On the Need for a Standard Method for Primary Calibration of the Frequency and Wavelength Response of a Magnetic Tape Reproducer*

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0. INTRODUCTION

Some workers have discussed apparent inconsistencies in the recorded flux versus frequency on some commercial calibration tapes [1]–[5]. One cause suggested there for the inconsistencies is some inadequacy in the theory of magnetic reproduction. The other cause suggested is practical measurement problems. We believe that the theory is adequate, but that we are severely handicapped by the lack of a standard procedure for primary calibration of the frequency and wavelength responses of a magnetic tape reproducer which is to be used for manufacturing or calibration of reproducer calibration tapes.

1. ON THE MAGNETIC RECORDING AND REPRODUCING THEORY

Westmijze [6] has given the theory of the gap-length loss of a reproducing head. (Practical gap-length loss formulas based on Westmijze's theory are given by McKnight [7].) McKenzie has suggested that the present gap-length response theory may be incorrect or incomplete [5]. But we know of no theory of the short-wavelength response of a reproducing head that in any way suggests *any* effect of the gap length on the reproducing short-wavelength response other than that given in Westmijze.

It is certainly true that the depth of the magnetic layer does affect the wavelength response of both the recording and the reproducing processes. Bertram presents the theory of the distribution of the recorded magnetization through the depth of the magnetic layer and its effect on the wavelength response in ac-bias recording in [8], and the theory of the effect of medium permeability and orientation on the magnetic reproducing process [9]. But neither the layer depth nor any other factor that Bertram or we know of (other than the Westmijze gap-loss itself) affects the reproducing gap-length loss.

2. SINCE WE SEE NO THEORETICAL ERROR IN THE GAP-LOSS THEORY, WHAT IS THE SOURCE OF THE PRACTICAL DISCREPANCY?

A prime candidate for errors by all people involved in the calibration of the magnetic recording and reproducing processes is the lack of a *detailed* "how-to-do-it" standard for primary calibration of the frequency and wavelength response of a reproducer. This is equally true for professional studio systems and cassette systems.

The German standards on the calibration tapes DIN 45 513 [10] give the amplitude and the amplitude versus frequency characteristics in terms of "effektiver Kurzschlussfluss je mm Bandbreite," which is literally the "rms short-circuit flux per [unit] tape width," which is exactly what we say in English, because we took it from the German. (We have given it the coined name "fluxivity.") Although not specifically cited in DIN 45 513, the measurement methods are given in DIN 45 520 [11]. Section 5 on measuring the flux versus frequency is given in our translation in the Appendix of this paper. Although this is a rather sketchy description, it is the best we now have, and we don't know how many manufacturers are even aware of its existence.

IEC Publication 94, Part 2, on calibration tapes [12] is likewise in terms of the short-circuit flux per unit track width. Mr. Andriessen of BASF and this author participated in the preparation of this standard. We discussed

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the need for a measurements section, but we did not want to delay publication of the standard—which mainly concerns the format of the calibration tapes (frequencies, reference fluxivities, etc.)—until an adequate measurement section could be prepared.

Everyone (ourselves included) says that we all know how to calibrate the system, but in fact there are many calibration factors to be included, and omitting any one, or making an error of calibration, could give errors of the sort McKenzie has found. We listed all the factors that we were aware of at the time in [13]. Table 1 there lists six factors to consider at long wavelenth, and Table 2 lists five factors at short wavelength. Since that time, Mallinson has published on the gap irregularity effect [14], which should be added to the known effects given in Table 2 of our paper. Also, van Herk has recently given an improved fringing-effect theory and calculation [15], and Melis and Nijholt have shown a serious limitation in the fringing theory at wavelengths comparable to the head-core length [16].

Also consider the following important practical factors.

1) We are studying another factor, and will report on it later, namely, "gap smear" in metallic heads. It appears that there is some kind of wear process whereby the core material on the leading edge of the gap is pulled across the gap. This is easily seen in scanning electron microscope (SEM) photographs which Ampex Research Department has taken for us. The gap smear seems to cause two effects. First, the gap length is *reduced,* so that a head with a gap spacer of say 3 μm gives a gap-null frequency corresponding to a gap length of less than 2 μm. Second, there is a "pileup" of the dragged-over core material that causes a *spacing* between the trailing edge of the gap and the tape. Therefore we measure a "spacing loss" at the upper middle frequencies, then a crossover where the moved gap-null response equals the spacing loss, then finally an increased response because of the moved gap null.

Some tapes cause this "smear" very quickly (playing 100–300 meters of tape); others do not seem to cause the spacing effect at all, but we are not sure whether they cause the gap-shortening effect. Only relapping of the head face will restore the spacing loss and the gap-length loss to the expected operating conditions.

This "gap smear" effect seems to occur only with metal heads, but we do not know whether the "gap smear" is a function of gap length, all other things being equal. It *does* seem to be a general effect, that is, we have seen the "smear" with heads made in different ways by different manufacturers, so it is not a freak occurrence with one particular batch of core material, or some such thing.

We find that the smear typically corresponds to a spacing (using $L = 55$ s/λ) of about 350 nm. This would give a loss at 48 mm/s, 10 kHz, of 4 dB. This is identical to the loss that McKenzie observes. Is this coincidence, or more?

2) With ferrite heads there is a "gap erosion" effect. "Everyone" knows about it, but we do not know if anything has been actually published, or whether there is any way to measure it other than by comparison with a "good" head. And we do not know whether "gap erosion" is a function of gap length, all other things being equal (and we are sure that all other things are *not* equal!).

3) There are a number of ways that the gap-loss compensation is carried out. We have written a fairly detailed report on this [7]. (The gap-null shift mentioned in the above paragraph was found after the preprint was released; it will either be put into the final paper, or at least referenced if we make the "smear" effect a separate paper.)

In that paper we point out that it is difficult to determine accurately the gap length, and that the gap-loss curve becomes very steep as you approach the gap null. Thus a small error of gap-length measurement can cause a large error in the compensation. For instance, McKenzie mentions the use of a 2-μm gap length. If this is used for measuring a 10-kHz signal at 48 mm/s, the gap loss would be about 3.5 dB; if the gap were really 12% longer or shorter—and this is probably an optimistic evaluation of anyone's ability to measure the gap length by any technique—then the response would be about $\pm$ 1 dB of the calculated value.

4) We found that the "flux loop" calibration method for the *frequency* losses of a reproducing head may be seriously in error when the head loss is more than a few decibels [17]. There are, luckily, other ways to make this frequency response measurement, as discussed in [13].

5) Errors in the calibration of the long-wavelength response of a system can produce *apparent* errors of the short-wavelength response. Long-wavelength calibration is discussed in [18].

3. CONCLUSIONS AND RECOMMENDATIONS

No one—neither the IEC, nor any researcher, nor any manufacturer—has thus far been willing to tackle the task of writing down a detailed calibration method.

Perhaps now is the time for an IEC TC-60A working group to be established to prepare this measurement standard. It will require a lot of work writing down methods and verifying just what constitutes a "necessary and sufficient calibration procedure." It will take "round robin" confirmation of measurements by several participants.

This author frankly would be unwilling to support any particular calibration requirement until we are *sure* that everyone who is calibrating reproducers is doing it the same way, and also taking into account the factors described above (gap smear and gap erosion included).

Unfortunately Magnetic Reference Lab is not now set up to calibrate or manufacture calibration cassettes, so we are unable to verify anyone's measurements of cassettes. We do of course have facilities for calibrating 6.3-mm tapes at speeds from 95 mm/s to 760 mm/s, and we would be pleased to cooperate with all other manufacturers in comparing measurements of particular recordings. We would also be pleased to cooperate in the writing and evaluating of particular measuring procedures necessary for calibrating reproducers over a broad range of wavelengths.

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[17] J. G. McKnight, "Magnetic Design Theory for Tape Recorder Heads," presented at the 60th Convention of the Audio Engineering Society, Los Angeles, May 1978 (to be published in the March 1978 issue of the *Journal*). (See Sec. 2.4, "Frequency Response of the Heads.")

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APPENDIX
GERMAN STANDARD DIN 45 520, 1973 January
Magnetic Tape Equipment for Sound Recording: Method for Measuring the Absolute Value and Frequency Response of the Magnetic Flux on Magnetic Tapes

An unofficial translation by Brigitte McKnight; edited by John G. McKnight. Sections 1 through 4 are not included here.

5. MEASURING THE TAPE FLUX VS FREQUENCY

The tape flux versus frequency of a test sample recording is measured by using the principle that when a tape recorded with constant flux at various wavelengths is reproduced with an "ideal magnetic reproducing head," the head EMF (the open-circuit output voltage) will rise at 6 dB per octave with decreasing wavelength. The practical magnetic reproducing head used for this test will have some loss;[2] therefore the open-circuit voltage of the reproducing head must be corrected for its losses, and then compared with a voltage which rises 6 dB per octave.

The losses of a practical reproducing head are due to the fact that the gap length is not in general short enough, and its surface contacting the tape is not long enough in comparison with the wavelengths to be reproduced; and that eddy-current and hysteresis losses, the winding resistance, self-capacitance, and leakage inductance are also present. When using a suitable head design the latter can generally be neglected, but the gap-length and eddy-current factors must be considered.

Finally, when reproducing long wavelenths the errors arising from the finite length of the contact surface must be corrected.

5.1 Determining the Gap Loss

Gap loss is dependent upon the recorded wavelength λ. A swept frequency is recorded on a high coercivity tape at a slow tape speed at the greatest possible flux without causing "bias beat" distortion. This recording is reproduced. The longest wavelength is measured at which a null point of the open-circuit voltage of the reproducing head can be found. The wavelength of this null in the output[3] is null wavelength λ_n.

The gap loss function for the necessary correction is

$$k(\lambda) = 20 \log \frac{\pi \lambda_n/\lambda}{\sin(\pi \lambda_n/\lambda)} \text{ [dB]}. \tag{3}$$

[2] The term "loss" refers to any deviation of the response from the ideal.

[3] This measurement of null wavelength λ_n includes the effect of any gap irregularity.

The reproducing head gap length used for the measurement must be short enough so that the gap-length correction does not exceed 5 dB. Further gap losses occur through faulty gap construction such as nonparallel or rounded edges and poor contact between magnetic tape and reproducing head. These factors are seen as a broadening of the null; they cannot be determined numerically at this time, but can be kept sufficiently small by use of a suitable head construction and a choice from a number of head samples.

5.2 Determining the Eddy-current Losses

To determine the eddy-current losses, position a conducting loop parallel to the reproducing gap of the reproducing head. Apply a constant current at all frequencies, of such magnitude that it induces in the head a voltage equal to that from the reference fluxivity of the calibration tape of DIN 45 513. The deviation of the frequency response of the reproducing head voltage from a straight line increasing 6 dB per octave is the correction function for the eddy-current losses.

5.3 Evaluation

The reproducing head EMF obtained by reproducing a test sample is corrected by superposition for the gap loss as a function of wavelength, as determined in Sec. 5.1; and for the eddy-current losses as a function of frequency, as determined in Sec. 5.2. The result represents the output voltage obtained with an "ideal reproducing head." The difference between this curve and a straight line with a slope of 6 dB per octave is the tape flux versus frequency as defined in Sec. 5.

John G. McKnight's biography appears on p. 886.