Factors Affecting Frequency Response and Distortion in Magnetic Recording

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Methods of improving fidelity in magnetic recording are discussed.

AS ONE physics professor often remarks to his classes, before one can make rabbit soup one must first obtain the rabbit. Such is the case in magnetic recording—before one can intelligently design and use a system one must first obtain certain fundamental information concerning its operation. It is the purpose of this discourse to shed a little light on some factors affecting the frequency response and distortion occurring in magnetic recordings.

It is well known that the speed at which a recording medium is moved past the recording and reproducing heads affects, to a very great extent, the frequency response to be expected. This is true regardless of the method of recording, but it is very easy to demonstrate in the case of magnetic recording.

High Frequency Response

All things being equal, the high-frequency response of a magnetic recording system varies nearly directly as the speed of the medium is varied. This can be readily understood when one considers that a certain minimum wavelength can be reproduced by the playback head. A certain wavelength will be recorded for a given frequency and recording medium speed. Thus it follows that by increasing the speed a shorter wavelength will be recorded which the reproducing head will be able to resolve.

The finite scanning width of the gap used in the recording and reproducing heads has a considerable effect on the high frequency response. Generally, the shorter the scanning gap the greater will be the resolution and consequent high frequency response. Heads for recording on and reproducing from a 0.004 inch wire are usually manufactured with a small piece of 0.001 inch non-magnetic material inserted in the magnetic structure to provide the gap. However, heads for use with tape may be constructed with practically no physical gap, the magnetic gap being caused by a butt joint in the pole piece structure. The resultant discontinuity causes the effective gap.

It is interesting to note that the gap in the *recording* head is not too important because the high-frequency response is a function of the sharpness of the field at the leaving edge of the head.[1] Heads have been constructed which give a very good high frequency response when the wire is run over them in one direction while running the wire in the other direction resulted in very poor high-frequency response. This phenomenon was due to the field at one side of the gap being very sharp while the other side was very broad. In the case of *reproducing* heads such is not the case because the resolution depends upon the sharpness of the entire gap field. Of course, it is usually the case that the recording head serves also as the reproducing head so it is necessary that this head be very carefully constructed to give a symmetrical and sharp field distribution.

Heads can be constructed which have a very peculiar frequency response. Reference to *Fig. 1* will illustrate this fact. The frequency response curve is for a wire running at four feet per second, and it will be noticed that the first peak occurs at approximately 90 cycles. Consideration of the dimensions of the head will indicate that the first peak should occur at 96 cycles, which is the frequency at which the head structure is one-half wavelength long. These bumps are a result of residual poles which occur at or near the edges of the pole piece used in the head. Various dodges have been used to overcome these irregularities. They usually involve making the head long with respect to the longest wavelength to be reproduced. One head, known as the closed type, when properly constructed, gives very smooth response at low frequencies resulting in a curve having a slope of approximately 6 db per octave, increasing with frequency. This head, however, has a very great disadvantage in that the wire must be threaded through the coil which completely surrounds the wire. Similar effects are noticed in tape heads but to a lesser extent than in wire heads.

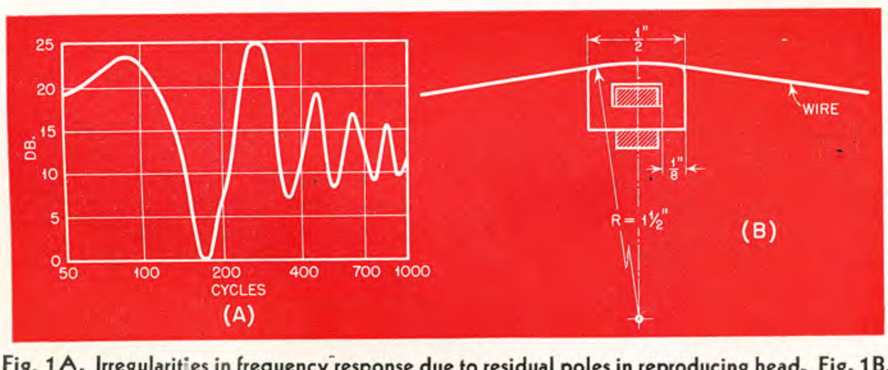

Fig. 1A. Irregularities in frequency response due to residual poles in reproducing head. Fig. 1B. Dimensions of head producing curve shown.

Magnetic Characteristics

The magnetic characteristics of the medium and their effect on the frequency response have been well discussed in the literature.[2] It has been shown that, from a consideration of the principles of magnetism, the high-frequency response is a function of the coercive force while the output at low and middle frequencies is a function of the residual magnetism. This generally is true, but some data have been obtained which tend to show

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[1]Field Measurements on Magnetic Recording heads, Clark & Merrill, Page 1580. *Proc. I. R.E. & Waves & Electrons*, Vol. 35, No. 12, Dec. 1947.

[2]Theoretical Response from a Magnetic-Wire Record. Marvin Camras, *Proc. I. R. E. & Waves & Electrons*, Vol. 34, No. 8, Aug. 1946.

TABLE I.

Hc	Ratio of output at 12 kc to output at 1 kc
320	−9.5 db
285	−2 db
285	−6 db
285	−5 db
260	−13 db
260	−9 db

Speed = 4′/sec.
Bias frequency = 65 kc.
Amplitude adjusted for maximum output at 1 kc.

otherwise. *Table 1* illustrates this fact by showing that the wire with coercive force of 320 gauss has a lower high-frequency output than one with a coercive force of 285 gauss, and is about the same order as one with a coercive force of only 260 gauss. It will also be noted that the three wires with a coercive force of 285 gauss have rather wide variations in their 12 kilocycle outputs. These data were taken, and very carefully checked, using a wire drive of four feet per second, a bias frequency of approximately 65 kilocycles, and with the bias amplitude adjusted for the maximum reproduced signal at 1000 cycles. The exact cause of this effect is not known but there seems to be reason to believe that it lies in the composition of the material. Wires of other alloys than the widely used 18-8 stainless steel greatly affect both the output and frequency response with the result that some wires give as much as 10 or 12 db higher output for the same recording level.

The supersonic bias, used to enhance the recording characteristic of a medium, affects the high frequency output of a magnetic record in the following manner. As the bias is increased from a very low value, the output from the reproduce head increases with little change in frequency response. However, after the value of bias which gives maximum output at a medium frequency is reached, any further increase will cause a decrease

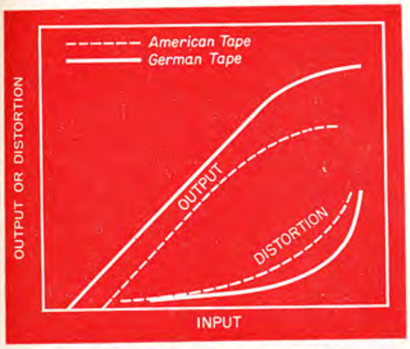

Fig. 2. Relation of input-output curves to degree of distortion.

in the high frequency output. This effect, which may be very serious at high bias currents, is apparently caused by self-erasing of the recording due to the strong bias field.

It is obvious that the amplifiers used with a magnetic recording system must be capable of reproducing the desired frequency response. It is well known that the output from a magnetic reproducing head in the low frequency region is a differential function. In view of this fact, it is necessary to add integration to the "reproduce" amplifier to compensate for the decreased output at the low frequencies. This imposes very stringent requirements on high quality systems in that the hum originating in the reproduce amplifier must be held to a very low value. Likewise the stray pickup of the reproducing head must be very low. This leads to various shielding and hum bucking schemes, none of which works to perfection! In wide band *wire* recorders particularly, the reproduce amplifier must have very low noise for best results because the output from the playback head at, say 50 cycles, is in the order of 200 microvolts at the first grid with a signal having low distortion. Tape systems can be designed to give considerably greater outputs than this, making

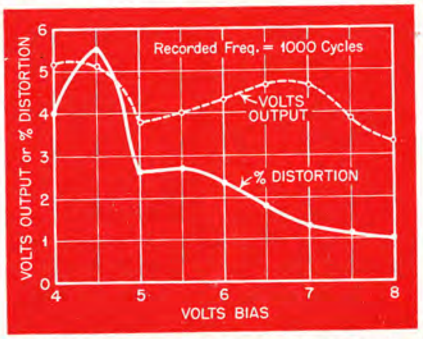

Fig. 3. Distortion as a function of bias applied to the recording head.

amplifier noise requirements less stringent.

The distortion in magnetic recordings is affected principally by the bias and medium used, and to a lesser extent by the amplifiers associated with the equipment.

As will be seen in *Fig. 2*, the input versus output curve of a magnetic recording medium is a fairly good indication of the distortion characteristics. The dashed curve is characteristic of most available magnetic recording media in which the straight portion of the input-output curve is relatively short, resulting in appreciable distortion at relatively low outputs. The solid curve is characteristic of some newly developed material in which the input-output curve has a relatively longer straight portion resulting in higher output for a given amount of distortion. However, it should not be overlooked that the two approach the same value of distortion at high recording levels. Furthermore, the medium with the longer straight portion will give very serious distortion on overload if it is not operated properly. The fact that some magnetic recordings do not "blow up" on serious overload, as is the case in other recording systems,

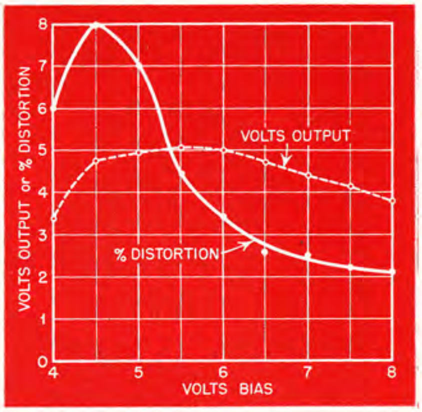

Fig. 4. Distortion vs. bias curves at 100 cycles.

may be attributed to the shape of the distortion characteristic as compared to the recording level.

The decision as to the shape of the distortion curve at maximum recording levels could very easily be difficult in some materials. Naturally it would not be desirable to use a material which had a very steep and abrupt curve because the distortion would increase very rapidly with even slight overload. Conversely, a medium would not be particularly desirable which has a very shallow curve because appreciable distortion may be generated at very low recording levels, thus limiting the signal-to-noise ratio available. It follows, then, that a compromise must be made in which a suitable signal-to-noise ratio is obtained with a satisfactory distortion curve.

When a system using direct current for bias or erasing purposes is designed the engineer must take into account the fact that serious even order distortion will result therefrom. This is not the case in a system using alternating current for bias and erasing purposes. It should be noted that some materials have more susceptibility to even order distortion arising from d-c bias or erase than others. Furthermore, it should not be assumed that just because a system is using a.c. for bias and erase that no even order components are present. Some peculiar effects arise, from time to time, due to accidental magnetization of improperly treated heads through switching transients, head construction, and other causes. Usually it is possible to detect magnetization in heads through the increase in background noise.

Bias Level

In general, the higher the value of the supersonic bias used on a recording head the lower will be the distortion in the reproduced signal. Here a compromise must be made between the maximum level which can be recorded and the desired frequency response because, as mentioned above, higher bias reduces the output at high frequencies. *Figure 3*

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bottom. An enlarged view of the control panel is shown in *Fig. 13*. The four controls on the bottom row are the microphone faders; at the upper left is the feedback gain control while the one at the upper right is the reverberation main gain. Transfer switch S_1 is at upper center. Equalizer and filter elements, except Eq. 3, are mounted at the rear of this unit.

The coils of one-inch aluminum pipe shown in *Fig. 14* have a maximum diameter of approximately five feet. Taping of the microphones was done after the photograph was made. Eq. 3 was mounted in a small aluminum box below the lower driver unit. The supporting framework shown was shock mounted to one wall of a relatively unused room, and so far no trouble has been experienced from accidental pickup of voices in the room. Each turn of pipe was isolated from the wood frame by a layer of sponge rubber. Forming the coils was easy because the tubing was quite soft.

REFERENCES

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[2]P. C. Goldmark, P. S. Hendricks, Synthetic Reverberation, *Proceedings IRE*, p. 747, December, 1939.

[3]J. K. Hilliard, Reverberation Control in Motion Picture Recordings, *Electronics*, p. 15, January, 1938.

[4]H. F. Olson, Elements of Acoustical Engineering, 1940. D. Van Nostrand Co.

Magnetic Recording

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shows the distortion in a reproduced signal of 1000 cycles from a 0.004 inch 18-8 stainless steel wire running at four feet per second as a function of the bias applied to the recording head. Also shown is the output resulting for the bias used. The input to the head was maintained at a constant value for these data. It can be seen that for the higher values of bias considerably less distortion is generated. However, this curve does not show the reduction in high frequency response caused by the higher bias. *Figure 4* is similar to *Fig. 3* except that a frequency of 100 cycles was used instead of 1000 cycles. It will be seen that the shape of the distortion curve has changed, and also the output curve is much broader than for the 1000-cycle case. The distortion for 100 cycles is higher than that for 1000 cycles even though the same recording level was used. This is not always the case. Wires have been tested which have just the reverse of this operation in that the low frequency distortion is much lower than that at medium and high frequencies. No data is available on tape concerning this phenomenon but it would seem that similar operation should be found.

Again, as was the case regarding frequency response, the amplifiers associated with a magnetic recorder must be capable of handling the output and input circuits without generating appreciable distortion if the full capabilities of the system are to be realized. Because magnetic recording, when properly handled, does not generate even order distortion it would seem advisable to use an amplifier which has the same general characteristics. This tends to lead to the use of push-pull output stages at least.

Audible Beats

One factor in the design and testing of a magnetic recorder, which has not received much attention, is the production of audible beats between the recorded material and the bias frequency. This effect generally occurs at the higher audio frequencies. The spurious signals appear to be the sum or difference, or both, of the harmonics of the audio signal beating with the supersonic bias. This effect is not appreciable except at recording levels which somewhat exceed the maximum permissible level for low distortion. However, most magnetic recorders use some sort of pre-equalization in which the current in the recording head is boosted at the higher audio frequencies. The level is usually adjusted for maximum signal at some low or medium frequency and, if the input which gives this level is maintained at the higher frequencies, beats, due to overload, are nearly certain to occur. However, if the input is adjusted in accordance with the pre-equalization the beats will not be present because little or no overload will occur. If the pre-equalization is properly designed it will take into account the maximum probable energy at a given frequency and adjust the head current so that overload will not occur at any point under normal conditions.

The designer of a magnetic recorder must consider all of the above factors in working out a unit. However, many of them at this time are nearly entirely empirical and thus must be determined by trial and error methods. Thus a great deal of experimental and developmental work is necessary to arrive at a satisfactory solution.

Finally, it may be said that, in magnetic recording, as in most other things, nearly anything can be done if one just wants to do it badly enough, but sometimes the desire must be extremely intense. Excellent frequency response, with low distortion and good signal-to-noise ratio may be achieved if one is willing to expend the time and effort necessary. However, the art of magnetic recording is essentially just beginning, and the means to achieve these ends are sometimes extremely difficult.