wall opposite the hole.

1646 In his work "Ars magna lucis et umbrae", the Jesuit Priest Athanasius **KIRCHER** describes a device "for the **projection of drawings**, writings and other flat documents using natural or artificial light".

1727 Johann Heinrich **SCHULZE**, Professor at the University of Altdorf near Nuremberg, discovers the light sensitivity of silver carbonate; he is the first to produce a copied image.

1743 Father Jean Antoine **NOLLET** (France) describes in his "Lecons de physique experimentale" various experiments attesting to the phenomenon of **persistence of vision.**

1747 Leonhard **EULER** (Switzerland, Russia, Germany) publishes the principles of the mathematical calculation of an **achromatic lens.**

1802 Thomas **WEDGEWOOD** and Humphrey **DAVY** produce copies of glass drawings on paper sensitized with silver salts. Wedgewood is the first to employ the camera obscura for photographs.

1810 The physicist Thomas Johann **SEEBECK** is the first who observes in **GOETHE'S** "theory of colour" the characteristics of the different spectral beams transmitted to silver chloride. He produces the first colour spectrum of the sun on paper sensitized with silver chloride.

1816 Nicéphore **NIÉPCE** produces the first **sensitive asphalt layer** on metal plates.

1819 Sir John Frederick William **HERSCHEL** discovers the solvent property of sodium thiosulfate on silver salts, later to be used by **TALBOT** and **DAGUERRE** as a solution to the **"fixing" problem.**

1822 Nicéphore **NIÉPCE** creates **positive images** with the help of bitumen of Judea coated on a glass plate.

1833 With the **"Phénakistascope"**, an optical toy showing moving subjects drawn around the edge of a disc, Belgian physicist Joseph-Antoine Ferdinand **PLATEAU** invents the first device making it possible to synthesize one movement from single successive pictures.

1834 The **"Zootropes"** by **STAMPFER** (Austria) and **HORNER** (Great Britain) perfect **PLATEAU's Phénakistascope** by replacing the circular arrangement of pictures with a horizontal arrangement of pictures drawn on interchangeable paper strips.

1835 Announcement of the **Daguerreotype** technique by Francois **ARAGO** at the Paris Academy of Science.

1835 William Henry Fox **TALBOT's "photogenic drawings"** on silver chloride sensitized paper and fixed with potassium iodide.

1839 **HERSCHEL** recommends the term **"negative"** to designate the initial image in which light values are reversed, and the term **"positive"** to designate the copy which restores natural light values.

1839 Friedrich **VOIGTLANDER** (Vienna) builds the first **metallic camera** with a specially calculated lens by **PETZVAL.**

1839 The discoveries of **NIÉPCE** and **DAGUERRE** are made public property by the French government and offered to the other countries.

1841 Henry Fox **TALBOT's "Calotype"** or **"Talbotype"**: photographic negative image on paper which was treated in a silver nitrate and potassium iodide solution, developed in a gallic acid and silver nitrate solution and fixed with thiosulphate.

1845 Franz von **UCHATIUS** combines the phase images of the Phenakistascope developed by **PLATEAU** and **STAMPFER** with the projecting technique **(projecting moving pictures).**

1846 **SCHÖNBEIN** and **BÖTTGER** discover **gun cotton** which goes into the making of **collodion.**

1848 First unfixed **colour image** of the solar spectrum on silver chloride plate, by Edmond **BECQUEREL.**

1850 Frederick Scott **ARCHER** perfects **wet collodion** (the sensitization of the photographic plate and its

development can be carried out only just before and just after the photograph is taken).

1851 **CLAUDET** and **DUBOSCQ's "Phénakistascope photographique"**, known also as **"Stéréofantoscope"** or **"Bioscope"**, made possible synthesis of machine motion through successive photographic exposures.

1852 First unfixed **colour photograph** on a silver plate by **NIÉPCE** and de **SAINT VICTOR.**

1857 G L W **SCOTT** obtains a graphic recording of the human voice with his **"phonautographe"**. A membrane with a stylus attached records the oscillations on a cylinder which is covered with sooted paper.

1861 In accordance with the principle of colour analysis and synthesis set forth by himself in 1855, Sir James Clerk **MAXWELL** invents **trichromatic projection** using a triple lens magic lantern; (additive synthesis: red, green and blue images).

1862 Louis Ducos **DUHAURON** makes public his **three-colour** process theory involving the **superimposition** of "prints in tones of magenta, yellow and cyan" (i.e. **"subtractive synthesis"**).

1863 The physiologist I M **SECHENOV** (Russia) publishes in his book "Reflexes of the brain" studies on the length of storage of visual impressions (**persistence of vision**).

1865 Invention of celluloid by the **HYATT** brothers (USA). H **GOODWIN** and H M **REICHENBACH** are also separately credited with invention of celluloid.

1869 Ducos **DUHAURON** describes in his brochure "Les couleurs en photographie: solution du probleme", the way to obtain three analytical negatives and two possible **syntheses: additive** (homeochromatic synthesis) and **subtractive** (antichromatic synthesis).

1871 Dr Richard Leach **MADDOX** develops a dry, stable, **silver gelatinobromide** emulsion.

1873 Hermann Wilhelm **VOGEL**, Germany, discovers the **colour sensitivity** which is one of the few basic discoveries in photochemistry which continues to remain important. This discovery made it possible to achieve photographs with an accurate colour value, and without it there would be no colour photography. By adding small quantities of certain dyes, the silver chlorides become sensitive to several ranges of the spectrum.

1874 Ducos **DUHAURON** patents the **"chromographoscope"** for three-colour photography (not constructed until 1897 by **MACKENSTEIN**).

1874 With his **"revolver astronomique"**, J **JANSSEN** records 47 successive images of Venus passing in front of the sun.

1875 John **KERR**, the English physicist, discovers the rotation of the oscillating plane of the polarized light in an electric field, the so-called electro-optical effect (hence **Kerr cell for optical sound** in film cameras).

1876 W **DONISTHORPE** patents his "**Kinetograph**" which records successive views on separate plates with high-speed shutter movement.

1876 P N **YABLOTCHKOV** (Russia) obtains a patent for an arc lamp with two parallel carbon bars, insulated against each other.

1877 Emile **REYNAUD**'s "**Praxinoscope**" produces the synthesis of movement from drawings by a system of optical compensation.

1877 V V **LERMANTOV** (Russia) conducts studies on the physical term of the "**latent image**" and about its development. He emphasizes the role of the metallic silver particles which have the effect of electrodes during development.

1877 Charles **CROS** (France) sets forth the **principles of sound recording** and reproduction.

1877 Thomas Alva **EDISON** (USA) invents the **Phonograph**.

1878 Charles R **BENNETT** (Great Britain) improves the photographic emulsion by his discovery of the **maturing (digestion) process** by which the sensitivity **of the silver bromide layer** increases fortyfold.

1878 **HUGHES** (Great Britain) invents the **carbon microphone**.

1878 With a **special installation of 24 cameras**, Eadweard **MUYBRIDGE** records the motion of a galloping horse in Palo Alto, California.

1880 Sir William **ABNEY** (Great Britain) uses **hydroquinone as a film developer**.

1881 **FORTIER** and **DAVID** (France) use for the first time **celluloid as a film support**, and produce plane surface films with a gelatin layer of silver bromide which they submit on 3rd March, 1881 to the Photographic Society in Paris. Their films are, however, still far from perfect.

1882 Etienne-Jules **MAREY** (France) invents the "**photographic gun**" capable of photographing 12 frames per second.

1883 First attempts by **SAINT-GEORGE** (Great Britain) and by **SCHWARTZ** (Germany) to **photographically record sound**.

1884 Theory of **Television** set forth by Paul **NIPKOW** (Germany).

1886 Ernst **ABBE** (Germany) invents the **apochromatic lens**, corrected for all wavelengths (including the red light).

1887 Ottomar **ANSCHÜTZ** invents in 1885 (first public showing) the electric **"rapid viewer" (Electrical Tachyscope)**, a forerunner for the cinematograph which makes proper viewing of objects in movement possible.

1888 A G **STOLETOV** (Russia) carries out studies on the influence of light on electric gas discharge; he also designs the first **photo-electric cell.**

1888 **MAREY's flexible film "Chronophotographe"**, capable of taking 10 to 20 frames per second on a strip of film measuring 90 mm x 2 metres.

1889 Karl **FRISCHEN**, Technical Manager of Siemens and Halske, invents the **electrical loudspeaker.**

1889 In a show lasting several minutes, Emile **REYNAUD** projects the first cartoon with his **"Theatre optique"** for **"Pantomimes lumineuses"**. The frames (5.5 x 5.5 cm) are painted on a transparent crystalloid strip transported by a pin which fits into equidistant perforations on the film.

1889 A **VYSHINSKI** (Russia) obtains a patent for optical sound recording, based on the method of **variable area.**

1889 **Flexible cellulose nitrate film stock** based on research by Henry M **REICHENBACH** at the Eastman Company.

1891 Thomas Alva **EDISON** and William Kennedy Laurie **DICKSON** invent the **"Kinetograph"** and the **"Kinetoscope"**. the "Kinetograph", a chronophotographic device for filming intermittent movement (Geneva Cross, then an escapement system with two perpendicular discs) records frames of 25 x 19 mm on a flexible 35 mm transparent film strip, 15 metres long.

The film is transported by a sprocket wheel mesh with rectangular perforations on both sides of the film.

The "Kinetoscope" is a continuous drive viewing apparatus running at 23 to 30 frames per second which allows one person at a time to view a positive print through an eye piece.

1892 Georges **DEMENY's "Phonoscope"**, a chronophotographic camera employing revolving discs capable of photographing and projecting 24 frames.

1892 Léon **BOULY's "Cinétographe"**, motion photography and projection.

1892 Max **SKLADANOWSKY** builds his first camera and obtains **48 moving frames** (Germany).

1893 Ottomar **ANSCHÜTZ**'s (Germany) **"Electrotachyscope"** (a large wheel with glass "Chronophotographs" placed around the edge and exposed by an intermittent electric spark).

1894 G **DEMENY**'s **"Biographe"**, a cam-driven chronophotograph using a flexible unperforated film strip 8 metres long (frame: 45 x 65 mm), and **"Bioscope"** to project positive prints.

1894 C Francis **JENKINS**' **"Phantoscope"** projector (USA).

1894 Max **SKLADANOWSKY**'S **"Bioscope"** projector.

1895 Louis **LUMIÈRE**'s **"Cinématographe"** is a movie camera-cum-projector allowing projections on a screen (at 15 frames per second) before a large audience. The 35 mm film transport mechanism, with two round symmetrical perforations per frame is operated by an alternating movement transmitted to the shuttle by a triangular cam (Hornblauer cam). Patent no. 245.032 - February 13, 1895. First admission showings to the public: March 22, 1895 in Paris. First showings at a charge: December 28, 1895. Skladanowsky held the first paid showings with his "Bioscope" at the same time in the great "Wintergarten" Variety theatre in Berlin.

1896 Oskar **MESSTER** (Germany) designs and manufactures his projector using the **maltese cross** mechanism with four wings which produce intermittent movements of the picture in the projector.

1896 **GRIMOIN-SANSON**'s **"Phototachygraphe"** escapement system.

1896 Thomas **ARMAT**'s cam driven **"Vitascope"** 35 mm projector (sold to **EDISON** Co. and marketed under EDISON's name).

1896 Auguste **BARON**'s **"Graphophonoscope"**; equipment for synchronous cinematography and projection with a cylinder phonograph for the recording and reproduction of sound.

1896 Louis **LUMIERE**'s **"Kinora"** for direct viewing of a series of paper photographs printed from a motion picture film ("flip-book" principle).

1897 **EDISON**'s **"Kinetoscope"**; film transported by maltese cross.

1897 Georges **DEMENY** and Leon **GAUMONT**'s cam-driven **"Chronophotographe"**.

1897 System **combining microphone and cine-camera** by **BERTHON, DUSSAUD** and **JAUBERT** (patented July 1, 1897).

1898 Cecil M **HEPWORTH** applies the **continuous development** principle to film, already used for the mass production of picture postcards.

1898 Valdemar **POULSEN** discovers how to **record a magnetic sound track** on steel wire. Patented December 10, 1898).

1898 Louis **LUMIÈRE's 75 mm wide film** stock (frame: 45 x 60 mm).

1898 William **FRIESE-GREENE** carries out **three-colour tests** with a camera equipped with rotating filters.

1899 **Three-colour cinema process** by Frederick Marshall **LEE** and Edward Raymond **TURNER**; in projection (black-and-white positive print), three separate colour-separation images are superimposed on a single screen. Colouring is obtained by a three-coloured disc forming part of the shutter.

1900 **GRIMOIN-SANSON's "Cinéorama"**: cinematography and projection "in-the-round" (360 degrees) by means of ten 70 mm cameras and projectors.

1900 **GAUMONT's "Chrono de poche"** (portable camera), using centre perforated 15 mm film stock.

1900 W **DUDDEL** (Great Britain) and E **RUHMER** (Germany) invent the first photographic recordings of sound on film stock based on the **"singing arc"** phenomenon.

1901 **Nonflammable film** made of cellulose acetate by A **EICHENGRUN** and T **BECKER**.

1901 **Hand-coloured positive prints** (Georges **MELIÈS** followed by **PATHÉ**).

1902 **GAUMONT** presents his first **"talking portrait"**; synchronism by flexible mechanical connection between a gramophone and a 35 mm projector.

1905 E **RÜHMER** develops sound reproduction with a **selenium photoelectric cell.**

1906 **HOCHSTETTER** (Germany) patents the principle of the **"Kerr cell"**.

1906 Eugène-Auguste **LAUSTE** patents the first machine allowing **simultaneous sound and image recording** on the same film: when recording, microphone currents react to an electro-magnetic grid modulator; during reproduction, the selenium cell triggers the receiver membrane. Headphones are used for listening.

1906 James Stuart **BLACKTON's** "The haunted hotel": first **animated film.**

1906 **"Kinemacolor"** by George Albert **SMITH** and Charles **URBAN.** Two-colour process based on alternating red and blue-green separation frames when filming at 32 frames per second. The projector embodies a shutter with red and green filter sectors.

1907 Lee **DE FOREST** patents the **"Audion" vacuum tube,** essential component for sound amplifier construction.

1907 B **HOMOLKA** (Germany) sets forth the principle of **chromogenic processing.**

1908 **The first reversal film:** direct positive obtained by reversal on black-and-white film, making possible colour projection through the use of a three-colour filter placed in front of the lens both while filming and projecting. Patent by R **BERTHON,** who will join with A **KELLER-DORIAN** in 1914, then with **SIEMENS** in 1937 to perfect the process.

1909 **EDISON**'s 35 mm film stock becomes the **international standard.**

1909 Charles **PATHÉ** and H **FOUREL**'s **"Pathécolor":** Mechanical cutting of stencils was carried out by a cutting needle controlled by a pantograph the stylus of which was made to follow the outlines of the picture projected onto a translucent screen. Up to seven colours were used, the colours being aniline dyes. Before the introduction of the pantograph technique, stencils had been cut by hand.

1910 **"Chronomégaphone"** by Leon **GAUMONT** and C **LAUDET.** For sound projection by electromechanical coupling between the projector and a two-horned, twin turntable gramophone driven by synchronized electric motors and with compressed air amplification.

1912 Leon **GAUMONT**'s **"Chronochrome":** camera and projector using the three-colour process. Three frames are simultaneously photographed through three colored filters (green-yellow, red-orange, blue-violet) on the same black-and-white film. Then, at projection, the three separate picture tracks run simultaneously, optically superimposed by a split lens. The system requires a very strong light.

1912 **"Pathé-Kok":** camera and projector for 28 mm nonflammable film.

1914 First **Kodachrome** process by J G **CAPSTAFF** for Kodak: positive print with emulsion on both sides, for copying bichromatic films. The colour-separation frames are simultaneously recorded with a split lens. In the printing process the colour-separation frames are printed one on each side, an appropriate chemical treatment being used to tone the images blue-green on one side, red-orange on the other.

1915 **First Agfacolor process using "three-colour mosaic"** by the Agfa Company.

1917 **Bichromatic Technicolor process** by E J **WALL,** Herbert T **KALMUS,** Daniel Frost **COMSTOCK,** W B **WESTCOTT** (USA). After abandoning the additive process, the inventors

thought of printing colour separations on two distinct positives cemented back to back (cemented-pairs process). The first film, produced in 1922, was "The Toll of the Sea"; the first feature film shot in artificial light was "The Black Pirate" with Douglas **FAIRBANKS** (1925).

1919 H **VOGT**, G **MASSOLLE** and J **ENGL** found the **"Tri-Ergon"** Company and join together their respective patents concerning the "Kathofophon" microphone; a resistor coupling amplifier, a discharge lamp modulator and an electrostatic "Statophone" speaker. They produce in 1922 a photographic recording of sound (shown in Berlin).

1920 V N **KOVALENDOV** (USSR) obtains a patent for his **"talking cinema"**. With the help of this device, magnetic sound recording becomes possible, and the sound can be reproduced simultaneously with the projection of the film.

1922 **"Pathé-Baby"** system, for films distributed in 9.5 mm, with cueing notches for freeze frame projection of intertitles, reduced to one or two frames. Projectors holding 10, 20 and then 120 metres of film (1926); camera (1924).

1923 **Reversal** black-and-white 16 mm film by Eastman Kodak Company; first 16 mm camera for amateurs ("Cine-Kodak A").

1923 Lee **DE FOREST** (USA): optical sound process (**"Phonofilm"**): combination of glow lamp recording and photoelectric cell for playback; and first public showing of a film having an optical sound track on the same film as the picture.

1926 Western Electric's **"Vitaphone"** process is adopted by Warner Brothers (USA); sound movies using disc recording (40 cm), 33 1/3 RPM, tracking from centre to edge. "Don Juan" with Lionel **BARRYMORE** shown in New York on August 7.

1926 Theodor W **DE CASE** experiments with a process using an oxide-cathode glow lamp ("aeo-light") and joins with William **FOX** to develop the sound system **"Fox-Movietone"**. First "canned songs" with Raquel MELLER in 1927.

1926 P G **TAGER** (USSR) publishes the results of his work on the development of a cinema sound system with **variable density** recordings.

1927 Henri **CHRETIEN**'s patent for the **"Hypergonar"**, a widescreen **cylinder lens** which, placed in front of a normal lens, compresses the image onto normal film stock, enlarging the field of vision (horizontally or vertically). The first **anamorphic** film was "Building a fire" by Claude **AUTANT-LARA** (1925).

1927 **Panoramic projection** on a triple screen of Abel **GANCE**'s "Napoleon".

1927 **WARNER BROTHERS** present the **first "singing and talking" motion picture** "The Jazz Singer" with Al **JOLSON.** The film runs at 24 frames per second.

1928 **Principles of colour television** based on three-colour process set forth by John Logie **BAIRD.**

1928 **"Photophone"** sound system of the Radio Corporation of America, Westinghouse and General Electric Co. Variable area optical recording on film, based on the work of **LAUSTE** (1910).

1928 Partnership **GAUMONT-PETERSEN-POULSEN** for a tentative commercialization of the GPP process of synch-sound projection in 35 mm double system (one film for picture, the other for sound, printed on a separate film stock). "L'Eau du Nil" was the only film distributed using this process.

1928 Western Electric sets at 0.1 inches (2.5 mm) the **standard width of the optical sound track.**

1929 Wide film, of 50 mm and 70 mm width, used by FOX ("The Big Trail") and by RKO ("The Danger Light").

1929 Demonstration of **"Radiovision"** (mechanical process) by R **BARTHELEMY,** H **DE FRANCE** (France) and J L **BAIRD** (Great Britain) while **ZWORYXIN** perfects the "Iconoscope" system for RCA.

1929 **TOBIS-KLANGFILM** is set up as a corporation monopolizing the German and American sound processes: Klangfilm, Movietone, Photophone and Tri-Ergon.

1930 **Agreement** between American and German corporations **to divide the world** into zones of influence for the exploitation of sound techniques. Photoelectric recording is definitively adopted.

1931 The Technicolor dye-transfer (imbibition) process extended to three colours. The colours are transferred to the final print film from three special dye-carrying positives (matrices). The final print also carries a grey "key image" and a sound track, both of silver. The first three-colour dye-transfer film was Disney's cartoon "Flowers and Trees" of 1932. The first live action was the short film "La Cucaracha". The first complete three-colour dye-transfer feature was "Becky Sharp", 1935.

1931 16 mm sound film by Eastman Kodak Company.

1932 **8 mm camera and projector.** The film was 16 mm wide. First one half width was exposed and the film was then turned round and the other half exposed, then cut in two after development, by Eastman Kodak (camera "Cine

Kodak Eight" and projector "Kodascope").

1935 **Kodachrome** 16 mm: views shot directly on **reversal integral tripack film** with 3 layers of emulsion superimposed tripack, by Leopold **MANNES** and Leo **GODOWSKI** based on Rudolph **FISCHER**'s works (1908). The process will be applied to 8 mm in 1936.

1935 Louis **LUMIÈRE** and André **DEBRIE** carry out **three-dimensional (3-D) cinematography** experiments with superimposed images onto a 35 mm film running horizontally through camera, with the use of blue and yellow-green filters for separation, and coloured glasses for viewing (anaglyphs).

1937 Agfa 16 mm colour film (integral tripack reversal).

1939 **New Agfacolor**, chromogenic integral tripack negative positive process based on the principle of "couplers" set forth by R **FISCHER** and **HOMOLKA**: the negative contains three silver halide layers, respectively, sensitive to red, green and blue; during development the couplers tied into each emulsion layer produce dyes; silver is then removed, producing a negative image in which colours and values are complementary to those of the subject. First feature film in Agfacolor "Die Goldene Stadt" (1942). **Ferraniacolor** (1947), **Gevacolor** (1949), **Anscocolor, Sovcolor** and **Eastman Color** all derive from the same patents, which were free after the end of World War II.

1939 Demonstration at New York World's Fair of **3-D colour film** by projection with polarized light, the audience wears polarized glasses.

1942 20th Century Fox produces "Thunderhead" feature film made on **'Monopack' film** stock derived from Kodachrome; positive prints in Technicolor.

1945 Research by G **BRAUNMUHL** and W **WEBER** on **magnetic sound recording**; (film stock magnetized at high frequencies).

1947 **Holography theory** by Denis **GABOR**, an Hungarian living in Great Britain.

1948 **"Polaroid 95"** instantaneous development still camera, by Edwin H **LAND** (USA).

1949 André **COUTANT** carries out the first picture recording on **1/4-inch magnetic tape** (patented September 23, 1949).

1950 35 mm Eastman Color Negatives and Positives by Eastman Kodak Company, Rochester, USA: the couplers contained in two of the three layers are coloured in the negative to form a corrective mask (integral colour mask) so as to remedy inherent deficiencies in the dyes which are formed in the layers during chromogenic development (colour couplers were invented in 1943).

1951 **Magnetic tape sound recording,** in many countries, replaces optical recording for sync-sound filming and sound mixing.

1953 **CinemaScope** widescreen film (2.55 : 1 ratio) by 20th Century Fox, exploiting Henri **CHRETIEN**'s "hypergonar" patent (1927).

1956 Development in USA of **Ampex process** for recording picture on tape.

1962 U N **DENISSUKE** (USSR) make hologram recordings in one layer and reproduced three-dimensional colour images.

1964 **Compact tape cassette** recording and play back by Philips, Holland.

1964 Philips **"Video 3400"** picture recording device using magnetic tape (25.4 mm, 1 inch) at a speed of 19.5 cm/sec 7.5 ips) lasting 45 minutes.

1965 **"Super 8 mm"** cassette (frame size: 4.22 x 5.60 mm) by Eastman Kodak Co.

1968 Thomson-CSF's **video disc** transparent video disc in which playback is obtained by laser beam focused on one or the other side of the disc; 45,000 pictures or grooves per side; transmitted to a television set, at a uniform speed of "one to one" (still frame) or at high speed (sequence search).

1968 **"Electronic Video Recorder"** (EVR): recorded programs on nonperforated magnetic tape; "read" on a television receiver; by the Columbia Broadcasting System (CBS) USA.

1971 **"Video Cassette Recorder"** (VCR). Cassette machine for recording and playing back, in black and white or in colour, programs presented on television, Philips and Radiola (Holland).

1972 **"Video Long Playing"** (VLP) video disc with metallic surface, Philips.

1975 **"Betamax"**, Sony (Japan)'s half-inch long playing video tape cassette recorder.

1976 **"Video Home System"** (VHS), Japan Victor Company.

1978 **"Polavision"**, "Super 8" camera with instantaneous development by Edwin H **LAND** (Polaroid) USA.

1978 The NIKFI Institute (USSR) photographs and projects a three-dimensional holographic film.

1980 After many years of preparatory work, PHILIPS Co. (Holland) together with MCA (USA) start to market video discs (discs and devices) in the USA.

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