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ILLINOIS INSTITUTE OF TECHNOLOGY, ARMOUR RESEARCH FOUNDATION, CHICAGO (REPORT NO. 90-782A-12)

FINAL ENGINEERING REPORT ON RESEARCH AND DEVELOPMENT OF COUNTERMEASURES RECORDING EQUIPMENT, MODELS, TEST EQUIPMENT, AND SERVICES - AND APPENDIX A - VOL. I - MAGNETIC RECORDING - [illegible] 1949 THRU 31 DEC 1951

[illegible], W.R.; TOBEY, A.R.; MILLER, H.C. (SUBMITTERS) [illegible] JUN '52 52PP PHOTOS, DIAGRS, GRAPHS

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RECORDERS, MAGNETIC
RECORDING AND PLAYBACK
EQUIPMENT
COUNTERMEASURES, ELECTRONIC

ELECTRONICS (3)
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Report No. 90-783A-12

RESEARCH AND DEVELOPMENT OF COUNTER MEASURES RECORDING EQUIPMENT, MODELS TEST EQUIPMENT, AND REPORTS

Final Engineering Report

~~Volume I. Magnetic Recording~~

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

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Armour Research Foundation
of
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois

Report No. 90-783A-12
FINAL ENGINEERING REPORT
on
RESEARCH AND DEVELOPMENT OF COUNTER MEASURES
RECORDING EQUIPMENT, MODELS, TEST EQUIPMENT,
AND REPORTS

Volume I. Magnetic Recording

Period Covered: 1 December 1949 through 31 December 1951
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ABSTRACT

The results of efforts to increase the bandwidth of a single magnetic recording channel to include 20 to 5×10^6 cps are reported. This program consisted of experimental work aimed directly at the problem and both experimental and theoretical studies aimed at furthering basic knowledge of magnetic recording.

The ultimate goal was not realized although the upper frequency limit of magnetic recording was significantly raised, and the problems involved were more clearly defined.

Present efforts have resulted in marginal record and playback of 1.4 mc using a Ferroxcube III head and plastic tape moving at 1,000 inches per second. The present bar to a substantial increase in the maximum frequency is the mechanical problem of maintaining good contact between head and tape at high tape speeds. In view of these limitations emphasis was shifted to other recording methods in July 1950.

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COUNTER MEASURES RECORDING EQUIPMENT

Part I

A. Purpose

It is desired that the art of recording be advanced far beyond its present state, so as to ultimately permit the construction of equipment having the characteristics described in Exhibit MCREE-565. A basic aim is the continuous recording of signals having component frequencies of 20 to 5×10^6 cps. This work has been done for the Air Force under Contract AF 33 (038)-6921.

The first method to be investigated, and the one to which this volume of the Final Report is devoted, was magnetic recording. The problem was to investigate, both experimentally and theoretically, means by which the bandwidth of magnetic recording could be expanded. An investigation of fundamental magnetic processes was carried forward at the same time since these processes are fundamental to magnetic recording.

B. General Factual Data

1. References

A bibliography of magnetic recording is given in Appendix A. In addition the following references are pertinent.

"Magnetic Recording Tapes", M. Camras, A.I.E.E. Trans., 66, 597, 1947.

"Graphical Analysis of Linear Magnetic Recording Using High Frequency Excitation", M. Camras, Proc. I.R.E., 37, 569, 1949.

"Magnetic Recording with AC Bias", R. E. Zenner, Proc. I.R.E., 39, February 1951.

H. Ekstein and T. L. Gilbert - Report on ARF Project No. 90-648A, Contract N171 s-85154.

Armour Research Foundation Licensee Bulletins.

2. Formulas

Below are listed formulas specifically used in this report; for details of derivation and other associated formulas and equations the reader is referred to the detailed interim reports Nos. 90-783A-1 through 4.

$$\bar{\nu} = \nu_x + j\nu_r \text{ and } \bar{\mu} = \mu_x + j\mu_r \tag{1}$$

$$\mu_x = \frac{\nu_x}{\nu_x^2 + \nu_r^2} \; ; \quad \mu_r = \frac{\nu_r}{\nu_x^2 + \nu_r^2} \tag{2}$$

$$\bar{Y} = \frac{\ell(\nu_r - j\nu_x)}{4\pi N^2 \omega a} \times 10^9 \text{ mhos} \tag{3}$$

$$\bar{Z} = \frac{4\pi \omega N^2 a}{\ell} (\mu_r + j\mu_x) \times 10^{-9} \text{ ohms} \tag{4}$$

$$M(T) = f\left[H(t)\right], \; 0 \leq t \leq T \tag{5}$$

$$m_1(T) = f\left[H(t)\right] = 1/h \int_0^T H(t)\, \delta(t-t_o)\, dt \tag{6}$$

$$m_2(T) = m_1(T) \left\{ 1 - F\left[h + m(T)\, H(T)\right]\right\} \tag{7}$$

$$M_3(T) = \int_0^{Hs} m_1\,(h, T)\; n(h)\; dh \tag{8}$$

$$M_4(T) = \int_0^{Hs} m_2\,(h, T)\; n(h)\; dh \tag{9}$$

$$V_1 = \sqrt{2}\,\pi f\, M I_m \tag{10}$$

$$H_m = \frac{0.4\,\pi\, N_1\, I_m}{l} \tag{11}$$

$$V_2 = \sqrt{2}\,\pi\, f\, \Phi_m\, N_2\, 10^{-8} \tag{12}$$

$$B_m = \frac{\Phi_m}{A} \tag{13}$$

3. Symbols:

μ - permeability of the core material, cgs units.

ν - reluctivity of the core material, cgs units.

$\bar{\mu}$ - complex permeability

$\bar{\nu}$ - complex reluctivity

a - cross-section of a ring of core material, cm^2

l - mean length of ring core, cm

$\bar{I}$ - complex current, rms cgs units.

$\bar{B}$ - complex average flux density, rms cgs units.

$\bar{V}$ - complex current, rms cgs units.

ν_x - magnitude of real part of $\bar{\nu}$

ν_r - magnitude of imaginary part of $\bar{\nu}$

μ_x - magnitude of real part of $\bar{\mu}$

μ_r - magnitude of imaginary part of $\bar{\mu}$

$\bar{Y}$ - admittance of coil terminals, mhos.

$\bar{Z}$ - impedance at coil terminals, ohms.

j - $\sqrt{-1}$

M(T) - magnetization in material at time T, cgs units.

H(t) - magnetizing field, cgs units.

H_s	-	field required to saturate material.
T	-	time, seconds.
t	-	time variable measured from t_o.
t_o	-	last time H exceeded H_s, seconds.
$f[H(t)]$	-	functional of $H(t)$
n	-	integers 1, 2, 3, 4, - - - -
$h, - h$	-	critical values of H at which particles "flip".
$m_1(T)$	-	functional for first model.
$\delta(t-t_o)$	-	Dirac delta function.
m	-	magnetization of single particle, cgs units.
$m_2(T)$	-	functional for second model.
$F(x)$	-	an unspecified function representing the curve along which m approaches the asymptote ± 1.
$M_3(T)$	-	magnetization functional for third model.
$n(h)$	-	relative volume of particles which have critical fields lying between h and h + dh
$M_4(T)$	-	functional for fourth model.
H_m	-	peak magnetizing field, oersteds.
f	-	frequency, cps.
L	-	Inductance, henries
I_n	-	peak current in sample primary, amperes.
N_1	-	number of primary turns.
B_m	-	peak induction in sample, gausses
Φ_m	-	peak flux in sample
V_1, V_2	-	Voltages measured as shown in Fig. 2
G	-	gap length of head

λ - recorded wave length in same units as gap length

K - empirical constant.

C. Detail Factual Data

1. Present State of Magnetic Recording

a. General

Magnetic recording as a method of importance is a relative newcomer to the recording field. It has seen the greatest development and use in the audio range (including most instrumentation applications), but there have been some special applications, such as computer memory devices and delay units, which have exceeded the audio range in upper frequency requirements, if not in pulse repetition rate. In general, the audio applications have the common characteristic that the head and record medium are in physical contact. On the other hand, in special applications both heads in contact and spaced heads have been used. The attempts to make use of spaced heads have been in connection with magnetic storage systems which have short access times.

Magnetic media fall into three categories; magnetic powders, magnetic platings, and solid magnetic materials. The powders and platings must be supported by some rigid or non-rigid material which is usually non-magnetic, while the solid magnetic materials are self-supporting. The magnetic powders are considered to have the highest resolution (best short wavelength response) but havd a lower energy storage. The powders are usually coated on paper or plastic tape using a non-magnetic binder.

The heads used for most present day applications are the "open type", so named because the head structure does not surround the medium. Almost all magnetic recording is "longitudinal", therefore, the plane of the gap in the head is transverse to the direction of movement of the medium. In "longitudinal" recording the average field due to the head travels from one gap edge to the other in a direction which is parallel (or anti-parallel) to the direction of motion of the medium. This is to be contrasted with transverse recording in which the two sides of the gap are on opposite sides of the medium and the recording field passes through the medium essentially perpendicular to the direction of motion of the medium. The head structure is usually a single lamination bent into a "C" with the edges forming the gap, or a lamination (or stack of laminations), the plane of which is perpendicular to the plane of the gap. These heads are satisfactory for use at audio frequencies but at higher frequencies eddy current losses become important.

A large number of mechanical drives for magnetic recording have been built, ranging from low quality systems to more complicated systems with excellent speed characteristics. There has not been much work on high speed drives except for rotating drums using spaced heads and perhaps isolated special applications.

Very important to the field of magnetic recording have been investigations of the more general and fundamental aspects of magnetism. Theories of the fundamental mechanisms of magnetism are still not firmly established, although a number of empirically derived rules are used to practical advantage. These rules do not permit theoretical extension into new regions with any certainty.

b. Previous Work Accomplished at Armour Research Foundation

(1) High Frequency Magnetic Testers

Design considerations and some construction for an investigation of core material properties at high frequencies started prior to this project. In this work, which was Foundation sponsored, it was planned to investigate properties in the range of 20 to 80 KC (normal bias and erase frequencies for magnetic recording). Provision was to be made for testing materials at high inductions approaching saturation and to make measurements using sinusoidal flux waves, from which it would be possible to determine parameters relating effective permeability and loss per unit volume to the frequency and induction.

(2) 60 Cycle Hysteresis Loop Tracer

A hysteresis loop tracer, designed and built by D. E. Wiegand and W. W. Hansen (A.I.E.E. Trans., 66, 1947), has been used for determining the magnetic properties of small samples such as magnetic recording wires and tapes. The instrument operates at the power frequency (60 cps); and, therefore, does not give information which can be applied without question to operation at much higher frequencies. A paper describing this instrument may be found in Appendix C of Report No. 90-783-3 of this project. As a result of work with this instrument the Foundation was able to develop a number of correlations between B_r-H curves and performance factors (ease of erase, transfer, proper bias level, linearity, and frequency response), and to develop improved magnetic recording mediums (magnetic powders, 18-8 alloy for wires, plated nickel-cobalt).

(3) Theoretical Works

Theoretical analyses of demagnetization effects in magnetic recording have been made for wire by Camras (A.I.E.E. Trans., 66, 597, 1947) and for tapes by Ekstein and Gilbert (Project No. 90-648A, Contract N171 s-85154). These analyses involve idealizations which are not valid at very short wavelengths and therefore are not reliable for short wavelength prediction.

Harmonic analyses carried out by Camras (Proc. I.R.E., 37, 569, 1949) and Zenner (Proc. I.R.E., 39, No. 2, 1951) have been specifically directed towards explaining the effect of bias used in magnetic reocrding. The latter paper is more general and, hence, is more adaptable to further development.

The theory of playback phenomena is, in contrast to record phenomena, more completely known; the differential equation and boundary conditions which relate the distribution of magnetization in the record and the flux distribution in the pick-up coil are known. This differential equation has been solved for a specialized set of boundary conditions. The solution appears as a single integral relating the output voltage to the magnetization in the record. This solution was obtained by Ekstein and Gilbert in the work mentioned previously. The solution is capable of application or extension to somewhat more general situations than those for which it was derived. Mr. Camras has performed a similar analysis for closed type wire heads (Proc. I.R.E. 37, 567, 1949).

(4) Experimental Work with Nickel-Cobalt Plating

Nickel-cobalt plating on wire, tape and rigid backings has been investigated as a magnetic recording medium in the audio range and for special instrumentation applications at somewhat higher frequencies. At the Foundation some work was done under contract (NObsr-42251) using a nickel-cobalt alloy electro-plated on the edge of a brass disk six inches in diameter driven at speeds as great as 7500 rpm. Using ring type low impedance heads and 15 milliwatts of recording power, detectable signals as high as 200 KC were recorded and played back. In a later test, an audio signal was recorded with the disk rotating at a low speed and played back at very high speeds. The signal was detectable at speeds which gave playback frequencies up to 800 kc.

2. Work Accomplished During this Contract

a. Extension of Fundamental Magnetic Knowledge

(1) Theoretical Analysis

(a) Complex Parameters for Magnetic Materials

Various methods of expressing the a-c properties of core materials have been used. The most common system has been the use of "effective a-c permeability" and "watts per pound" units. In this project a system of parameters of a more basic nature and more convenient to use in apparatus design were derived.

The permeability (μ) and reluctivity (ν) of core materials, ordinarily real quantities, are made complex quantities. By this means, equations for magnetic circuits can be written in complex form, and the phase angle actually existing between fluxes, voltages, and currents will be properly indicated by the equations.

The complex quantities $\bar{\mu}$ and $\bar{\nu}$ are defined by considering a ring of magnetic material having a uniform cross section, a, mean length, l. This is linked by a toroidal winding of N turns having negligible resistance, excited by alternating current of $\omega/2\pi$ cycles per second. The core parameters are required to satisfy the following conditions: If the core material is a loss-less material such as free space, the current, $\bar{I}$, and flux, $\bar{B}a$, are in phase, and both lag the terminal voltage, $\bar{V}$, by 90 degrees. Under this condition $\bar{\mu}$ and $\bar{\nu}$ must degenerate to real values. If losses are present in the core, the current lags the voltage by an angle less than 90 degrees, but an exact quadrature relation exists between the flux and voltage, as before.

The parameters have the following complex form,

$$\bar{\nu} = \nu_x + j\,\nu_r \quad \text{and} \quad \bar{\mu} = \mu_x + j\mu_r \tag{1}$$

where

ν_x, ν_r, μ_x and μ_r are real numbers.

Using the fundamental reciprocal relation between μ and ν yields the following conversion equations.

$$\mu_x = \frac{\nu_x}{\nu_x^2 + \nu_r^2} \; ; \quad \mu_r = \frac{\nu_r}{\nu_x^2 + \nu_r^2} \tag{2}$$

The admittance at the coil terminals is given by,

$$\bar{Y} = \frac{l(\nu_r - j\nu_x)}{4\pi N^2 \omega a} 10^9 \quad \text{mhos} \tag{3}$$

The impedance can be expressed in terms of $\bar{\mu}$ as,

$$\bar{Z} = \frac{4\pi\omega N^2 a}{l} (\mu_r + j\mu_x)\, 10^{-9} \text{ ohms.} \tag{4}$$

The components of $\bar{\mu}$ and $\bar{\nu}$ can be determined by measuring the complex admittance or impedance of the coil. An a-c bridge, used to measure the coil impedance, is subject to special requirements due to the high flux densities and sinusoidal exciting voltage required. The impedance of the bridge arm inserted between the generator and the sample must be low compared to the sample, and the bridge components must withstand relatively high voltages and currents. A number of bridge configurations are possible and each has its own pecularities and shortcomings; experimental evidence would be necessary to determine the best configuration in this application.

(b) Relation Between the Magnetization of a Ferromagnet and the Applied Field

An attempt has been made to determine a general relation between the magnetization of a ferromagnet and the applied field for a uniform field of arbitrary time dependence, since this relation is fundamental to magnetic recording. The relation between the magnetization M at time T may depend upon all of the values which H has assumed in the time interval $0 \leq t \leq T$ where $t = 0$ at the last time H exceeded the saturation field H_s. This fact is expressed mathematically by saying that M is a functional of $H(t)$, or,

$$M(T) = f\left[H(t)\right], \quad 0 \leq t \leq T \tag{5}$$

The object of the theoretical analysis is to reduce the general expression above to a more specific and useful form. The desired functional will obviously be non-linear. To obtain an insight into the character of this functional, five models, based on ferromagnetic materials which consist of dispersions of single domain ferromagnetic particles in a nonmagnetic matrix, were considered. The dispersed particles were assumed to have two stable orientations of magnetization which are anti-parallel to each other when no field is present. The models chosen were as follows:

1 Single particle - oriented parallel to field.

2 Single particle - arbitrarily oriented.

3 Dilute dispersion (noninteracting particles) with axes of stability of the individual particles parallel to the field.

4 Dilute dispersion - arbitrarily oriented particles.

5 Dispersion with interacting particles.

The behavior of the first model generates a square hysteresis loop as follows: Before the field is applied, the magnetic moment of the particle will be in one of two stable positions. When a field is applied anti-parallel to the moment, no change will occur until the field exceeds some critical magnitude, h, at which the anti-parallel position ceases to be a stable one. At this time the moment of the particle will rotate rapidly to the parallel position and no further change will occur with increased field. If the field is now reversed, the position of the moment will remain unchanged until the field has exceeded the value, -h, at which time it will again rotate rapidly to be parallel with the field, thus returning to the starting position. A functional which will describe this behavior is,

$$m_1(T) = f\left[H(t)\right] = 1/h \int_0^T H(t)\,\delta(t-t_o)\,dt \qquad (6)$$

where $\delta(t-t_o)$ is the Dirac delta function and t_o is the last time that H passed through a critical value, h or -h.

In the second model the axis of the two stable positions is at an angle with respect to the direction of the external field. As the field is increased in value, the stable position furthest from the field direction will rotate towards the field and then disappear (i.e., cease to be stable). When it disappears, the moment will "jump" to the remaining stable position, which will be more nearly parallel to the field direction. As the field increases, the remaining stable position will rotate towards the field but will not disappear. The magnetization, m, of the particle will then approach asymptotically a value of +1 as the field is increased further (Fig. 1). A similar process occurs when the field is reversed and raised to large negative values. In this case m approaches the value -1 asymptotically. The functional for this model may be expressed in terms of the functional for the first model.

$$m_2(T) = m_1(T)\left\{ 1-F\left[h + m(T)\ H\ (T)\right]\right\} \tag{7}$$

where: $F(x)$ is an unspecified function representing the curve along which m approaches the asymptote $\pm$ 1.

The magnetic properties of the third model are obtained by averaging over the magnetic properties of the individual single domain particles making up the model. These particles differ only in the value of the critical field, h, at which the moment flips from an antiparallel position to a parallel position. Because of the different values of h required, the moments will not all flip at once, and the average effect will be a deviation from the square hysteresis loop of the single particle (Model No. 1). The hysteresis loop for the third model is shown in Fig. 1. The functional for this model is obtained by considering the magnetization functional of an individual particle as a function of the parameter, h, as well as of T and averaging over the contributions of particles with different h.

$$M_3(T) = \int_0^{H_s} m_1(h, T)\, n(h)\, dh \tag{8}$$

where: $M_3(T)$ is the magnetization functional, $n(h)$ is the relative volume of particles which have critical fields lying between h and $h + dh$, $m_1(h, T)$ is a functional of $H(t)$ for a single particle, and H_s is the saturation field.

This model gives hysteresis properties which, in certain respects, resemble those of ordinary materials; but it still falls short of describing magnetic phenomena in general.

The fourth model is similar to the third except that the basic particles correspond to the second model rather than the first. In carrying out the averaging for this model it should be noted that the different single particles which "flip" for a given h value may not have the same reversible magnetic properties. The function F(x) in this case is assumed to represent the average reversible contribution of the particles which "flip" at some value of h. The hysteresis loop for this model is shown in Fig. 1. This model, although general enough to describe some of the hysteresis properties of actual materials, is not sufficiently general. The magnetization functional for this model is,

$$M_4(T) = \int_0^{H_s} m_2(h, T)\, n(h)\, dh \tag{9}$$

Where $M_4(T)$ is the functional for model 4 and the other symbols are as defined previously.

The analysis based on the above models is empirical in the sense that only a general form of the functional is obtained. The functions and constants must be evaluated by using experimental data such as the saturation hysteresis loop; however, these data are not sufficient to determine the behavior of a ferromagnet for all possible choices of the time dependence of the magnetizing field. Many functionals will fit given data but there is no guarantee that any one of them will properly predict the behavior for all combinations. The problem is to determine one of these functionals which will predict correctly the behavior of ferromagnetic materials for a large (if not an all inclusive) useful class of magnetizing field functions. The four models described above do not achieve this result. The fifth model appears to show greater potentialities; however, the shift in emphasis on this program away from magnetic recording prevented further investigations of this type.

(2) Experimental Work

(a) Ferroxcube III Head Material

Samples of Ferroxcube III magnetic core material were obtained and the magnetic properties were examined by a-c and d-c methods. The normal magnetization curve of a core material can be obtained with fair accuracy by 60 cycle ac measurements. The circuit used for the 60 cycle measurements is shown in Figure 2. The voltmeter was a Ballantine Model 300 which responds to the average value of the applied voltage. The peak magnetizing force, H_m, in the sample is computed from V_1 (See Fig. 2) using equations,

$$V_1 = \sqrt{2}\,\pi\, f\, M\, I_m \tag{10}$$

$$H_m = \frac{0.4\pi N_1 I_m}{\ell} \tag{11}$$

where: f is the frequency, cps.

M is the mutual inductance, henries

I_m is the peak current in sample primary, amperes

H_m is the peak magnetizing field, oersteds

N_1 is the number of primary turns

ℓ is the mean length of flux path, cm

The peak induction in the sample, B_m, is calculated from V_2 (Fig. 2) using the equations

$$V_2 = \sqrt{2}\pi f \Phi_m N_2 10^{-8} \qquad (12)$$

$$B_m = \frac{\Phi_m}{a} \qquad (13)$$

where: Φ_m is the peak flux in the sample

N_2 is the number of sample secondary turns

B_m is the peak induction, gauss

a is the area of sample, cm^2

A ring sample of Ferroxcube III with a rectangular cross-section was used for these measurements; the sample dimensions were 1.4" I.D. and 1.768" O.D. with a height of 0.631". Other parameters were; N_1 = 178 turns, N_2 = 30 turns, ℓ = 12.63 cm, M = 1.83 x 10^{-4} henries. The results of the 60 cycle measurements are plotted in Figure 3.

A short cylindrical sample of Ferroxcube III was tested at high magnetizing forces in a Sanford-Bennett high-H permeameter. In this test method, the sample is placed between the poles of a powerful electromagnet with the parallel end surfaces of the specimen abutting the pole faces; thus, the magnetizing field is applied parallel to the axis of the sample. Because of the variable and unknown effect of the two joints in the magnetic circuit, this method is useful only for materials of relatively low permeability. For magnetically soft materials the chief use of this method is the determination of characteristics near saturation. The results of the DC measurements are also plotted in Figure 3.

The design and construction of a high frequency magnetic tester for core materials was carried forward during this project, but with the cessation of the magnetic recording investigation, further work on this tester was discontinued. At the time work was stopped, the general plan of operation had been determined; and the power supply, power oscillator and power amplifier had been designed. Construction of the unit, using Foundation funds, had been started.

(b) Tests on a Wire Sample

To provide experimental data which would be helpful in the establishment of a basic ferromagnetic model, a series of tests on a long wire sample were performed. The sample used for these tests consisted of 100 strands of medium carbon steel magnetic recording wire with nominal diameters of 0.004 inch. The length of the sample was 21 inches. The sample was used straight, without a yoke or return path, which allowed the measurement of flux by rapid removal of the sample from the coil. The end effect errors due to the use of a straight sample were minimized by proper design of sample and equipment. The details on the design of the equipment are given in Report No. 90-783A-3.

The data for hysteresis loop, initial and residual induction curves were obtained with this equipment, since it was considered that these data were the most important starting points in the development of a ferromagnetic model. The equipment was also used to determine the residual flux in the sample after oscillatory magnetizing pulses had been applied. The exponentially decaying current in an oscillatory RLC circuit was used as the source of the magnetizing pulses. After exposure to the oscillatory pulse the residual flux in the sample was determined with a fluxmeter. An oscillographic record was obtained for the ϕ - H relation as the sample was subjected to the decaying, oscillatory pulse. These traces show in detail the devious route by which the final value of residual flux is reached (Fig. 4).

b. Extension of the Frequency Limits of Magnetic Recording

(1) Theoretical Analyses

(a) General

Theoretical investigations of magnetic recording phenomena can be divided into two natural and clearly defined classifications: (1) investigations of recording phenomena, and (2) investigations of playback phenomena. Although a study of playback phenomena proceeds from a knowledge of the distribution of magnetization in the recording medium and hence cannot be carried through exactly until this distribution is known from a study of recording phenomena, it appears that the most important characteristics of playback phenomena can be deduced by making reasonable assumptions regarding the distribution of magnetization in a recorded medium. It is possible, therefore, to investigate playback and recording phenomena independently. It should be recognized that the use of multiple channels would allow the recording of any bandwidth within reason; however, the number of channels required will be determined by the bandwidth of each channel. It is, therefore, reasonable to concentrate on the expansion of the channel bandwidth and leave the multiple channels determine the residual flux in the sample after oscillatory magnetizing pulses had been applied. The exponentially decaying current in an oscillatory RLC circuit was used as the source of the magnetizing pulses. After exposure to the oscillatory pulse the residual flux in the sample was determined with a fluxmeter. An oscillographic record was obtained for the ϕ - H relation as the sample was subjected to the decaying, oscillatory pulse. These traces show in detail the devious route by which the final value of residual flux is reached (Fig. 4).

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The bandwidth of magnetic recording can be expanded by redesign and improvement of the component parts of present magnetic recording systems and/or by developing new techniques. Since a suitable basic theory of magnetics is lacking, it follows that improvement in either of the two directions given above must be by either an empirical or fundamental analytical approach. In the previous section, efforts to increase the basic knowledge of magnetics in general were discussed; this section will deal specifically with magnetic recording.

(b) Comparison of Recording Media

Experimental work on this project was for the most part concerned with tape recording, but it is not to be inferred from this that tape is the most suitable medium on all counts. Tape does have two distinct advantages: approximate synchronization of channels is provided by recording all channels on the same tape; tape is much easier to handle.

Wire has the advantage over tape from the standpoint of volume per cycle recorded; it also has a smaller change in spool diameter for a given length recording. Both steel wire and steel tapes have a longer shelf life than do paper or plastic tapes. The relative importance of wire rotation effects, tape skew and head contact variations have not been evaluated.

In Appendix A of Report No. 90-783A-3 a comparison of the various media for a two hour recording is made. In this study the following points of comparison are considered: typical dimensions, physical stacking factor, signal packing factor, spool and reel sizes and speeds, ultimate speeds based on stress in medium, eddy-current effects. The results of this comparison are as follows: Wire is capable of approximately twice the speed of plastic tape, but its minimum wavelength is approximately three times as long as that for tape. Wire will store approximately fifteen times the amount of information per unit volume. Because of its superior short wavelength response and self synchronizing characteristics, tape is indicated for multiple channel uses while wire, except for the high linear speeds required, appears best for a single channel application.

(c) Recording Processes

The recording processes in magnetic recording can be divided into two groups for the purpose of analysis: (1) recording head processes, by which the input current in the recording head produces a time and space varying magnetic field, (2) recording processes, by which the time and space varying field produces a fixed distribution of magnetization that remains on the medium after it leaves the recording head.

One of the factors which limits the highest frequency which can be recorded is the shielding effect of eddy currents in a metallic medium. The eddy currents prevent the magnetizing field from penetrating into the interior of the recording medium. This shielding effect depends upon the geometry of the magnetizing field as well as upon the signal frequency and wire magnetic and electrical properties. Thus, In Appendix A of Report No. 90-783A-3 a comparison of the various media for a two hour recording is made. In this study the following points of comparison are considered: typical dimensions, physical stacking factor, signal packing factor, spool and reel sizes and speeds, ultimate speeds based on stress in medium, eddy-current effects. The results of this comparison are as follows: Wire is capable of approximately twice the speed of plastic tape, but its minimum wavelength is approximately three times as long as that for tape. Wire will store approximately fifteen times the amount of information per unit volume. Because of its superior short wavelength response and self synchronizing characteristics, tape is indicated for multiple channel uses while wire, except for the high linear speeds required, appears best for a single channel application.

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The further analysis required to formulate a useful theory of the recording process was not finished due to the change of emphasis away from magnetic recording.

(d) Playback Processes

The theory of playback phenomena is in a better state than that of recording, in that the differential equation relating the distribution of magnetization in the record and the flux distribution in the pick-up coil is known. The problem is one of solving a differential equation with boundary conditions corresponding to the shape of the head. During a previous project, this differential equation was solved for boundary conditions corresponding to an idealized head model. The solution appears as a single integral relating output voltage to the magnetization in the record. This integral was reduced to a form suitable for numerical evaluation for the case of a sinusoidal signal, on an infinitely thin tape with a wavelength which is small compared to the over-all head dimensions. Extension of this work would involve:

(a) further calculations to obtain numerical results for tapes of arbitrary thickness and for wavelengths which are not small compared to head dimensions, (b) modifications of the analysis directed toward obtaining a solution for less idealized head models.

(2) Experimental Work

(a) General

Experimental work on magnetic recording was aimed at obtaining fundamental data on recording and playback processes and attempting to increase the upper frequency limit of magnetic recording. In general, the fundamental processes of magnetic recording are expected to be independent of frequency, and for this reason, the investigation of these fundamental processes can be taken at low tape speeds and audio frequencies. The extension of the upper frequency limit necessarily involves high tape speeds, or at least high writing rates, in addition to an investigation of the frequency characteristics of components, heads in particular, at the higher frequencies.

(b) Low Speed Experiments

Two Speed Data: To verify the prediction of simple theory that the playback voltage is proportional to the speed, a commercial Magnecord tape recorder was used to playback recordings at two different speeds. Recordings of various wavelengths were made by recording different frequencies at 15 inches per second; these recordings were played back at 7.5 and 15 inches per second. Standard Magnecord heads were used in these tests, and the results are shown in Table I below.

Table I

db above 10 mv

Wavelength	15 in/sec	7.5 in/sec	db Difference
.150 inch	25	18	7
.050	32	25	7
.025	37	31	6
.015	39	33	6
.0075	40	36	4
.00375	37.5	33	4.5
.002	31	27	4
.0015	29	25	4
.001	23	18.5	4.5

In the absence of other effects the difference should be constant and equal to 6 db. The difference between the measured value and 6 db at the longer wavelengths is probably due to better head-tape contact at 15 inches per second caused by increased tape tension. The difference at the shorter wavelength is believed to be due to high frequency losses in the playback head.

Wide Gap Experiments: Recording and playing back of high frequencies will ultimately be limited by the short wavelength characteristics of the recorder. The short wavelength characteristics of a system are dependent upon the resolution capabilities of the medium and the effective size of the scanning gap. The limit imposed by the record medium is absolute, in that it cannot be altered by design or refinement in construction techniques. The short wavelength limit imposed by the playback scanning gap is relative to the width of the scanning gap and, with the exception of head contact, effects of gap phenomena can be studied as well with wide gaps as with small ones. This is a distinct advantage, since it is much easier to construct a 10 mil gap to a given per cent. tolerance than it is to construct a one mil gap. Data were taken for 10, 20, and 36 mil gaps in the playback head; recordings being made with a commercial recording head. In figures 5 and 6 are shown typical response curves for 10 and 20 mil gaps. A number of observations based on the wide gap data can be made.

(1) Zero output occurs at approximately those frequencies for which the gap length is equal to an integral multiple of the wavelength.

(2) The output level at frequencies higher than that for which the gap length equals the wavelength is less than is observed when the same frequencies are played back with a smaller playback gap head. This is true even at peaks of response.

(3) Some of the heads show a more regular and extended pattern of peaks and zeros than others. Visual examination indicates a correlation between regularity of the response pattern and both sharpness and parallelism of the gap edges.

The above information on gap effects of playback heads might well prompt the question as to whether similar effects are noted in recording heads. General experience had indicated that good recordings could be accomplished with wide or narrow recording gaps so long as the final gap edge was well defined and made good contact with the record medium. To investigate this problem in more detail, recordings were made with wide gap heads and played back on a commercial small gap playback head. Fig. 7 shows the response curve obtained with a recording head which had a 36 mil gap. It will be noted that the points $n\lambda = G$ are consistently slightly to the left of the response peaks and that in $n\lambda = KG$, where $K<1$, there is some value of K which will cause the points to fall directly on the response peaks. This may be interpreted as indicating that the effective gap width (KG) is slightly smaller than the nominal head gap width (G). The effect is also evident for a 2 mil recording gap (Fig. 8), but it occurs at such a short wavelength that it would probably be obscured by other effects in normal recordings.

To explain this observed recording phenomenon, consider Fig. 9, which is a plot of field strength in the vicinity of the gap experienced by an infinitely thin tape close to but not touching the pole pieces. It will be noted that there are two positions of maximum intensity and that these positions are less than the gap length apart. If it is assumed that the recording field is both bias and audio and that the tape is passing across the head, then all possible phase relations will occur between the recording made on the tape by the first peak field value and the recording attempted by the second peak value of the recording field. When the two peak recording fields are in phase a maximum level recorded signal should remain on the tape; and when they are not in phase a partial erasure and re-recording by the second peak field value should result. This seems satisfactorily to explain the observed phenomenon when using wide gap recording heads. It was found that with saturation values of bias and/or audio recording currents the response curve became smooth. It is believed that in this case the second peak field is strong enough to obliterate the recording of the first peak field.

Single Edge Gap: A logical step from the wide gap heads is the production of a recording head in which the double peaked field is not present. The single edge gap head constructed to eliminate the second peak is shown in Fig. 10. The gap spacer is laid over one pole piece so that the tape cannot contact this pole piece and so that the copper overlay will constitute an eddy-current shield to weaken the peak field associated with the covered pole. The results of recordings made with this head and played back on a conventional head are shown in Fig. 11. Although the head had a nominal 20 mil gap, the curves are quite smooth. The two curves are for different directions of tape travel relative to the head; the short wavelength recordings are better when the tape contacts the exposed pole tip last.

As a matter of interest, this head was also tested as a playback head for recordings made with conventional head. The curve is smooth, free of gap-effect zeros of output, low in level at all frequencies and poor in short wavelength output.

Zero-Gap Playback Head: In Fig. 13 is shown a picture of a so-called "Zero-Gap" head. The intended principle of operation is shown schematically in Fig. 12. Recordings were made over the full width of the tape with a conventional recording head and played back with the zero-gap head. In conventional playback heads the short wavelength response improves as the gap length is reduced, so long as the reluctance across the gap is significantly greater than that of the path threading the coil. Practical difficulties become great as the gap is reduced below 1.0 mil although commerical heads have been produced with less than .0005 inch gaps. The zero-gap head was designed in an effort to overcome some of these difficulties by allowing the gap edges to be any distance apart in the direction of the tape travel. This is accomplished by having each gap edge traverse a different path on the tape; however, both edges scan a recording made at the same time by the recording head. One of the zero-gap heads constructed was adjustable by means of a screw while the other was adjustable only by reassembly. In the sense given above, the heads could be adjusted to a negative gap.

Figures 14 through 18 are representative of data obtained on the zero gap playback heads. The following observations are noteworthy.

(1) For the curve of Fig. 14 the gap was adjusted to a positive 10 mils. The dips at wavelengths of 12 and 5.4 mils are in approximate accord with theory.

(2) For the curve of Fig. 15 the gap was adjusted to a negative 10 mils; that is, 10 mils of the tape length touched the iron of the head at two positions of the tape width (Fig. 12). It will be noted that the response maxima and minima are reversed for the positive and negative gap data. A possible explanation is as follows. Elements of the tape length which contact both ends of the iron circuit contributed no flux through the coil, since equal surface pole strength is applied to each end of the iron circuit. When an integral number of wavelengths

is included in the length of tape touching both pole pieces, the ends of the pole pieces are presented to the adjacent recorded sections of the tape in the same relation as the ends of the pole pieces in a conventional head, the gap of which is small compared to the wavelength. In this case a higher output results.

When an odd number of half wavelengths are included in the length of tape touching both pole pieces, the adjacent recorded half-waves, which touch only one head pole piece, find low reluctance paths through the contacting pole pieces without threading the coil in a useful manner; low output results.

(3) In no case was the short wavelength response of the zero gap head as good as that of a conventional small gap head. This may be due in part to the difficulty in adjusting the gap, since it can no longer be set by pressing the edges against a non-magnetic spacer as in the conventional construction.

The improved relative low frequency response is due to attenuation of the mid-frequencies and not due to low frequency boost. It is believed that this effect is due to the peculiar flux path across the tape, giving in effect a number of different gap widths simultaneously. This is not considered a useful form of equalization.

(c) High Speed Experiments

High Speed Loop Drive: In order to attempt test recordings at high tape speeds, the loop tape drive of Fig. 19 was constructed. A variable speed d-c motor drives the large capstan drum through a stage of speed up pulleys. The tape is driven by the capstan and passes over the head and the guide posts which keep it aligned with the head. Provision is made to key the recording circuit in order that a single recording will be made on the tape loop. This is accomplished by having a low speed cam driven from the capstan shaft through a belt and gear reducer. The length of the cam lobe is such that a microswitch is actuated for a time equal to the period of one passage of the loop of tape over the head. In order that the microswitch will not be actuated the next time the cam lobe passes the microswitch, a second cam pushes the assembly clear of the cam wheel immediately after the recording has been made. By various combinations of pulleys and motor speeds, tape speeds up to 2100 inches per second can be attained.

The loop of tape for use on this drive is made by splicing a length of 1/4 inch tape with a short piece of scotch tape. Unfortunately this does not provide a loop with constant mass per unit length; the splice causes serious mechanical disturbances. At high tape speeds, the tape vibrates as the splice passes over the successive sections of the drive; the effect of this vibration is to cause uneven wear on the tape (particularly severe near the splice). The damage to the tape progresses from an initial light abrasion to a rapid stripping of the magnetic material from the tape. The increase in the rate of tape damage as the tape is run continuously is apparently due to the increase of temperature caused by friction between head and tape. As the tape damage proceeds, the magnetic material with its binder is deposited on the head, which further increases the friction and accelerates the rate of damage. The use of tapes with higher melting point binders did not significantly alter the results. Photographs of damaged tapes and a head with magnetic material deposited on it are shown in Figures 20 and 21.

The mechanical difficulties encountered point to the desirability of obtaining a suitable lubricant for the tape. The primary purpose of such a lubricant is to minimize abrasion of both tape and head. In addition, it is desirable that the lubricant prevent the loading of the head with dirt, and it should also have a damping influence on vibrations. Attempts to impregnate the Ferroxcube III material with wax were unsuccessful. Some success was achieved by using a thick soap solution applied to the guides over which the tape runs. The technique of operation was to lubricate the guide with soap, bring the tape up to speed and record, stop the tape and relubricate, and then bring the tape up to speed for playback. The average time at high speed was ten seconds. Some plastic tapes were operated in this manner at a tape speed of 1000 inches per second for as many as 150 cycles of operation without noticeable wear except at the splice. In general failure was due to splice separation. It is believed that continuous lubrication would result in practical tape life at speeds of 1000 inches per second or higher in a continuous (contrasted to loop) recording system.

Frequency Characteristics of Heads: The playback performance of a head, assuming a constant peak magnetomotive force from the tape at all frequencies, may be approximated by wrapping a few turns of wire around the head pole pieces at the gap, passing a current of constant amplitude through the coil at various frequencies; and measuring the voltage across the head winding coils (Fig. 26). In a head having zero losses the output should rise at a 6 db per octave rate.

In the design of a head to be operated at high frequencies, it is desirable to raise the self resonant frequency (usually by reduction in turns) and decrease the core losses at high frequencies. Also very important, but not concerned closely with the frequency characteristics of the head itself, is the construction of a head with a very small gap to aid the short wavelength resolution. A head was designed using Ferroxcube III core material, which has desirable low loss characteristics. This head was fabricated by grinding, since the mechanical properties of Ferroxcube III approach those of a ceramic. The head (Fig. 22) was wound with 50 turns on each leg of the core. The frequency characteristics of this head were compared to those of a standard Ampex head and an Ampex head which had been modified to have only 100 turns. The results are plotted in Figure 23. It will be noted that both of the heads with only 100 turns have self resonant frequencies which are much higher than the standard head. It is also to be noted that the losses of the Ferroxcube III head are significantly less than those of the modified Ampex head, as attested by the higher output at the resonant frequency. The Ampex head uses a stack of mu-metal laminations.

In addition to the frequency characteristics, as determined using the coupling turn, the inductance and Q were determined at various frequencies using data obtained from a Z-angle Meter at frequencies below 20 KC and from a resonated impedance test at higher frequencies. The results are plotted in Fig. 24; the rather peculiar shape of the curves is apparently due to the effect of the gap spacer acting as a shorted secondary. This was verified qualitatively by calculating the inductance and Q of a mutual inductor with a shorted turn; it has a similar shape.

The gap spacer used in the first Ferroxcube III head was .0005 inch while a .0003 inch spacer was used in the second head. To check the effective gap, recordings were made and played back at a tape speed of 6 inches per second. The results, plotted in Figure 25, show that neither of the Ferroxcube heads is as good as the Ampex head in short wavelength performance, and that the effective gap width is approximately 2-1/2 times the thickness of the gap spacer. An examination under a microscope showed the gap edge of the Ferroxcube heads to be rough due to the porosity of the material. This appears to be a bar to the achievement of very short wavelengths with this type of core material.

The use of Ferroxcube III or similar material appears to be advantageous for high frequency heads but the heads at present are not completely satisfactory for very short wavelength and frequencies of 5 mc.

Record-Playback Experiments: Record-playback experiments at tape speeds in the range of 1000 inches per second were conducted to establish the total frequency charcteristics of a system using the Ferroxcube III head and various tapes. The recording and playback were done with the same head using no bias for recording. Both permanent magnet and bulk type 60 cps erase were used; the ac erase producing a somewhat lower erased noise level. The record-playback system circuit is shown in Fig. 27. It will be noted that the total current measured with the series resistor and voltmeter is not necessarily the actual recording current. As the frequency passes through resonance, an increasing portion of the total current will be shunted past the head winding by the stray capacitance of the head and wiring. For this reason the frequency response data cannot be taken as constant current curves, and are probably pessimistic. Approximately 0.27 millivolt-amperes were supplied to the head at 1.0 to 1.5 megacycles.

The data are plotted in Fig. 28. Curves A and B, both obtained with the Ferroxcube III head, show a definite improvement in signal to noise ratio and probably in relative response when using plastic tape. The metal tape curve is inconclusive as far as relative response is concerned because the signal to noise ratio is very poor. The relatively poor response with metal tape is probably due to the inability of the tape to conform to the head contours as does the plastic tape.

Curves B and C compare the performance of the modified Ampex head and the Ferroxcube III head when used on plastic tape. On the basis of the original gap width, the short wavelength characteristics of the Ampex head should have been better; unfortunately the head must be disassembled to modify it and apparently this destroyed its original good mechanical characteristics. It apparently suffers from poor contact with the tape and an imperfect gap.

In the case of the Ferroxcube III head on plastic tape there was evidence of record up to 1.6 mc. This was deduced from the fact that, although there was no detectable 1.6 mc signal when played back at 1000 inches per second, there was a detectable signal at a playback speed of 570 inches per second. This situation is not unreasonable, since the recording process is less sensitive to gap effects, and there is better contact between playback head and tape at the lower speed.

Taking a signal to noise ratio of 5 db as a criterion, the highest frequencies which have been successfully recorded and played back at the same speed are 1.18 mc, 1.29 mc, and 1.11 mc, respectively, for Ferroxcube head on metal tape, Ferroxcube head on plastic tape and modified Ampex head on plastic tape. The corresponding wavelengths are 0.85, 0.78 and 0.87 mils. By increasing the tape tension considerably, it was possible to record and play back 1.4 mc using the Ferroxcube III head and plastic tape; the corresponding wavelength was 0.72 mils, which is the shortest wavelength thus far obtained at high tape speeds. Curve B in Figure 28 can reasonably be extrapolated to give an estimate of the effective head gap. By this procedure the effective gap, under the conditions of the test, for the Ferroxcube III head was 0.74 mil. Because of the low signal to noise ratio, such an extrapolation for the other curves is very much in doubt.

Since tape speeds up to 2000 inches per second were available, it should have been possible to increase the upper frequency limit by increasing the tape speed above 1000 inches per second. A frequency of 1.5 megacycles was recorded and played back (discernible above the noise) at 1400 inches per second tape speed. This corresponds to a wavelength of .92 mil, which indicates that the effective gap was increased. This increase in effective gap at high speeds is due to progressively poorer head-tape contact. The tape appears to bounce away from the head for greater and greater distances along the tape as the speed is increased. An observation which confirms this was performed by recording and playing back 1.0 mc at progressively higher tape speeds. Instead of increasing in amplitude, the signal decreased in average amplitude (meter reading), and the amplitude was noted on the oscilloscope to be modulated in a periodic fashion. Further increase in speed resulted in an increasingly severe amplitude modulation until the length of the recorded section was less than one-twentieth of the total tape length. The mechanical positioning of the head, and the wrap of the tape around the head were found to be extremely critical. The above observations indicate a traveling wave vibration phenomenon in the tape. The problem of increasing the upper frequency limit appears to be primarily concerned with controlling this vibration.

D. CONCLUSIONS

1. If the practical problem of handling the magnetic medium at tape speeds of 800 inches per second can be solved, recording and playback of frequencies up to 1.0 mc with a signal to noise ratio of at least 30 db appears quite feasible.

2. Usefully good contact between the tape and head at 800 inches per second can be maintained. The problem is therefore one of tape supply, storage and take-up in this speed range.

3. Above 1000 inches per second very serious mechanical vibrations destroy proper head-tape contact. These vibrations may be somewhat

reduced using continuous tape feed instead of the experimental loop.

4. Some form of lubrication between head and tape is desirable at speeds above 500 inches per second. Soap solution has been used with some success.

5. Heads can be constructed with satisfactory frequency characteristics at 1 mc and probably higher. A head of Ferroxcube III or other low loss core material has significant advantages.

6. The attainment of effective head scanning gaps less than 0.75 mil is extremely difficult at these speeds.

7. The requirement that the head contact the tape gives rise to serious practical problems; a high resolution method in which this is not necessary would be very desirable.

8. A useful analytic expression, founded on other than empirical considerations, is very much needed for the fundamental theoretical study of magnetic recording phenomena.

9. The goal of 5 mc recording by magnetic means appears unattainable at this time by other than multiple channel means.

Part II

A. RECOMMENDATIONS

On the basis of the observations and conclusions discussed earlier, it appears that magnetic recording is limited by severe practical difficulties to frequencies much below 5 mc. Direct attempts to obtain a solution within the framework of present and immediately forseeable developments in magnetic recording appear to offer little chance of producing a useable solution. New techniques of magnetic recording, at present unknown, may eventually solve the problem in a satisfactory manner, but it is not felt that these new techniques will be efficiently produced by a single concentrated effort. For this reason, emphasis was shifted in July 1950 to an investigation of other possible recording techniques, such as the recording by a modulated light beam upon film. The results of these investigations are reported in Volume II of this Final Engineering Report.

B. CONTRIBUTING PERSONNEL

The theoretical analyses were made by Dr. D. E. Wiegand and Mr. T. L. Gilbert, and the experimental work was done by Messrs. D. E. Wiegand, W. R. Chynoweth and C. W. Claras. Others contributing substantially to the program were Mr. F. G. Rest and Mr. Raymond E. Zenner who was the project engineer during this phase of the program.

Respectfully submitted,
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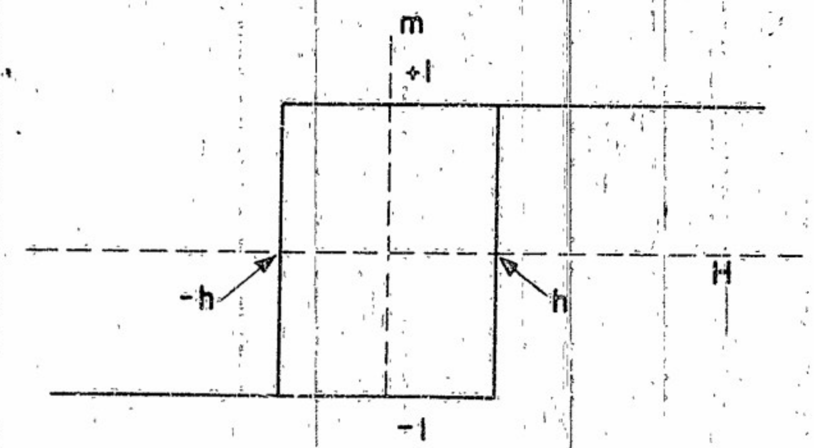

FIG. 1a – HYSTERESIS LOOP FOR FIRST MODEL (SINGLE DOMAIN PARTICLE WITH AXIS OF STABILITY PARALLEL TO FIELD)

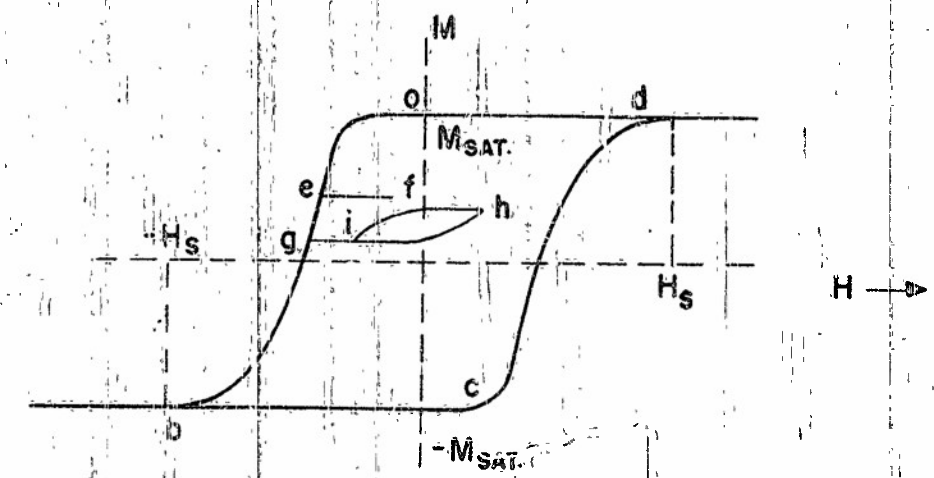

FIG. 1c – HYSTERESIS LOOP FOR THIRD MODEL (DILUTE DISPERSION OF PARTICLES TREATED IN FIRST MODEL)

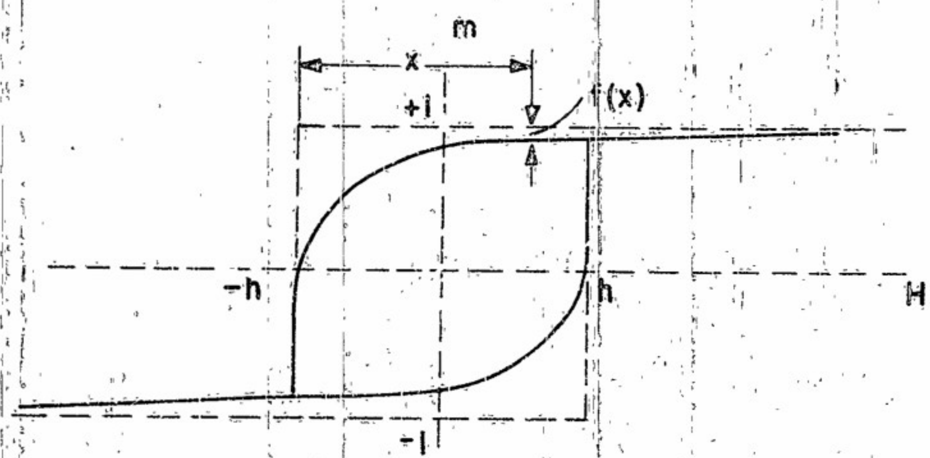

FIG. 1b – HYSTERESIS LOOP FOR SECOND MODEL (SINGLE DOMAIN PARTICLE WITH ARBITRARY ORIENTATION OF INITIAL AXIS OF STABILITY)

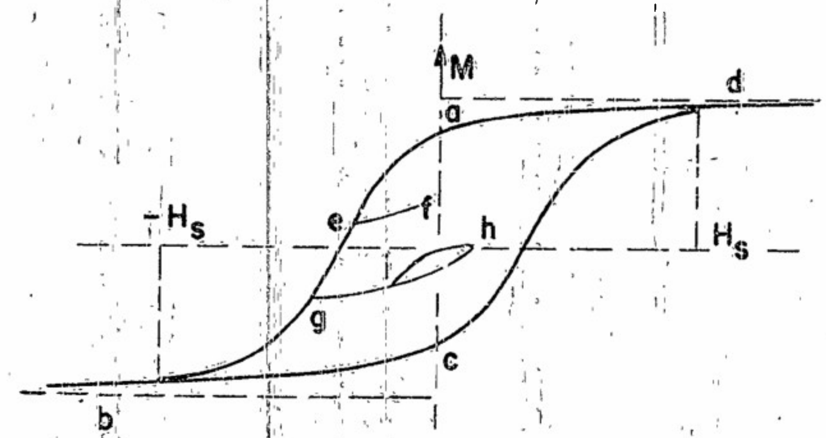

FIG. 1d – HYSTERESIS LOOP FOR FOURTH MODEL (DILUTE DISPERSION OF PARTICLES TREATED IN SECOND MODEL)

RESTRICTED

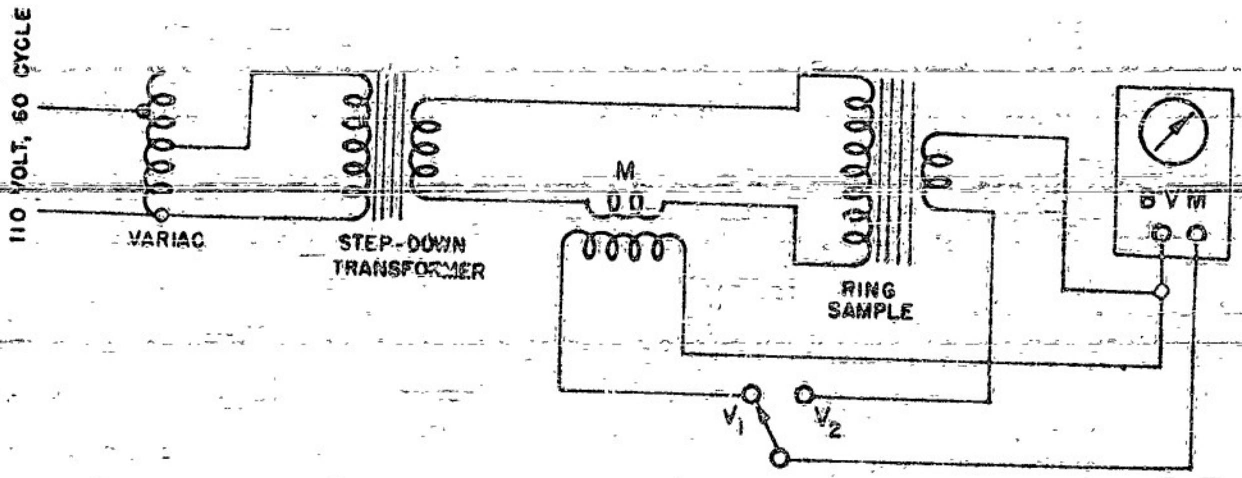

FIGURE 2

CIRCUIT FOR 60 CYCLE MEASUREMENTS ON FERROXCUBE III CORE.

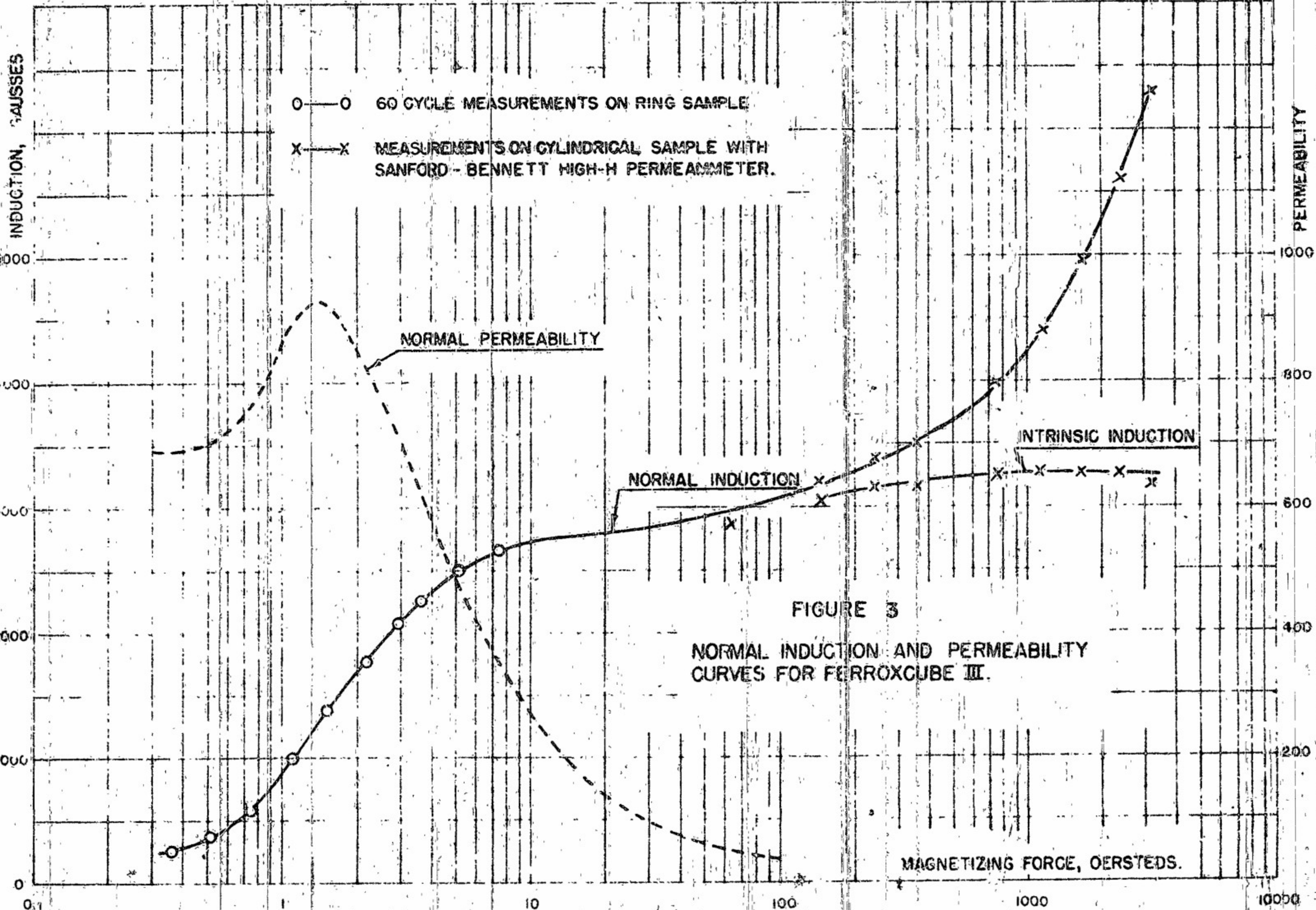

FIGURE 3

NORMAL INDUCTION AND PERMEABILITY CURVES FOR FERROXCUBE III.

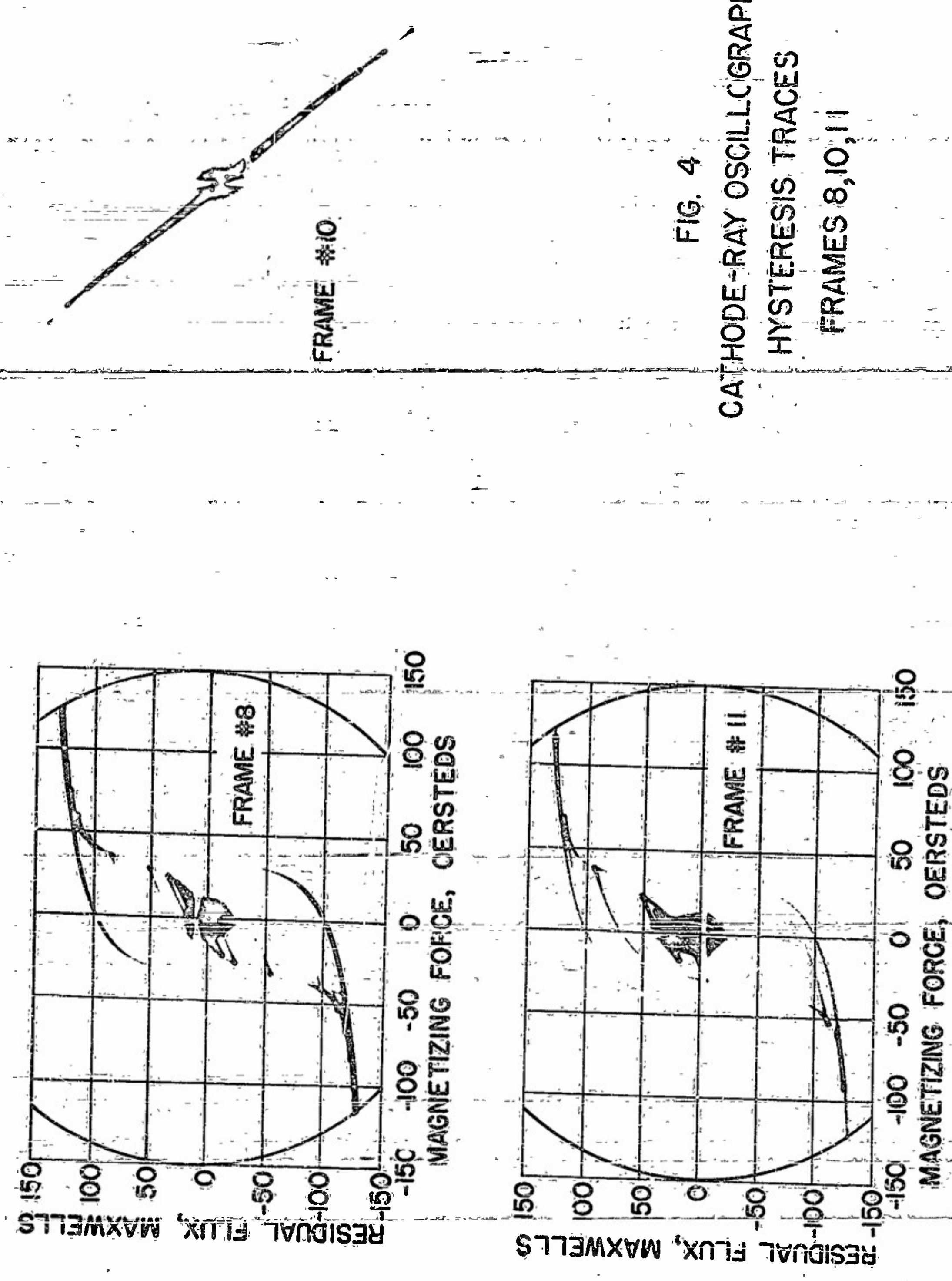

FIG. 4
CATHODE-RAY OSCILLOGRAPH
HYSTERESIS TRACES
FRAMES 8,10,11

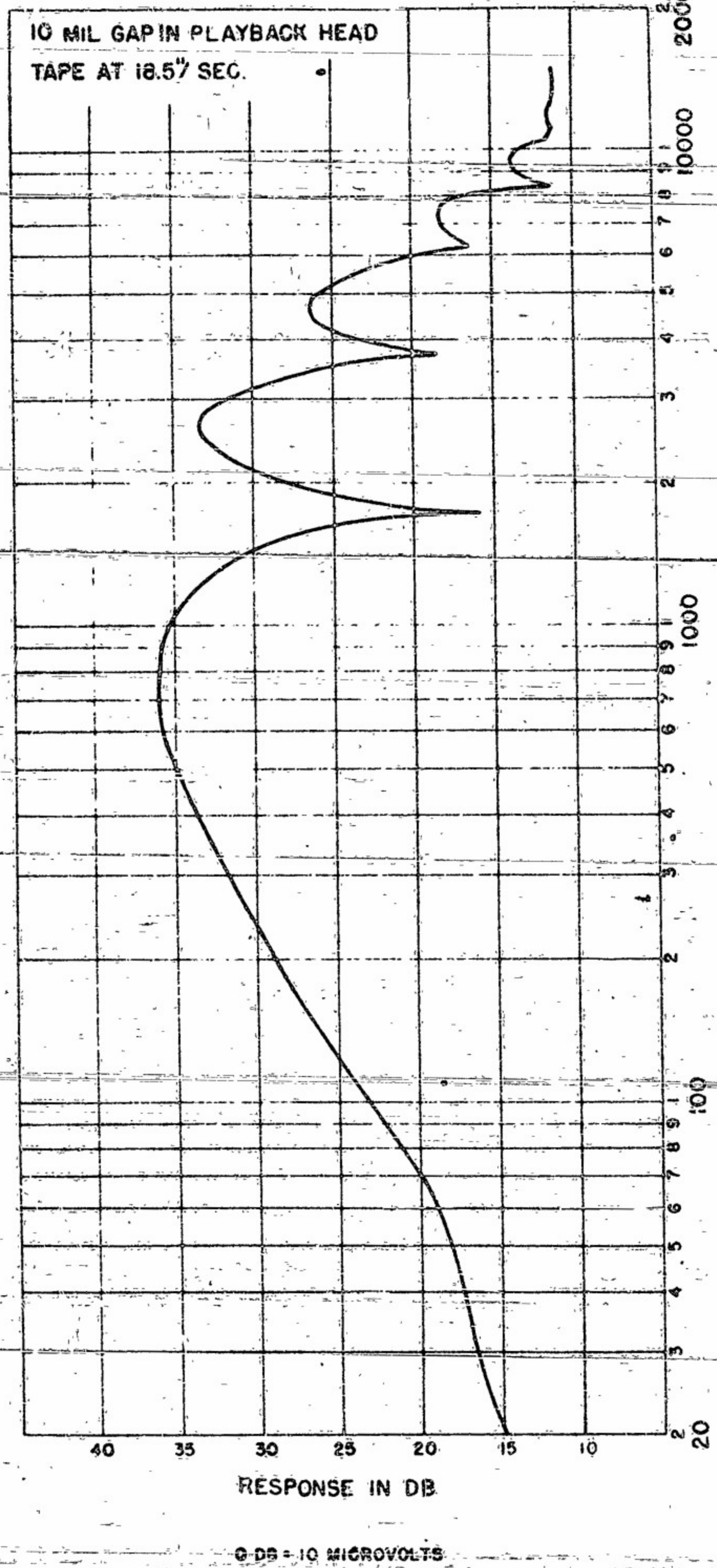

FIG. 5

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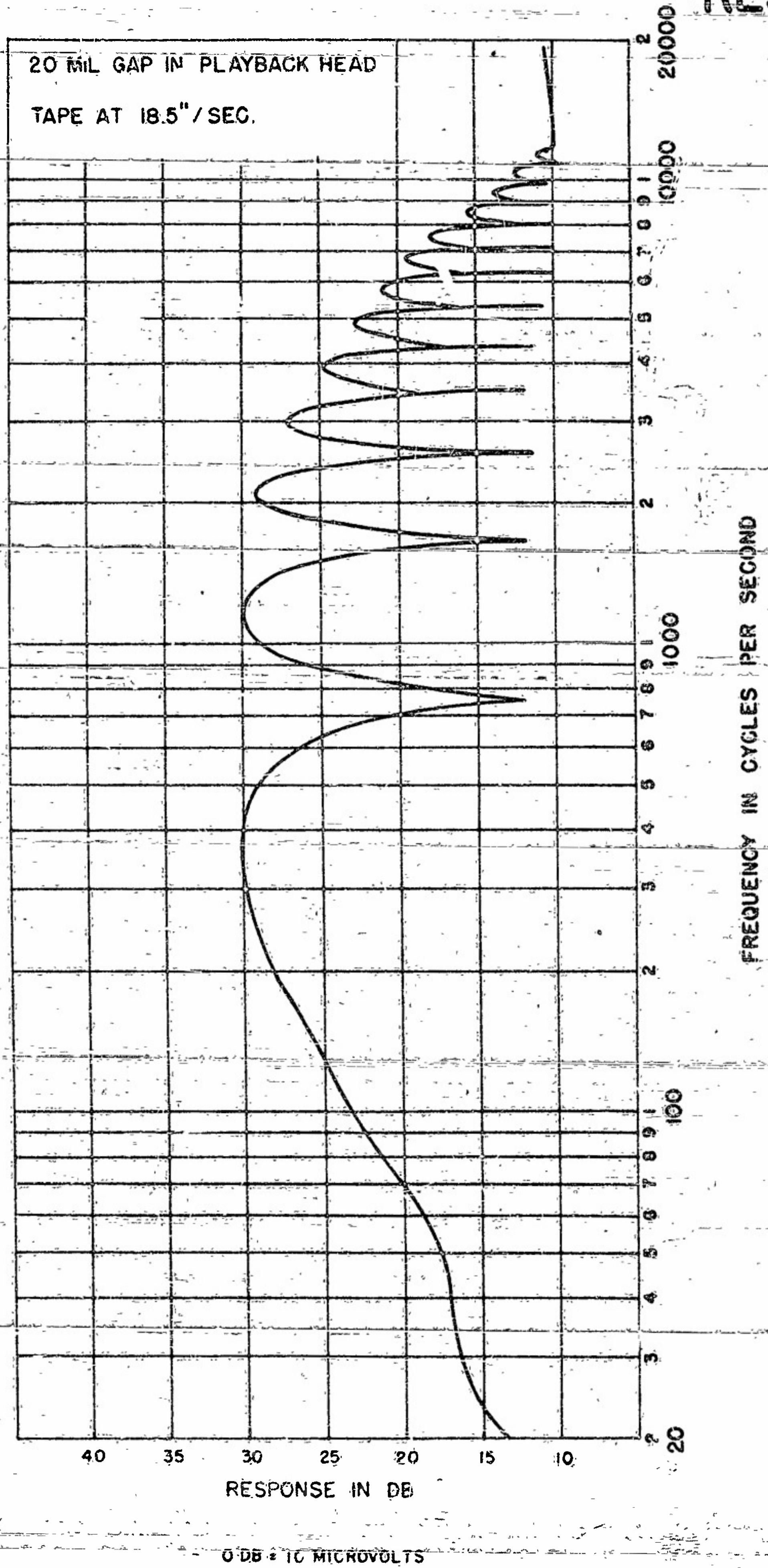
20 MIL GAP IN PLAYBACK HEAD
TAPE AT 18.5"/SEC.
FREQUENCY IN CYCLES PER SECOND
20
100
1000
10000
20000
40
35
30
25
20
15
10
RESPONSE IN DB
0 DB = 10 MICROVOLTS

FIG. 6

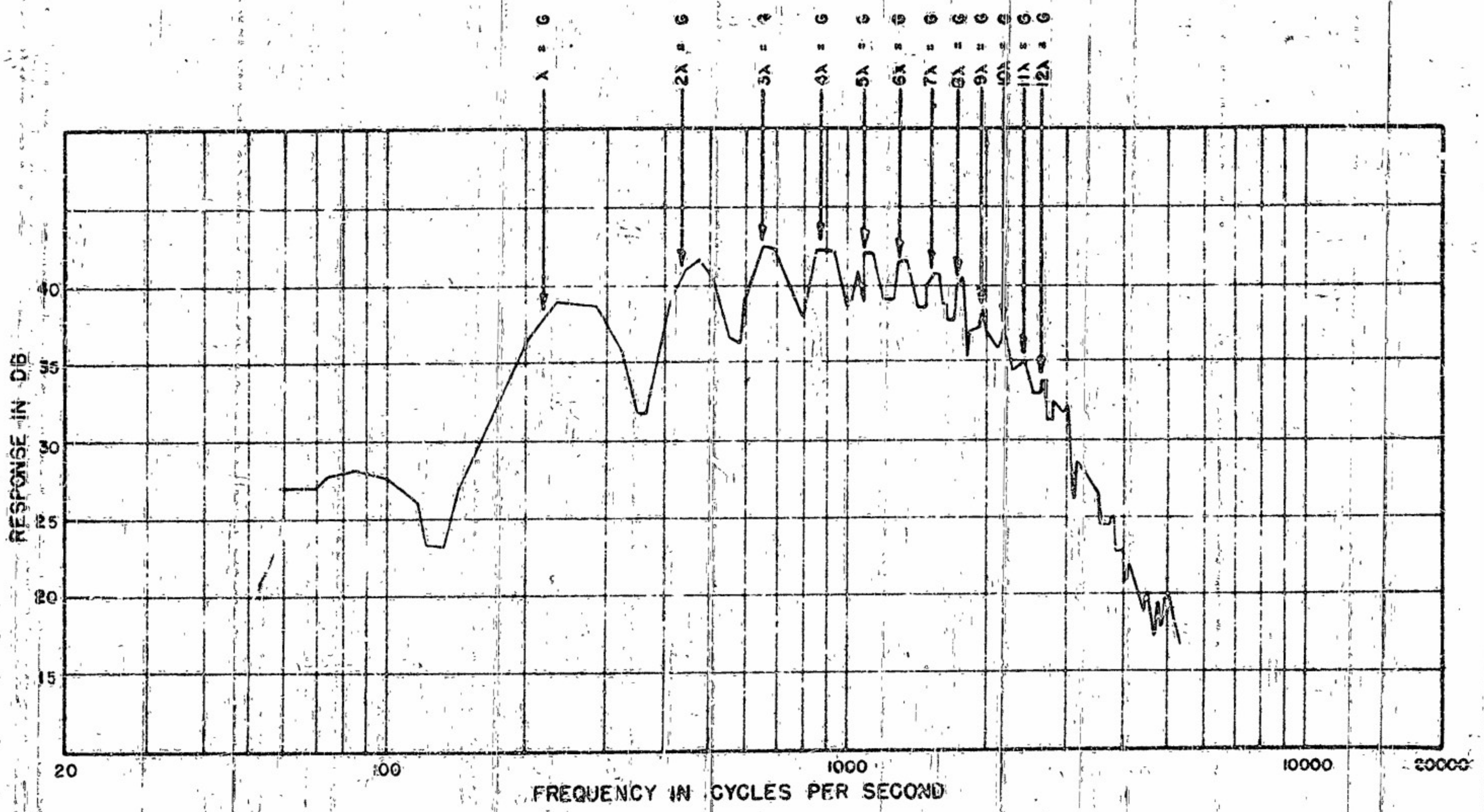

FIGURE 7

PLAYBACK RESPONSE USING CONVENTIONAL PLAYBACK HEAD — RECORDING HEAD HAD .038" GAP. TAPE SPEED 7.9"/SEC.

REPORT NO. CO-70CA-12

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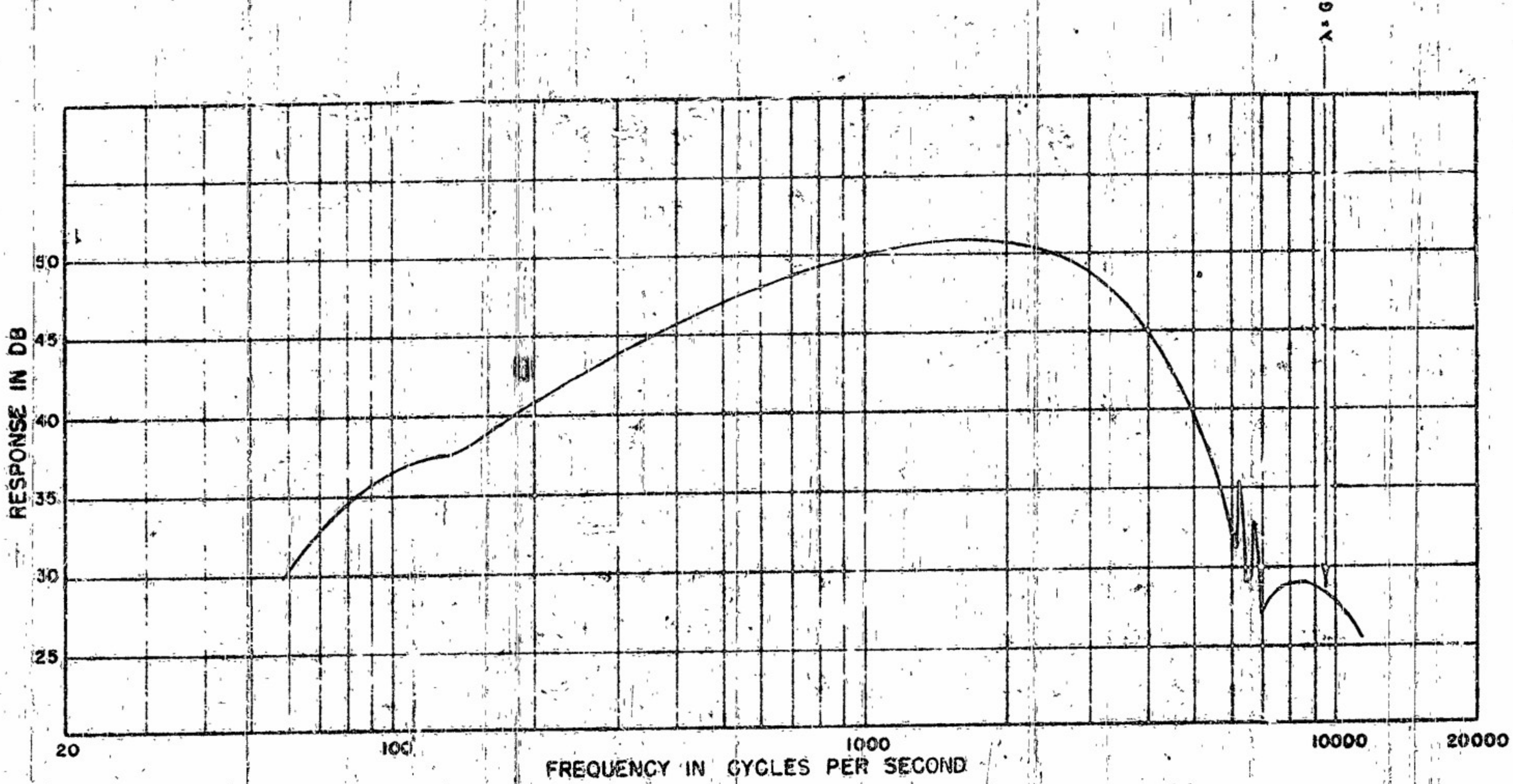

FIGURE 8

PLAYBACK RESPONSE USING CONVENTIONAL PLAYBACK HEAD – RECORDING HEAD HAD APPROX. .002" GAP – TAPE SPEED 19"/SEC.

REPORT NO. 00-7[illegible]-13

RESTRICTED

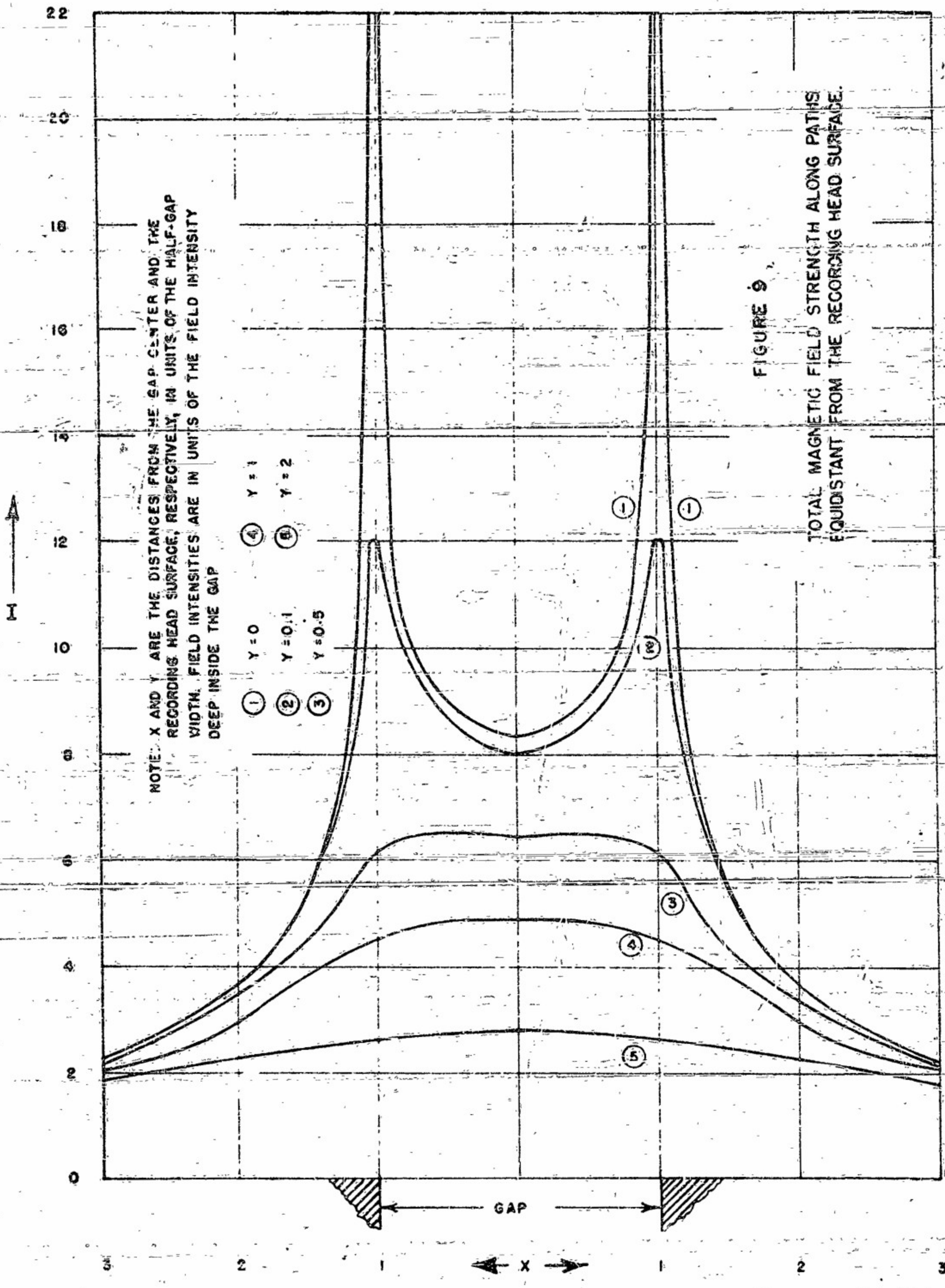

FIGURE 9

TOTAL MAGNETIC FIELD STRENGTH ALONG PATHS EQUIDISTANT FROM THE RECORDING HEAD SURFACE.

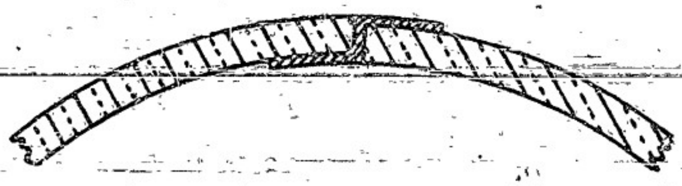

FIGURE 10

"SINGLE EDGE" HEAD-GAP SPACER FOLDED OVER ONE POLE TIP.

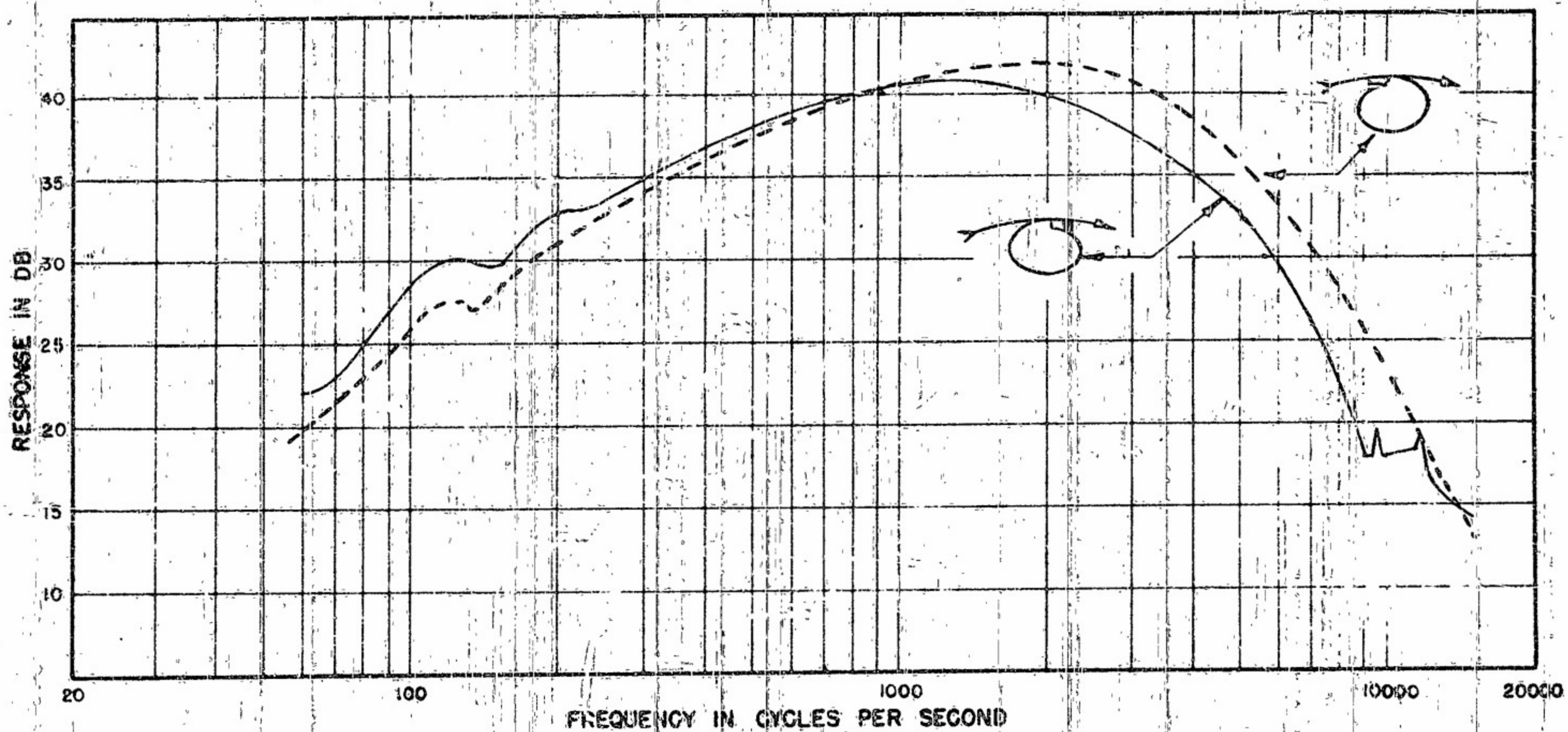

FIGURE 11

PLAYBACK RESPONSE - CONVENTIONAL PLAYBACK HEAD PLAYING BACK RECORDINGS MADE BY "SINGLE EDGE" RECORDING HEAD. TWO TAPE DIRECTIONS RELATIVE TO RECORDING HEAD.

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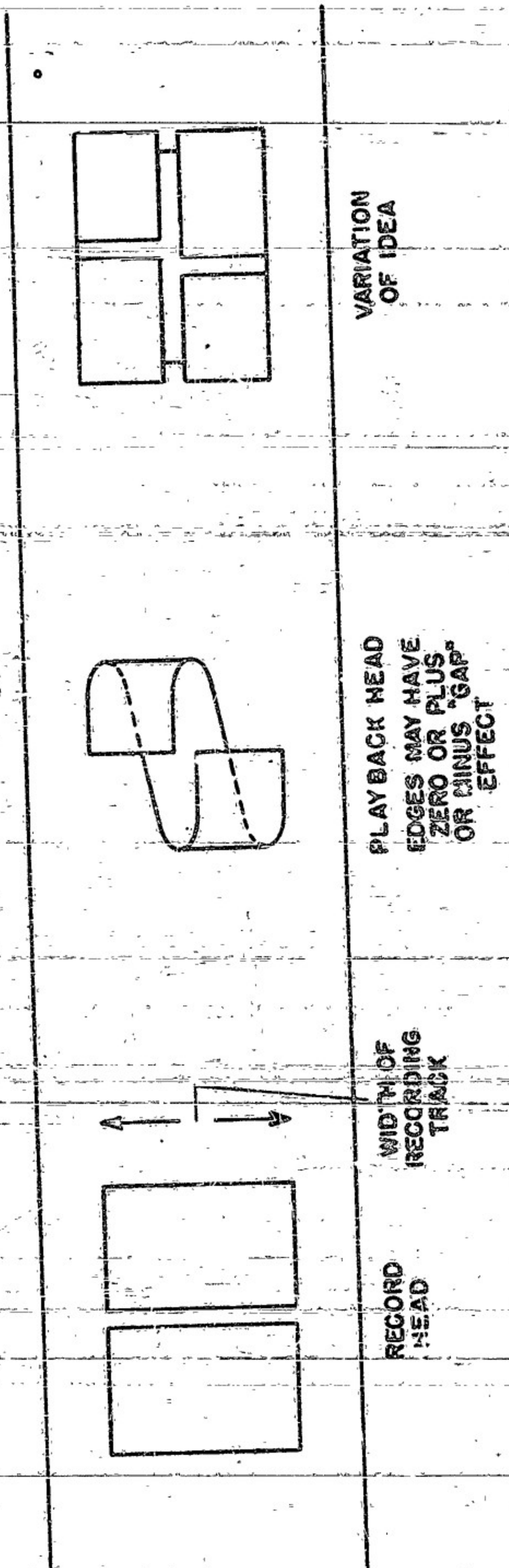

ZERO GAP PLAYBACK HEAD

FIG. 12

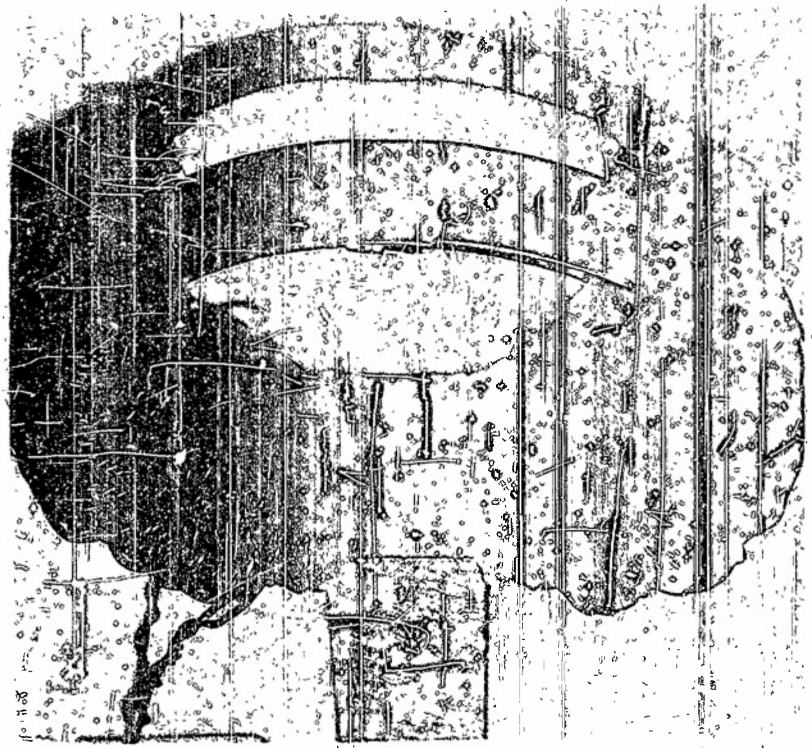

Fig. 13a WIDE GAP HEAD

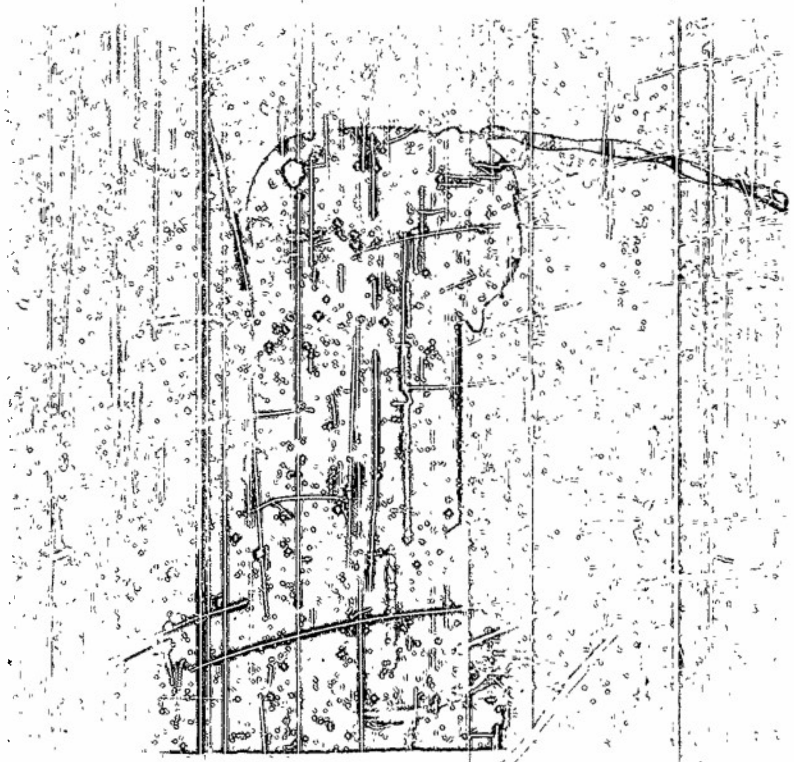

Fig. 13b ZERO GAP HEAD

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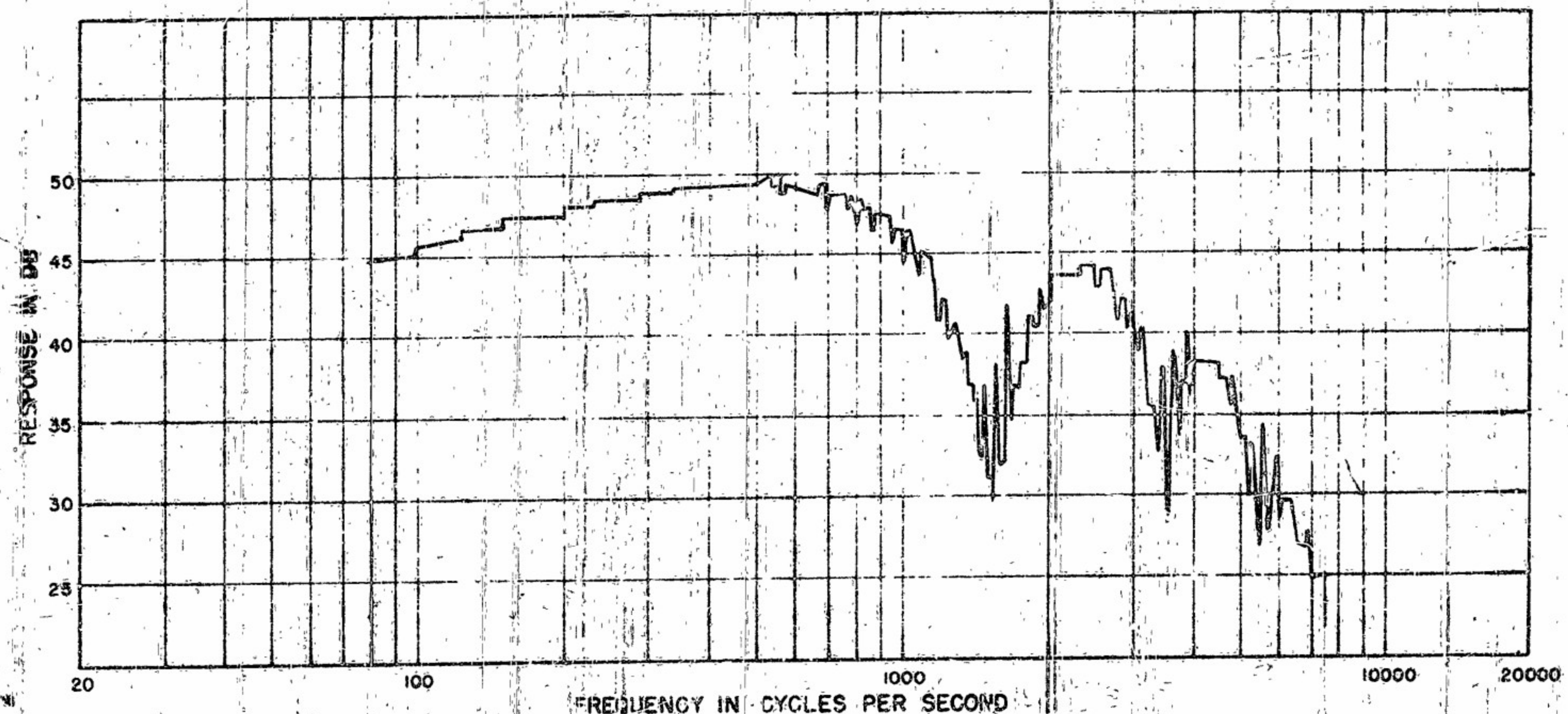

FIGURE 14

PLAYBACK RESPONSE - "NEGATIVE GAP" HEAD ADJUSTED FOR POSITIVE .010 GAP. RECORDING MADE BY CONVENTIONAL HEAD COVERING ENTIRE TAPE WIDTH — TAPE SPEED IS 3"/ SEC.

REPORT NO. 90-78CA-12

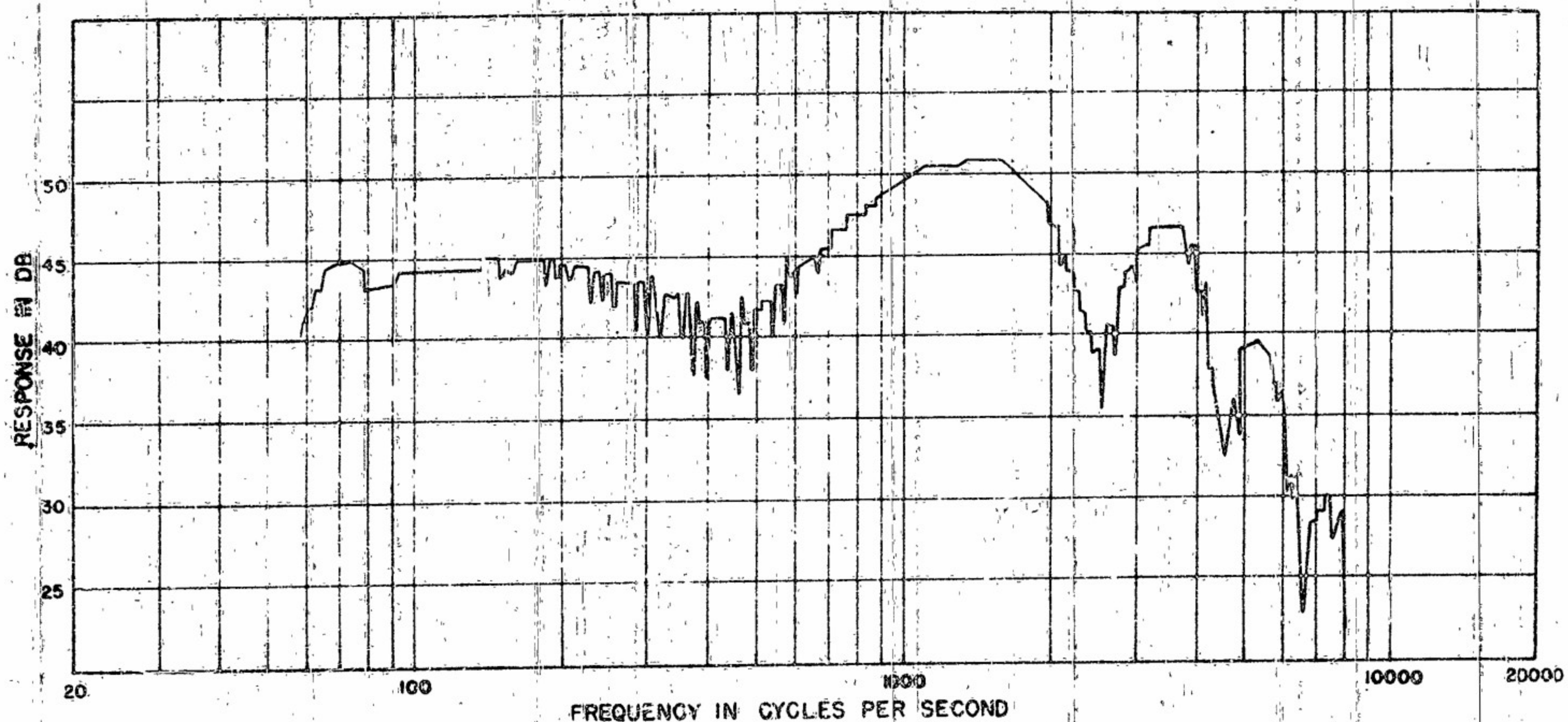

FIGURE 15

PLAYBACK RESPONSE - "NEGATIVE GAP" HEAD ADJUSTED FOR NEGATIVE .010 GAP. RECORDING MADE BY CONVENTIONAL HEAD COVERING ENTIRE TAPE WIDTH - TAPE SPEED 16.3"/SEC.

REPORT NO. 90-183A-12

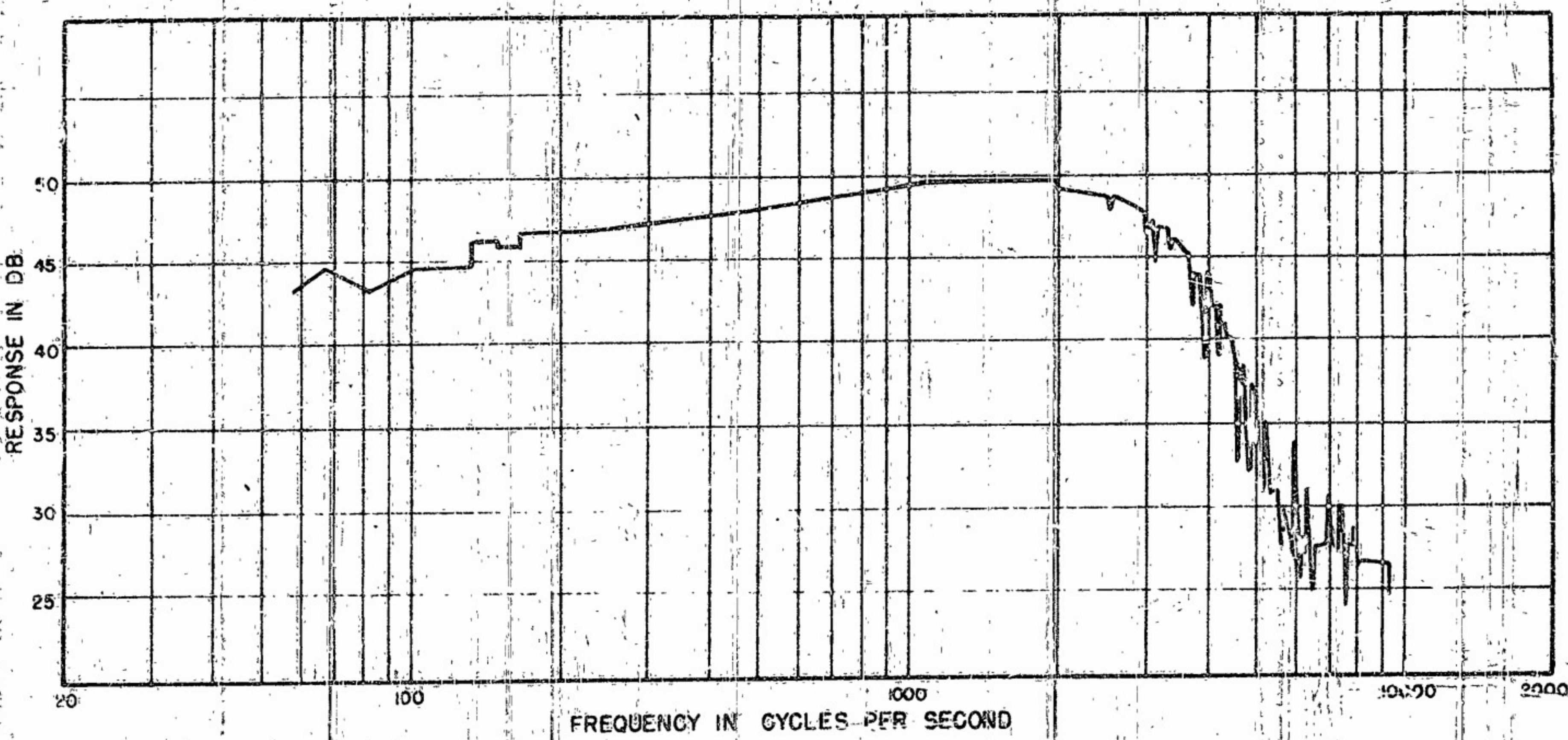

FIGURE 16

PLAYBACK RESPONSE - "NEGATIVE GAP" HEAD ADJUSTED FOR POSITIVE .002 GAP. RECORDING MADE BY CONVENTIONAL HEAD COVERING ENTIRE TAPE WIDTH – TAPE SPEED 18.3"/ SEC.

REPORT NO. 50 7566 12

RESTRICTED

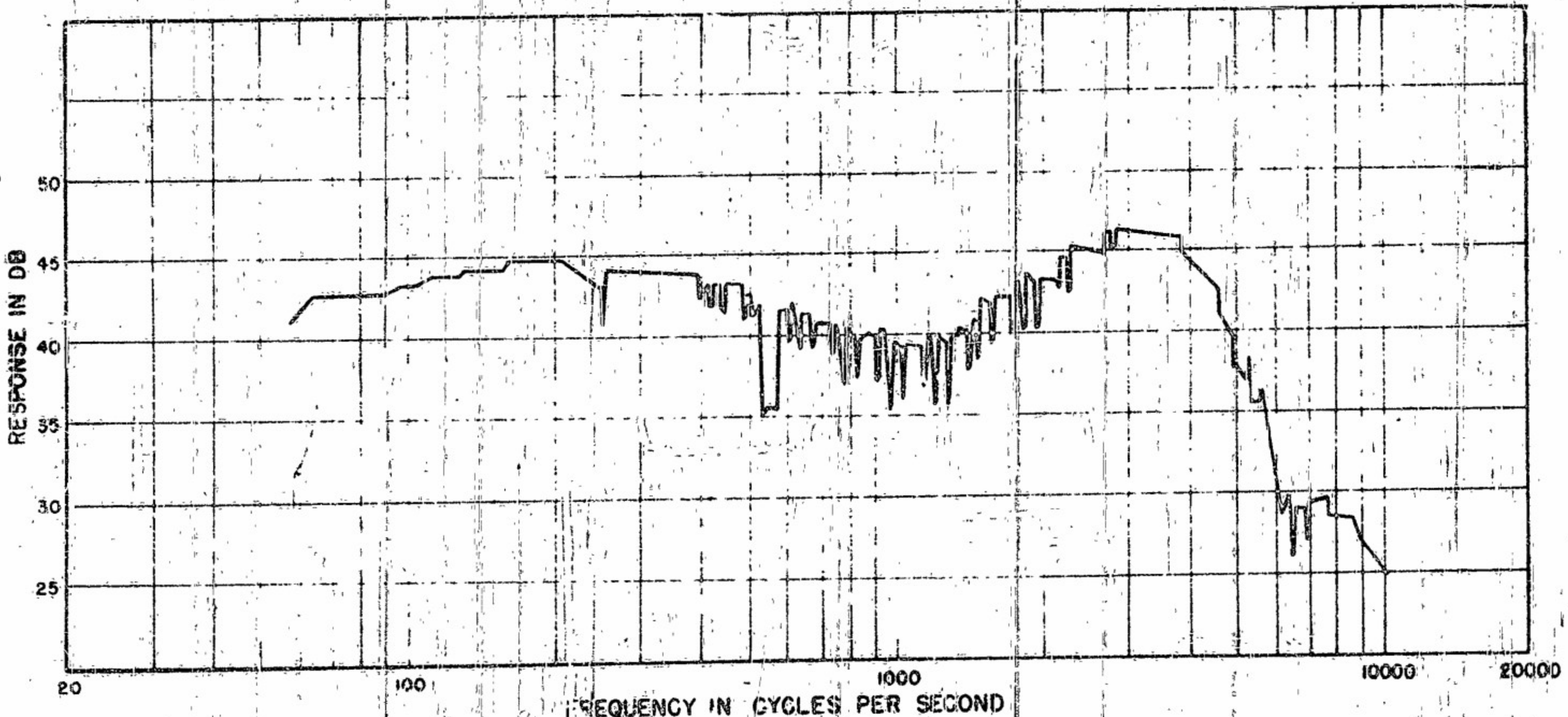

FIGURE 17

PLAYBACK RESPONSE - "NEGATIVE GAP" HEAD ADJUSTED FOR NEGATIVE .002 GAP. RECORDING MADE BY CONVENTIONAL HEAD COVERING ENTIRE TAPE WIDTH — TAPE SPEED 18.3"/ SEC.

REPORT NO. 90-7B3A-42

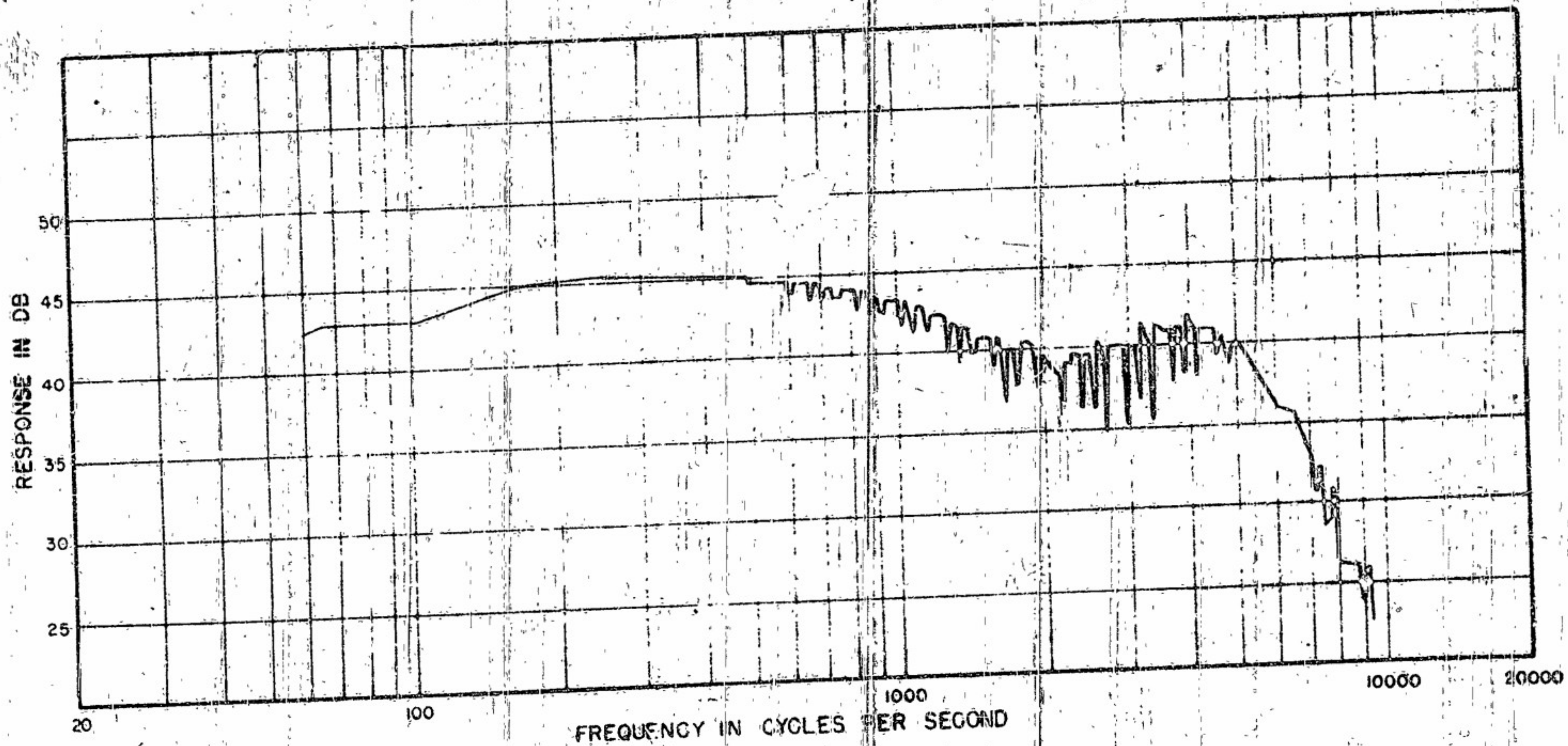

FIGURE 18

PLAYBACK RESPONSE - "NEGATIVE GAP" HEAD ADJUSTED FOR VERY SMALL NEGATIVE GAP. RECORDING MADE BY CONVENTIONAL HEAD COVERING ENTIRE TAPE WIDTH - TAPE SPEED 18.3"/SEC.

REPORT NO. 90-7[illegible]A-18

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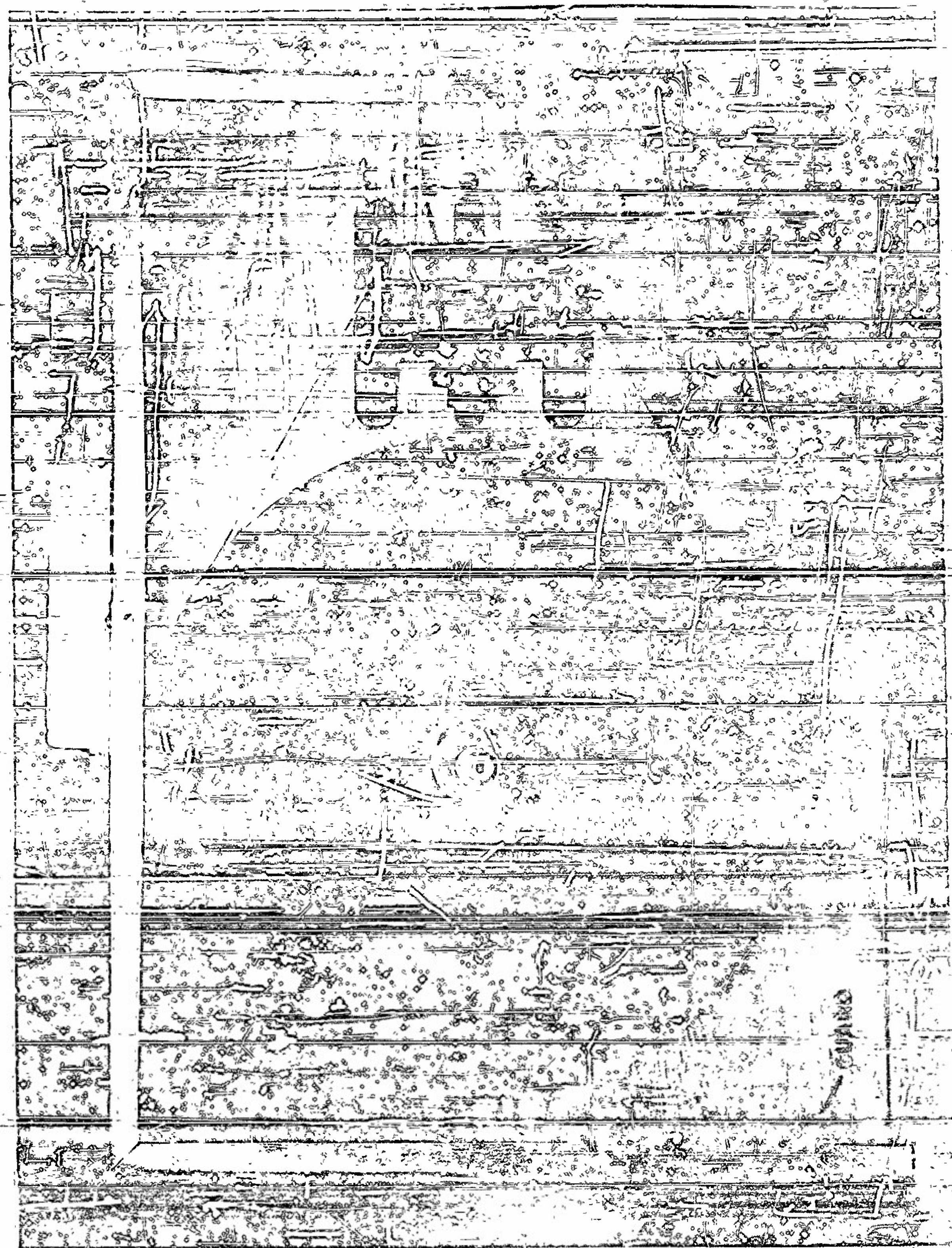


FIG. [illegible] - HIGH SPEED DRIVE FOR TAPE LOOP

FIGURE 20

PLASTIC AND PAPER BASE TAPES. COATINGS DAMAGED BY HIGH SPEED OPERATION.

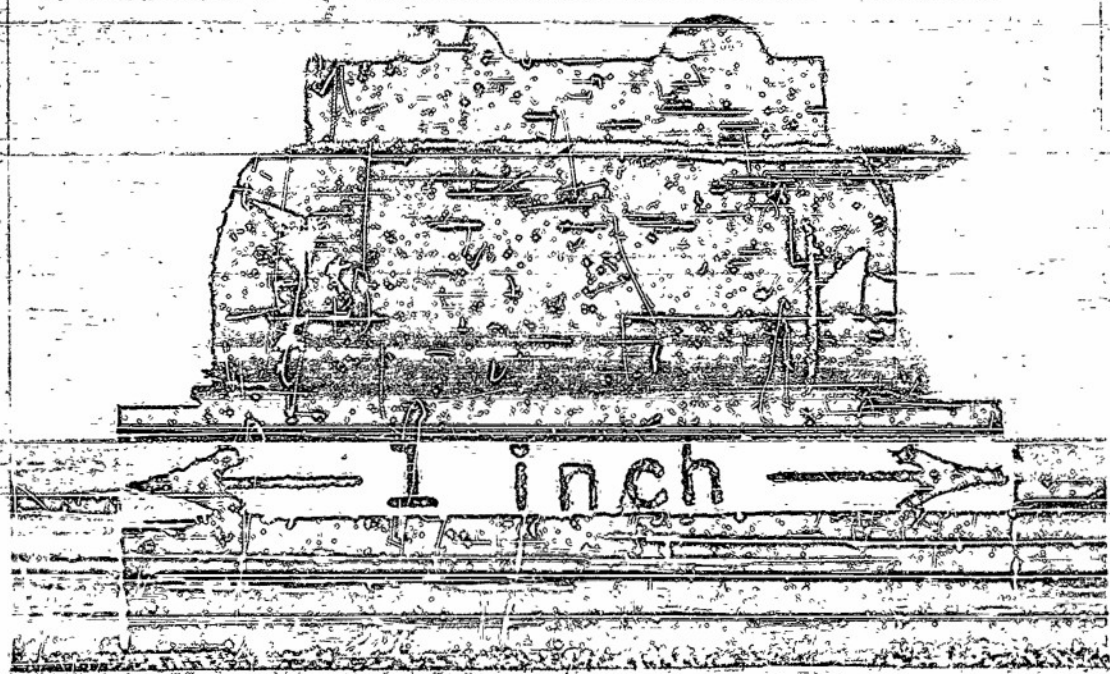


FIGURE 21

COATING DEPOSITS ON FERROXCUBE III HEAD

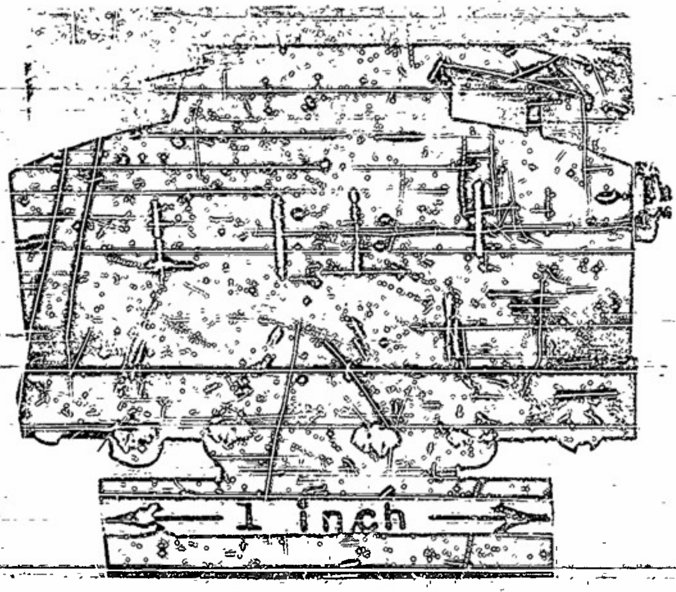


FIGURE 22

PHOTOGRAPH OF SECOND MODEL OF FERROXCUBE III HEAD

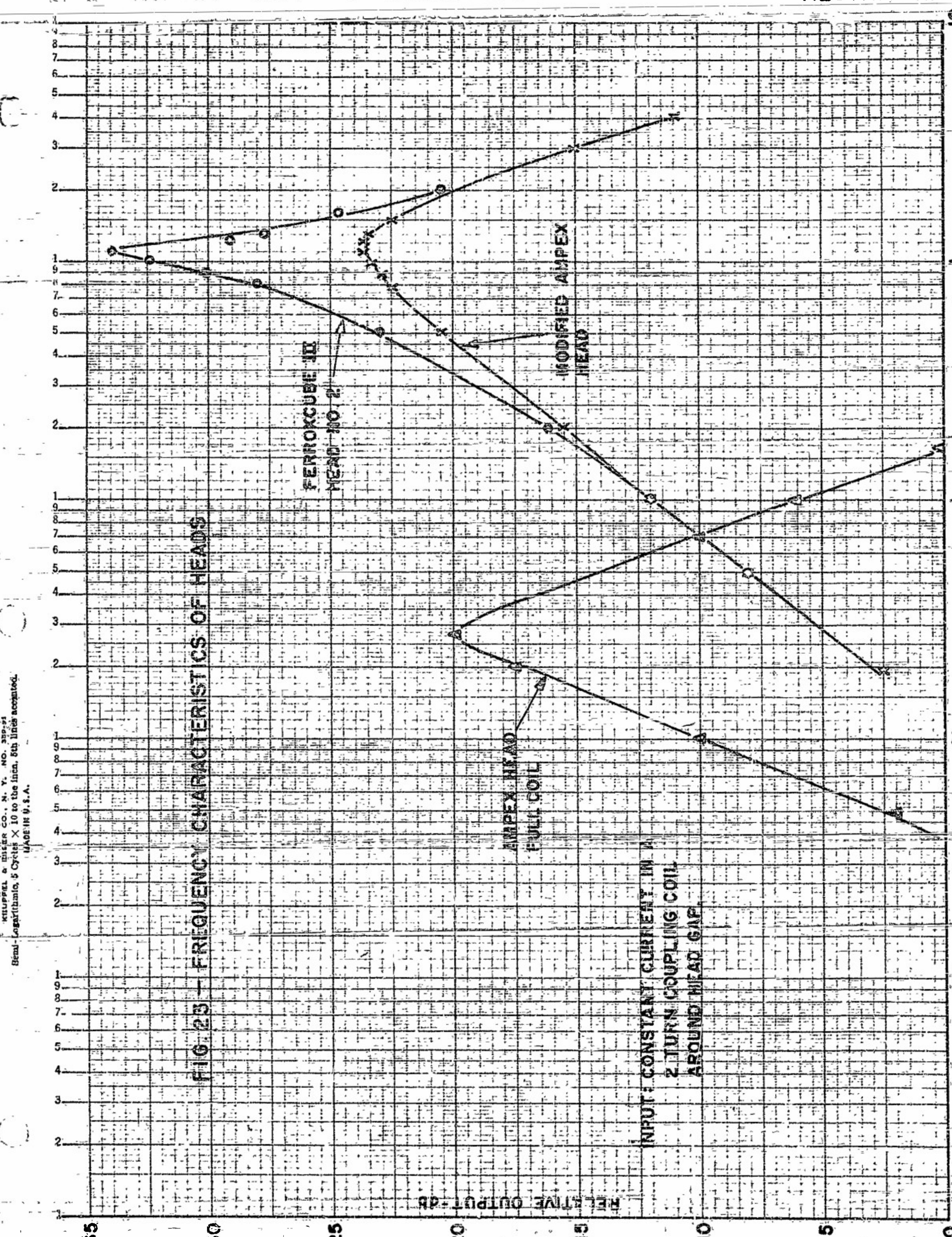
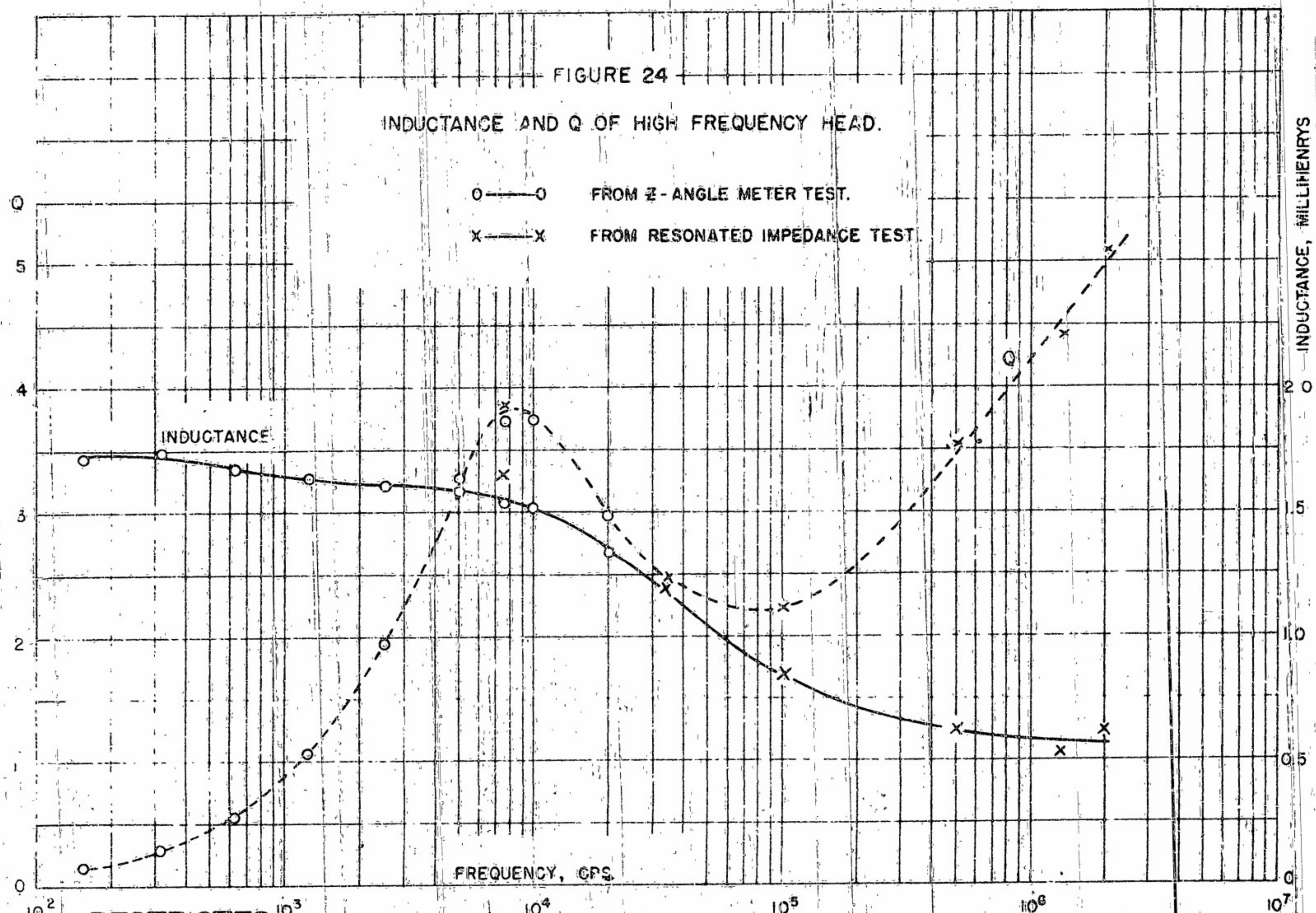


FIG. 23 — FREQUENCY CHARACTERISTICS OF HEADS

FIGURE 24

INDUCTANCE AND Q OF HIGH FREQUENCY HEAD.



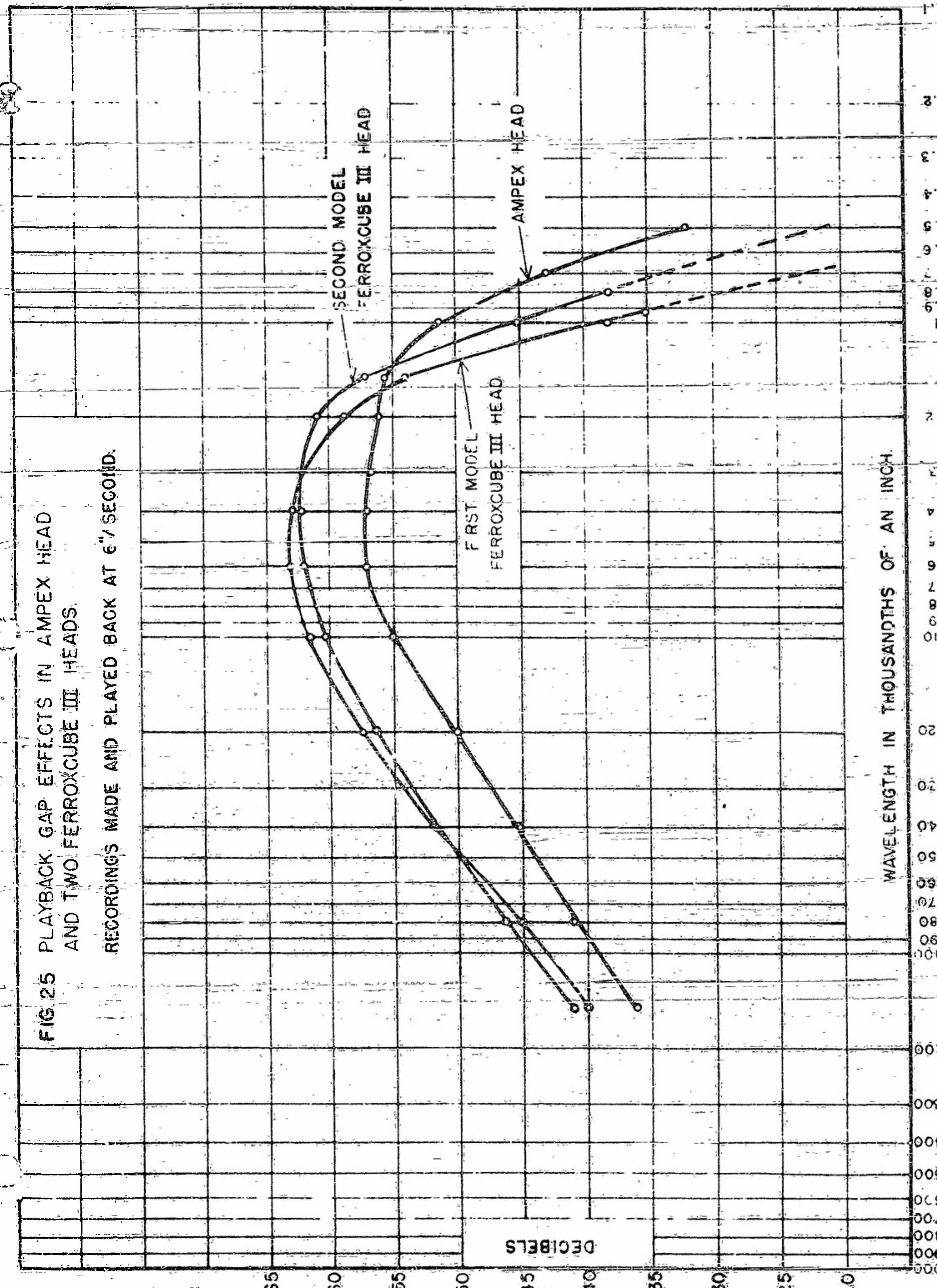


FIG. 25 PLAYBACK GAP EFFECTS IN AMPEX HEAD AND TWO FERROXCUBE III HEADS.

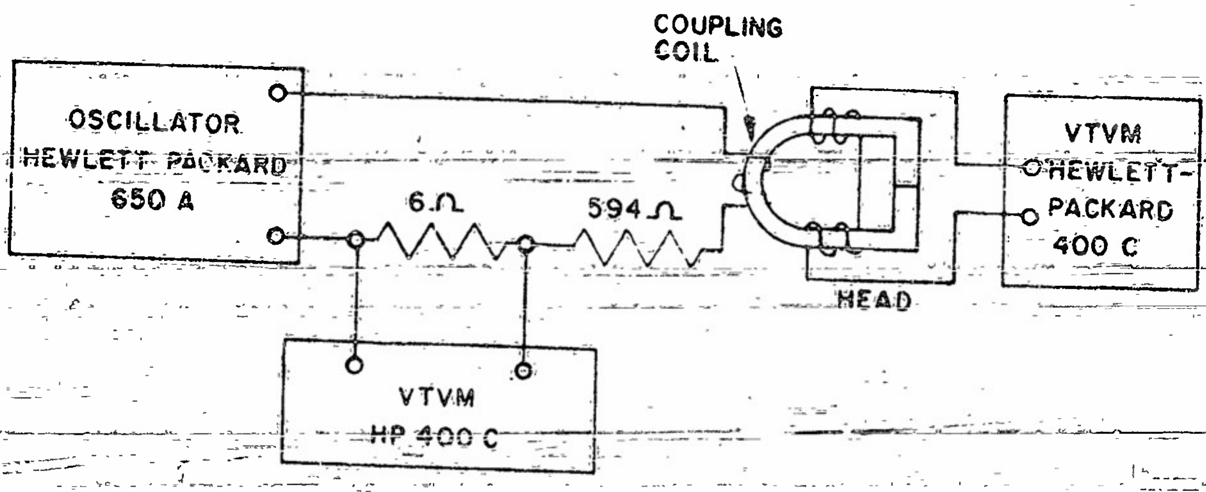


FIG. 26 - FREQUENCY TEST CIRCUIT

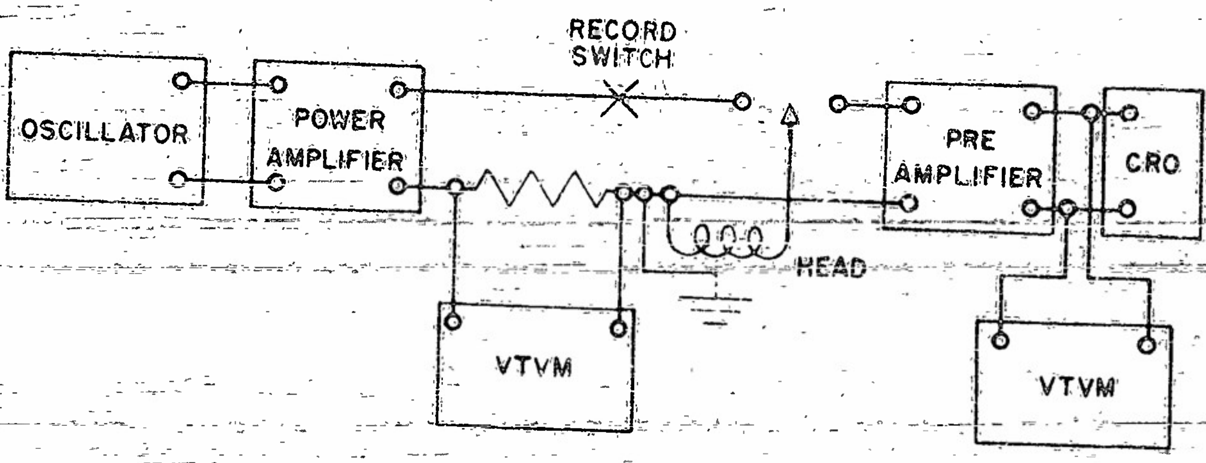


FIG. 27 - RECORD-PLAYBACK SYSTEM CIRCUIT

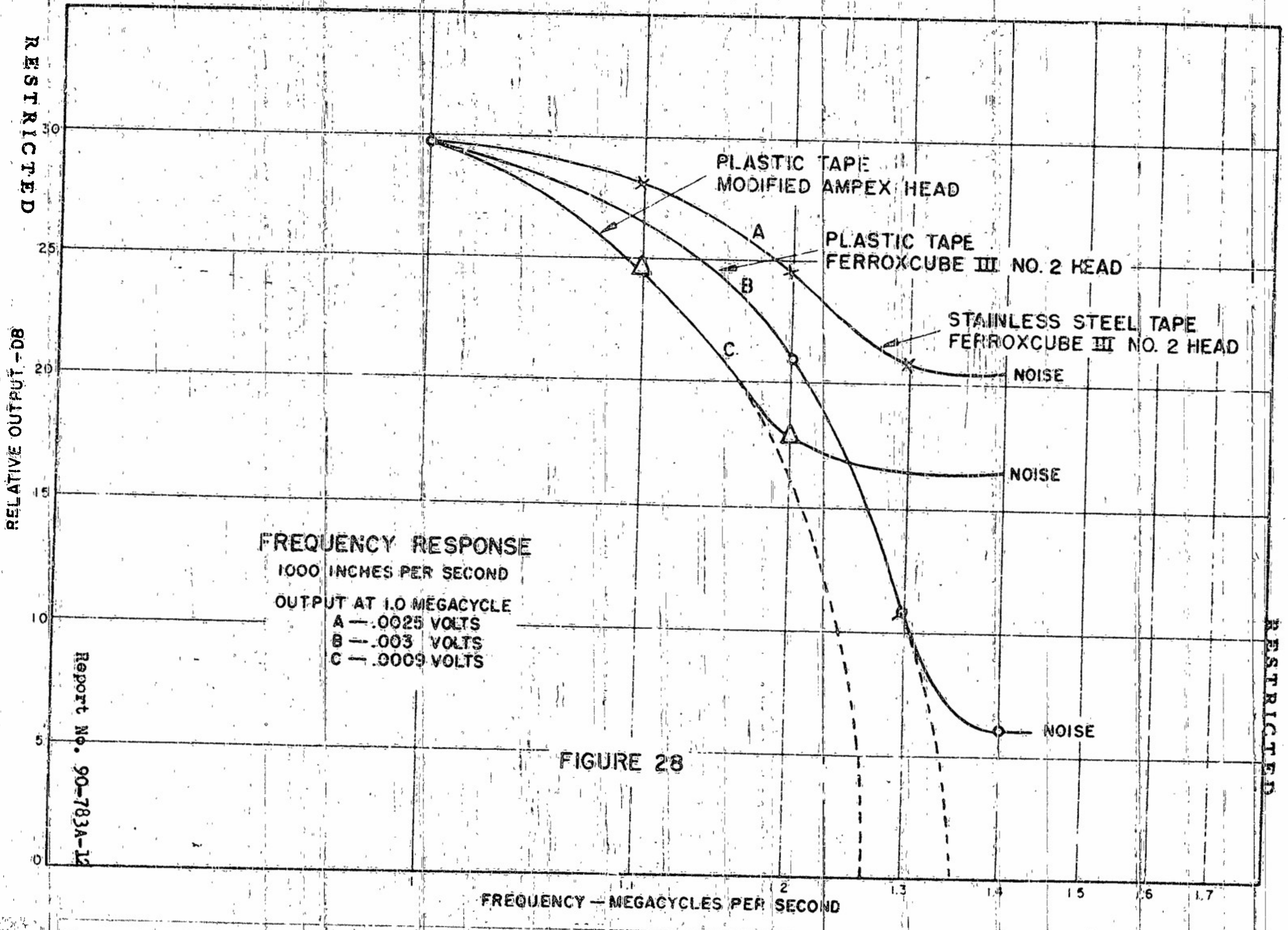


FIGURE 28

RESTRICTED

APPENDIX A

Bibliography of Magnetic Recording

ARF Licensee Bulletin No. 64

MAGNETIC RECORDER LICENSEE SERVICE

BULLETIN NO. 64

BIBLIOGRAPHY ON MAGNETIC RECORDING

From

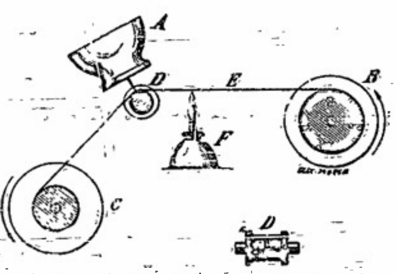
ARMOUR RESEARCH FOUNDATION
OF ILLINOIS INSTITUTE OF TECHNOLOGY

35 West 33rd Street

Chicago 16, Illinois

over . . . to the joint are well supported, and after the insertion of the discs the two parts of the supporting cylinder are drawn together by the bolts shown, and the outside of the flanges is insulated by wooden rings. There are four sets of brushes, two positive and two negative, diametrically opposite brushes being coupled together.

The electro-magnetic inertia in a circuit conveying 250 h. p. is necessarily very large, and on this account it would be dangerous to break the whole current suddenly. It would therefore be inadmissible to insert a fuse or other form of cut-out into the circuit, as might be done with smaller machinery, in order to save the generator from the effects of an accidental short circuit or heavy leak on the line. Any type of cut-out interrupts the current



FIGS. 1 AND 2.—SOME POSSIBLE FORMS OF PHONOGRAPH.

suddenly, and must therefore not be used where the self-induction of the circuit is at all considerable. To overcome this difficulty, and yet protect his generator effectively, Mr. Brown in all his transmission plants employs an automatic arrangement by which the field of the generator is demagnetized as soon as the line current exceeds a certain value. This apparatus, which is shown in Fig. 2, is an automatic circuit closer, the contacts C C of which are coupled to the terminals of the exciting circuit of the field magnets of the generator. The main current, before it is sent into the line, is caused to flow through the exciting coil of an electro-magnet M with poles P P, below which is pivoted an armature A. With the normal strength of current, the excitation of the magnet M is insufficient to cause attraction of the armature; but if a certain strength of current be exceeded, the armature is lifted, and liberates a catch by which the weight W is ordinarily held up. The weight then swings round on its arm, and with the force of a hammer jams itself between the spring contacts C C, thus short circuiting the field coils on the generator, which has the effect of at once lowering the E. M. F. to the very small amount due to residual magnetism. In a transmission plant, where an overhead line is used, care must be taken to protect the machinery against lightning. Both generator and motor should be insulated from earth and, in addition, some lightning protectors should be fitted. In the installation we are describing, lightning protectors are fitted at each end of the positive and negative line, but not at any intermediate point. The protector consists of a pair of metal plates with serrated edges facing each other, one plate being connected to the line and the other with an earth plate. That the electric transmission of energy has now become a most important branch of work in Switzerland and other countries where water power is abundant, will be seen from the following list of instal-

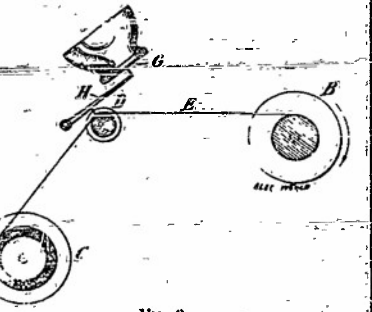


FIG. 3.

lations which have been erected, or are in course of erection, by the Oerlikon Maschinenfabrik.

Name of Installation.	Horse-power	Distance Metres.
J. Müller-Haiber, Solothurn	50	8,000
Gaetano Rossi, Piovene, Italy	250	450
The Worsted Yarn Mill of Derendingen, Switzerland	280	1,800
J. Amman & Wepfer, Pordenone, Italy	60	1,000
Troller Bros. & Co., Lucerne	120	8,000
R. & M. Frei, Aarau	15	1,000
J. & M. Legler, Diesbach, Switzerland	120	600
Paper Mills, Steyrermühl-Aichberg, Austria	100	600
C. F. Bally, Schoenenwerd, Switzerland (combined with electric lighting)	12	500
Bey & Co., Steinbach-Berne	15	1,800
J. Rauch, Mühlau, near Innsbruck	50	600

Some Possible Forms of Phonograph.

BY OBERLIN SMITH.

There being nowadays throughout the scientific world great activity of thought regarding listening and talking machines, the readers of THE ELECTRICAL WORLD may be interested in a description of two or three possible methods of making a phonograph which the writer contrived some years ago, but which were laid aside and never brought to completion on account of a press of other work.

One of these methods is rudely shown in Figs. 1, 2 and 3, the construction and operation being as follows: A is a mouth piece and diaphragm, with spring and indenting needle, as in the Edison machine. B is a reel, carrying a thin ribbon E of iron, steel or other substance capable of being temporarily softened by heat. This ribbon is unwound from B and wound on to another reel C, which is revolved slowly by clock-work or other means. D is a supporting roller (or stationary bar) with a flat groove the width of the ribbon E, and having a V-groove in the bottom of it for the needle to descend into, as seen in Fig. 2. F is a heating lamp, which, of course, must be protected from draughts, etc. All this is the recording apparatus or transmitter. The ribbon E being short of the point where, for the time being, it is hot, receives the indentations as easily as the tin-foil, or more so. It cools by the time it gets to reel C, and is then much harder and more durable than tin foil. The same apparatus can be used for the "talker," as in Edison's machine, but advantage may be taken of having the indented ribbon made of a hard substance by using a special talking-diaphragm G, Fig. 3, which will augment the vibrations in amplitude by means of a lever H, the ribbon E being hard enough not to lose its form by the increased pressure due to the leverage, as tin-foil would do.

The probable advantages of this form of apparatus are: 1. The loudness of voice produced by the increased amplitude of vibration. 2. The simplicity and cheapness of the whole machine—requiring no accuracy in "registering" devices beyond having the groove in roller D to about fit the width of ribbon E. 3. The cheap material of which the ribbon may be made. 4. Durability of rib-

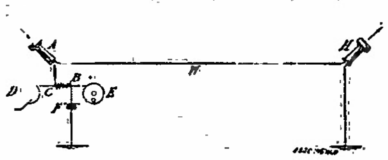


FIG. 6.

bon, even with oft-repeated use. 5. Convenience and freedom from injury in handling and transporting the ribbon record when wound upon spools like thread. This ribbon would, if of iron or steel, probably be about $\frac{1}{16}$ inch wide and $\frac{1}{500}$ inch thick.

Its disadvantages, possibly fatal ones, would be the difficulty of evenly heating the metal ribbon and the probable rasping noise which would occur in the diaphragm when the sound was reproduced. A modified and somewhat simpler form of the above process might be employed by using an ordinary wire instead of the ribbon E, and allowing a chisel-shaped needle to indent it into a flattened and somewhat widened form, wherever it was struck.

The above two methods are, of course, wholly mechanical as in the ordinary phonograph. The following proposed apparatus is, however, *purely electrical*, and is, as far as known to the writer, the only one fulfilling such conditions that has been suggested. Fig. 4 is the recording part of an electrical phonograph. Fig. 5 is the talking part of the same. Many of the pieces, as *D, E, B, C*, etc., can be the same ones as are used in Fig. 4. Fig. 6 shows the same ideas applied to a telephone line wire, so as to speak at a distance and at the same time record what is said, thus making a *recording telephone*. The sketches show only the essential parts, without the supporting framework, etc.

In Fig. 4 the voice or other sound is delivered into an ordinary telephone *A*. Preferably, this should be a carbon transmitter so as to have a battery *F* in the circuit, and thus use as strong a current as practicable. Possibly, however, a Bell telephone without a battery would answer the purpose. In either case the current, broken into waves of varying lengths and intensities corresponding with the vibrations of the diaphragm in the telephone, passes in its circuit through the helix *B*, converting into a permanent magnet any piece of hardened steel which may be at the time within the helix. Through this helix *B* passes a cord, string, thread, ribbon, chain or wire *C*, made wholly or partly of hardened steel, and kept in motion by being wound on to the reel *E* from off the reel *D*, *E* being revolved by hand, clock-work or other means. *J* is a tension spring or brake pressing against *D* to keep the cord *C* taut.

When in operation with the undulatory current from the telephone *A* passing through the helix, the cord *C* becomes, so to speak, a series of short magnets grouped into alternate swellings and attenuations of magnetism. The actual lengths of these groups depends upon the speed of their motion, but their *relative lengths* depend upon the *relative lengths* of the sound wave; and their *relative intensities* depend upon the *relative amplitudes* of these waves. The cord *C* therefore contains a perfect record of the sound, far more delicate than the indentations in the tin-foil of the mechanical phonograph. The probable construction of *C* would be a cotton, silk or other thread, among whose fibres would be spun (or otherwise mixed) *hard steel* dust, or short clippings of very fine steel wire, hardened. Each piece would, of course, become a complete magnet. Other forms of *C* might be a brass, lead or other wire or ribbon through which the steel dust was mixed in melting—being hardened afterwards in the case of brass or any metal with a high

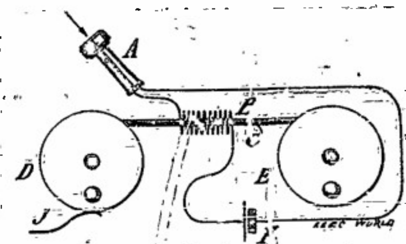


FIG. 4.

melting point. Another (but too expensive) form of *C* would be a chain with each link a magnet; or, if the magnets affected each other too much when in contact, each alternate link could be of non-magnetic material. This chain would not be so delicate as the dust magnets, because the effects of a given vibration might extend but part way along a link. Another imaginable form of *C* would be simply a hard steel wire, but it is scarcely possible that it would divide itself up properly into a number of short magnets. The magnetic influence would probably be distributed along the wire in a most totally depraved way, with nodal points just where they were not wanted. If it could be made to work it would obviously be the simplest thing yet suggested.

The cotton thread above mentioned would seem to be preferable to anything else on account of its cheapness, lightness and flexibility. The Lord's Prayer could be written upon a few feet of thread or string, while a young lady receiving a small spool of cotton from her lover would think herself abominably neglected if it was not "warranted 200 yards long."

In Fig. 6 the arrangement is precisely the same as in Fig. 4, except that the circuit is made through the telegraph wire *W* and the receiving telephone *H* in Boston or some other distant place. Of course the record might be made at the receiving instead of the transmitting end of the line, and thus our hypothetical young lady might, while listening to the impassioned pleadings of her chosen young man, be preparing the evidence for a future breach-of-promise suit.

To make the thread or cord *C* "talk back" it is, after having been rewound on to reel *D* again drawn through a helix *B*, Fig. 5, in whose circuit is the "talking" telephone *A*, probably a Bell receiver. Of course it is drawn through at approximately the same speed as before. In passing, the small permanent magnets in the cord *C* induce currents of electricity in their enveloping helix analogous to the currents in the field of a magneto-electric machine, or a dynamo with permanent magnets in its

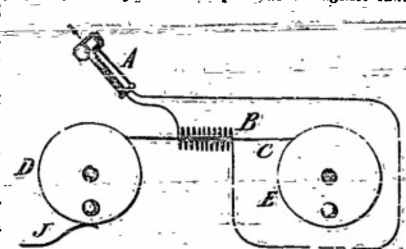


FIG. 5.

armature. A more exact analogy would, however be the currents in the helix of a solenoid if its ordinary action were reversed, and its core made a permanent magnet. These waves of current will correspond in length and relative intensity with the original wave currents, and will therefore reproduce the vibrations of the original sound in the diaphragm of the telephone at any time in the future. If such induced currents are not strong enough to produce sufficiently loud sounds it may be possible to insert at *X*, Fig. 5, some intensifying apparatus, such as a battery, but which has not yet been thought out.

Like the two mechanical methods first mentioned, this electrical method has never been worked out to completion. The writer went far enough with it to build a temporary apparatus and to develop a successful machine for spinning metallic dust into a cotton cord, but was obliged to lay aside the whole thing before arriving at any tangible results. His experiments showed that it was difficult, with ordinary tools, to harden steel filings on account of excessive oxidation. Experiments with hardened steel wire, broken in a special machine into very short pieces, showed that they must not be too short —say not less than three or four times their diameter—or they could not be saturated with magnetism to any appreciable degree. Possibly this is because the poles (or points of maximum polarity) of a magnet lie at some distance from the ends of the bar, and consequently neutralize each other when the bar is too short. If this theory is correct it would prevent making magnets of steel dust, the grains of which are supposed to be about as broad as they are long.

Digressing a little, it may be remarked that such a theory does not seem to agree with the fact of a magnetic polarity in approximately spherical or cubical bodies, like the earth, or a chunk of loadstone. Possibly, however, they would be much stronger magnets if elongated; and the tiny pieces of wire above referred to, may possess as much strength in proportion, though it be scarcely perceptible on account of their smallness.

The writer confesses to a good deal of ignorance upon the subject; but he was somewhat surprised to find an equal amount in several well known electricians whom he consulted; and also to find that none of the books he had at hand gave any definite data regarding the best proportions for permanent magnets or their actual strength (when saturated) in pulling power. Surely, there is in this department of electrical science a good sized (magnetic) field for a number of lines of force—mental ones—to work in, in the way of careful experimenting.

To return to our magnetized cord as a "phonogram," it is possible that an insuperable objection to it would be found in the great diameter and length which would be required to hold magnets of sufficient strength and quantity. This, however, can be determined by experiment only. Of course if this cord approached a clothes line rather than a piece of sewing silk in its general proportions it would be utterly useless as a practical recording medium. Regarding the general convenience of a record in a cord or ribbon-like form compared with one indented upon a cylinder or a flat circular tablet, there are probably advantages on both sides. One disadvantage of the cord is that if some small portion of the record near the middle has to be repeated there is a good deal of unwinding to do to get at it. The same objection, if it be one, applies to the first-mentioned methods, as well as the magnetic cord. In practice, however, it might prove that this unwinding was a small matter, if a rapidly-working automatic winder were used.

Another general principle which may perhaps be adapted for a phonograph is that of *variable conductivity.* Possibly a cord or ribbon may be made of a poor conductor (perhaps a flexible substance impregnated with carbon), and may then be made better and worse in certain spots by the action of the "transmitting" instrument, either by making spots of the cord denser or thinner, in some way, at the inward stroke of the diaphragm. This recording action would probably be entirely mechanical. The reproducing, on the contrary, would be wholly electrical, and would consist of passing a current through a conductor which was broken by a space filled by the cross-section of the moving record. This current would pass through a receiving telephone and would, obviously, be thrown into the proper undulations of strength by the varying conductivity of the cord, as it passed along by the motion of its reels.

The writer has not worked out the details of this latter scheme as completely as in the others mentioned—even upon paper. He has not the time, to say nothing of a properly equipped laboratory, to carry the ideas suggested to their logical conclusion of success or failure, and, therefore, makes them public, hoping that some of the numerous experimenters now working in this field may find in them a germ of good from which something useful may grow. Should this be the case, he will doubtless get due credit for his share in the matter; but if, on the other hand, these suggestions prove worthless, they will still have served a purpose, on the principle that a demonstration of what *can't* be done is often a pertinent hint as to what can be.

The Edison Patents in England.—A notice has been issued by the Edison and Swan United Electric Light Companies of London, to the effect that the late decision invalidating Mr. Edison's patent has been appealed from, and that the appeal will probably be heard before Christmas.

Reporting Electrical Executions.—Elbridge T. Gerry says that the New York newspapers will have no accounts of the first execution of a criminal by electricity in this State. Though Mr. Gerry is an authority on this subject, the managing editors of New York ridicule his statement in question, as well as his threat that any editor who, contrary to the statutes, publishes such an account, will be imprisoned for a misdemeanor. The editors agree with Chester S. Lord, of the *Sun*, that considerable imprisonment would be necessary to break up their habit of printing the news. Julius Chambers, of the *Herald*, says that a paper which had sent to the Polar Sea for news wouldn't mind the trivial danger of imprisonment. Another editor said: "There would be a struggle for the distinction of such an imprisonment."

THE ELECTRIC LIGHT CONVENTION.

The pages immediately following this will be found to contain a very full and complete report of the Convention of the National Electric Light Association just closed in this city. We believe that the promptitude with which the report is issued, and the care taken in its preparation, will be generally appreciated, the more especially when it is borne in mind that during the session we have issued no fewer than four editions of our bulletin, now so familiar to all frequenters of these meetings. As to the paper itself, we may "point with pride" to its size, not less than to its contents. It is four pages larger than any previous issue. At the August Convention last year we printed a paper of 56 pages. For the convention in February at Pittsburgh we printed 64 pages. Our number this week contains no fewer than 68 pages. We may point out too, that while the paper is so large, it is not late; but on the contrary is actually issued eight days ahead of date, and one day after the close of the Convention. This special effort has necessitated a little departure, it will be observed, from our usual method of making up the paper.

The growth of the electric light and power industry was admirably brought out by President Duncan in his brief but pithy opening address. The figures have, we are glad to see, arrested general attention, and the direct outcome of the publicity thus given to these facts will be a development of new work.

Perhaps the leading question before the Convention was that of overhead and underground wires. Mayor Hewitt was not slow in winning the applause of the meeting with his address of welcome, in which he vindicated his line of policy as to the overhead wires, and it must be said that a better address in form and matter than the Mayor's has not been made before the body. At the same time, what we may call the progressive element had its inning in the papers presented by Dr. S. S. Wheeler and Mr. Chenoweth. The paper of Dr. Wheeler will be found worthy of study, based as it is upon an intelligent comprehension of the subject as a whole and a full knowledge of the work being done in this city. Supplementing all this is the excellent paper by Mr. Acheson on disruptive discharges in cables, and the various discussions. Any one who reads that part of the report will certainly be abreast of the latest information of the day on the underground wire problem.

We have no doubt that when Mr. Leonard reads of the cordial reception given to his unpretentious but valuable little paper detailing his experience in Minneapolis with petroleum fuel he will be somewhat surprised. Like some other members, he appears to be afraid of boring the Convention, but the fact is that such papers, with their facts and details on vital questions of management, are the best that can be brought before the Association, which does not meet to discuss scientific theories, but to arrive at all the facts that concern the practical operation of light and power plants.

While we do not consider the choice of the Hotel Brunswick as the meeting place to have been at all a happy one, it is the opinion of all that the coming to New York has been a good thing, and that the Convention has been one of the best, and thoroughly enjoyable. New York is the capital of the country in every sense of the word, and will remain so, and it is also a convenient point of rendezvous for all who are interested in electrical matters. Moreover, it was three years since the Association visited the city, and the time was fitting to make a new impression on the metropolitan consciousness. The reputation of our city for hospitality, also, has been well maintained; and not a delegate can go home without feeling that everything possible was done to render his sojourn here pleasant and profitable.

In speaking above of the impression made by the Convention on the metropolitan consciousness, we have reference more particularly to the manner in which the press has dealt with the proceedings. Having attended all the conventions, we make bold to say that never before have the reports as a whole been *so* full, so fair and so accurate. In fact, it is hard to pick out the best, where all have been so good. The evening papers have greatly gratified the officers and members by the excellence of their reports. On Thursday night, for example, the *Evening Post* published two full columns, the *Commercial Advertiser* had a column and a half excellently done; and the *Mail and Express* supplemented a column of good report with another column of elegant and philosophic editorial. The New York *Graphic* made first-class portraits of the officers, and the *World* also came out with its neat thumbnail sketches of prominent speakers, while the *Sun*, *Herald*, *Tribune*, *Times* and others gave the convention an unusually large amount of editorial notice and reportorial care. If we may venture to do it, we would heartily congratulate our brethren of the daily press on their good work. They have certainly done the Association good, and we think that hereafter the electrical questions that come up will receive better treatment at their hands than has sometimes been the case hitherto.

It is natural that the electric power question should occupy part of the time of the Association, and the hour devoted to Mr. Lufkin's able paper was well spent. It will be noticed that the paper is an able effort to determine the average running of motors in the different classes of employment, so as to have data from which to deduce the right schedule of charges. This is a highly important part of the motor question; and affects very closely the prosperity of the business. It will be seen also that Mr. Lufkin dwelt upon the interesting question of small motors versus large motors. There is evidently something to be said on both sides, and it is likely that the matter will long be one provocative of differences of opinion in motor circles.

The various presentations made during the Convention were, after all, but a small recognition of services rendered the Association. The Association, as it stands to-day, is largely Mr. Morrison's handiwork, and it is only appropriate that his zeal and the wise use made by him of his marked executive ability should be rewarded in substantial shape. The testimonial to the Westinghouse Electric Company was not less graceful and fitting. The company's liberal contribution to the funds of the Association enabled it to catch up in the publication of its proceedings, and to present a healthy balance sheet.

It was a good idea to secure a photograph of the delegates before leaving, with the Electric Club as a background. An interesting memento is thus obtained of a pleasant gathering and of the hospitality that found its centre at the Club House.

Allegheny City, Pa.—Specifications have been approved by the sub-committee on gas for 45 electric-light towers with 3 to 5 lights on each; 85 single pole lights and 1,500 incandescents for the city hall, engine houses, etc.

Brush Carbons.—The Brush Electric Company, Cleveland, O., report that their carbon business is larger than ever before. They have shipped within the last month or two, eight or ten solid carloads of carbons to different portions of the country.

Buffalo, N. Y.—The Brush Electric Light Company of Buffalo, N. Y., are increasing their electric light plant. They have recently ordered from the parent company two 65-light 2,000 c. p. dynamos with lamps. This company is now burning, including the above dynamos, 1,300 arc lamps and a large number of incandescence.

The Graphophone in the West.—A company of Western men, with Hamilton S. Wicks, of Kansas City, at their head, has secured a contract with the syndicate controlling the Edison-Bell graphophone for all rights within the territory west of the Mississippi and east of the Rocky Mountains. Offices are to be established and the instruments introduced into the leading cities of that district by Oct. 1.

Electricity for Writers' Paralysis.—In one of the broad windows of the recording department of the office of James Bond, clerk of the superior court, is a small electric battery. It is used by the recorders for the relief of the cramp of the muscles of the hand which follows long continued and steady use of the pen. The relief is instantaneous, and the clerks who formerly were compelled at times to stop work for several days on account of swelling and contraction of the muscles of the hand now take a few gentle shocks of the electric current on the slightest approach of stiffness. They return to work at once, entirely relieved, and continue without inconvenience. Nearly every one of the score of clerks receives benefit from the electric current, and the battery is regarded as an indispensable fixture of the office.—*Baltimore Sun.*

Bell Telephone Output.—The instrument account shows gains in the output and a reduction in the instruments returned. For seven months there was an increase of 1,210 in instruments held by licensees. The income gains faster than the output of instruments. The latter is as stated below:

Month to Aug. 20.	1888.	1887.	Increase.
Gross output	5,794	5,633	161
Returned	1,760	3,353	*1,593
Net output	4,034	2,280	1,754
Since Dec. 20.	1887-8.	1886-7.	
Gross output	37,710	36,511	1,199
Returned	11,846	17,863	*6,017
Net output	25,864	18,648	7,216

*Decrease.

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