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MAGNETIC LOSSES OF IRON IN HIGH FREQUENCY ALTERNATING CURRENT FIELDS

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Abstract

A number of investigators have studied the power loss due to eddy currents and hysteresis in iron when placed in high frequency alternating current fields, but the results obtained are in wide disagreement. Using a new method, the author has investigated the variation of this loss with the frequency for several areas of cross section. The total loss is considered as that due to an equivalent resistance and by measuring the values of this resistance at resonance, the loss may be determined from the I^2R relation. With magnetizing currents of 3, 4 and 5 ampere-turns per cm, the measurements are made on short iron cylinders of various areas of cross section at frequencies ranging from 520 to 968 kilocycles. The loss is found to increase with frequency in the small samples and to decrease with frequency in the larger. At any particular frequency the loss per unit volume is less the greater the area. This is due to the magnetic shielding effects of eddy currents in the large samples and the disagreement between previous investigations may thus be explained.

The results obtained by a number of investigators who have studied the losses due to eddy currents and hysteresis in iron when placed in high frequency alternating current fields are in wide disagreement. Corbino[1], Alexanderson[2], Wilson[3], and others have found increasing losses with increasing frequencies; Tankadate[4], Weihe[5], and Nusbaum[6] have found decreasing losses with increasing frequencies, while Hopkinson[7], Gray[8] and Maurain[9] have obtained results indicating that the energy loss per cycle is independent of the frequency. An excellent resume of the principal work done in this field from 1827 to 1923 has been given by Bown.[10]

This paper describes a new method for determining the combined losses due to eddy currents and hysteresis, and gives the results obtained for certain specimens of soft iron at frequencies from 520 to 968 kilocycles. Three values of magnetizing current are used, and the total loss as a function of the frequency, the magnetizing current and the cross-sectional area are indicated.

Theory of the Method

The method used in this investigation is based on the assumption that the combined loss due to eddy currents and hysteresis may be considered as

[1] O. M. Corbino, Phys. Zeits. **6,** 64 (1905).
[2] E. F. W. Alexanderson, Trans. A.I.E.E. **30,** 2433 (1911).
[4] L. T. Wilson, Inst. Rad. Eng. Proc. **9,** 56 (1921).
[4] A. Tankadate, Phil. Mag. **28,** 207 (1889).
[5] F. A. Weihe, Wied. Ann. **61,** 578 (1897).
[6] C. Nusbaum, Inst. Rad. Eng. Proc. **7,** 15 (1919).
[7] J. Hopkinson and B. Hopkinson, Electrician **29,** 510 (1892).
[8] T. Gray, Phil. Trans. **184,** 531 (1892).
[9] C. Maurain, Jour. de Phys. **7,** 461 (1898).
[10] R. Bown, Jour. Frank. Inst. **183,** 41 (1917).

the equivalent of a pure resistance inserted in an oscillating circuit, in which energy is absorbed at the same rate as in the iron. If then, the resistance of the oscillating circuit is measured at resonance, first with the iron sample inserted in the magnetizing coil, and again with the iron removed, the difference between these two values will give the value of the "equivalent resistance." Thus, calling the circuit resistance with the sample in the coil R_1 and without the sample R_2, the magnetizing current I and the equivalent resistance of the losses X, we have

$$X = R_1 - R_2$$

and the power loss

$$P = I^2 X$$

the same magnetizing current being used for both cases.

The problem therefore resolves itself into the problem of the accurate measurement of the change of the resistance of a circuit at high frequencies due to the insertion of an iron sample in the magnetizing coil, and the variation of this change of resistance with frequency and with the physical dimensions of the sample. The power loss for various values of magnetizing current may then be determined from the I^2R relation.

The assumption thus made is similar to those made in other determinations of power loss at high frequencies, such as the "series resistance" of a condenser, the "radiation resistance" of an antenna, etc.

Measurement Method and Apparatus

The familiar "resistance variation" method was used for measuring the circuital resistance, the measurement and power circuits being shown in Figure 1. The power circuit is a vacuum tube oscillator using a 50 watt tube supplied with 500 volts from a motor generator, the frequency being controlled by a condenser C_1. The power circuit is coupled to the measurement circuit through a single turn coil, and also to an accurately tuned wave-meter for indicating the frequency of the oscillations. The measurement circuit consists of a magnetizing coil, a standard tuning condenser, milliammeter, and a special switch for inserting the standard resistances. A single layer solenoid of 70 turns wound on a glass form was used as a magnetizing coil, with a large ratio of length to diameter in order that the magnetizing field might be as uniform as possible. Calculation of the strength of field for various points along the axis of the coil shows that a length of sample of 4 cm can be used, and this length was used for all samples. The standard resistances consist of manganin strips of equal lengths and of a small enough diameter that the variation of resistance due to skin effect may be considered negligible for the range of frequencies used. For easy removal of the magnetizing coil and the standard resistances a special switch similar to that used by Dellinger and Preston[11] in their deter-

[11] J. H. Dellinger and J. L. Preston, Bureau of Standards Sci. Paper No. 471 (1923).

mination of dielectric losses was used. A thermocouple milliammeter was used for indicating the value of the magnetizing current, and the measurement circuit was tuned with a precision type condenser.

This circuit was very carefully shielded to guard against stray electromotive forces, and the utmost precautions were used to prevent interaction

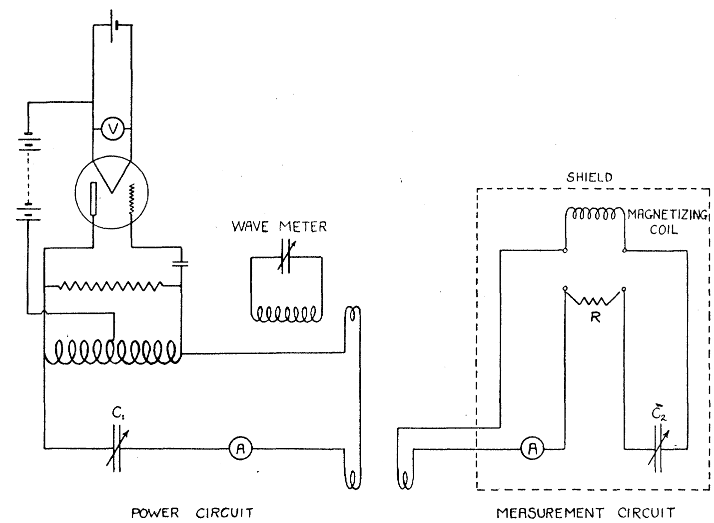


Fig. 1. Diagram of electrical circuit.

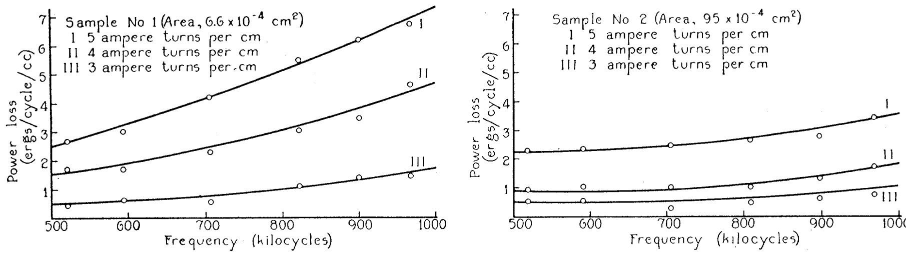
between the measurement and power circuits. The minimum coupling necessary to give the desired magnitude of current was used, and at all times during the measurements the circuits were carefully checked to see that no interaction took place.

Method of Observation

In making the measurements the oscillator was set at the desired frequency as determined by the wave meter. The measurement circuit was then tuned to resonance, and the coupling adjusted until there was no reaction of the measurement circuit on the power circuit. The magnetizing current was then adjusted to the desired value by varying the oscillator plate voltage, and the circuits again checked for absence of reaction. The circuital resistance was then determined by inserting three values of resistance, the current for each inserted resistance and for zero inserted resistance being observed. The observation was then repeated and the results averaged. The sample was then inserted in the magnetizing coil, and after readjusting the power circuit, the observations were repeated as before. The difference between the two values obtained for the circuital resistance is taken as the value of the equivalent absorbing resistance of the sample.

The observations were made on three different samples of low carbon iron drawn from the same ingot, of areas 6.6×10^{-4}, 95.0×10^{-4}, and 630.0×10^{-4} cm^2 and of length 4 cm in each case. The samples were sealed in small glass tubes and were accurately centered along the transverse axis of the coil.

The measurements were made on each sample at frequencies of 520, 592, 706, 810, 900, and 968 kilocycles per second, using magnetizing currents of 3, 4, and 5 ampere turns per cm.



Figs. 2. and 3. Power loss as function of frequency.

From the data thus secured, the loss in terms of ergs per cycle per cubic centimeter was determined for the samples with the frequencies and magnetizing currents stated. The results are shown in Figs. 2, 3 and 4.

Conclusions

In calculating the power loss from the measured values of the resistance, there is some question as to the proper value of current to consider as the magnetization current since by the very nature of the resistance-variation method, the current is a variable. In each case the current for zero inserted resistance was used for the I^2 factor. The difference is however small and did not seem to alter the results appreciably. The general variation as shown by the curves is indicated without a doubt.

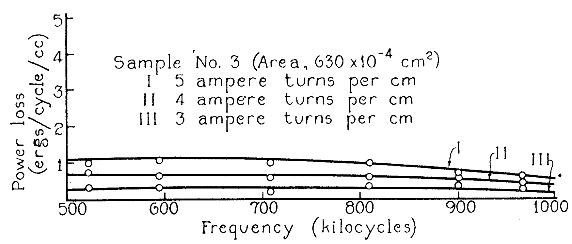


Fig. 4. Power loss as function of frequency.

The results indicate that the energy loss per cycle per unit volume is a function of the frequency, the magnetizing current, and the area of cross section. The loss seems to increase with the frequency for the smaller cross sectional areas, and to remain constant or to decrease slightly with the larger cross sectional area. This variation is probably due to the shielding effect of eddy currents, and explains the disagreement in the results of previous investigators.

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