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XXVII. *A Method of Comparing Capacities at Various Frequencies.* By ALBERT CAMPBELL, B.A. (*From the National Physical Laboratory.*)

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FOR the accurate determination of a capacity in terms of a resistance and a frequency Maxwell's commutator method (shown in Fig. 1) is well known.* It gives excellent results with condensers of all kinds, and two capacities can be compared with one another, by testing one after the other, by this method. But such a comparison cannot be made quickly, as the accurate determination of the frequency requires a run of eight or ten minutes on the chronograph in each case.

It would be possible to avoid this trouble by having two separate complete bridges (each as in Fig. 1) with the two com-

FIG. 1.—MAXWELL'S COMMUTATOR METHOD.

mutators (C_1 and C_2) mounted on one spindle, thus making the frequency identical for each condenser.

A simpler method, however, is shown in Fig. 2; it gives a comparison under much the same conditions of charge and discharge as hold in the Maxwell method.

A rotating double commutator is arranged, as shown, to charge and short-circuit each condenser simultaneously, the resistances R and S and the frequency being such that the

* In Maxwell's original description a rocking commutator ("wippe") was mentioned. In 1888 Dr. Fleming brought the method into its present form by the introduction of a *rotating* commutator.

charge and discharge are practically complete for both K_1 and K_2 in each cycle. The galvanometer must be of long period.

Let us first assume that the two commutators are so mechanically perfect that their corresponding contacts are made simultaneously. When K_1 and K_2 are of the same type as regards absorption and leakage, the current through the galvanometer will be practically zero at every instant if $R/S = K_2/K_1$.

If the condensers are not of the same type an alternating current will pass through the galvanometer, but, by suitable adjustment of the ratio R/S , the mean current can be brought to zero and an exact balance obtained. To a near approximation we may then take $K_2/K_1 = R/S$.

FIG. 2.—DOUBLE COMMUTATOR METHOD.

Especially at tolerably high frequencies it is not possible to ensure that the two commutators start the charging of each condenser at precisely the same instant,* and so, to eliminate any errors due to the difference between the two commutators, a second balance should be taken with the commutators interchanged. The mean of the two results gives the ratio of the capacities to a high degree of accuracy. The truth of this statement has been established by experimental evidence, as several condensers of widely different absorption have given

* Mr. D. W. Dye has suggested that this could be ensured by arranging another part of the commutator to break the battery circuit at A just before, and make it just after, the condensers come into connection with B and D.

results consistent with those of other methods even when the galvanometer resistance has been varied from 700 to 10,000 ohms, R and S being of the order of 500 to 1,000 ohms. When the condensers differ much in absorption the complete theory of what occurs during the periods of charge is very difficult, as the laws of absorption are still too obscure to give sufficient basis to work upon. Further experiments, however, are desirable. The advantages of the method are that alternating current is not required, and that, as a direct-current galvanometer is used, very high sensitivity can be attained. With condensers of 1 mfd. each, a reasonably sensitive galvanometer and a battery of 20 volts, a change of 1 part in 1,000,000 in one condenser gives a deflection of 0.5 mm. at 1 meter. Frequencies from 5 up to 200 $\searrow$ per sec. have been used.

The methods (such as Wien's or Carey Foster's) in which alternating current is used are really preferable, although, when the highest accuracy is desired, the very small residual inductances of the resistances used have to be taken into account. The latter methods employ a sine wave voltage, the commutator methods a voltage of square-topped wave form. A long series of experiments which we have made appears to have established the following relation between the methods. *For condensers with negligible leakage the results of the two kinds of method are in agreement, provided that the respective frequencies are chosen so that the period of charge (or the equal period of discharge) with the square-topped wave is equal to $2/\pi$ times the half period of the sine wave.* When this condition is satisfied the results given by the two kinds of wave-forms come into agreement within one or two parts in 100,000 over a wide range of frequency. By "leakage" I here mean what is sometimes called "direct-current leakage."

An account of the experimental work here mentioned will appear in a paper shortly to be published on the determination of the Ohm in absolute measure.

ABSTRACT.

To compare the capacities of two condensers under conditions similar to those in Maxwell's commutator method, they are charged and short-circuited periodically in two adjacent arms of a bridge by a double rotating commutator, the corresponding contacts being made simultaneously. If the other arms of the bridge are resistances R and S, and a battery and direct-current galvanometer (of long period) are used, then a balance is obtained when $K_2/K_1 = R/S$. The method is highly sensitive. Methods (like the above) in which the

applied voltage has a square-topped wave-form give results in agreement with those using sine wave-form when the period of charge (and equal discharge) with the square-topped wave is $2/\pi$ times the half-period of the sine wave.

DISCUSSION.

Dr. J. A. FLEMING remarked: Mr. Campbell's suggestion for using a double commutator for comparing capacities on a Wheatstone's bridge is not altogether new. Many years ago a double commutator was made in the Pender Electrical Laboratory at University College for this identical purpose, and the commutator part of this apparatus is exhibited by me on the table. Mr. Campbell speaks of the method of using a single commutator as "Maxwell's Commutator Method." As a matter of fact, the kind of commutator Maxwell suggested was a tuning fork, and this particular mode of commutation was mentioned in a Paper by me on "Problems on the Distribution of Electric Currents in Networks of Conductors," read before this Society in June, 1885. It was found, however, in practice that the tuning-fork commutator did not allow sufficient time for the contacts, and when this method of determining the capacity of a condenser was used by Sir J. J. Thomson in 1883 and by Dr. Glazebrook in 1884 at Cambridge they used the tuning fork to control another make-and-break contact of the vibrating-reed type. In the year 1888 I sent a short Paper to be read at Section A at the meeting of the British Association at Bath, in which a motor-driven revolving commutator was described for this purpose. In 1903, in conjunction with Prof. Clinton, I read a Paper before this Society in which a much more perfect motor-driven commutator was described for capacity measurements, and also a double commutator for inductance measurements. This motor-driven commutator has been used for nine years with the greatest success. To avoid the trouble of standardising the galvanometer, and for the sake of comparing two condensers by a null method, a double commutator on one shaft was made a few years later. Since a condenser plus a commutator behaves like a resistance, and lets through a certain quantity of electricity per second, it was an obvious application to insert in the two branches of a Wheatstone bridge two condensers and a double commutator, so arranged as to charge and discharge the condensers simultaneously. The method seemed so obvious that we did not trouble to describe it. The double commutator was also intended to be used in another way to measure the absolute capacity of a guard tube or guard ring condenser. It is well known that when a condenser of predetermined capacity with guard ring or tube is measured by the commutator method the guard tube must be discharged at the same instant as the main condenser, only the guard tube is discharged through a bye-pass circuit and the main condenser is discharged through the galvanometer. This method was a common subject of conversation in my laboratory some years ago. The double commutator method can also be used with advantage for comparing together by a bridge method the capacity of a small adjustable air condenser with the capacity of a wireless telegraph antenna. The small air condenser can have its capacity determined by the Carey Foster method, and it is then not necessary to carry about apparatus for standardising the galvanometer. In the case of our double commutator there is a counting mechanism which enables the operator to know the frequency of the discharges and to regulate them, and also special means for preventing the battery sending current directly through the galvanometer.

Dr. RUSSELL queried the utility of finding the ratio of the effective capacities of two condensers having different absorptive properties by a double commutator method. He also asked whether the author's experimental result could not be expressed more simply by saying that

the ratio of the effective capacities was the same with sine and square-shaped periodic waves when the charges given to the condensers were the same in the two cases.

Mr. E. H. RAYNER pointed out that in tests of condensers with alternating currents the polarisation was continually reversed, but in the present method the polarisation was always in the same direction.

The AUTHOR, in reply, said that the method did not appear to have been described before. He was interested to hear that Dr. Fleming had been using it for some time past. In reply to Dr. Russell, he pointed out that in the alternating-current methods the absorption was separated from the capacity, and hence the latter might reasonably be called the true capacity at the particular frequency used. He did not think Dr. Russell's remark about the curves having equal areas was quite valid. In reply to Mr. Rayner, he stated that when, in Maxwell's method, a reversing commutator was used, it gave with a mica condenser exactly the same results as the usual short-circuiting commutator.