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Mutual Induction and the Internal Resistance of a Voltaic Cell

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MUTUAL INDUCTION AND THE INTERNAL RESISTANCE OF A VOLTAIC CELL.

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The usual method of making a rapid determination of the internal resistance of a voltiac cell, primary or secondary, is by means of the condenser in circuit with a ballistic galvanometer. The deflection of the galvanometer due to the discharge of the condenser is first taken on open circuit with the cell and again when the cell is on a closed circuit the known resistance. The working formula is $r = d - d^1$ over $d^1 \times R$, in which d and d^1 are the different deflections of the galvanometer needle and R is the external resistance of the closed circuit. The explanation of this method can be found in Carhart and Patterson's Electrical Measurements. Not having a good standard condenser it occurred to me some time ago while working with a number of students in electrical measurements that an induction coil might be substituted for a condenser in such determinations. The idea appealed to me particularly as I thought that such a method might indirectly bring the student to a definite, elementary understanding of the terms self induction and mutual induction. Every one who has ever attempted to teach these conceptions to a class of students in secondary work, possessing as they usually do an inadequate mathematical training, must realize the difficulty of the task. And yet in view of the general commercial use of periodic currents at the present time, it becomes quite necessary to pay some attention to these phenomena in a practical way.

The diagrammatic sketch below, Figure 1, represents the arrangement of the apparatus for the determination of the internal resistance of a primary or secondary cell by means of an induction coil. In my work I used a small induction coil like that found in the ordinary telephone transmitter.

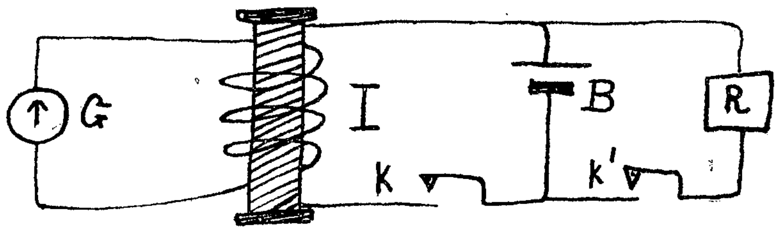

Fig 1.

The mutual induction of the coil under the action of a current of one tenth of an ampere was approximately 30 millihenrys. In the diagram I is the induction coil, G is the galvanometer in the secondary circuit. The galvanometer should be ballistic although type H D'arsonval made by Leeds, Northrup & Co. gave very good results. The primary circuit contains a resistance box R, a battery B and a key K^1; preferably a knife

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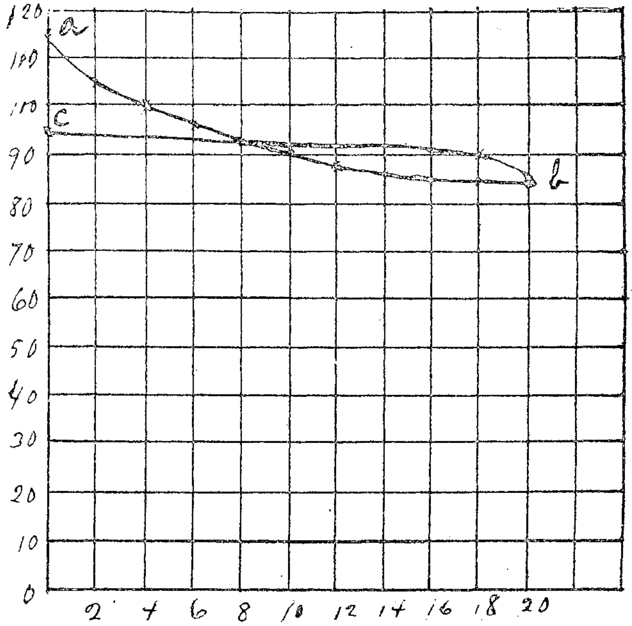

MINUTES.

Fig. 2. Curve of Sampson Cell.

switch. The shunt circuit contains a resistance box R, and a key K^1. The operation consists, first, in closing the key K a moment and reading the deflection of the galvanometer. Then a second reading is obtained by closing the keys K and K^1 in quick succession and in the order named.

The demonstration of the working formula depends on the principle that the deflection of the galvanometer is directly proportional to the maximum current in the primary. This is evident since the quantity of electricity which passes through the galvanometer is equal to MC over R^2 in which M stands for the co-efficient of mutual induction, C for the current in the primary, R^2 for the resistance in the secondary. To simplify the demonstration let R^1, the resistance in the shunt circuit, be an aliquot part of R, the resistance in the primary. Applying Ohm's law and the principle of the divided circuit we get the following proportion:

$$d : d^1 :: \frac{1}{r+R} : \frac{1}{(n+1)\,r+R}$$

Solving, $$r = \frac{R\,(d-d^1)}{(n+1)d^1-d}$$

In the above formula r stands for the internal resistance of the cell, R for the external resistance of the primary circuit, d and d^1 for the two different deflections of the galvanometer and n denotes what aliquot part the shunt resistance is of the primary resistance.

The method of the induction coil gives excellent results when used to obtain the polarization and recovery curves of a voltaic cell. In such a determination the primary circuit remains closed and the key is elevated at regular intervals to obtain the readings of the galvanometer.

To obtain the recovery curve the operation is reversed after changing the galvanometer connections with a commutator. The curves of an old Samson cell are represented in Figure 2.

In obtaining these curves the cell was placed on a closed circuit with an external resistance of 2.54 ohms including that of the primary coil. The maximum deflection obtained was 116 and represented a voltage of 1.07. The line a b is the polarization curve, and the line e d is the curve of recovery. It will be noticed from the diagram that the recovery of the cell was slight in the time considered, indicating that the depolarizer was exhausted.

The method also provides the data for the determination of M the coefficient of mutual induction of the coil from the equation MC over R^2=kd. In this equation k stands for the constant of the galvanometer and d for the deflection. Consult Jackson's Alternating Currents for this method. It is evident also, that, knowing the E. M. F. of any one cell, the method can be used to determine the voltage of any other with approximate accuracy. The method gives good results in determining voltages in cases where the internal resistance is low or negligeble compared to the external resistance of the primary circuit.

The advantages of the use of the induction coil in such work as has been suggested are as follows:

First. The induction coil is inexpensive compared with the cost of a standard condenser.

Second. The range of adjustment is far greater than that of the best subdivided condenser. The resistance in the primary circuit can be adjusted to secure any convenient deflection of the galvanometer.

Third. The deflections of the galvanometer are practically unvaried. The differences in the successive readings are very small. With a condenser the readings may vary considerably, particularly when the instrument is not of the best make. Some condensers seem to have a "soaking in" property which results in a variable charge, if the time of depressing and elevating the key during charge and discharge is not constant.