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The fundamentals of magnetic recording

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Lecture delivered for the Nederlands Radiogenootschap and the Geluidstichting on 17th June 1955.

SUMMARY

A short description is given of the magnetic recording method in general, and some details are treated more elaborously. For the understanding of the h.f. biasing method use is made of a simplified hysteresis curve. In this way an explanation can be given of some of the peculiarities met in the recording and erasing.

The recorded signal is attenuated by the demagnetizing field, and during reproduction not all the flux in the tape is reproduced. This is treated for short, long and intermediate wavelengths.

Finally, the factors are surveyed which influence distortion, frequency response, noise and print effect.

1. *Introduction.*

The development in recent years of the magnetic recording system, invented in 1898 by Poulsen, has led to a system that is highly reliable, simple in operation, and of an excellent sound-quality. It is therefore not surprising that it has reached an outstanding place among the existing sound-recording systems.

The physical processes involved are not always so simple, especially in the recording process itself. In the survey that follows we shall not go into all the details of these processes, but give where necessary a schematic representation that simplifies understanding.

A magnetic recording system is in principle made up of a magnetizable medium (e.g. tape), a recording- and a reproducing head. In the recording head a magnetic field is excited by the

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recording current, and the tape is moved with uniform velocity through this field. In this way the variations of the electric current with time are converted into a varying magnetization along the tape. In reproducing, the tape is led with the same

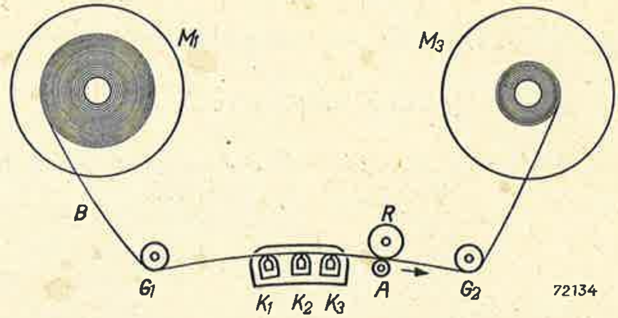

Fig. 1.
Schematic representation of a tape-recorder.

velocity along a reproducing head where the varying magnetic flux introduces voltages that can be amplified and give rise to a signal that, if the apparatus is functioning well, is equal to the original signal.

A schematic representation of a tape recorder is depicted in fig. 1. The tape, driven along by the capstan A and the pressure idler R, passes, on its way from the supply reel M_1, to the take-up reel M_3, three magnetic heads: the erasing head K_1, which erases what may have been recorded on the tape previously; the recording head K_2 and the reproducing head K_3.

Fig. 2 gives a schematic construction of a magnetic head. It

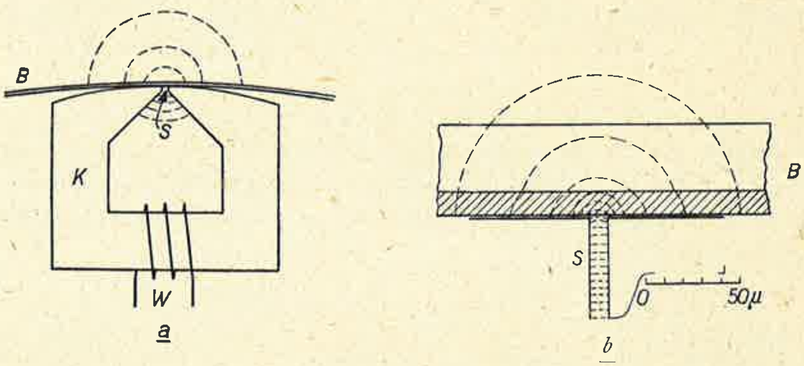

Fig. 2.
Schematic construction of a magnetic head (a), with relative proportions of tape and gap for a recording or reproducing head (b).

consists of a high-permeable magnetic core interrupted by a non-magnetic gap. The differences between erasing-, recording- and reproducing head are to be found mainly in the dimensions of the gap.

The magnetic recording medium is moved along the gap. Usually it consists of a plastic base, 40 μ thick, covered with a magnetic coating of 15 μ. The coercive force of the magnetic material is about 250 Oersted, and its remanence 600 Gauss.

One of the difficulties with the investigation of the magnetic recording process is that, although the recording and the reproducing process are really well separated, the intermediate result, the recorded tape, cannot be examined independently. This is different from the situation with gramophone or sound film, where the in-between result can be examined optically.

2. *The recording process.*

Two points are of special importance here:

1. the attainment of a linear relationship between the current in the recording head and the resulting magnetization of the tape;
2. the recording of as wide a frequency range as possible.

As to the first point, we shall assume a linear relationship between the field in the recording gap and the current in the coil of the recording head. (This implies that no saturation occurs in the core material). The tape moves through the stray field of the recording gap. In doing so a particle of the tape experiences a field that, assuming that the gap-field remains constant, increases from zero to a maximum value when the particle is exactly in front of the gap, and then decreases again. The maximum value experienced is a measure for the magnetization brought about in the tape. To make the relationship linear two methods exist:

a. the d.c. biasing method;
b. the a.c. biasing method.

The main importance of the former method is that it can be readily understood. The second method is used in practice, but is much more difficult to understand. Here a high-frequency current is superimposed on the current to be recorded, while care has been taken that the tape is magnetically neutral when it reaches the recording gap.

An entirely satisfactory explanation of the linearization process has not yet been given, and will be very difficult to give because of the complexity of the phenomenon. We shall give here a simplified representation based on the considerations of Toomin and Wildfeuer [1]. This simplification relates to the magnetization-curve which we shall suppose to consist of two steep irreversible branches (CD and FB in fig. 3) connected by less steep reversible branches. The slope of the latter corresponds to the initial permeability.

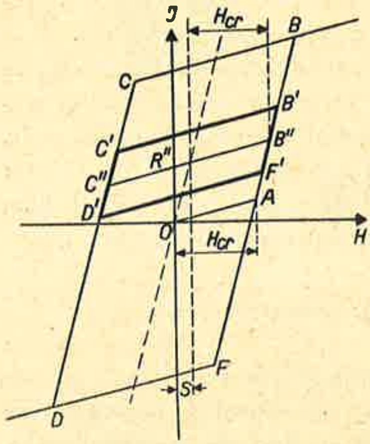

Fig. 3.
Simplified magnetization curve (B C D F) with minor hysteresis loop (B′C′D′F′).

Starting from the demagnetized state, an applied magnetic field will cause the magnetization at first to follow the reversible branch OA. After A is reached the magnetization will further follow the irreversible branch. When the magnetic field starts to decrease after the magnetization has reached B'', the latter will from then on follow the reversible branch $B''C''$.

Suppose now that the recording head is fed with a superposition of a direct and an a.c. biasing current, and that the amplitude of the latter is such that in front of the gap the field amplitude surpasses the coercive force of the tape. In approaching the gap a particle of the tape will experience a growing field amplitude until in front of the gap it traverses a loop as is, for example, depicted by the loop $F'B'C'D'$. This loop is shifted with respect to the origin because of the direct component. After leaving the front of the gap the field experienced by the particle decreases. At a certain moment it has decreased so far that the amplitude of the a.c. field equals H_{cr}, and from then on the magnetization follows the reversible branch $B''C''$. After the particle has left the recording head its magnetic state is represented by R''. The position of $B''C''$ corresponds to a displacement of A along BF in accordance with the applied d.c. field S. Since BF is a straight line the remanence R'' is strictly proportional to S. This is what was meant to be obtained by the application of the d.c. bias.

During the passage of the gap the d.c. field experienced by the tape varies in the same way as the a.c. biasing field. If it be asked what d.c. field is decisive for the recorded signal, the answer must be that it is the field that exists at the moment that the minor hysteresis loop just closes, that is if the tape has travelled such a distance past the recording gap that the amplitude of the a.c. field equals H_{cr}.

With the simplified representation given above, the qualitative behaviour of the curves of output and distortion versus biasing current may be explained. Moreover it may be extended if we suppose the magnetic material not to be built up ot domains each having the same rectilinear hysteresis loop, but of domains the coercive forces of which are scattered around a certain mean value. The picture is then no longer very academical, but resembles to a certain degree the physical picture that can be made of a magnetic material.

The consequence of this extension, and of the fact that particles deeper in the tape experience a smaller stray field, is that the recording does not take place at a fixed point but in a small area. The greater the spread in the coercive force and the thicker the tape, the larger this area will be. As a consequence the instant of recording is spread in time and, if the signal can no longer be regarded as constant during the passage of the gap, a kind of average of the signal over a period of time is recorded. To a rapidly varying signal this will mean an attenuation and it sets an upper limit to the highest frequency that can be recorded. The more rapidly the stray field around the gap falls off, the shorter the period over which is to be averaged, and the smaller the attenuation of the higher frequencies. From the above it further follows that the reproduction of the higher frequencies can be enhanced by making the spread in coervice force in the tape as small as possible, and by making the magnetic coating thin.

3. *Erasing.*

The erasing process is essentially the same as the recording process, carried out in absence of a d.c. current. The a.c. current must be high in order that saturation in the tape can be reached.

The magnetization in the tape is brought to zero by action of the gradually decreasing a.c. field, when leaving the head. Care must be taken that the a.c. field decreases slowly since otherwise a remanent magnetization may be brought about that is a recording of the a.c. field. To appreciate this let us return to our simplified representation of fig. 3. Suppose that in one oscillation of the a.c. field B'' is reached, but that the amplitude falls off so rapidly that in the next half period C'' is no longer reached, then a remanent magnetization R'' is brought about. An estimation can be made of the remanent magnetization in the most unfavourable case. In order that it be $I_{R''}$ the value of the a.c. field must have been $H_{cr} + \frac{I_{R''}}{\tan\alpha}$, while half a period later it was $H_{cr} - \frac{I_{R''}}{\tan\alpha}$ (α is the slope of the irreversible branch of the magnetization curve). Thus $\triangle H = 2\frac{I_{R''}}{\tan\alpha}$ is the decrease of the field in a time $\triangle t = \frac{1}{2f}$ (f = frequency of the a.c. field),

$$\text{whence } I_{R''} = \tfrac{1}{2}\tan\alpha\,\frac{\triangle H}{\triangle x}\cdot\frac{\triangle x}{\triangle t}\cdot\frac{1}{2f}\,.$$

In order to reduce the remanent magnetization $I_{R''}$ as much as possible at a given tape speed $\frac{\triangle x}{\triangle t}$ it is desired that the frequency f is high and the fall-off of the stray field around the gap, $\frac{\triangle H}{\triangle x}$, small. The latter is obtained by supplying the erasing head with a wide gap. This also serves to let the field penetrate the remote layers of a thick coating.

For the recording gap, where the same reasoning holds, $\frac{\triangle H}{\triangle x}$ must be high for the recording of the higher frequencies, as we have seen, and a recording of the biasing current can be avoided only by using a high biasing frequency.

4. *Self-demagnetization.*

Once the magnetization has been brought about by the recording head, the magnetic states of adjacent particles influence each other. In the case of longitudinal sinusoidal magnetization, say $B_x = B_0 \sin 2\pi\frac{x}{\lambda}$, a magnetic field is generated that tends to decrease the magnetization. For a tape-thickness d, small compared to the wavelength λ, this demagnetizing field can be easily calculated. From div $B = 0$ it follows that at the surface of the tape $B_y = -\frac{\pi d}{\lambda} B_0 \cos 2\pi \frac{x}{\lambda}$. Outside the tape the sinusoidal solution satisfying the Maxwell equations is:

$$H_x = H_0 e^{-2\pi y/\lambda} \sin 2\pi \frac{x}{\lambda}$$

$$H_y = H_0 e^{-2\pi y/\lambda} \cos 2\pi \frac{x}{\lambda}$$

(The y-direction is the direction perpendicular to the plane of the tape).

Since at the surface of the tape the normal component of the induction, and the longitudinal component of the field strength are continuous, it follows that inside the tape the demagnetizing field is given by

$$H_0 = -\frac{\pi d}{\lambda} \cdot \frac{B_0}{\mu_0}.$$

For smaller wavelength the demagnetizing field is no longer constant over the thickness of the tape. A calculation [2], which we shall not reproduce here, shows that the demagnetizing field has its maximum value in the centre of the tape. The remaining

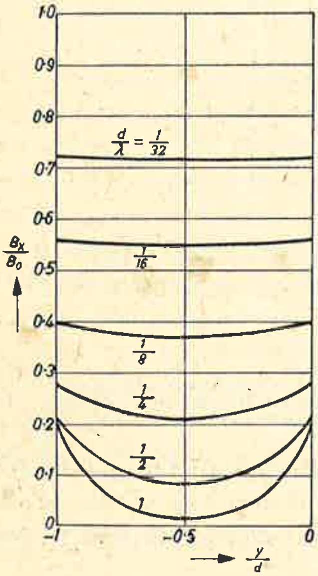

Fig. 4a.

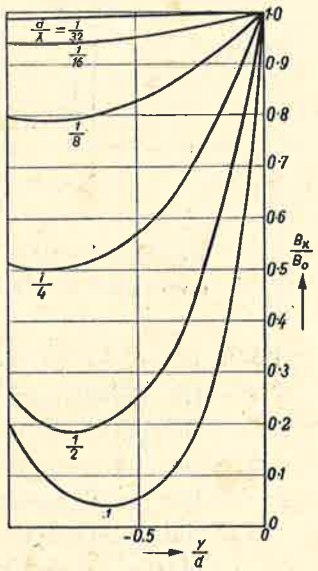

Fig. 4b.

Longitudinal component of the induction in a tape of permeability $\mu = 4$: *a.* tape free in space *b.* tape on one side ($y = 0$) in contact with the head.

magnetization is therefore concentrated near the surface of the tape. In fig. 4a the result of the calculation is shown for several values of $\frac{d}{\lambda}$, and for a tape with a relative permeability $\mu = 4$.

When the tape is brought into contact with the soft-magnetic material of the reproducing head, this forms a magnetic short-circuit which decreases the demagnetizing field. The resultant magnetization for this case is shown in fig. 4b.

5. *Reproduction.*

When a magnetized tape passes the reproducing head, part of the lines of force leaving the tape find their way through the core of the head (fig. 5). The non-magnetic gap takes care that these lines of force pass through the reproducing coil, introducing in the latter a voltage that is proportional to the rate of change of the flux.

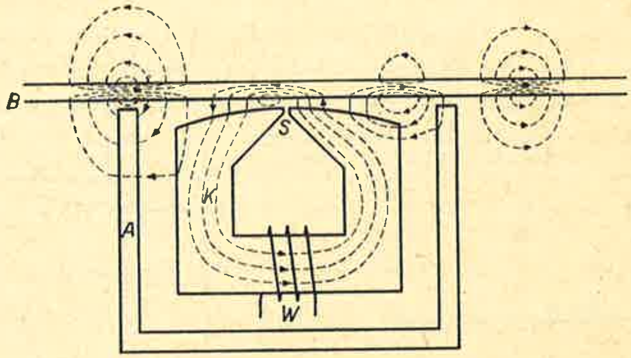

Fig. 5.
Reproducing head with screening (A) in contact with magnetized tape (B). The lines of force are indicated schematically.

Three cases can be distinguished:

1. the wavelength is of the same order of magnitude as the gap-length.
2. the wavelength is large compared to the gap-length but small compared with the dimensions of the head,
3. the wavelength is of the same order as the dimensions of the head.

The second case is the most simple one. It is seen from fig. 5 that, provided the tape is in contact with the head, all lines of force in the tape close through the core, and the reproduced flux equals the flux in the cross section of the tape just above the gap. If the tape is not in close contact with the head, part of the lines of force will be lost in the space between tape and head, and at the opposite side of the tape. This effect will be the more serious the shorter the wavelength, and it can be calculated [3] that the loss owing to this effect may be expressed as 55 a/λ dB, where a is the spacing between head and tape.

When the wavelength is of the same order as the gaplength, part of the lines of force will close in the gap, without traversing the coil of the head (fig. 6). The fraction traversing the coil is to a first approximation given by $\frac{\sin \pi\, l/\lambda}{\pi\, l/\lambda}$ [4]. The voltage on the reproducing coil is proportional to the frequency $f\left(=\frac{v}{\lambda}\right)$, and the output voltage will be proportional to $\frac{v}{l}\sin \pi\, l/\lambda$. This means that a tape recorded with a constant flux-amplitude will give rise to a sinusoidal response curve. A more rigid calculation [5] shows that the successive maxima of the response curve are not of equal height, but rise 2 dB/octave, and that the first zero occurs at $l = 0{,}88\,\lambda$ (fig. 7). This result is in accordance with measurements [6], and is the basis for the calibration of the recorded flux.

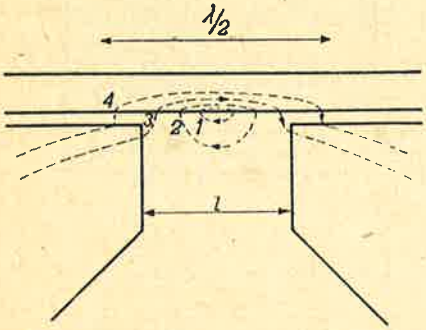

Fig. 6.
Induction lines in the case that the wavelength λ is comparable with the length l of the gap.

For long wavelength the head is too small to pick up in its entirety the flux leaving the tape. This is aggravated by the shielding that has to be present in order to eliminate hum pickup. Only the lines of force leaving the tape over a length equal to the head-length L are picked up and the reproduced flux can be estimated to be proportional to

$$\frac{2\pi}{\lambda}\left\{\int_{-L/2}^{0}\cos\left(2\pi\frac{x-x_0}{\lambda}\right)dx-\int_{0}^{L/2}\cos\left(2\pi\frac{x-x_0}{\lambda}\right)dx\right\}=$$

$$=2\sin\frac{2\pi x_0}{\lambda}\left(1-\cos\frac{\pi L}{\lambda}\right).$$

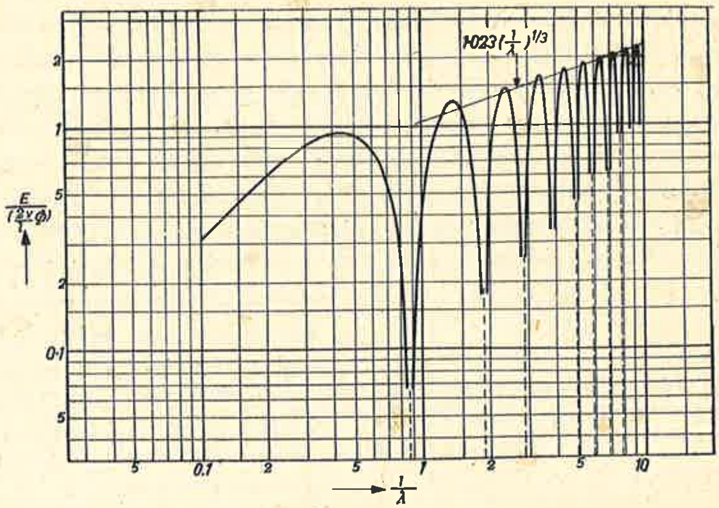

Fig. 7.
Calculated response curve for short wavelengths.

Fig. 8 shows that the experimental result is in reasonable agreement with this rough approximation, minima occurring for $\frac{L}{\lambda} = 2{,}4 \ldots$, and maxima for $\frac{L}{\lambda} = 1{,}3 \ldots$. The undulations are damped because the transitions at the edges are not as sharp as was supposed in the calculation.

It is seen from the formula that for very long wavelenghts the reproduced flux is proportional to $\left(\frac{\pi L}{\lambda}\right)^2$.

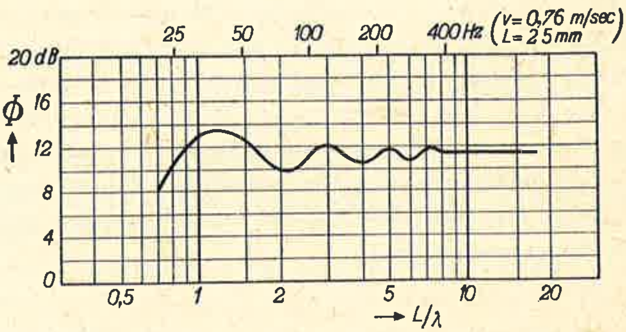

Fig. 8.
Measured response curve for long wavelengths.

6. *Distortion.*

Having now considered the fundamental processes separately we will review the predominant properties of the system as a whole.

Distortion, or non-linearity between output and inputsignal, occurs in particular in the recording, and we have pointed out the method to eliminate it. It should be borne in mind, however, that it is difficult to arrive at a sufficient biasing fieldstrength deeper in the tape, since the stray field of the gap decreases rapidly with distance. Therefore some degree of distortion for the deeper layers of the tape cannot always be avoided.

The demagnetizing field in the tape can also introduce distortion. To show this we refer to fig. 9. The magnetization gives rise to a demagnetizing field that is proportional to the magnetization, and that can be represented therefore by line I or II, depending on whether a longer or a shorter wavelength was recorded. In the first case a magnetization R' will be brought down to R_0 on the reversible branch by the demagnetizing field. In the second case, however, the magnetization is brought down to the point D'' on the irreversible branch and when passing over the reproducing head, will not return to R', but to R''. This means that for larger signals the peaks are flattened.

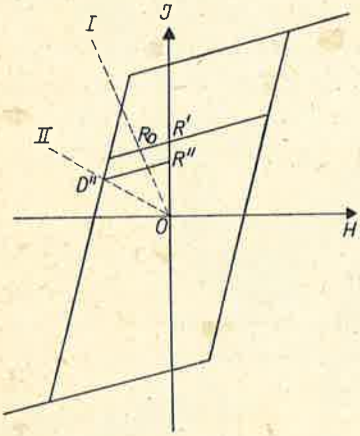

Fig. 9
Magnetization curve with demagnetization-line for a longer (I) and a shorter (II) wavelength.

It will be clear that the lower the coercive force of the tape the sooner this distortion occurs. For the recording of short wavelengths a high coercive force is desired.

7. *Frequency response.*

The losses in a recording system may be divided into two categories. In the first place those that are a direct consequence of frequency, e.g. eddy current losses. More important for the magnetic recording are the losses for which the wavelength, or the ratio frequency over tape speed, is a measure.

For long wavelengths it is only the reproducing head that sets a limit to the reproduction. In the case of short wavelengths however, wavelength-dependent losses occur in all three phases of the process. The losses at the recording side, introduced by the finite area over which the recording takes place, belong to this category. So do the losses caused by the fact that the audio signal changes during the actual recording.

The demagnetizing field in the tape is only dependent on wavelength. The losses caused by this demagnetizing field are the more serious the higher the permeability of the tape, since the change in induction caused by equal fields is higher in the case of a high permeability. For the reproduction of short wavelengths a low reversible permeability is desired.

At the reproducing side, as we have seen, the finite gap-length, and a spacing between tape and head, introduce losses. The spacing between tape and head can be caused by rough surface of the tape, or dirt on the head, e.g. from material abraded from the tape.

The losses caused by the factors mentioned above can, at a given tape speed, be partly restored by correcting networks in recording and reproducing amplifiers. The possibilities are, however, limited. On the recording side because of overload of the tape, and on the reproducing side by noise. In normal practice wavelengths are recorded down to about 10 μ.

8. *Noise.*

Like every recording system, the magnetic too is afflicted with inherent noise. In the first place recording-, bias- and reproducing-amplifier must be free of noise. Difficult though this task may be in practice, it is not of a fundamental nature.

The fundamental noise is that generated by the grainy structure of the magnetic material. Fig 10 shows an electron-microscopic photograph of the particles $\gamma Fe_2 O_3$ making up a coating. The size of these particles is about $0{,}5 \times 0{,}1\ \mu$. At a tape speed of 0,76 m/sec, about 10^{12} particles a second pass the head. A rough estimation of the noise in a bandwidth of 10^4 Hz shows that this is $\sqrt{10^8}$ or 80 dB below saturation level, corresponding to about 70 dB below maximum signal level. This is, in effect, the order of magnitude of the noise measured on a demagnetized tape.

If the tape is magnetized the noise appears to be much higher.

Since the rise of the noise is strictly related to the presence of a modulation, it is called „modulation noise".

The origin of this noise is a fluctuation of the sensitivity of the tape, caused for instance by an irregular distribution of the magnetic particles, or by thickness-variations of the coating. A fluctuation of 1 % in the number of magnetized particles

Fig. 10.
Electron-microscopic photograph of iron oxyde particles of a magnetic tape.

passing the head will give rise to a modulation noise of 40 dB below signal, which corresponds to the figure measured in practice. For normal noise such a figure would be intolerable, but in the case of modulation noise we meet the fortunate circumstance that the noise is partly masked by the signal. Care must be taken, therefore, that an infra- or ultra-acoustical signal is not recorded, *e.g.* a d.c. signal or the h.f. bias. In this case a noise would be generated that is not masked by an audible signal, and would therefore be very troublesome in silent passages of the recording.

9. *Print-effect.*

It was feared at first that if a magnetic recording were stored for a considerable time, something might be lost of the recorded magnetization. This fear, however, has not been confirmed, provided that the tape is not exposed to strong magnetic fields.

More serious is that, on the contrary, something is added to the recording on a stored reel, namely a weak copy of the magnetization stored on the next layer of the reel. This is brought about by the weak field originating in this layer, which, although much weaker than the coercive force, on the long run is capable of effecting a remanent magnetization.

At a given induction B_0 in a layer the field at a distance Δ in the adjacent layer may be calculated as

$$\mu_0 H = \frac{\pi d B_0}{\lambda} e^{-2\pi\Delta/\lambda}$$

As a function of the wavelength λ this field has a maximum value for $\lambda = 2\pi\Delta$. For a tape-thickness $\Delta = 55\ \mu$, and a tape speed of 0.76 m/sec this corresponds to a frequency $f \doteq 2300$ Hz. The corresponding fieldstrength in case that $B_0 = 80$ Gauss, is about 5 Oersted.

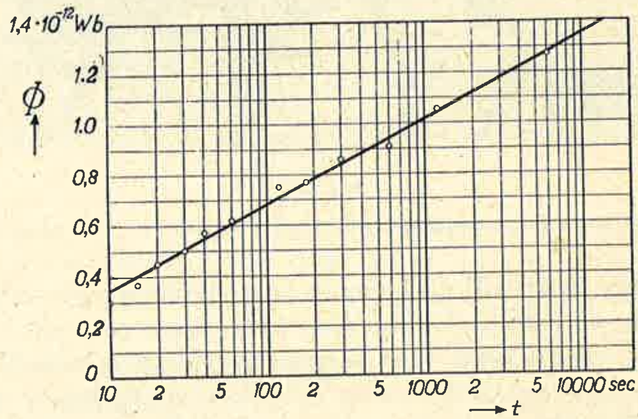

Fig. 11.
Measured printed flux as a function of the duration of the influence.

Even with a coercive force of the tape of 250 Oersted this field gives rise to a magnetization that increases logarithmically with time (fig. 11). The explanation for this print-effect must be that in magnetic domains where the local coercive force is small, the direction of magnetization is changed under the combined action of the small disturbing field, and the thermal agitation.

This printing is specially troublesome when during a silent passage it gives a pre-echo of a fortissimo that is to follow. Most modern tapes, however, have a print-effect not exceeding – 55 dB as compared to the printing signal.

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Mechanical aspects of magnetic-recorder design

by G. P. Bakos *)

Lecture delivered for the Nederlands Radiogenootschap and the Geluidstichting on 17th June 1955.

SUMMARY

The quality of magnetic recording is determined to a great extent by electro-mechanical design of the tape-drive mechanism. The task of this mechanism is to make the tape run with a constant speed and in intimate contact with the magnetic heads.

It depends on the constructional details how far this task is fulfilled. This article deals with the various factors which have to be taken into account when designing magnetic recorders.

Introduction.

The first proposals as regards the application of magnetism for sound recording were made last century [1]. The first working model was designed by the Danish physicist Valdemar Poulsen [2]; his "Telegraphon" was one of the sensations at the World Exhibition in Paris in 1900 where it won the "Grand Prix". The construction of this first magnetic recorder showed much resemblance with the "Phonograph" of Edison; it consisted of a cylinder rotating with constant speed, and with steel wire spiralized round its periphery. The magnetic head rested on the wire and was guided by it. The linear speed of the wire was about 80 in./s (2 m/s), and the recorded frequency range was about 2000 c/s.

In spite of its initial successes in Germany and in the U.S.A., the "Telegraphon" could not compete with the mechanical sound-recording methods; it was not until the problem of electronic amplification had been solved that the development was taken up again.

During and after the first world war, the United States Navy did some research work on magnetic recording and in 1921, A.C.-biasing was already being used [3]. Curiously enough,

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it was not until 20 years later that A.C.-biasing entered into industry, thereby starting the development of magnetic recorders in their present form.

Between the two world wars, German designers worked intensively on the improvement and further development of recorders using magnetic steel-wire, steel-tape and later also plastic-tape. The invention of the ring-shaped magnetic head [4] and the development of magnetic tape on plastic base [5] were important mile stones. In conjunction with efficiently constructed tape-drive mechanisms, they enabled the first commercial tape-recorder to be demonstrated at the Berlin Radio Show in 1935. This "Magnetophon" already possessed most of the features of modern tape recorders, with the exception of A.C.-biasing which, when it was introduced in 1940 [6], so improved the quality of magnetic recording that it henceforth surpassed by far all other sound-recording systems.

The recording medium.

Decisive for the construction of magnetic recorders are in the first place the physical properties of the recording medium. The steel wire and steel tape used in the beginning were soon superseded by plastic tape, although wire recorders are still used for some special purposes.

The 1/4 in. magnetic tape mostly used nowadays consists of a base of polyvinylchloride, cellulose acetate or polyesters, 20-50 μm thick and coated with iron oxide ($\gamma - Fe_2 O_3$). The thickness of the different makes of coated magnetic tape varies between 30 and 60 μm and their strength, elongation and ease of handling vary accordingly. The first task of the driving mechanism of magnetic recorders is to ensure that all kinds of tape will run smoothly and reliably in the machine without mechanical deformation.

Tape speed.

The design of the tape-drive mechanism depends largely on the adopted tape speed. Five speeds have been standardized internationally: 30, 15, 7½, 3.3/4 or 1.7/8 in./s. (76.2 – 38.1 – 19.05 – 9.53 – 4.76 cm/s), each tape speed being half the foregoing.

The speeds of 30 and 15 in./s are used exclusively in professional recorders; 7½ in./s is used as a Secondary Standard, in the professional field as well as in semi-professional and in high-quality home recorders. At present, the speeds of 3.3/4 and 1.7/8 in./sec. are intended especially for normal home recorders.

This relatively large number of tape speeds soon created a demand for multi-speed recorders. Nowadays, most professional recorders are made for tape speeds of 30 and 15 in./s or of 15 and $7\frac{1}{2}$ in./s; non-professional recorders for two or even three tape speeds. In professional recorders, the speed is changed electrically by switching the number of poles of the driving motor; in home recorders it is generally changed by mechanical means.

Tape transport.

However different the constructions of the various tape-drive mechanisms may be, they all aim primarily at making the recording medium run with constant speed and in intimate contact with the magnetic heads. The tape-drive mechanism also has to fulfil quite a number of secondary but no less important demands, e.g.: simple and easy operation, correct winding of the tape on the take-up spool, instantaneous stopping without excessive stress on the tape or formation of loops, facility of rapid winding and rewinding, simple location of a given passage on the tape with the aid of a programme indicator, etc.

To satisfy these demands, the basic professional design (fig. 1) uses three motors: the driving, the supply and the take-off motors.

During operation, the rubber pressure roller 8) is pressed against the capstan 7) by which it is driven; the rubber roller in its turn drives the tape by means of the friction existing between roller and tape, this friction being much larger than that between capstan and tape. Essentially thus, the tape speed is determined by the speed of the capstan. The supply spool 1) is fixed to the shaft of the supply motor which is circuited in such a way that it exerts on the tape a force opposite to the direction of tape travel (arrow in fig. 1). This force gives the tape the necessary tension to keep it well in contact with the erasing, recording and playback heads 3) 5) 6). It will be obvious that to avoid slip, this force must be small with respect to that exerted by the capstan/pressure-roller assembly.

The take-up motor supplies the torque necessary for winding the tape correctly on the take-up spool 11), which is fixed to the shaft of its motor. A programme indicator (time or footage counter) 10) is coupled with the right-hand guide roller. (9)

During rapid winding in either direction, the rubber pressure roller is lifted from the capstan (see dotted line in fig. 1), so that the tape runs free from both. At the same time a predetermined overvoltage is applied to either the supply or the take-up motor, depending on the direction in which the tape has to run, thus increasing the torque of the motor in question and hence the tensile force on the tape. By means of a circuit to be described later on, it is possible to adjust both the speed and direction of rapid winding with only one control. A tape lifter 4) enables the tape to be lifted from the magnetic heads

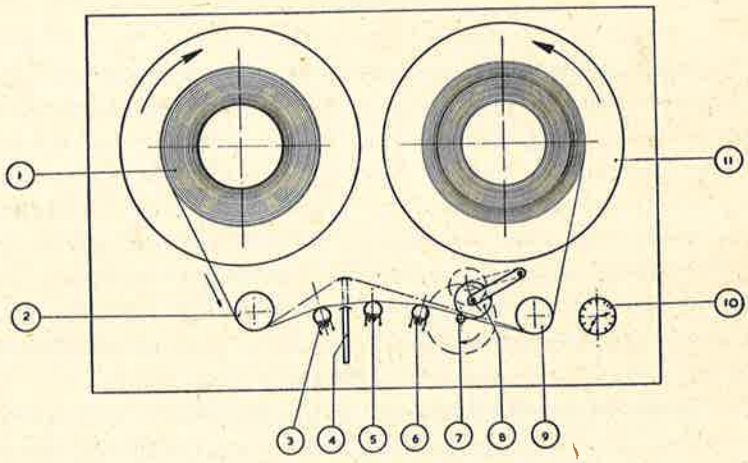

Fig. 1.

Tape transport.

1. Supply spool. 2. Guide roller. 3. Erase head. 4. Tape lifter. 5. Recording head. 6. Play-back head. 7. Capstan. 8. Rubber pressure roller. 9. Guide roller. 10. Time indicator. 11. Take-up spool.

during rapid winding, so as to minimize wear of the heads and also of the tape.

Nowadays, most professional and some semi-professional magnetic recorders are equipped with this three-motor tape-drive system. In lower-priced home recorders, only one motor is used; it not only drives the capstan but — via a mechanical link — it also supplies the required energy for take-up and rapid winding. These recorders usually have only one magnetic head for both recording and play-back and a common recording and play-back amplifier.

Speed control.

The considerable number of moving parts in magnetic recorders and the physical properties of the tape — which, because of its elasticity, is subject to length variations — make constancy of tape speed a leading, all-important problem of the mechanical design.

Variations in the speed with which the recording medium passes over the recording and the playback heads will result in undesired frequency variations during playback. These frequency variations can be cyclic if they are caused, for example, by the eccentricity of rotating parts, or complex if the tape is subject to varying elongation, e.g. due to unequal tensile force.

The physical magnitudes of speed i.e. frequency variations, are expressed in the rms or peak-to-peak deviation of either the speed or the frequency. When the tape speed v is subject to variations Δv, then the percentage of speed or frequency deviation is:

$$\varphi = \frac{\Delta v}{v} 100\,\% = \frac{\Delta f}{f} 100\,\% \ .$$

When the speed variation is caused by the eccentricity e of the capstan with the radius r, then the peak-to-peak deviation (fig. 2) is:

$$\varphi = \frac{\Delta v}{v} 100\,\% = \frac{2e}{r} 100\,\% \,.$$

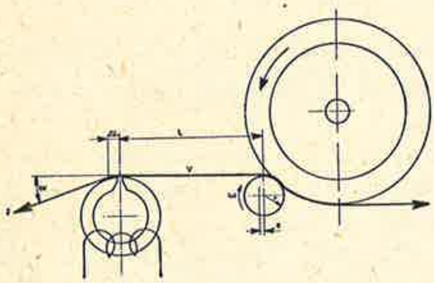

Fig. 2.
Capstan drive.

From this equation it can be seen that for a given eccentricity the peak-to-peak deviation increases as the diameter of the capstan decreases. Consequently, — although as will be explained later on, a capstan with a small diameter offers constructional advantages — the diameter cannot be reduced at will, this reduction being limited by the admissible variations of speed and by the precision which can be achieved in the manufacture of the capstan.

When the speed variation is caused by variations in the elongation of the tape due to a non-constant tensile force Z

and if this force Z varies sinusoidally with an amplitude $a Z_0$ (Z_0 = constant part of the tensile force), then $Z = Z_0 (1 + a \sin \omega t)$ (fig. 2) and the magnitude of the peak-to-peak deviation is:

$$\varphi = \frac{\Delta v}{v} 100\% = \frac{a Z_0 L}{v q E} 100\%,$$

in which L is the distance between the capstan and the head, v the rated tape speed, q the cross-section and E the modulus of elasticity of the tape.

From this equation it will be seen that the magnitude of the variation of speed is proportional to the distance between capstan and magnetic head and inversely proportional to the rated speed and the cross-section and modulus of elasticity of the tape. Consequently, the aim when designing magnetic recorders should be to make the distance between playback head and capstan as small as possible, whilst it should be taken into account that lower speeds and thin tape make the speed variations increase.

As regards the frequency of the speed variations, a distinction is made between "drift", "wow" and "flutter".

The term "drift" is normally used for slow deviations of speed which may be undirectional or which, if cyclic, occur at frequencies below about 0.1 cycles per second.

The term "wow" is normally used to refer to undesired variations of speed and frequency which can be recognized as changes of pitch, i.e. those occurring at frequencies below about 10 cycles per second.

The term „flutter" is normally used to refer to variations that are too high to be recognized as change of pitch, i.e. above about 10-20 cycles per second.

Whilst "drift" to a value of ± 2% is not annoying to persons with normal hearing, "wow and flutter" have — depending on the frequency at which it occurs — a more or less annoying psychological effect. Generally speaking, a percentage of "wow and flutter" up to a peak-to-peak value of 1% is tolerable; from 0.1% downwards the effect is imperceptible. However, this is only a rough approximation, since the frequency at which „wow and flutter" occur largely determines the extent of perceptibility.

For professional magnetic recorders, a "drift" of ± 0,2% and "wow and flutter" of 0,2% peak-to-peak are considered as admissible; for home recorders these values are — depending on the quality class – max. ± 2% for "drift" and upto 1% peak-to-peak for „wow and flutter".

In this connection it should be remarked that, due to the lack of standardization of the measuring methods, the values for "wow and flutter" as published by the manufacturers are not always comparable.

Capstan drive.

One of the most important factors in obtaining uniformity of tape motion is the design of the capstan drive, which is used almost universally in magnetic recorders. The relatively high speed of the capstan makes for a relatively great energy storage in the flywheel, which is normally attached rigidly to the capstan. The rubber pressure roller which normally is substantially wider than the tape, is a fairly simple means of transmitting the motion of the capstan to the tape. It will be obvious that the uniform angular velocity of the capstan and — as explained above — its eccentricity, largely determines the constancy of the tape speed. The moment of inertia and the speed of the capstan/flywheel unit are eminent design factors; they depend on the adopted tape speed, the diameter of the capstan, the bearing, the admissible weight and the required starting time. The lower the tape speed, and the smaller the chosen diameter of the capstan, the more difficult it is to maintain the tolerances of "wow and flutter".

The rubber pressure roller is required to run lightly on its axle and also to be reasonable free of eccentricity, otherwise the capstan would be loaded too heavily or unequally. As the rubber surface of the roller is deformed by the pressure with which it bears against the capstan the surface speed of the rubber changes at the place where the roller is in contact with the capstan. This "creepage" of the rubber affects to some extent the speed of the tape and may cause drift. The harder the rubber, the slighter this effect will be, but the smaller will also be the friction between capstan and rubber, resulting in an increased risk of slip. The hardness and the friction coefficient of the rubber, as well as the pressure between capstan and roller, have therefore to be matched and adapted to the tensile and take-up forces provided for in the general design. Moreover, it should be kept in mind that the tape should contact the capstan before it contacts the rubber surface of the roller.

In professional recorders of modern design the driving motor, the capstan flywheel unit, the solenoid-operated rubber pressure roller and the solenoid-operated stop brake are assembled to one unit (fig. 3). The driving motor may be either a synchro-

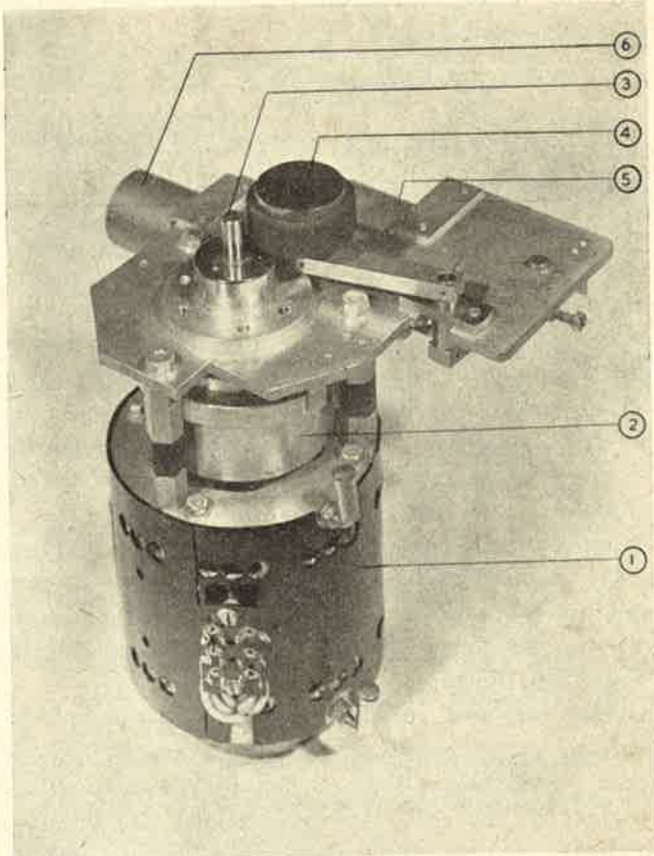

Fig. 3.
Capstan drive assembly.
1. Synchronous motor. 2. Flywheel with flexible coupling. 3. Capstan. 4. Rubber pressure roller. 5. Solenoid actuating the rubber pressure roller. 6. Solenoid actuating the flywheel stop-brake.

nous induction or a hysteresis type, both with two interchangeable speeds. This motor drives the capstan/flywheel unit via a flexible coupling. The mass of the flywheel, together with the compliance of the coupling, constitutes a mechanical filter which effectively filters out any irregularities in the angular velocity of the synchronous motor. For tape speeds of 30 and 15 in./s, the motor speed is mostly 1500 and 750 r.p.m. respectively and the diameter of the capstan about 9,7 mm with a maximum admissible eccentricity of 0,0015 mm.

Non-professional recorders often employ the motor shaft itself as a capstan or the capstan/flywheel unit is driven by an asynchronous induction motor via a rubber-covered idler or plastic belt.

Tape supply.

The most convenient method of maintaining the necessary tension in the recording medium is to use a constant-torque supply motor. A torque motor is any motor with a maximum torque at standstill, and the type mostly used is an A.C. induction motor with a three-phase stator and a high-resistance rotor. This type of motor can also be fed by a single-phase source, the necessary phase shift being introduced by a capacitor.

When a torque supply motor is used, the result is not only a smooth drag, but also a convenient high-speed drive for fast winding. A drawback arising from the constant torque is that the drag force increases as the diameter of the tape reel decreases. As long as this drag force is small with respect to the force exercized by the capstan, this effect is not troublesome. When, for any reason, a constant tape tension is required, i.e. when it is not permissible for the drag force to alter along with the diameter of the reel, an additional variable torque has to be applied to provide for the necessary hyperbolic speed-torque curve.

Alternative methods of obtaining the necessary tape tension — used chiefly in the non-professional field — are the use of mechanical friction brakes on the supply reel or of pressure pads somewhere in the tape path between supply reel and magnetic-head assembly. Slipping belt drives or eddy-current magnetic clutches are also used for this purpose.

Whatever the adopted tape-tensioning system may be, it is chiefly the drag force and the design of the capstan drive that determine the extent of "wow and flutter" for the reasons explained above.

Rotating elements in the path between supply reel and capstan must run smoothly and be free of any appreciable eccentricity; the natural resonance of resilient pressure pads must be adequately damped.

Contact between head and tape.

Besides tape-speed control, the contact between tape and magnetic heads is the principal aim of magnetic-recorder design. It has been found that spacing loss in the reproduction of a recorded wave length λ can be expressed by the empirical equation:

$$\text{spacing loss} = 55 \frac{d}{\lambda} \text{ decibels}$$

when there is a distance d between the playback head and the magnetic medium.

This equation shows that the spacing loss depends on the wavelength and that this effect has to be taken into account especially at the shorter wavelenghts, i.e. the higher frequencies. For a recorded wavelength of 10 μm, for example — easily obtainable with recorders of good design — a spacing of only 1 μm causes a loss of about 6 dB.

When the tension in the tape is Z (fig. 2) and the angle of incidence (i.e. the angle at which the tape approaches the head) is a, the force with which the tape is pushed against the head is

$$P = Z \sin a\,.$$

Because of the relatively high tape speed — and subsequent relatively long wavelengths — of professional recorders, a drag force of about 100 grams, applied at a rather small angle, is sufficient for obtaining a good contact.

The smaller the tape speed (i.e. the shorter the wavelength) — and the stiffer the tape — the larger has to be the drag force for providing the adequate contact.

To avoid subsequent high stress on the tape at lower tape speeds, light pressure pads are often used at the head gaps. Pads increase the wear of the heads and introduce to some extent maintenance difficulties because of tape deposit, but the improvement in performance will often be decisive.

Take-up design.

The design considerations for tape take-up are similar to those for tape supply, although short variations of the take-up tension affect the "wow and flutter" much less than variations in the supply tension.

Normally, professional recorders are equipped with a separate take-up motor of the same or similar construction as the supply motor. This has the advantage that the motor can be used also for fast winding. When it is a constant-torque motor, the tape tension varies in accordance with the diameter of the reel. If this tension is small with respect to the retaining force exerted by the capstan/pressure-roller assembly, and if the capstan is driven by a synchronous motor, then it is, as a rule, permissible for the tape tension to alter along with the diameter of the reel. However, when constant tape tension is, for some reason, indispensable, the speed-torque curves of the motor have to be corrected as described for the supply motor.

For non-professional recorders where a common induction motor is used to supply energy to both the capstan and take-up spool, it is necessary to add a constant-torque mechanical take-up clutch so as to avoid a variable load on the motor, the power consumption of such a clutch being constant and independent of the slip. For a 7 in. reel, the tape tension then varies by approximately 3 : 1.

Brakes.

The task of the brakes is to stop the tape in the shortest possible time and without excessive stress during recording, playback and rapid winding, and to block the spools against rotation during standstill.

For low-speed recorders, this task is not difficult to fulfil; for professional recorders, however, which have a higher speed, spools of considerable mass and a higher winding speed (90 sec for 3300 ft = 1000 m of tape), special attention has to be paid to the construction of the brakes. The braking elements commonly used are feltlined strips, or cushions, coupled either direct or indirect with the supply and take-up systems. Important for stopping is that the hold-back spool be braked more powerfully than the take-up spool, so as to avoid the formation of loops.

This is achieved by employing opposite-action brakes for the supply and take-up system (fig. 4). When the braking wheels (1) rotate in anti-clockwise direction, the braking force is:

$$\text{on the left-hand brake: } Z_1 = Z_0\,(e^{\mu a} - 1),$$

$$\text{on the right-hand brake: } Z_2 = Z_0\,(1 - e^{-\mu a}),$$

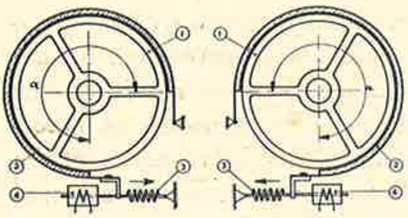

Fig. 4.
Braking system of tape supply and take-up in professional recorders.
1. Braking wheel. 2. Braking strip. 3. Spring. 4. Lifting solenoid.

in which Z_0 is the tensile force of the spring, α the angle over which the braking strips lie on the braking wheel and μ the friction coefficient between brakestrip and braking wheel. Because of the difference between the braking forces Z_1 and Z_2, the left-hand reel is braked more powerfully than the right-hand one and the tape is stopped under tension. When the tape runs in the inverse direction, the right-hand spool is braked more powerfully than the left-hand one and thus the effect is reversed automatically.

The most convenient method of operating the brakes is by means of solenoids (fig. 4). Thereby the braking strips, which during standstill are pushed against the brake wheels by means of the spring, are released against the force of the spring by means of the solenoid as soon as the recorder is started. This system has the further advantage that, should the mains voltage fail, the tape spools are braked automatically, and that the brakes can also be released whilst the recorder stands still, by operating the solenoids separately. This is very convenient for editing purposes.

When solenoids are used, even when direct current is applied for actuating the solenoids, special measures have to be taken to screen the magnetic heads against their magnetic stray field, because a weak constant field will cause an appreciable increment of the noise in the recording.

Rapid winding and rewinding.

A requirement of both professional and non-professional recorders is that the tape should be capable of rapid winding in either direction. With the three-motor tape-transport system this is achieved with the aid of the supply and take-up motors. When induction motors are used for supply and take-up, an increased voltage is applied via a common series resistor (fig. 5). When the sliding contact of the resistor is in its centre position, the same voltage is applied to both motors and they have the same torque. When the sliding contact is shifted to the

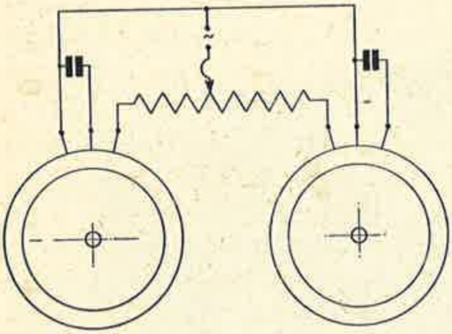

Fig. 5.
Circuity of supply and take-up motor for rapid winding.

right or to the left, an over-voltage is applied to the corresponding motor and its torque increases accordingly. Thus rapid winding in both directions and with adjustable speed is achieved with only one control.

With mechanical supply and take-up systems, the spool concerned is given an increased speed by means of idlers or belts, whilst at the same time the other spool is braked slightly. With this system, the winding speed is, as a rule, not adjustable, but most recorders with this braking system are so designed that a full reel of tape is wound or rewound in max. 2-3 min.

Operation and maintenance.

Simple operation is of the utmost importance for magnetic recorders. Push-buttons are preferred both in the professional and in the non-professional field. Modern studio recorders are operated fully electrically with the aid of relays and can be remotely controlled (fig. 6). Reliability and minimum of maintenance require "field tested" constructions.

The method of bearing of rotating parts and maintenance of the bearings call for the special attention of the designer. With a view to easy maintenance, ball-bearings are most favourable, but they are noisy and not accurate enough, unless they are of the highprecision type and mounted with the utmost care. Because of their inherent noise, it is not advisable to use ball-bearings for parts rotating with a speed of more than 1500 r.p.m.; these parts run mostly on sintered oilite bearings. Home recorders are equipped exclusively with these bearings which — due to their self lubrication — have favourable running properties.

For the choice of the most adequate lubricants, it should be borne in mind that magnetic recorders are used at greatly divergent temperatures and therefore only those lubricants enter into consideration whose viscosity is as little as possible affected by ambient temperature.

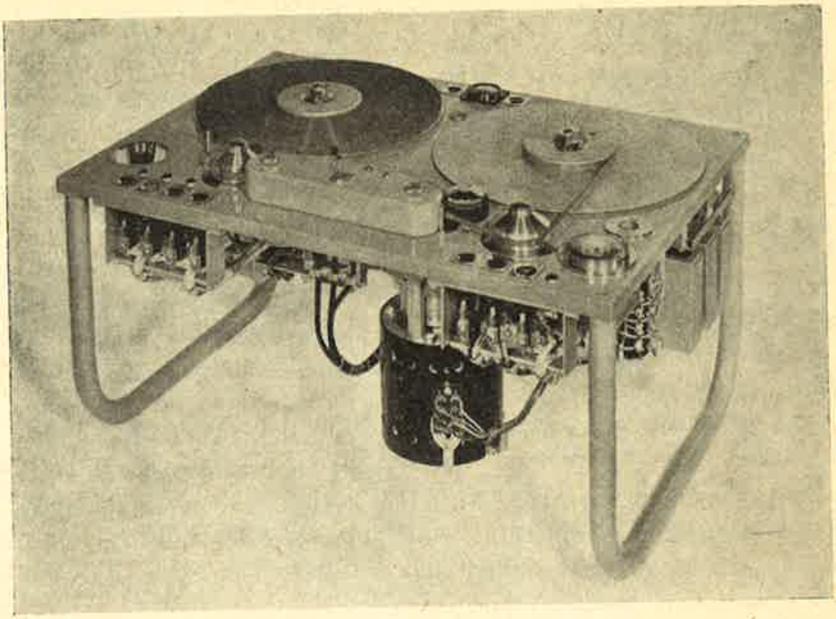

Fig. 6.
Tape deck of a two-speed magnetic recorder for professional use.

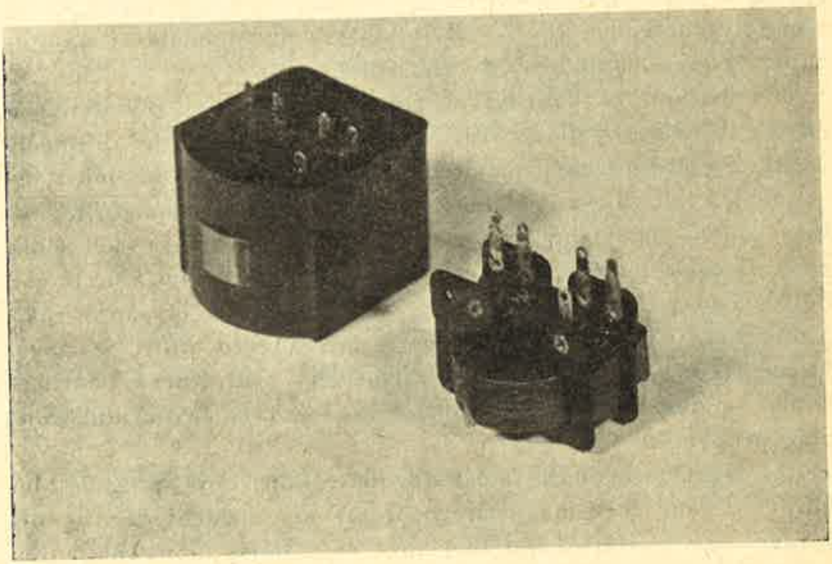

Fig. 7.
Play-back head, mechanical assembly (right) and completely embedded (left).

Well designed recorders are expected to operate at least 500 hours without requiring maintenance.

Magnetic heads.

Erasing heads of modern construction are built up of ferroxcube pole pieces; they have one or two gaps each with a length of 100-300 μm. These erasing heads have much lower eddy-current losses than those of mu-metal and their wear-resistance is much higher. Because of the relatively long gaps, the design and manufacture give no difficulties.

The recording and the playback head, with a gap length of 5-10 μm, have, as a rule, laminated pole pieces of high-permeability, low-remanence materials such as Permallcy or mu-metal. These metals have to be annealed and laminated carefully, in order to achieve and to maintain the required magnetic properties.

From the multitude of constructions, one playback head will be described as an example for obtaining maximum precision with a minimum of parts.

The head (fig. 7) is built up of two identical pole pieces, each provided with a coil; the coils are circuited in such a way that the generated voltages are series-additive for the magnetic field across the gap, but phase opposing for external magnetic fields. Because of these properties and of their geometric symmetry, pick-up of hum by the head is reduced to a minimum. The surfaces of mutual contact on the pole pieces are lapped with optical precision and a spacer of non-magnetic material is inserted between them. The spacer — mostly of beryllium-copper or another wear-resistant material — prevents the accumulation of dirt or metal particles in the gap and allows narrow manufacturing tolerances to be maintained in the length of the gaps. In professional recorders, the maximum admissible tolerance in self-inductance of the head is 5%, and as the tolerances of self induction are approximately proportional to those of the gap length, a gap with a rated length of for example 7 μm should have a tolerance of about 0.1 μm while other parts, such as coils and the permeability of the pole pieces are also subject to tolerances!

A convenient method of protecting the head is to embed it in a suitable epoxy resin and let only that part of the pole pieces protrude over which the tape runs. This part is lapped after the resin has hardened. Nuts or other fixing parts of the head can also be embedded in the resin.

In order to avoid static charges forming on the tape, the pole pieces must be carefully earthed. Measures must be taken to compensate for differences in the thermal-expansion coefficients of the pole pieces and the resin.

Equipment for non-standard magnetic tapes.

For special applications, other tapes than the standardized 1/4 in. size are used. As a rule, special recorders, which differ from the conventional design, have been developed for this pur-

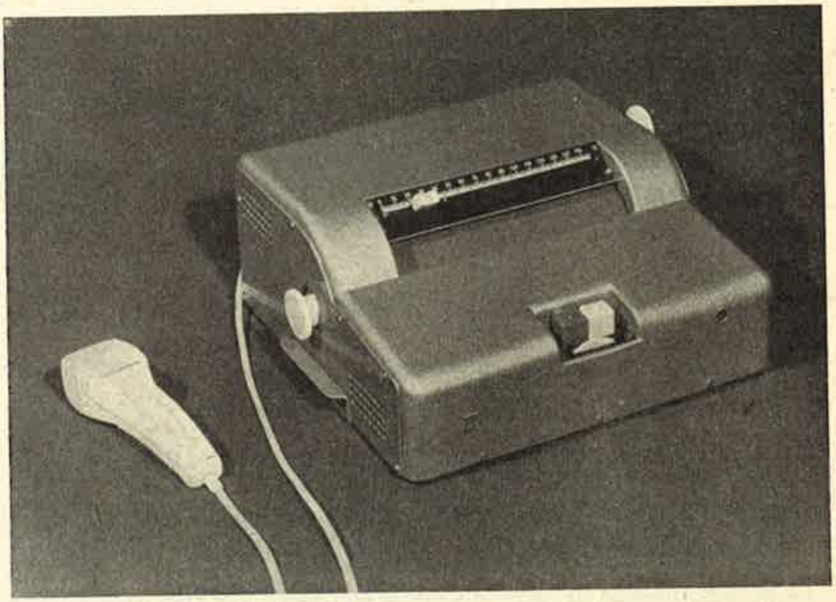

Fig. 8.
Dictating machine using an iron-oxyde coated sheet as the recording medium.

pose. Some examples may illustrate this field which is steadily extending.

For dictation machines, it has been found favourable to use magnetic sheets of letter size. These sheets have the same thickness as tapes; in the dictation machine (fig. 8) they are wound on a cylinder which rotates at constant speed. The end of the sheet overlaps the beginning. The magnetic head, which is used both for recording and for playback, lies against the cylinder and is moved with constant speed parallel to the axis of the cylinder, thereby recording a helicoidal sound track on the sheet. The head can also be moved by hand for starting rapidly from any desired „line".

The linear speed of the sheet is about 1.7/8 in./s and the registered frequency range extends to about 3000 c/s. The signal-to-noise ratio for a track width of 1 mm is about 40 dB.

Magnetic discs are also used for dictation purposes. In prin-

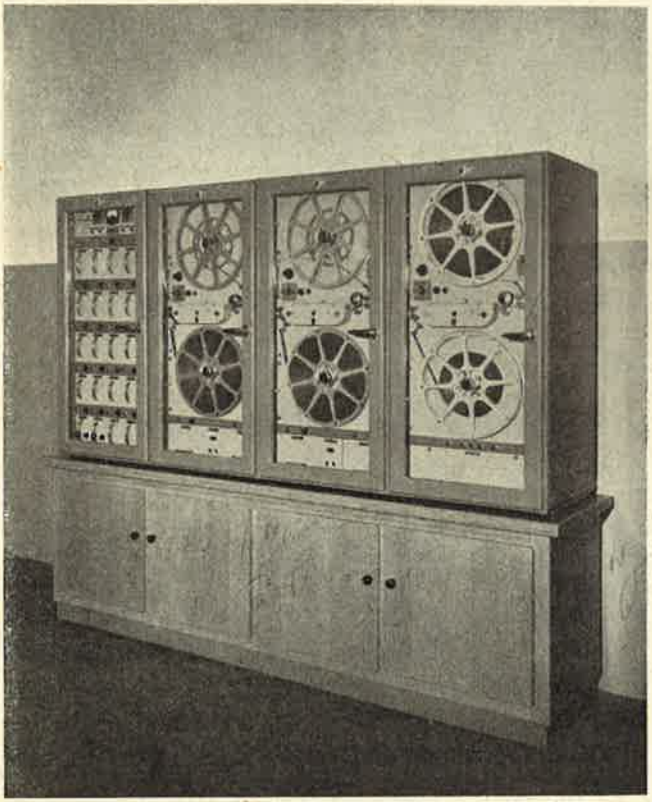

Fig. 9.
Multichannel magnetic recorder using 16 mm tape as the recording medium.

ciple, the recorder resembles a record player, but with a magnetic head instead of a pick-up. The magnetic head can be led either by grooves in the disc or by means of the mechanism itself. It will be evident that with this system, as in a record player, the linear speed of recording is not constant.

For multichannel recording, magnetic tape of non-standard width is mostly used. One of the latest designs (fig. 9) employs

16 mm tape and is suitable for recording simultaneously 15 tracks, each having a width of 0.7 mm and each spaced 0.35 mm apart. Cross-talk between the tracks has to be better than -40 dB. The tape speed normally used is 1.7/8 in./sec and the capacity of the reels is sufficient for uninterrupted recording up to 12 hours. Tape transport is rather conventional. The multichannel magnetic heads (fig. 10/11), however, with a gap length of 5 μm, present special problems as regards positioning of the tracks, shielding and manufacturing tolerances.

In the cinema field, fully iron oxyde coated or striped films of 8, 16, 35 or 70 mm width are in use for sound recording and reproduction. For these films, mostly conventional methods of propulsion are used, viz by means of sprockets. A special problem is here the contact between film and head, because cinema films are much stiffer (thickness 150 μm) than tapes.

For some applications, magnetic coating is applied to the periphery of a rotating wheel of metal or of another suitable material. Such wheels are used, for example, as a magnetic "memory" in electronic computers and in machines for producing artificial reverberation (fig. 12). In these machines, the heads are not in direct contact with the magnetic medium; they are placed at a distance of a few μm from the wheel. This guarantees a long life and constancy of the electrical parameters of both coating and heads. Because of the distance between head and wheel, the magnetic medium must have a higher linear speed for recording or reproducing a given frequency range than when there is a direct contact. Moreover, eccentricity of the wheel causes variations both in output and in frequency, Consequently, the wheel must satisfy very high centricity demands and special attention has to be paid to the thermal expansion of the system. The wheel diameter, the number of r.p.m. and the distance between head and wheel have to be carefully matched.

Probable future development.

There is a gradual tendency to consolidate the tape speeds for conventional sound recording and reproduction. Designers are therefore concentrating more on the refinement of details, the improvement of quality and the application of operational features. Examples are: the development of ferroxcube recording and playback heads; two or threechannel recording for stereo-

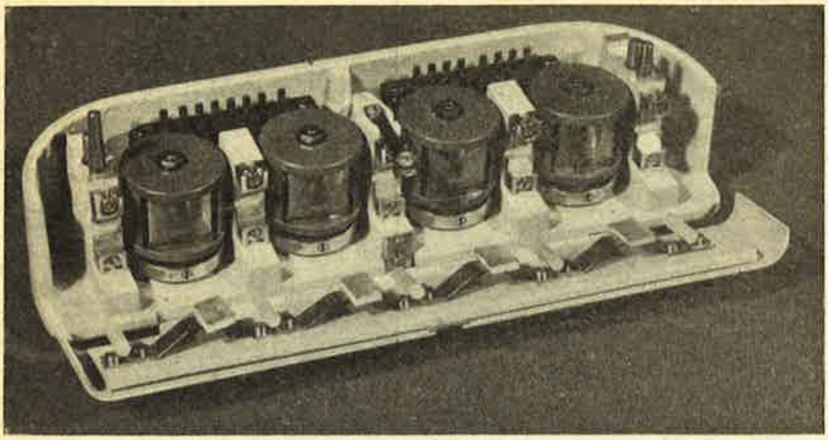

Fig. 10.
Magnetic-head assembly of a 15-channel recorder.

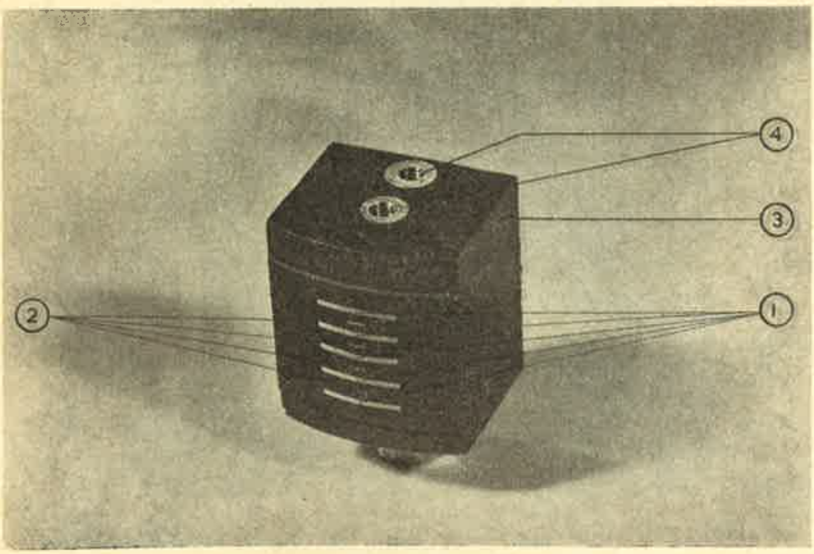

Fig. 11.
5-channel magnetic-head.
1. Head cores. 2. Mu-metal shielding. 3. Polyesther-resin.
4. Fastening nuts.

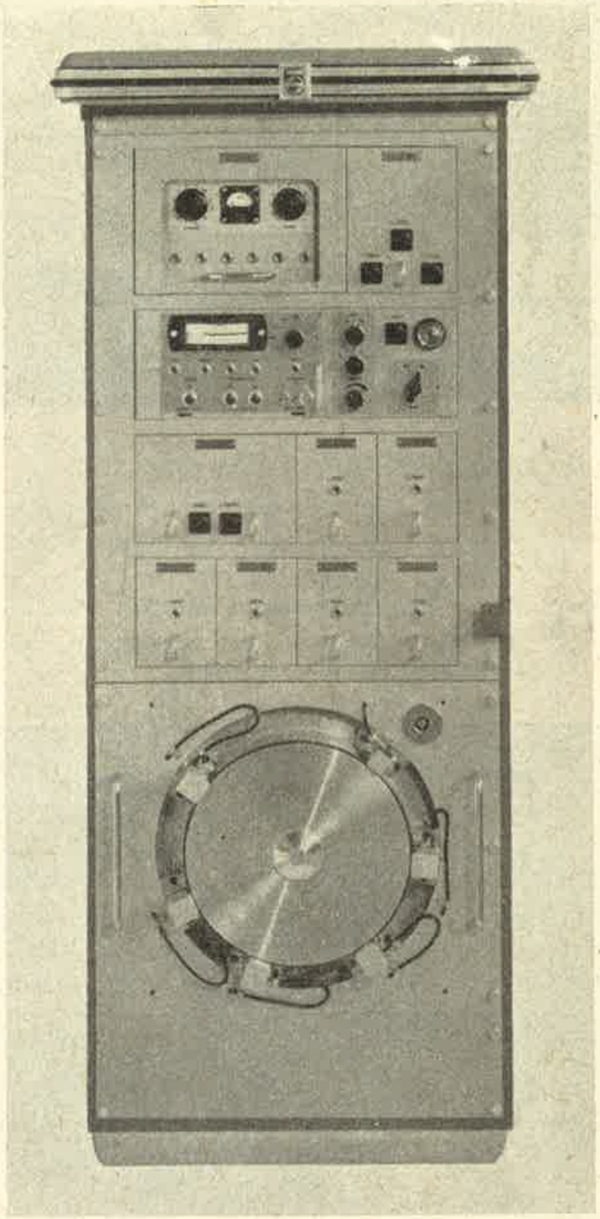

Fig. 12.
Artificial-reverberation machine, using an iron-oxide coated wheel as the recording medium.

phony; separate recording of high and low frequencies for the reduction of intermodulation distortion, and the incorporation of professional features in home recorders.

In the field of video recording on magnetic tape, many design problems still await a practical solution. Increased tape speed, higher demands on speed constancy and ferrite heads with gap lengths in the order of 1 μm are only a few examples of the multitude of difficulties which have to be overcome.

In industry, the automation of production is opening up an entirely new field of application. Magnetic recording represents a simple and flexible means of recording and transmitting the parameters for automatizing the operation of production machines or other stages of manufacture. The development of automation has just been started, and if it comes to that, so has magnetic recording.

APPENDIX

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Music-reproduction

by R. Vermeulen *)

Lecture delivered for the Nederlands Radiogenootschap and the Geluidstichting on 17th June 1955.

During the demonstration at the meeting of the „Nederlands Radio Genootschap" in the auditorium of the Philips Theatre in Eindhoven we took full advantage of the unique opportunity to let a large group of colleagues hear just those results of our work that cannot be expressed in words, still less in print. It is therefore difficult to render in this report the impression that the music made on the listeners. We can do no more than describe the experiments and hope that the reader will judge their results from the fact that they could be demonstrated successfully. The principles can be found in other papers [1] whereas a description of the apparatus used is not interesting because it was assembled from parts that are on the market. What we tried to prove is that at present the relevant problem is not to perfect the microphones, amplifiers, or even loudspeakers but to improve the ways in wich they are used.

When the performance of a small band, consisting of piano, clarinet or saxophone, accordeon, double bass and drum section was followed immediately by the reproduction of a magnetic recording of the same music, I think that all present were convinced that, although the difference was small, they were quite able to distinguish the "recorded" from the "live" music. In order to convince the listeners that this was really not so easy, we had to eliminate the visible clues, which influence our judgment much more than we realize. In former experiments we placed loudspeakers and musicians behind a very thin, but opaque curtain [2]. This time, instead of eliminating all clues, we gave more or less false ones. This was done by making beforehand a recording of the band in which alternatively several instruments, or even all but one, were silent part of the time. During the reproduction the musicians filled in the missing parts. This made it possible for a musician to stop in the

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middle of a solo, replace his clarinet by a saxophone, and start a duet with his own clarinet wich had gone on playing all the time. The same procedure was used in the „farewell-number", where one by one the musicians put down their instruments and walked away while the music went on. As they did so several bars after the recording had taken over, and made sham-motions in the meantime, it was only by their ears that the listeners could get a clue as to the exact moment when the recording replaced the "live" instrument. Another experiment was to make a recording of only two hands in a dance for four hands by Grieg, and to fill in the other part while this recording was reproduced.

For the reproduction of a piano and of the small band too, a record with only one track was sufficient, but many loudspeakers distributed over the stage had to be used, otherwise the listeners would have located the source in the one loudspeaker. For the reproduction of a symphony orchestra it becomes necessary to use stereophony. No matter how accurately one can imitate stereophonically a large orchestra, the results will not be satisfactory if the acoustics of the listening room are inadequate. For example, the acoustics of the Philips Theatre are quite good as such, but are unsuitable for a concert by a large symphony orchestra, still less for church music. Therefore to demonstrate the quality of pure stereophony we chose a minuet from a symphony by Mozart, for which a short reverberation time is preferable. No symphony orchestra was present to enable a comparison to be made.

The acoustics of a theatre can however be improved by supplying the missing wall-reflections by means of loudspeakers distributed along the ceiling. A microphone above the stage picks up the music, which is recorded on the magnetic rim of a wheel. Several reproducer heads feed the music with different retardations to the loudspeakers in such a way that no two neighbouring ones are connected to the same head. The signal from the last head is moreover fed back to the recording head. By changing this feed-back the reverberation time can be controlled.

Mr. Harm de Vries played a sequence of chords on the organ, while the artificial reverberation was switched on and off. In this way it was possible to hear the change in reverberation as such. To show its musical value Mr. de Vries extemporized in different tempi: adagio, allegro and majestuoso, and then accompanied Mrs. Groenenberg, who sang a piece of music by Joh. Sebastian Bach. I do not think there was any difference of opinion on the musical value of the "stereo-reverberation" as we call this electro-acoustic improvement of the acoustics of the hall. "Stereo-reverberation" is characterized, not so much by the lengthening of the reverberation time, as by the greater diffuseness of the sound, which gains a fullness and volume that is obviously missing when the loudspeakers are switched off.

The final chorus of the Passion according to St. Matthew by Joh. Sebastian Bach, as recorded in the Philips Theatre by the Philips Orchestra and the Philips Philharmonic Choir directed by Henri Arends, was reproduced in the same hall, but now with stereo-reverberation added. To eliminate the conflict between the visual and audible impression of the room the lights were dimmed. This demonstration has already been given many times but it never fails to impress on the listeners the magnificence of Bach's music. This proves that, even with amateurs as executants, recorded music can do justice to the essential values of music, if only attention is given to the distribution of the sound after it leaves the loudspeakers.

During the last season an experimental installation for stereo-reverberation in the „Gebouw voor Kunsten en Wetenschappen" in the Hague has been in use during all concerts of the „Residentieorkest" and several opera's and recitals. While the musicians are consciously aware of the improved acoustics and find it easier to play their instruments, most of the public is of the opinion that it is the orchestra that has improved and is playing much better than before. This is, in our opinion, the highest praise possible for an electro-acoustic installation.

Literature

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