Bridge for Measuring Small Time Intervals

By J. HERMAN

SYNOPSIS: A bridge circuit for measuring time intervals from about one ten-thousandths of a second up to several seconds is described and its operation explained. The device is fairly accurate and easy to operate and gives the results of measurements in fractions of a second directly. Its calibration can readily be determined mathematically since it is dependent only upon the values of certain capacities and resistances used in the measuring circuit.

TO the large family of measuring devices making use of certain principles of electrical balance there has recently been added a new member. This measures the elapsed time between the opening or closing of one set of contacts, and the subsequent opening or closing of another set of contacts, the agency employed for operating the contacts being immaterial. The particular form of the device described below, was designed primarily for use in adjusting the operating and releasing times of the voice-operated switching relays at the terminals of the transatlantic radio telephone circuit. In this form or with minor changes, it is applicable to the measurement of intervals of time in the operation of a large variety of other types of apparatus.

The new time measuring device is simple and easy to operate, its operation consisting merely of opening and closing a key repeatedly and securing a balance by observing a meter. The balance is secured by turning one or more dials which are calibrated in fractions of a second.

A range of measurements extending from about one ten-thousandths of a second up to several seconds is readily obtainable and an accuracy of measurement to within ± 1 per cent can probably be realized over the greater part of this range if sufficient care is taken in the design of the circuit and the selection of the apparatus. In a fairly rugged type of bridge, now in commercial service (See Figs. 3 and 4), which covers the range from one ten-thousandth of a second to one second, and in which little attempt was made to secure a high degree of sensitivity, the results of measurements are accurate to within ± 5 per cent for time intervals down to about five thousandths of a second. For time intervals below this value the accuracy decreases rapidly, due partly to the fact that the smallest step provided for on the dials is one ten-thousandth of a second and partly due to the effect of variations in the operating time of the relays used in the bridge.

Because of its simplicity and accuracy, the bridge is especially valuable for making a series of time measurements to determine the best adjustment and the most desirable circuit condition for the operation of a relay or similar device. With the bridge, this requires very little time, especially since the results of the individual measurements are immediately available to guide the work. With the oscillograph, several hours may be required and the results obtained are available only after developing and analyzing the oscillograms.

The calibration of the bridge is determined by the values of certain capacities and resistances in the measuring circuit. These may usually be selected with sufficient accuracy during manufacture so that the bridge requires no further calibration after it has been constructed. In fact, it has been found practicable to design the bridge so that the steps on a standard decade resistance box correspond to decimal fractions of a second.

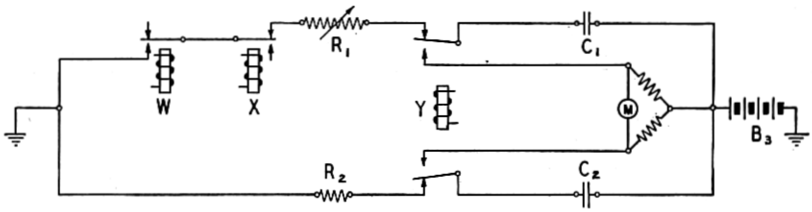

Fig. 1

The principles underlying the measurement of an interval of time will be explained in connection with Fig. 1. Two condensers C_1 and C_2 of unequal capacity are charged from a common battery B_3. The condenser C_1, which has a larger capacity than C_2, is charged through an adjustable high resistance R_1 during the time elapsing between the operation of relay W and the subsequent operation of relay X. This elapsed time is the interval of time to be measured and the charge accumulated on the condenser is an accurate means for doing so. The second condenser C_2 is used merely for comparison purposes. It is charged through a fairly low resistance R_2 and acquires its full charge in a relatively small interval of time.

After the completion of the charging interval, relay Y is operated and the two condensers are discharged simultaneously through a differential meter circuit. If the two charges are equal, the meter will show no deflection, but if they are unequal, it will show a momentary deflection, the direction of which will indicate whether the charge on C_1 is too high or too low. By repeating the charging and discharging process a few times and adjusting the value of resistance R_1 in series with the first condenser, the charges on the two condensers can be made equal. When this condition is obtained, the interval of time during which the charging took place may be determined from the value of the high resistance.

The relationship between the interval of time of charging and the value of resistance required to make the charges on the two condensers equal is a direct proportion. This will be obvious from an inspection of the general equation for the charge at any instant on a condenser which is being charged through a high resistance. The equation is

$$q = Q(1 - e^{-(t/CR)}), \tag{1}$$

where

q = charge at time, t,

t = elapsed time in seconds since the charging began,

Q = final or maximum charge on the condenser,

C = capacity of condenser in farads,

R = resistance in ohms in series with the condenser,

e = base of Naperian logarithms.

Since q is always made equal to the charge on the comparison condenser and since the charging battery is common to the two condensers, therefore, using the symbols shown in Fig. 1, C_2E may be substituted for q and C_1E for Q. The equation then becomes

$$C_2 = C_1(1 - e^{-(t/C_1R_1)}). \tag{2}$$

As mentioned above, the two condenser capacities are kept constant. Therefore, any change in t requires a proportional change in R_1 in order to satisfy the equation.

Fig. 2 is a schematic circuit diagram of the complete time measuring bridge showing the manner in which it may be connected to a representative type of circuit to be tested (shown by dotted lines). The symbols used to designate the various circuit elements in this figure are the same as those used in Fig. 1 and since the principles of operation have already been explained in connection with the latter figure, a comparison of the two figures will aid materially in understanding the detailed circuit arrangements of the bridge.

As shown in Fig. 2 the bridge is arranged to measure the operating time of a voice operated switching device consisting of a detector and a relay Z in the output circuit of the detector. The input circuit of the detector is connected to the output circuit of an oscillator and may be opened or closed by contacts on one of the bridge relays (relay W). This relay is under the control of key K which, when closed, causes relay W to operate and complete the oscillator connections to the detector thereby initiating the operation of relay Z. At the same time, another set of contacts of relay W close the charging circuit of condenser C_1 thereby permitting the charging of this condenser through the high resistance R_1. These conditions remain unchanged until the armature of relay Z has reached its m contact and caused the operation

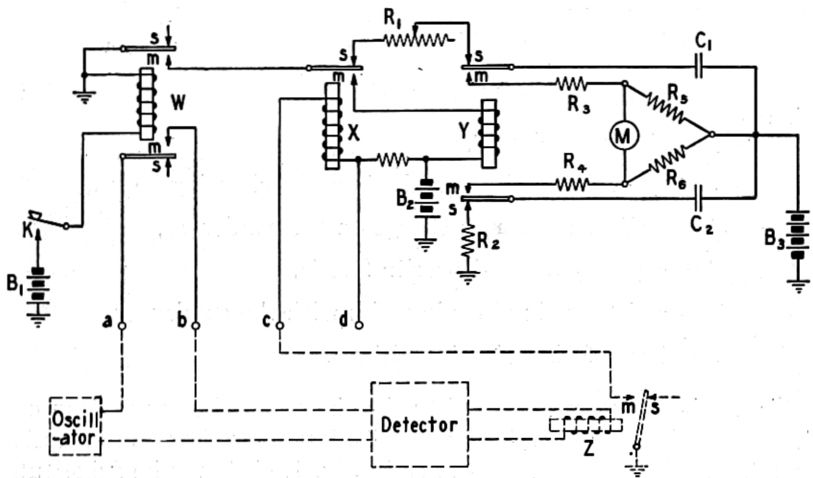

FIG. 2

of relay X. The latter relay first opens the charging circuit of condenser C_1 and then causes the operation of relay Y. The operation of relay Y discharges the two condensers C_1 and C_2 through the differential meter circuit composed of the meter M and the two equal resistances R_5 and R_6. Additional resistances R_3 and R_4 are connected into the discharge circuit to limit the discharge current and prevent sparking at the relay contacts.

If the meter shows no deflection at the instant of discharge, it indicates that the two charges are equal and that the operating time of relay Z is as indicated by the value of resistance R_1. If the meter shows a deflection, the key K should be opened and closed repeatedly and the resistance R_1 adjusted until the meter shows no deflection.

In order to prevent a quick double deflection of the meter when a balance has been reached, it is necessary that the time constant of the two branches of the discharge circuit be approximately alike. For this reason, the ratio $R_4 + R_6$ to $R_3 + R_5$ of the discharge circuit resistances should be approximately the same as the ratio C_1 to C_2 of the condenser capacities.

The releasing time of relay Z; that is, the time required for the armature to leave its m contact after the oscillator is removed from the detector, may be measured by making a few simple changes in the connections. The oscillator is connected directly to the input of the detector and the terminals *a* and *b* of the bridge are connected across the oscillator output. Contact *m* of relay *Z* is connected to terminal *d*, and terminal *c* is grounded. The closing of key *K* will then cause a short circuit to be placed across the output of the oscillator, thereby initiating the releasing of relay *Z*. As soon as the latter occurs, a short circuit is removed from the winding of relay *X*, allowing this relay to

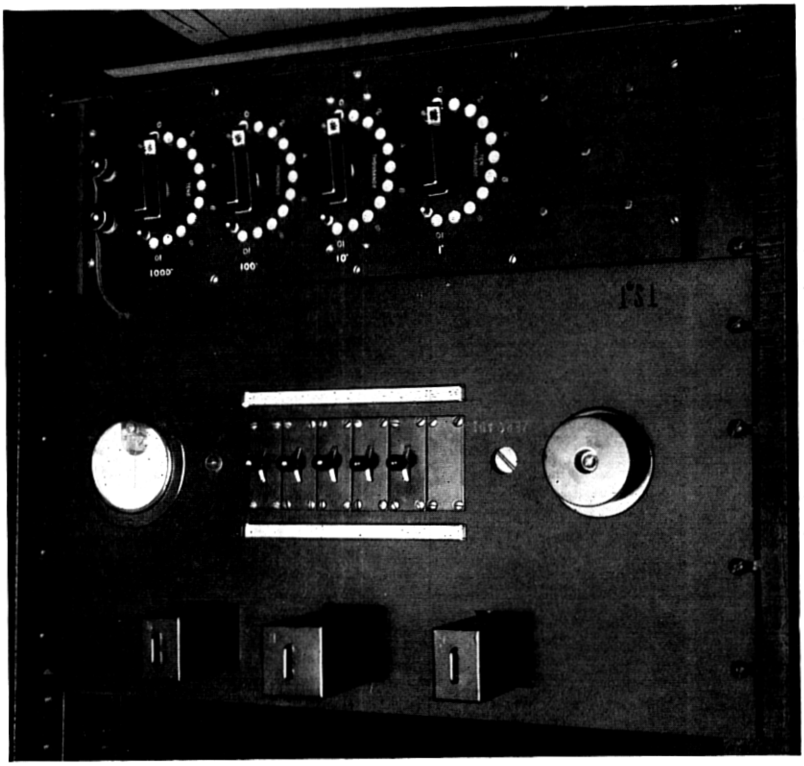

FIG. 3

operate and open the charging circuit of the condenser C_1. Except for the differences noted, the operation of the bridge is the same as described above.

Other conditions of measurement, for example, a measurement of the time required for the armature of relay *Z* to reach its *s* contact after a short circuit is applied to the output of the oscillator will be obvious from the two examples given. It should also be obvious that a battery and suitable resistances may be substituted for the oscillator and detector and measurements made in this direct-current circuit in the same manner as above.

Assuming that the bridge has been properly calibrated from theoretical considerations of the constants of the measuring circuit, there are two possible sources of error in the results obtained. These errors are due to the time of operation of the two switching relays *W* and *X*. In the case of relay *W* an error will be caused if its two sets of contacts do not close simultaneously. In the case of relay *X* the source of

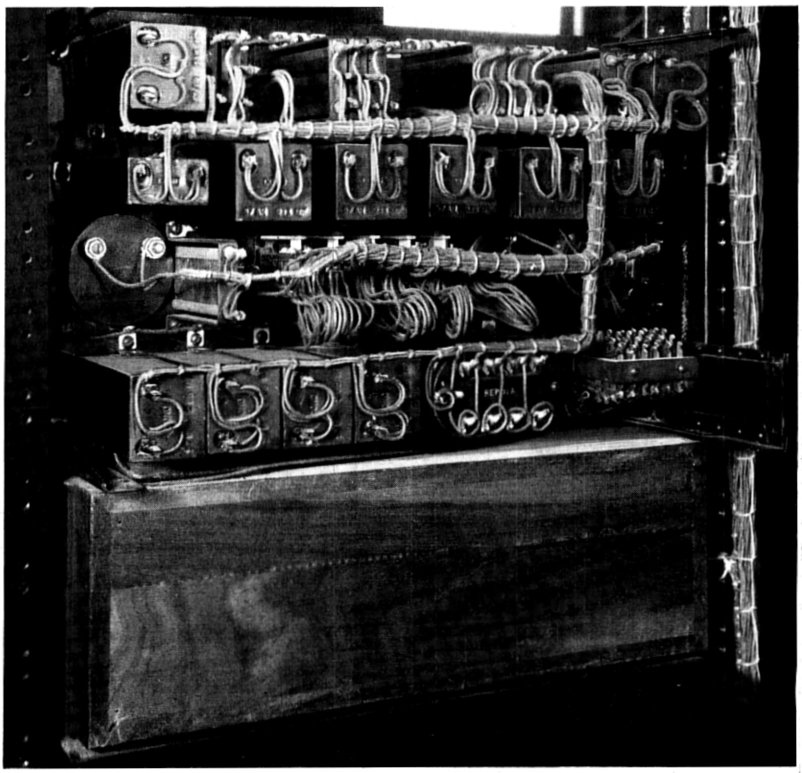

FIG. 4

error is due to the time required for the relay to open the charging circuit at its *s* contact at the end of the operating or releasing time which is being measured. The combined error due to the operation of the two relays may actually be determined by means of the bridge itself and substracted from the results of the measurements. To determine the error, terminal *a* is connected to ground and terminal *b* to terminal *c*. The key *K* is then operated in the normal manner and a balance secured on the meter. The readings of the dials will then indicate the error of the bridge.

In order to avoid the necessity of correcting the measurements for the error in the bridge, a value of resistance corresponding to the error may be connected permanently in series with R_1. This should be made variable if a high degree of accuracy is desired, because the operating time of the two relays in the bridge may change slightly from day to day and small readjustments of the resistance will, therefore, be necessary.

The sensitivity of the bridge, that is, the ease with which small intervals of time can be distinguished by the deflection of the meter, is dependent upon the sensitivity of the meter, the voltage of the common charging battery, the value of capacity, and the ratio of the capacity of the large condenser to that of the small condenser. With a particular type of meter, the larger the voltage, the condenser capacities, and ratio of condenser capacities, the more sensitive will be the bridge.

Although the chief use for the bridge up to the present time has been in connection with voice operated relay devices, its future use will undoubtedly be extended to other fields. Some indication of the uses to which it might be put may be obtained from the following suggested applications.

1. For measuring the functioning times of electromagnetic switching arrangements in various kinds of communication and signaling systems.
2. For measuring propagation time at different frequencies over telephone circuits and "lag" in telegraph instruments and circuits.
3. For studying the operation of a machine with a view to improving it by measuring the speed of operation of various parts and the relative time of operation of certain parts with respect to other parts. Electrical contacts would have to be provided temporarily at suitable places on the machine.
4. For maintaining the proper adjustment of time-limit over-load relays, circuit breakers, etc., on power circuits.
5. To determine the rate of acceleration of motors or other machinery by employing a suitable centrifugal contact arrangement.
6. In psychological tests for determining whether the time of response of a person to a particular signal is above or below a required value.

Numerous other applications to laboratory and field work might be suggested where such a time measuring device could be employed to considerable advantage. The cases mentioned above are not necessarily the most practical but they serve to illustrate the capabilities of the device as described or when provided with simple modifications.

ERRATA: *Bell System Technical Journal*, April, 1928

Page 327, Table 2—Interchange the number "200" of column 6 and number "600" in column 8.

Page 328, beginning line 4, should read—(*a*) Phantom to phantom; 1 represents the two wires, connected in parallel, of one pair of a quad. 2 represents the two wires in parallel of the other pair of the quad, and 3 and 4 represent similarly the pairs of another quad.

Page 347—Figure 3 should be inverted.