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THE TESTING OF INSTRUMENT TRANSFORMERS

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The determination of the ratio and phase angle of instrument transformers has now become a very important part of the work of electrical testing laboratories. The method now almost universally used in accurate work depends upon the potentiometer principle. Various modifications of this method have been suggested and used*. A modification of the method has recently been developed at the Bureau of Standards which, while involving no entirely new principles, possesses some distinct advantages over any of these.

FIG. 1

The connections for the current transformer are shown in Fig. 1. Current from the source flows in series through the primary winding T of the transformer under test and through a standard non-inductive low-resistance shunt R_1 . The secondary current flows through the normal load of instruments, through the primary winding of a variable mutual inductance M and through a non-inductive resistance R_2 , a variable part of which

* For a resumé of these methods and a bibliography, see *Bulletin*, Bureau of Standards, Vol. VII, p. 423, 1911, reprint No. 164.

may be included in the galvanometer circuit. The resistances R_1 and R_2 have values inversely proportional to the currents flowing in them so that the IR drop is the same in both. The potential terminals are connected so that these equal voltages are in opposition and if there were no phase difference between them no current would flow through the vibration galvanometer G . On account of the phase-displacement in the transformer, however, it is necessary to introduce an e.m.f. in quadrature with $I_2 R_2$. This is done by the mutual inductance M . The procedure is therefore to adjust successively R_2 and M until the galvanometer shows no current. It can then be easily shown that the ratio of the currents is

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \frac{1}{\cos \theta}$$

FIG. 2

and the phase angle is

$$\theta = \tan^{-1} \theta = \frac{P}{R_2} \frac{M}{R_2} \text{ radians} = 3438 \frac{P}{R_2} \frac{M}{R_2} \text{ min.}$$

In most transformers the factor $\frac{1}{\cos \theta}$ differs from unity by less than one part in 2000, and hence for most engineering work it may be omitted. It may be necessary, however, to correct the phase angle for the inductance of the shunts.

The connections for the potential transformer are somewhat analogous and are shown in Fig. 2. A high resistance R_1 is connected in series with a smaller resistance R_2 and a self-inductance L across the high-voltage side of the transformer. The low-tension winding is connected in a reversed sense to the points a and b of this resistance, the galvanometer G being in series with the low-voltage winding. The procedure is to adjust R_2 (or better

R_1) and L until a balance is obtained. It can then be shown that the ratio of transformation is

$$\frac{E_1}{E_2} = \frac{R_1 + R_2}{R_2} \cos \theta,$$

neglecting terms of higher order; and, assuming R_1 and R_2 to be non-inductive,

$$\theta = \tan \theta = P L \left(\frac{1}{R_2} - \frac{1}{R_1 + R_2} \right) \text{ radians} = 3438 P L \left(\frac{1}{R_2} - \frac{1}{R_1 + R_2} \right) \text{ min.}$$

The adjustment for the phase angle may be made by a variable self-inductance in R_1 or R_2 , or by a mutual inductance, or by shunting a variable amount of R_1 or R_2 by a condenser. This latter combination is sensibly equivalent to a negative self-inductance of magnitude $C r^2$. In practise it has been found best to use a self-inductance in series with R_2 , together with a condenser shunting a variable portion of R_2 .

With this arrangement the effective inductance of the circuit is

$$L - \frac{C r^2}{1 + p^2 C^2 r^2}$$

and the resistance is

$$\frac{R_2}{1 + p^2 C^2 r^2}$$

The term $p_2 C_2 r_2$ is practically always negligible, compared with unity, so that $L' = L - C r^2$, and R_2 is unaffected by the condenser. The advantage of this arrangement is that it is possible without changing the set-up to test a transformer in which the phase angle changes from leading to lagging.

Considerable difficulty was encountered in obtaining a sufficiently sensitive self-contained detector in the case of the current transformer. At first sight this seems surprising, since one naturally associates instrument transformers with heavy currents and high voltages. The trouble arises from the fact that the entire performance of the apparatus depends on the magnetic properties of its iron core, and consequently it must be tested under exactly the conditions of use, and sensitivity can-

not be gained by forcing an abnormal amount of power into the circuit for a short time, as is possible with condensers, etc.

For the current transformer, in order to obtain a sensitivity of 1 in 10,000 at one-tenth load, it is necessary to use a detector capable of responding to about 2 microvolts a-c. We obtain this sensitivity by using a vibration galvanometer of the Campbell type, the moving system of which was reconstructed largely in accordance with suggestions of Dr. Wenner. The moving coil consists of but 4 turns of No. 28 wire. The total resistance is 0.66 ohm. The sensitivity is such that at 25 cycles one microvolt gives a deflection of 0.5 mm. at a scale distance of one meter. A range of frequency between 40 and 80 may be obtained by varying the length and tension of the suspensions. For lower frequencies between 40 and 20 cycles the moment of inertia is increased by the addition of a brass washer which may be dropped on a tiny cone at the top of the coil, thus automatically centering itself.

The advantages of the method are that only a single instrument is needed for all ranges of transformers, but one observer is required, and neither a polyphase source of voltage, a phase-shifting device, nor a rotating commutator is required.