AN INVESTIGATION OF NON-VIBRATORY TYPES OF FREQUENCY METERS.

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FLEMING¹ and Pierce² have mentioned the fact that the deflecting moment acting on the suspended ring of the former's A.C. galvanometer is a function of the frequency. No experimental data showing the performance of this galvanometer when used as a frequency indicator have been found after a careful examination of the literature.

It is the object of this paper first to describe a modification of this instrument for the purpose of frequency determination and to give an account of its performance; secondly to discuss in a similar fashion a bolometric frequency meter devised by the writer. This was suggested by a paper on kinetic hysteresis by Guye and Hertzfeld,³ reference to which was made in a previous paper.⁴ Inasmuch as this paper is practically a continuation of the one just mentioned, details given in the former will be omitted in this.

PART I.

Fig. 1 is a diagrammatic sketch of the first instrument referred to and is self explanatory. To call it a modified form of the Fleming galvanometer may seem at first to be in error, for the instrument is just as truly a core type transformer with a secondary free to turn about an axis perpendicular to the plane of the core. The reaction between the field due to the current in this short-circuited

¹ Fleming, *The Principles of Electric Wave Telegraphy*, Section 13, p. 150, and 12, p. 397. (As a matter of historical interest it may be mentioned that the invention of the Fleming A.C. galvanometer bears an uncertain date. On page 150 of the above reference Fleming says he devised his A.C. galvanometer in 1884 and on p. 397 of the same treatise he says he devised the instrument in 1887.)

² G. W. Pierce, *Experiments on Resonance in Wireless Telegraphy Circuits*, *PHYS. REV.*, Sept., 1904, Vol. 19, p. 201.

³ Guye and Hertzfeld, *C. R.*, 136, p. 957, 1903.

⁴ Hiatt, *PHYS. REV.*, Vol. 29, No. 5, p. 432, 1909.

secondary and the inducing field gives the turning moment. The instrument is, however, still essentially a Fleming galvanometer, the Fleming instrument being merely an application of an air core alternating current transformer with a short-circuited and movable secondary. The one under discussion differs from it merely in the fact that it has an iron core.

The disc forming the short-circuited secondary is a copper washer 2 mm. thick and 2.38 cm. in diameter with a 0.79 cm. hole in the center. The inner edge is slightly beveled for a reason which will appear shortly. From this disc there extends a copper wire to support a mirror mounted at 45° to the plane of the disc. This copper wire also extends as shown in the figure to a disc immersed

Fig. 1.

in oil which serves as a damper. The suspension is of phosphor bronze 0.025 mm. thick and 0.43 mm. wide. The copper disc is threaded on an iron wire 1.27 mm. in thickness; the beveling of the inner edge permits it to swing freely through a large angle. The iron wire is between the central laminations of the transformer core. These laminations are of silicon steel 0.356 mm. thick and form a core 2.54 cm. by 5.08 cm. in cross section. The sides of the core rectangle are 15.24 cm. and 10.16 cm. respectively; the air

gap is 0.60 cm. in length. The winding consists of two coils having 900 turns each of double cotton covered copper wire 1.62 mm. in diameter connected in multiple.

An inverted Westinghouse rotary converter run by storage cells furnished the alternating current for the transformer. By changing

Fig. 2.

the field excitation a fair range of frequencies was obtained. The alternating voltage supplied to the instrument was kept constant by means of a multicellular electrostatic voltmeter across the A.C. mains and a rheostat in the D.C. supply. The frequency was determined with a Starrett revolution counter and stop watch, the

shaft of the revolution counter being connected to the shaft of the alternator by a short piece of high-grade rubber tubing.

The copper disc was initially set with its plane at approximately 45° to the iron wire, the 45° position being the one for maximum torque on the disc. Any deflection of the disc from this position was observed by means of the attached mirror and a telescope and scale. The scale distance was one meter.

Fig. 3.

Curve I, plotted from the data of Table I., shows the performance of the instrument when the supply voltage was kept constant at 60 volts.

TABLE I.

TABLE II.

TABLE III.

Frequency.	Deflection.	Volts.	Readings.	Volts.	Readings.
41.7	7.32	43.5	18.02	43.6	17.1
43.8	6.43	47.5	18.80	47.0	17.50
46.7	5.90	51.5	19.70	52.5	18.30
50.0	5.19	56.0	20.56	56.6	18.75
55.5	4.18	60.6	21.90	61.0	19.20
61.7	3.50	69.0	22.48	65.0	19.52
66.7	3.08			69.0	19.78

For the lower frequencies it is quite sensitive, but beyond this and the fact that it is easy and cheap to construct, it has little, if anything, to commend it. To get a high torque and high sensibility it is necessary to use for the disc a low resistance metal with its accompanying high temperature coefficient. Furthermore, the indications of the instrument are seriously dependent upon the variation of wave form and voltage. This dependence upon the voltage may be seen from curves *II* and *III* plotted from the data of tables II. and III. which have been placed by the side of Table I. Curves *II* and *III* were obtained by keeping the frequency constant at 48 and 60 cycles per second respectively and varying the voltage by means of a non-inductive resistance in series with the instrument. The voltage given is that across the transformer terminals and was read from a Weston A.C. voltmeter of the dynamometer type. The dependence upon variation of wave form may be inferred from the results of numerous experimenters, those of Lloyd in the various Bulletins of the Bureau of Standards being perhaps in the most complete and available form.

PART II.

The writer's bolometric frequency meter which depends for its action on the rise in temperature of a thin iron wire subjected to cyclic reversals of magnetic flux seems to be a more satisfactory instrument. Its range is far more extended; in fact, there is reason for the belief that a single instrument can now be made which will measure any frequency from 10 to 10^6 cycles per second with a very fair degree of accuracy. The bolometric type of instrument has some decided advantages over the thermo-hysteretic frequency meter described by the writer in the article already referred to. This last type of meter is dependent on the production of hysteretic heat at a thermo-junction. In brief the advantages just mentioned are exactly those which the resistance thermometer has over the thermo-couple thermometer. The former with its bridge arrangement permits the use of sturdy indicating instruments while the thermo-couple demands a highly sensitive galvanometer. In the case of the resistance thermometer much larger quantities of energy are available for measurement. The thermo-couple type of instru-

ment is compact and easy to construct, but beyond this the more elaborate and expensive bridge arrangement seems preferable. Having made a frequency meter on the thermo-couple principle, it was merely a logical development to construct the more elaborate bolometric type.

The instrument and testing equipment are shown diagrammatically in Fig. 4. The iron wire bridge of which *A*, *B*, *C* and *D* are

Fig. 4.

the arms is enclosed in a tight box of insulating material which shields it from external temperature changes. Two opposite arms of this bridge are mounted on thin rectangular strips of mica as shown on the right side of the figure. Each arm consists of an iron wire 0.0513 mm. in diameter and about half a meter long, strung zig-zag fashion through holes in the mica strips. The two rows of holes in the mica are about 4.6 cm. apart. As adjacent lengths of wire are separated by the mica sheet, short circuiting of portions of the wire is effectively prevented. The stringing of such fine, springy wire on such a frame is a rather delicate and tedious process. Two frames are made containing the arms *A* and *B* and *C* and *D* respectively. *C* and *D* are then placed in a solenoid of 1,740 turns of double silk-covered copper wire 0.508 mm. in diameter and wound on a wooden spool. *A* and *B* are placed in a solenoid containing the same amount of wire and exactly like the first except that it is wound non-inductively. These two solenoids are permanently connected in series and attached to the wires *M* and *N* coming from the switch *S*, which furnishes the exciting current. When

alternating current is supplied to these solenoids the bridge arms *C* and *D* get hotter than *A* and *B* and due to the high temperature coefficient of iron, the bridge becomes unbalanced. This is indicated by the mirror galvanometer G_1 . The current in the coils is kept constant by means of a variable resistance and the thermo-comparator *C* used in conjunction with the galvanometer G_2 to form a thermo-ammeter.¹ By means of this arrangement the current used was kept constant to 0.2 per cent. or better.

In preparation for a test of the instrument direct current of the value to be used was taken from the storage cells shown at the left of the figure. This was passed through the coils for some time in order that a steady temperature state might be had in the box,

Fig. 5.

thus eliminating possible thermo-electric disturbances due to a sudden heating of the coils and bridge arms when measurements were begun. This steady current with the ammeter A_1 served also to calibrate the thermo-ammeter. The lower corner of the bridge rectangle is shown equipped with a slide wire rheostat. This was used to secure an initial balance of the bridge. For the low frequencies this initial balance was taken with direct current in the coils, but for the high frequency obtained from the inductor alternator it was convenient to balance at a frequency of about 800 cycles per second and observe deflections at the higher frequencies. The Ayrton shunt connected to G_1 proved very convenient.

Curves *IV* and *V*, Figures 5 and 6, show the performance of the

¹ Hiatt, *PHYS. REV.*, Vol. 29, No. 5, p. 441.

instrument under two different ranges of frequency. They are plotted from the data of Tables IV. and V. respectively. The frequencies of Table IV. were obtained just as those of Table I.; those of Table V. from the inductor alternator driven by a high speed motor also supplied from the storage cells.

Fig. 6.

For Table IV. the current through the two solenoids was 0.09 ampere and for Table V. 0.07 ampere.

TABLE IV.

TABLE V.

Frequency.	Deflection.	Frequency.	Deflection.
45.5	2.98	850	2.0
47.7	3.12	940	4.5
50.0	3.30	1,030	7.4
52.7	3.48	1,110	9.5
58.2	3.75	1,190	12.2
63.3	4.10	1,270	14.5
68.5	4.42	1,330	16.4
72.5	4.68	1,400	18.6

This first instrument can be improved by the use of finer iron wire in the bridge arms to eliminate an annoying sluggishness of action. As iron wire of almost one fourth the diameter of that used in this work can now be obtained of Hartmann & Braun, it is believed that the objection just stated may be eliminated. It is the writer's intention to try an improved mounting for the bridge arms similar in general to that of a tungsten lamp filament. A variation in wave form of the exciting current must cause variations in the readings of the bolometric frequency meter just as in the case of the thermo-hysteretic device and the Fleming galvanometer. This necessitates empirical calibration. The most valuable feature about the instrument is its high sensibility, even in its present unrefined state.

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