Effect of Temperature on the Hysteresis Loss in Iron in a Rotating Field

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only be secured by the use of round numbers, such as the above, for the frequencies of the oscillations.

In conclusion, we wish to thank Dr. Glazebrook for the kind interest he has taken in the working out of the method.

DISCUSSION.

Mr. H. BECK expressed his interest in the method, which he said was the most satisfactory yet produced. It was difficult to say exactly what to call exposure. In photographing moving objects it was advisable to use as the effective time the time during which the central eight-tenths of the shutter was open.

Mr. DUDELL said the method was an ingenious one for determining the efficiencies of shutters. He suggested that by using an arc it might be possible to reduce the size of the mirror and thus work at higher frequencies. Instead of using a slit it might be better to use a short focus cylindrical lens.

Mr. CAMPBELL, referring to Mr. Duddell's remarks, said that with a Nernst lamp it was possible to obtain high frequency curves showing very little tendency to tail off.

LIV. *Effect of Temperature on the Hysteresis Loss in Iron in a Rotating Field.* By W. P. FULLER, *B.Eng.*, and H. GRACE, *B.Eng.**

It was shown by Professor Bailly † that the hysteresis losses due to a rotating field in iron reached a maximum value with an induction density (B) of about 16,000 C.G.S. units. With a value of B equal to 20,000 the hysteresis was approximately $\frac{1}{20}$ of the value. These results were confirmed by Messrs. Beattie & Clinker ‡. The experiments described below were undertaken in order to determine to what extent the results attained by Professor Bailly were modified by variation in temperature.

In these experiments, the rotating field was produced by means of two phase-currents. Fig. 1 shows the arrangement, the two magnetizing coils carrying the two phase-currents being marked E, D. A is a slab of plaster 2 cms. thick and

* Read May 14, 1909.

† Phil. Trans. 1896.

‡ 'Electrician,' 1896.

22 cms. square, having a circular hole $8\frac{1}{2}$ cms. diameter in the centre. At the top and bottom of the hole the heaters B are placed, and in the chamber so formed the iron specimen is suspended. Each heater was made by winding No. 40 s.w.g. nickel wire zigzag fashion over the surface of a circular piece of mica. Its resistance cold was 13 ohms, but

Fig. 1.

General arrangement of the magnetizing coils and specimen.

increased rapidly with temperature. With the two in series a current of 1.6 amps. at 180 volts produced a maximum temperature of 500°C . at a point close to the iron disk. The specimen used was a circular disk of iron 4 cms. diameter, .027 thick: it was attached by nuts to a brass spindle C, which had a weight attached to one end, and a *concave* mirror

at the other for indicating the motion of the specimen. The whole was supported by a bifilar suspension, the sensitiveness of which could be varied by altering the weight or by varying the distance apart of the supporting wires. The weight of the whole moving part was 285 grams.

The two magnetizing-coils D D, belonging to one phase, are each made by winding 14 turns of 7/14 asbestos-covered cable. The two coils are arranged to slide over the plaster slab to within a short distance of each other, at the centre. The coils for the second phase, E E, are placed so as to produce a field at right angles to that of D D. They are of the same shape as D D, so that the two together produce a close approximation to a uniform rotating field at the centre of the coils where the specimen is placed. The large coil was found to produce a field 10 per cent. greater than that of the smaller for the same current, but with 25 amps in one and 27·5 in the other, the maximum values of the two fields were equal, each being about 250 c.g.s. units, and the two together producing a uniform rotating field of this magnitude. At a distance of 2 cms. from the centre of the coil the field produced was $1\frac{1}{2}$ per cent. less.

The phase relationship of the currents in the two phases was indicated by means of a wattmeter, the thick coil being in one circuit and the thin coil connected between the ends of a non-inductive resistance in the circuit of the other phase. A phase-difference of 90° between the currents in the two circuits was shown by a zero reading on the wattmeter. The phase-difference was kept within ·3 per cent. of 90° by using a variable choking-coil in the primary of one of the transformers supplying current.

The numerous adjustments which have to be made are a disadvantage of the alternating current method compared with the rotating magnet method used by Baily and others; but the absence of rotating parts is a distinct advantage, and this fact would render the method very suitable for high-frequency experiments.

To measure the flux in the iron, a coil of 8 turns of bare wire was wound round it and insulated therefrom with mica. As the E.M.F. induced in the coil is alternating and of the order of ·04 volt, a suitable galvanometer had to be con-

structed in order to measure it. The instrument constructed for the purpose is shown in fig. 2. A B C D are four coils of conical shape and wound with no. 28 wire. A and B were connected in series through a resistance to one phase, C and D to the other phase, of the machine supplying current to the magnetizing-coils of the test apparatus D E. With a current of .31 amp. a rotating field of about 20 C.G.S. units

Fig. 2.

was produced at the point O. A small coil, made up with 200 turns of no. 46 wire (140 ohms resistance) 5 cms. long and 1 cm. broad, is suspended in the central space between the coils, and is connected to the search-coil on the iron specimen. In the galvanometer-coil there are two E.M.F.'s, one, $E \cos pt$ (say) due to the flux in the iron specimen, and one due to the rotating field of the galvanometer itself. Referring to fig. 2, let HH' be the direction of the rotating

field of maximum value H when $E \cos pt$ is a maximum. The angle between it and the coil at a time t will be $\theta + pt$, and the component along the coil $H \cos \overline{pt + \theta}$. The flux normal to the coil is $H \sin \overline{pt + \theta}$, and the E.M.F. induced is proportional to

$$H p \cos \overline{pt + \theta} = E_1 \cos \overline{pt + \theta}.$$

If R be the resistance of the coil and the self-induction is negligible, the resultant current is equal to

$$\frac{1}{R} (E \cos pt + E_1 \cos \overline{pt + \theta}).$$

The torque at a time t will be proportional to

$$H \cos \overline{pt + \theta} \left\{ \frac{1}{R} (E \cos pt + E_1 \cos \overline{pt + \theta}) \right\}.$$

Hence the mean torque acting on the coil is proportional to

$$\frac{H}{R} \{E \cos \theta + E_1\}.$$

This deflecting torque therefore consists of two parts, one constant and one which depends on the position of the four magnetizing-coils $A B C D$. In the apparatus used these coils were fixed to a turntable, which could be rotated until the deflexion was a maximum. The deflecting torque would then be proportional to $\frac{H}{R} (E + E_1)$. Another way of using the instrument is to get E and E_1 in opposition, in which case the minimum deflexion is proportional to $(E_1 - E)$; and this is the better method because the total deflexion is smaller, and greater sensitiveness is obtained.

The instrument was calibrated by putting a resistance of 4000 ohms in series with the coil and applying a measured pressure of 1.95 R.M.S. volts to it. The deflexion, after deducting that obtained by shortcircuiting the coil through the 4000 ohms, equalled 22.4 centimetres, consequently one centimetre corresponds to a voltage of maximum value .00416 applied to the moving coil.

The induction density in the iron disk was readily calculated from the maximum voltage measured as above, the dimensions of the search-coil on the iron being known.

The disadvantage of this type of instrument is that the

constant part of the deflexion depends on the cube of the frequency, so that the speed of the machine must be very exactly regulated for a constant value. The E.M.F. induced in the coil on the iron varies approximately as the frequency, and so the torque on the galvanometer due to this current depends on the square of the speed. It was found better in practice to have the two voltages E and E_1 in opposition, as mentioned above, so getting a deflexion proportionate to $E_1 - E$.

One other measurement required to be made, namely, that of temperature. This was effected by means of a Platinum-Platinum-Rhodium junction (placed close to the specimen) connected to a suitable galvanometer.

Fig. 3.

Curves showing relation between Hysteresis Loss and Induction at different Temperatures in a sample of armature iron from Messrs. Sankey.

The results obtained are shown in figs. 3 and 4. The temperature of 107° C. was the lowest at which it was found possible to make any measurements, on account of the heating effect of the magnetizing-coils. The results in fig. 4 were

obtained after the iron had been heated to 580° and cooled slowly. These experiments show that the effect of increasing the temperature of iron is to greatly reduce the hysteresis

Fig. 4.

loss at a given induction, and to cause the maximum to occur at a lower value of B . At a temperature of 580°C . the maximum hysteresis loss occurs at an induction density of 11,000 C.G.S. units instead of 16,000, while the maximum hysteresis loss is only 2600 as compared with a maximum of over 15,000 per c.c. per cycle at ordinary temperatures. The effect of heating to 580° , as shown in fig. 4, is most marked; although the actual maximum hysteresis loss is not greatly altered at the higher temperature, the reduction in the hysteresis loss at the lower temperature is considerable. The shape of the curve between ergs per cycle and B is quite different, the hysteresis loss falling off much more rapidly from the maximum.

The permeability of the iron is not greatly affected by changes in temperature within the limits of the experiment, as was shown by Morris*.

* Phil. Mag. Sept. 1897.

The above experiments were carried out at the Applied Electricity Laboratories of the University of Liverpool, and the authors thank Professor Marchant for his valuable advice and assistance.

DISCUSSION.

Dr. W. H. ECCLES remarked that the effects of previous thermal treatment, and of the nature of the material on the properties studied by the Authors, were so enormous that comparison of the present experiments with similar ones with alternating fields was difficult; but the Authors' curves seemed to show that the effect of rise of temperature on hysteresis loss was less for rotating fields than for alternating fields if the fields were below about 12 c.g.s. The curves showed also that the maximum values of hysteresis loss in rotating fields were reached at lower and lower flux densities the higher the temperature, although the permeability varied but little. This was of importance from the point of view of the molecular theory of magnetism: it showed that smaller forces sufficed to rotate the molecules within a magnetically stable group at high than at low temperatures. The Authors' experiments might be regarded as adding strong confirmation to the molecular theory of magnetism.

Prof. MARCHANT said the iron tested was obtained direct from the manufacturers and its previous thermal treatment was not known. A permeability curve had, however, been obtained. He expressed his interest in Dr. Eccles's remarks upon the bearing of the experiments on the molecular theory of magnetism.

Mr. A. CAMPBELL remarked that the methods and results described by the Authors were interesting, particularly the novel instrument employed. There is a source of considerable uncertainty, however, which does not appear to have been taken into account, namely that the total power spent in the iron disk includes eddy-current losses. For the thickness of sheet used, the eddy-current loss at 50 $\sim$ per sec. and B maximum = 10,000 would be about 20 per cent. of the total amount measured when the induced voltage has sine wave-form. With other wave-forms the eddy-current loss depends on the square of the form factor and might easily rise to 40 per cent. of the whole, even although the source of current was a sine-wave alternator. Thus tests made without simultaneous measurement of the form factor are open to serious error. It is highly probable that the form factor would vary considerably along any one of the curves given in the paper. The eddy-current loss also would be very much reduced at the higher temperatures owing to the increased resistivity of the iron.