11. NEW ALTERNATING-CURRENT COMPENSATION APPARATUS FOR TELEPHONIC MEASUREMENTS

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Description of the Apparatus.

The essential parts of the apparatus are (see Fig. 1): Two calibrated slide-wires M_1 and M_2 (each having a resistance of about 50 ohms) with a millimetre graduation in both directions from a central zero; two standards of self-induction P, each of 0.01 henry and 3 ohms; two non-

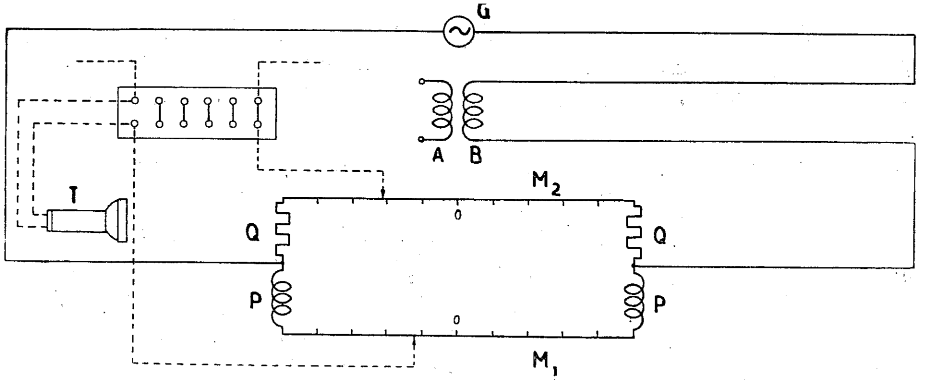

Fig. 1.

inductive coils, Q, of exactly the same resistance as the standards; a transformer, containing no iron, and consisting of a primary coil B and a secondary coil A, the mutual inductance being variable within certain limits by moving one of the coils. Two sliding contacts, each movable along one of the wires M_1 and M_2, are during the measurements generally connected with different points on the object to be measured (which is not shown in the illustration); these connexions (and others which are found desirable later) are facilitated by a junction-board having a number of terminals. A telephone receiver T, the cords of which are led to this junction-board, forms part of one of the above connexions.

The Pressure Diagram.

When a simple periodic alternating current flows through the two parallel circuits consisting of the coils P with the wire M_1 and the coils Q with the wire M_2, the pressure along the wires can be represented by means of a vector diagram, as in Fig. 2. The numbers shown on this diagram correspond directly with the marking of the two scales of the apparatus.

Knowing the frequency ω of the current, and the constants of the wires and coils, the angle α between the two lines can easily be determined. Taking, for instance, the values given previously, we have —

$$\omega = 2{,}800 \tan \alpha.$$

To check the accuracy of the wires, &c., the two junction-terminals used for connecting up to the object to be measured can be short-circuited; in that case, on placing the sliding contacts at zero, the telephone should be silent.

The Generator and the Frequency.

Any alternating-current generator capable of producing currents of the desired frequency or frequencies (for instance $\omega = 5{,}000$) may be used, provided it gives a wave sufficiently free from harmonics. Its output need not be large or very constant, but it is important that the frequency should remain practically constant during each measurement.

For determining the frequency, two methods have been found very convenient. First, use can be made of a tuning-fork of the desired frequency of vibration by comparing the pitches and observing the beats. The second method is purely electrical. By connecting the terminals of the secondary coil A to the junction-board, it is possible by moving the sliding contacts to balance the secondary pressure against the potential difference between two points of the wires. Having obtained silence in the telephone, the two readings a and b are noted. It is, by the way, advisable here to reverse the connexions and to take a second set of readings, which ought to be equal to the first with the signs reversed. A similar check may be applied to all the following measurements. Now it can be shown[1]) that

$$\tan \alpha = \sqrt{2\,(b/a - 1)},$$

and by using the formula for ω given above, ω can easily be found. It must be realized that the ratio b/a will be independent of the distance between the coils A and B; on the other hand, if the same distance is

[1]) The proof of this must here be omitted.

always chosen the reading "*a*" will be the same for every value of ω, and the frequency can accordingly be measured rather more easily.

Impedance Measurements.

The unknown impedance is connected, together with a known resistance, say, 1,000 ohms, in series with the secondary coil. Now, by compensation, the pressures across the known resistance and across the unknown impedance are ascertained, the corresponding vectors being at once determined from the pressure diagram (Fig. 2). From the lengths of the vectors and the angle between them, the vector representing the unknown impedance (the ohm being taken as the unit) can easily be found.

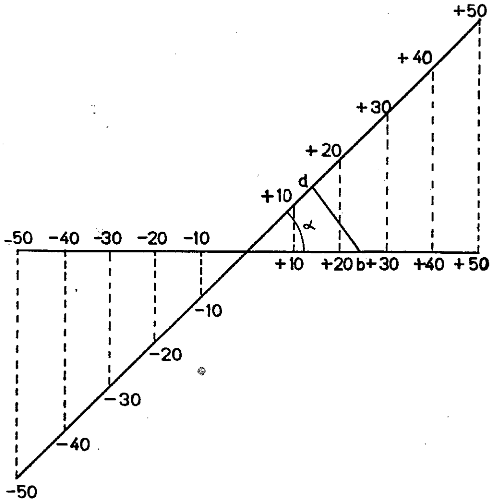

Fig. 2.

Transmission Measurements on Telephone Conductors.

For the sake of simplicity only homogeneous conductors will be considered. One method is to measure the impedance (A and K) of the conductor with the far end first open and then closed. The constant, z, known as the "characteristic impedance" or "initial sending-end impedance", can then be found as the geometrical mean of A and K.

The propagation constants, generally denoted by β and α, are most easily found by constructing a triangle, the two sides of which, A and K, enclose the correct angle between them. The third side will be C (Fig. 3). Now, denoting by l the length of the conductor, we have —

$$\cosh\ 2\,\beta\,l = \frac{A + K}{C},$$

$$\cos\ 2\,\alpha\,l = \frac{A - K}{C}.$$

In these equations, A, K, and C denote the absolute values of the vector quantities. Of course, in order to determine $\alpha\,l$ it is necessary to have a preliminary approximate knowledge of its value.

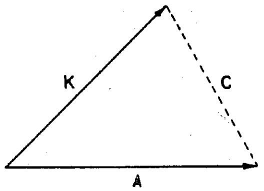

Fig. 3.

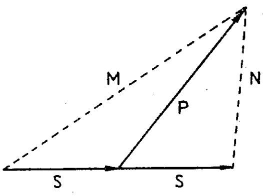

Fig. 4.

Another method of finding β and α consists in measuring the potential differences, P and S, at the near end and at the far end — it must here be assumed that the far end of the conductor can be brought within reach. For obtaining the values of β and α the construction shown in Fig. 4 may be used; we then have —

$$\cosh\,\beta\,l = \frac{M + N}{2\,S}$$

$$\cos\,\alpha\,l = \frac{M - N}{2\,S},$$

M, N, and S being the absolute values of the vector quantities.

Generally speaking, from the point of view of accuracy the latter method is preferable if the conductor to be measured is long, the former if it is short.

Instead of the potential difference, S, it is sometimes better to measure the fall of pressure from the near end to the far end.

In the case of a non-homogeneous conductor, the methods are not quite so simple as in the case just considered. A complete measurement consists of 3 impedance measurements, one of which can be omitted by measuring the pressure at the far end.

The case of a transformer is analogous.

Special Methods.

While the above-mentioned methods are sufficient for the telephone measurements most commonly required in the laboratory or in practice, a somewhat different arrangement of the main parts of the apparatus

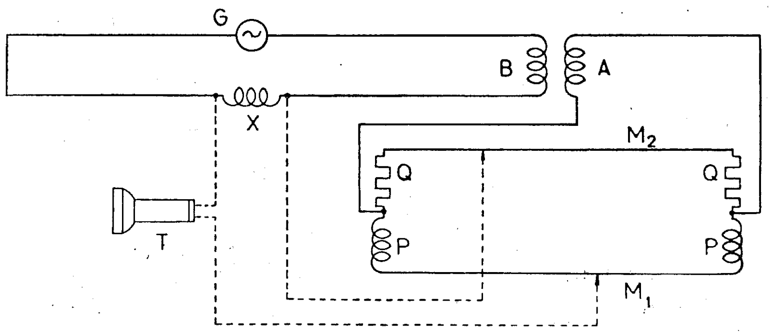

Fig. 5.

will occasionally be more convenient. Thus for impedance measurements the arrangements indicated in Figs. 5 and 6 can be used under certain circumstances, the former for not too great, the latter for not too small impedances. It is here unnecessary to have a known comparison resistance in series with the impedance X to be determined, provided that once for

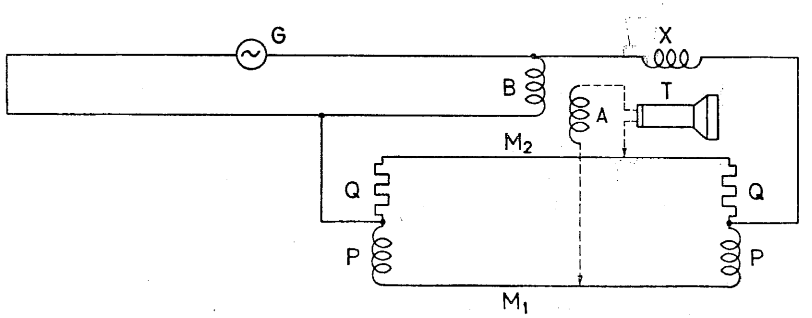

Fig. 6.

all such a resistance is inserted in place of X and the corresponding readings are taken.

The arrangement shown in Fig. 7 is very convenient for determinations of the propagation constants β and α[1]) (the near-end pressure may be measured once for all, it being the same in all cases).

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[1]) β denotes the attenuation constant and α the phase constant.

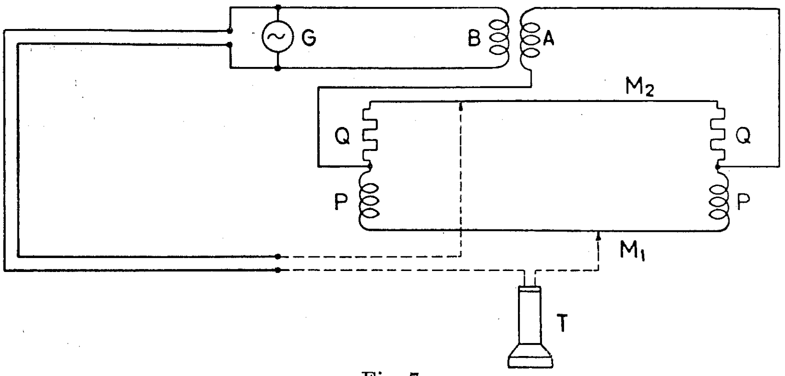

Fig. 7.

The arrangement indicated in Fig. 8 is suitable for microphone tests, and some difficulty will naturally be experienced owing to the somewhat irregular behaviour of the microphone.

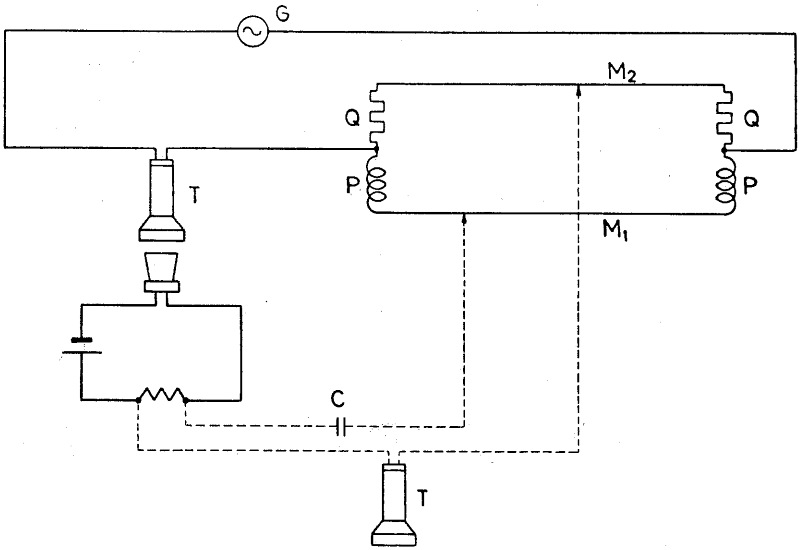

Fig. 8.

Conclusion.

A description has here been given of a simple, cheap, and transportable apparatus for telephonic and other alternating-current measurements, which has already done good service for some years in the research laboratory of the Copenhagen Telephone Company, and which may prove of interest to others handling similar problems.

In conclusion, it is a pleasant duty to express my grateful acknowledgments of several very valuable researches already made on similar lines, especially the work of Professor *Absalon Larsen* of Copenhagen[1]). My special thanks are also due to Mr. *J. L. W. V. Jensen*, Chief Engineer of the Copenhagen Telephone Company, under whose supervision the present work has been carried out.

[1]) I refer to the following two papers by Professor Larsen in the *Elektrotechnische Zeitschrift*: "Ein akustischer Wechselstromerzeuger mit regulierbarer Periodenzahl für schwache Ströme" (vol. 32, p. 284, 1911), and "Der komplexe Kompensator, ein Apparat zur Messung von Wechselströmen durch Kompensation" (vol. 31, p. 1039, 1910).