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A GRAPHICAL PRESENTATION OF SOME FERRITE CHARACTERISTICS

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ABSTRACT

The radio frequency permeability and Q of some ferrite materials commercially available as of January 1955 are given and compared with the properties of some ferrite materials manufactured in the Electrical Engineering Department of the University of Michigan. Different methods of presenting this information are discussed. A new type of plot giving μ and Q versus frequency on one graph is used to display these properties.

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1. INTRODUCTION

This report presents a method of graphically representing in one plot the magnetic characteristics of some ferrite cores. The characteristics of specific interest are the permeability and the Q, or inverse tangent of the loss angle, as a function of frequency. The frequency ranges considered are from several hundred kilocycles to several hundred megacycles. This report does not include information on either square loop material or materials applicable to the microwave region.

The material types considered here are from three sources: the General Ceramics Corporation, Keasbey, New Jersey; Ferroxcube Corporation of America, Saugerties, New York; and those manufactured in the Electrical Engineering Department of the University of Michigan. The values quoted for cores from the first two types of material are those available in the commercial literature.

It is quite difficult to obtain an accurate absolute measurement of the permeability and the Q of ferromagnetic materials in the frequency range of interest, although relative measurements can be made quite easily. For the cores manufactured at the University of Michigan, the Q was measured on a Boonton 160-A Q-Meter to about 2 mc. The permeability from 900 kc to 18 mc and the Q from 5 mc to 18 mc was measured using a General Radio Type 821-A Twin-T Bridge and a National Electronics Company Type B Permeameter. The measurements of both μ and Q from 50 to 500 mc were made using a Hewlett-Packard Model 803-A Impedance Bridge and a coaxial inductor described in EDG Technical Report No. 35.[1] Information on the

1. Nace, P. E., "A Toroidal Sample Holder for Measuring VHF Permeability and Losses," Technical Report No. 35, Electronic Defense Group, University of Michigan, July, 1954.

Ferroxcube and General Ceramics materials was obtained in January, 1955. The information on the University of Michigan cores was also that of January, 1955. The magnetic properties of the Michigan cores were measured on cores manufactured for various purposes. No attempt has been made to optimize their behaviour. There is every reason to expect that such an effort would be beneficial. The primary purposes of this report are (1) to show how the Michigan cores compare with those commercially available, and (2) to make this information easily available to those interested in the application of both types of cores.

2. FERRITE CHARACTERISTICS

2.1 Discussion

The high permeability of ferrites as circuit elements is the chief reason for their low frequency application. The inductance of a specific geometry increases with permeability, and, indeed, in a closed magnetic circuit is nearly proportional to it. Associated with increased inductance is an energy loss in the core material. A standard method of describing this loss is $\left[2\pi \frac{\text{Energy Stored}}{\text{Energy loss/ cycle}}\right]$. It is customary to define this term as the Q of the material.

Therefore, it is obvious that for ideal core materials, both μ and Q should be as large as possible. In practice it is found that an increasing μ is associated with a decreasing Q. It is becoming common to use the loss factor $\left(\text{defined as } \frac{1}{\mu Q}\right)$ as an indication of the relative merits of comparable cores. It is to be noted that for large μ, and large air gap, the loss factor is independent of the air gap.[1]

The question of the relative importance of the roles played by μ and Q depends upon the specific application. There is no best answer for all conditions

1. Mullard, Limited, "Components and Materials," Century House, London.

For the inductive element of a resonant tank circuit it is often mandatory that the losses be small, and in such cases μ can be sacrificed for Q. For high frequency chokes the inverse is true. Thus, for optimum conditions, a quantity, $\frac{1}{\mu^a Q}$, could be maximized where "a" depends upon the application.

There are several common methods of describing the loss mechanism producing a finite Q. This loss mechanism can be described in terms of a phase angle δ between applied or resultant fields. Tan δ, equal to $\frac{1}{Q}$, is a common measure. Another way of expressing this loss mechanism is to describe the permeability as a complex number, giving rise to an effective series resistance. If $\mu = \mu_1 - j\mu_2$, then $Q = \frac{\mu_1}{\mu_2}$.

2.2 Methods of Presentation

The most common methods of presenting the performance of ferrite materials are:

(1) A plot of permeability versus frequency. The permeability usually stays constant or increases slightly as the frequency is increased to a certain definite frequency, after which it falls off rapidly with increasing frequency. A typical plot is shown in Figure 1.

(2) A plot of Q, the quality factor, versus frequency. One such plot is shown in Figure 2 for the same material as that shown in Figure 1. The Q curve always falls off at a lower frequency than does μ.

(3) The loss factor, $\frac{1}{\mu Q}$, versus frequency. Figure 3 shows a plot of these parameters for the same ferrite material as that represented in Figures 1 and 2.

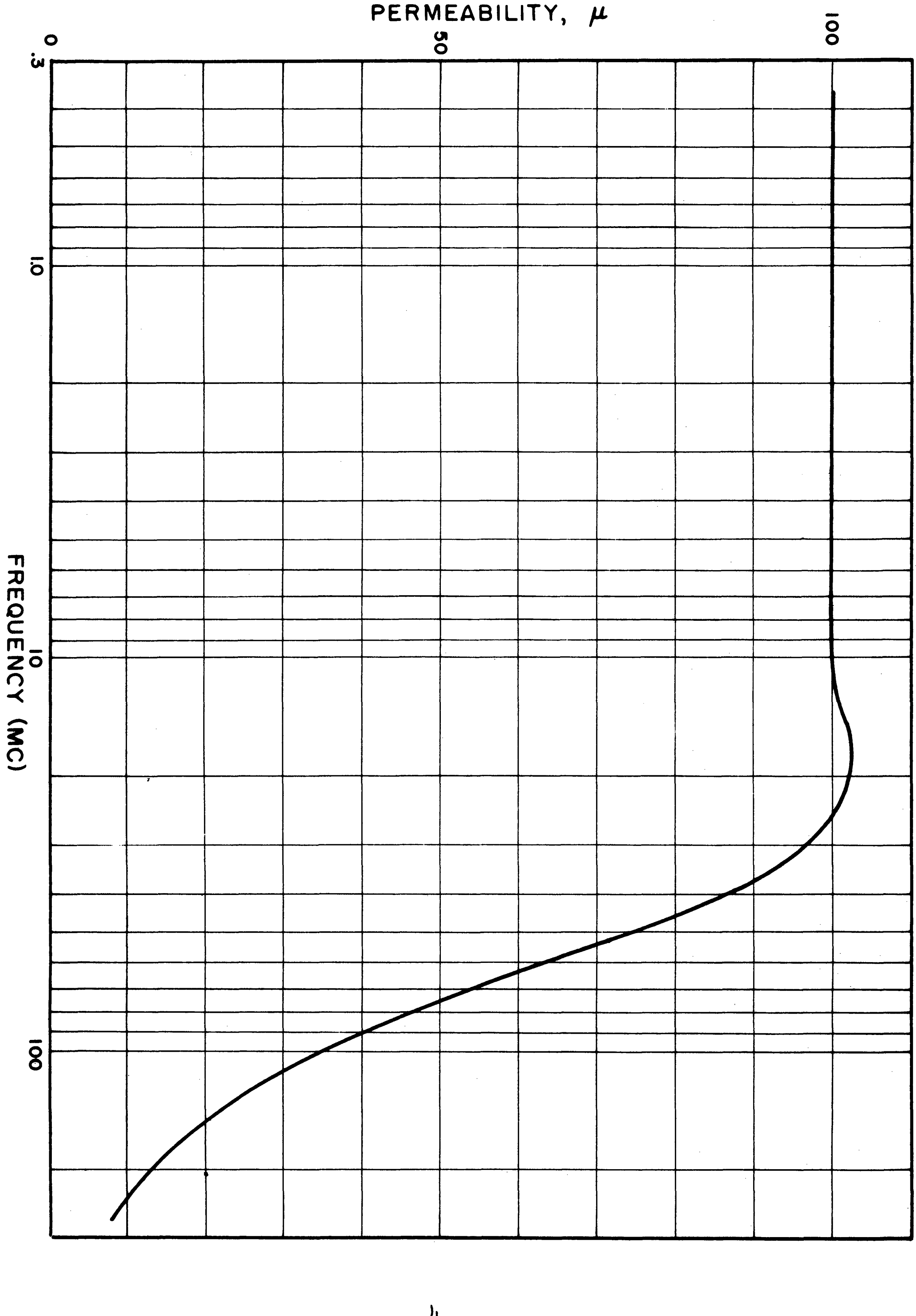

FIG I
PERMEABILITY VS FREQUENCY

2262 A-G6-119 RFR 4APR55

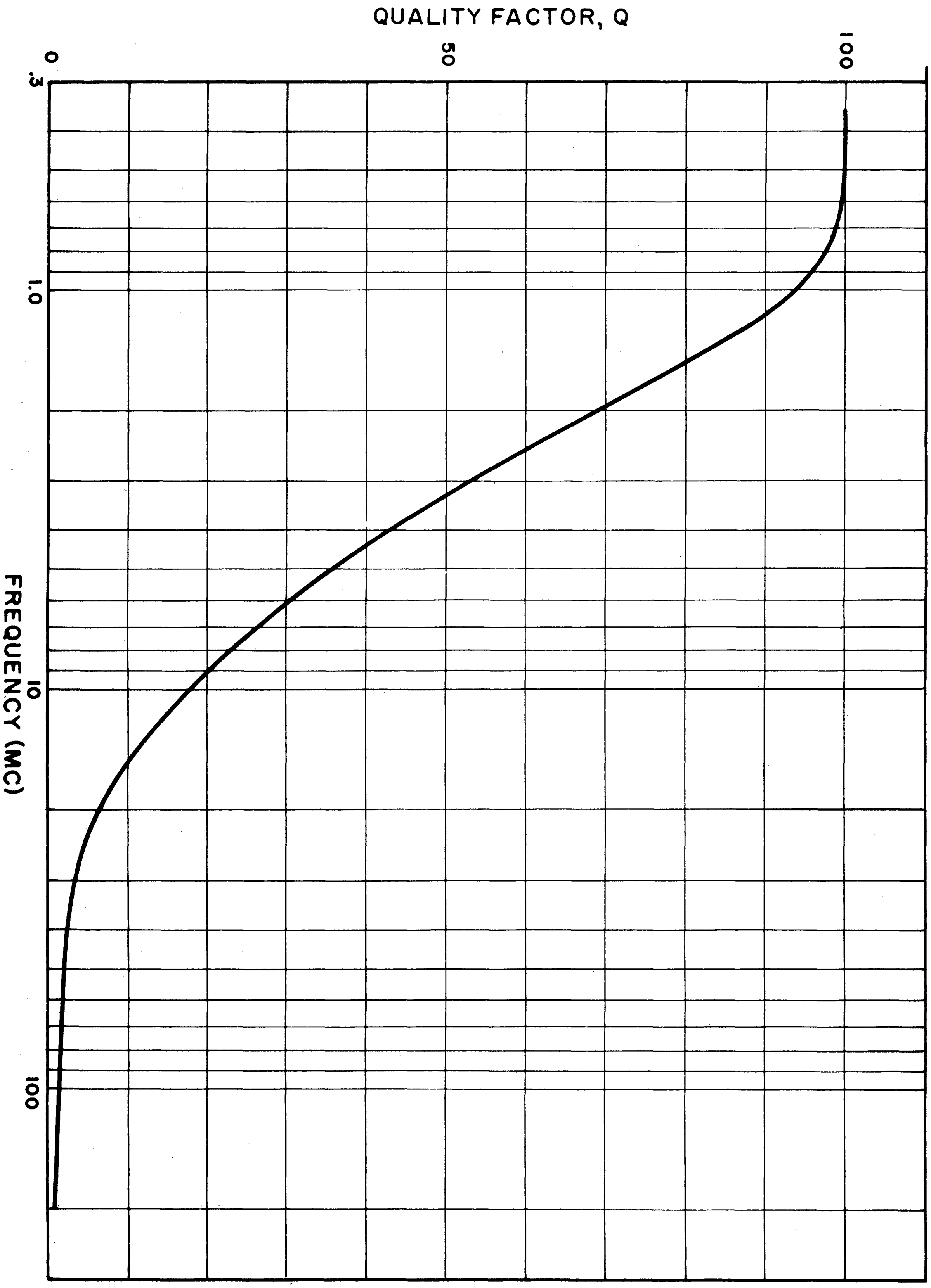

FIG 2
QUALITY FACTOR VS FREQUENCY

2262 A-G6-120 RFR 4APR55

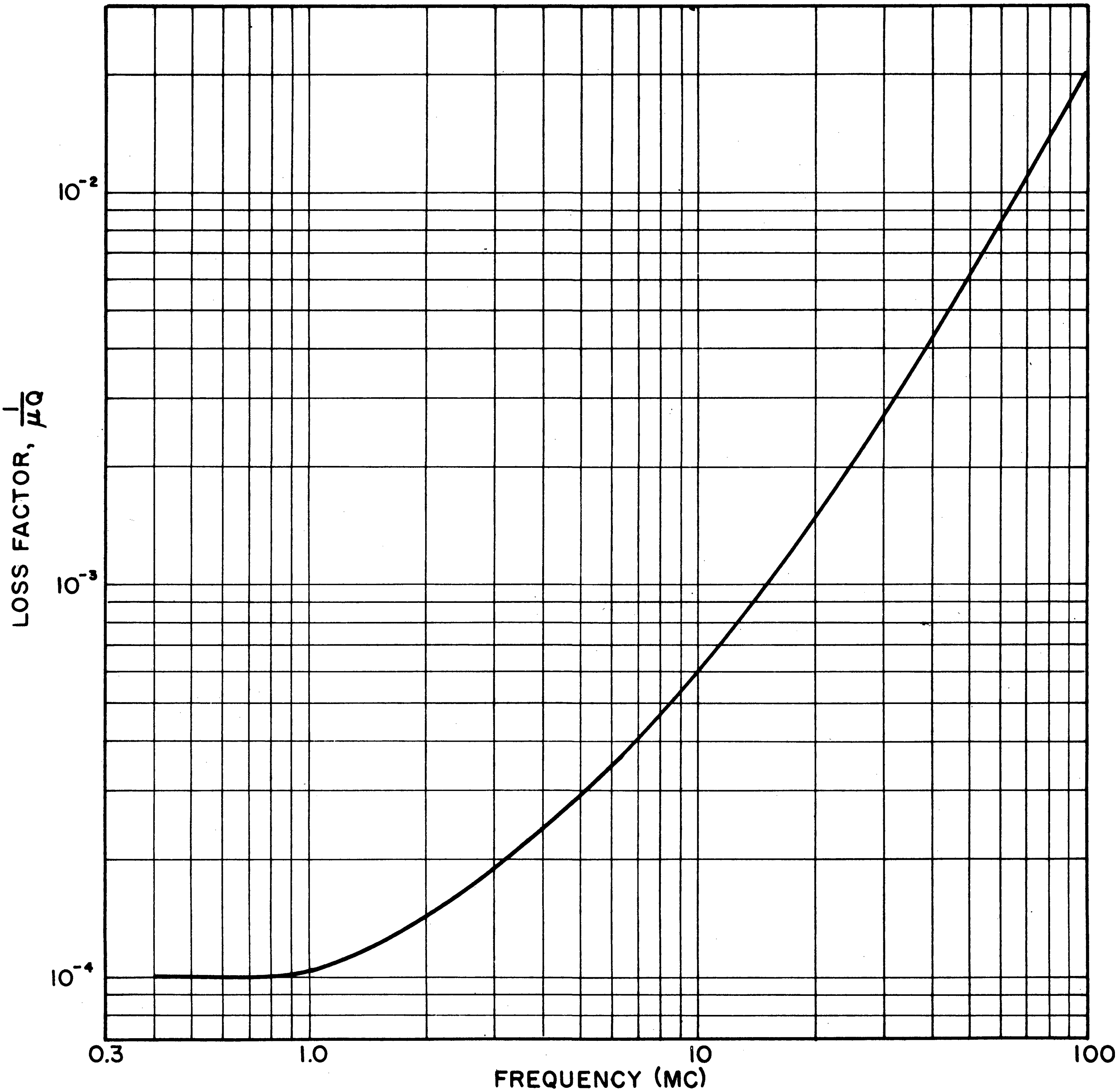

FIG 3
LOSS FACTOR VS FREQUENCY

Any two of the above curves are sufficient to show the relationship between μ, Q, loss-factor, and frequency for a single type of ferrite material. However, a comparison of the performance of two ferrite materials through the use of the above methods requires at least four curves.

A new technique, as far as is known, of plotting the ferrite performance is the μ-Q plot. This method shows μ versus Q on a log-log plot. Representative values of frequency are indicated on the curve. On this plot, constant loss-factor lines will appear as straight diagonal lines. Therefore, the curve will show μ, Q, loss-factor, and frequency dependence in one plot. The one variable which is not easily read is the frequency, but as many frequency points as desired may be indicated on the curves. Figure 4 shows a μ-Q plot of representative commercially available core materials, as well as some materials produced at Michigan. As can be seen on this plot, the different ferrite materials can be easily compared. The Q readings for the Michigan cores at frequencies less than 2 mc have not been corrected for copper losses in the windings. Therefore, the actual Q will be larger than the values shown. As an example, the 2 mc point on curve 3 of Figure 4 changes from a Q of 76 to a Q of 89 when the reading is corrected for the winding resistance.

As an example of the use of the plot, compare curves 1 and 2 of Figure 4. It is readily seen that the material represented by curve 2 is superior at higher frequencies. Another use of the μ-Q plot is to demonstrate that the entire curve for any specific ferrite slides to the right and down (Figure 4) along isoloss factor lines as an air gap is introduced.

3. CORE CHARACTERISTICS

The general trends are demonstrated in the μ-Q plot, which shows that Q falls off more rapidly with frequency than does μ, and this fact accounts for

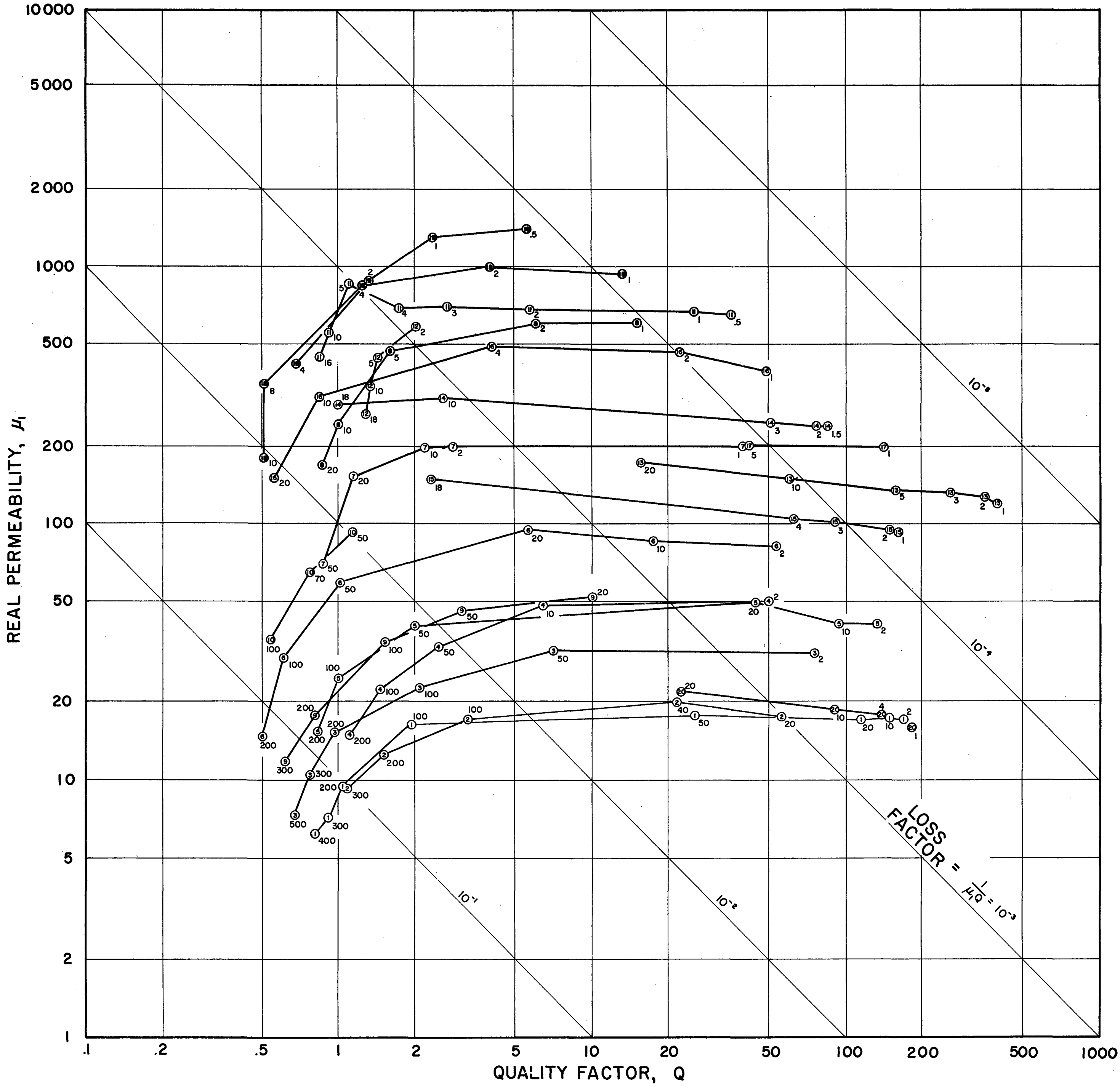

FIG 4
μ-Q PLOT OF SEVERAL FERRITES

CORE TYPE

①	Ferroxcube B-5	⑪	EDG A-231-5
②	EDG D-150-1	⑫	" A-290-4
③	EDG D-143	⑬	GC Q
④	EDG C-80-1	⑭	EDG E-101-1
⑤	Ferroxcube B-4	⑮	" D-121-1
⑥	" B-3	⑯	GC F-146-D
⑦	" B-2	⑰	" N
⑧	" B-1	⑱	" F-174-E
⑨	EDG D-142	⑲	" F-141-E
⑩	" A-105	⑳	" F-34-A

FREQUENCY (mc) SHOWN FOR EACH MEASUREMENT

most of the changes in the loss factor for Q's greater than two.

The ferrites shown indicate a rapid change in μ with frequency when Q is less than two. The plot also shows that, in general, for a fixed frequency the loss factor decreases with decreasing μ. The higher the frequency the larger this effect becomes.

The desired improvement of the ferrites shown in the μ-Q plot would be to move a decade lower as far as the loss factor is concerned; this applies particularly to the high frequency part of the curve. In the operating range of each core, most of the change in μ-Q is due to a change in Q. Thus, an improvement should most probably lie in increasing Q.

For a sample in which the magnetization occurs by wall movement, the rf magnetization can be described by an equation of the type[1]

$$\beta \frac{d(\Delta M)}{dt} + \alpha (\Delta M) = \Delta H$$

where α and β are constants, t is time, ΔM is the change in magnetization when an incremental field ΔH is applied. This is Hooke's Law with an added damping term. If the above equation is valid, Q will be unity when μ has been reduced to approximately one half of its original value. The frequency at which this occurs is defined to be the relaxation frequency ω_r and it occurs when $\omega_r = \alpha/\beta$. The data of Figure 4 indicate that an increased ω_r is accompanied by a decreased low frequency permeability. This is to be expected since the low frequency permeability is inversely proportional to α.

[1] A discussion of this equation is given by Galt, J. K., B.S.T. J., 33, 1023-1054 (1954).

4. CONCLUSIONS

The enclosed data will be of use to the practicing engineer. The described method of presenting data provides a ready means for comparing the properties of different ferrite materials. For the various types of applications materials can be chosen from the various regions of the chart and the engineer can quickly select the optimum material for a given application.

There are additional characteristics that are of varying importance depending upon application. These include the dependence of the enclosed curves on such parameters as biasing field, temperature, geometrical configuration, and magnitude of signal. The method described here suggests convenient means of efficiently introducing additional parameters. For example, a set of characteristics for a given material might show a family of curves obtained by varying the applied bias, or other parameters of interest.

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