THE General Radio EXPERIMENTER

VOLUME XIV NO. 1 JUNE, 1939

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A 500-VOLT MEGOHM BRIDGE

● **THE TYPE 544-B MEGOHM BRIDGE** with a 90-volt power supply operated either from the 60-cycle supply or from batteries was introduced less than two years ago* and has been widely used for the measurement of insulation resistance. This bridge uses a vacuum-tube voltmeter as a detector of balance, which permits the measurement of resistances much higher than the limit of a few megohms imposed by the low resistance of a wall galvanometer. While the bridge is designed so that 500 volts may be applied to it, this higher voltage has seldom been used because of the bulkiness of the necessary batteries. The TYPE 544-P3 500-volt Power Supply now available allows the full possibilities of the bridge to be realized.

VOLTAGE COEFFICIENT OF RESISTANCE

The need for the higher voltage on the bridge comes not from a lack of sensitivity, but from the fact that insulation resistance has a

FIGURE 1. The TYPE 544-B Megohm Bridge with cover removed to show the TYPE 544-P3 Power Supply.

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*General Radio *Experimenter*, July, 1937.

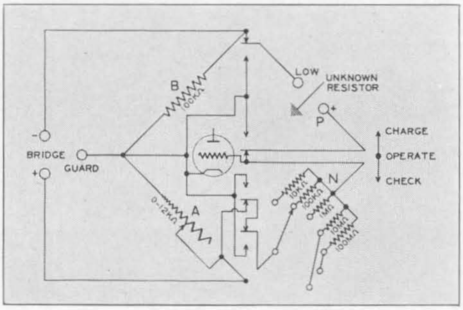

FIGURE 2. Schematic circuit diagram of the TYPE 544-B Megohm Bridge.

huge voltage coefficient. It is not at all unusual for this resistance to decrease by a factor of two or even three when the voltage is increased from 100 to 500 volts. The magnitude of this change in resistance varies with the type of insulation and also with temperature, humidity, and time. No single multiplying factor exists by which resistance at one voltage can be converted to resistance at some other voltage. It is, therefore, desirable that all insulation resistance measurements be made at the same voltage to facilitate the intercomparison of results. A value of 500 volts has been widely adopted as standard.

DIELECTRIC ABSORPTION

It has long been recognized that the apparent insulation resistance of an electric machine or cable rapidly increases after the application of voltage. In spite of this fact it became standard practice to take the value of resistance at the end of one minute and to disregard the further increase. While this method is reasonably satisfactory for the poorer types of insulation, it fails entirely for the better grades, particularly those that are laminated, like the pasted mica used in high-voltage generators. The time needed to attain equilibrium is measured in hours and even days.

This phenomenon has been referred to as dielectric absorption or volume charge. An extra charge of electricity, other than that associated with the normal capacitance of the insulation, appears to be stored throughout the volume of the material. This is now better described as interfacial polarization.* A building up of charge occurs at every interface between the different materials of a heterogeneous insulation. While the effect is most pronounced in a laminar structure, it also occurs in materials whose component parts are finely divided and thoroughly mixed. The smallest particles are still molecular aggregates which present interfaces to each other. The total charge stored throughout the volume of the dielectric may be many times that of the con-

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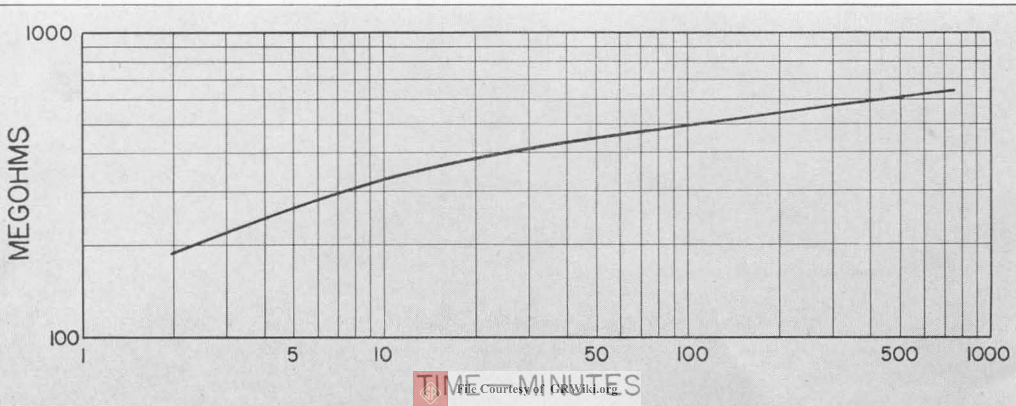
*Murphy & Morgan, "The Dielectric Properties of Insulating Materials," *Bell System Technical Journal*, October, 1937.

FIGURE 3. Plot of insulation resistance vs. time for a 23,750 kva generator.



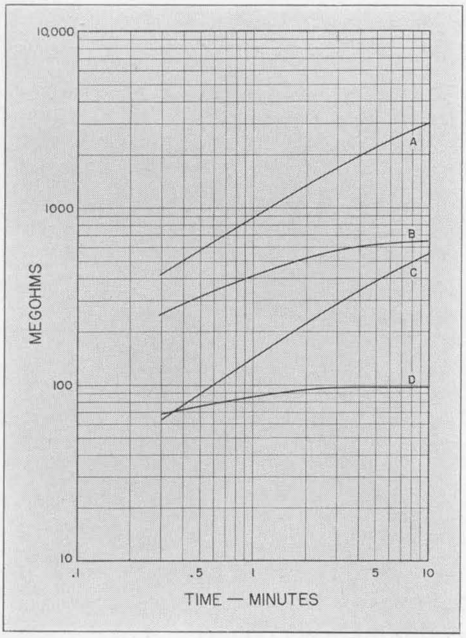


FIGURE 4. Plots of insulation resistance for four generators having the same type of insulation, but differing in voltage, age, and physical condition.

denser formed by the external electrodes, and the larger part of this charge can be recovered on discharge.

Under these conditions the apparent resistance for one minute electrification bears no relation to true insulation resistance, but merely measures the current due to volume charge at that instant. The value of the true insulation resistance can be estimated by observing the resistance at increasing time intervals and plotting the observed data. The slope of the resistance-time plot at some convenient time interval is also of considerable significance.†

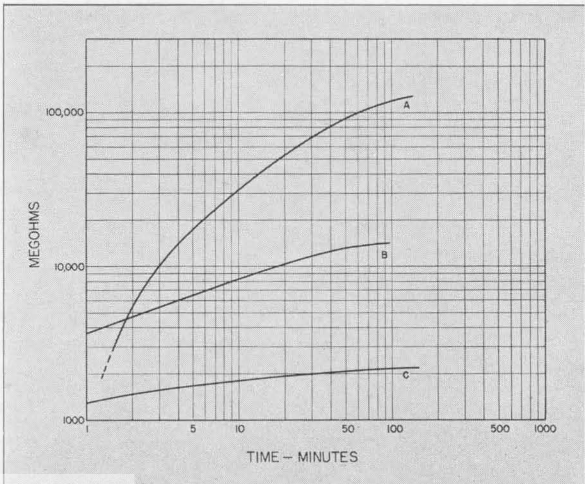
INSULATION RESISTANCE OF ELECTRICAL MACHINES

A plot showing the way the apparent insulation resistance of a 23,750 kva generator varies with time is shown in Figure 3. A reasonable estimate of its true insulation resistance is 900 MΩ, while the one-minute reading is only 140 MΩ. Similar curves for a group of generators varying widely in age and power rating are given in Figure 4. Although the insulation is the same for all of these machines, its physical condition and moisture content at the time of measurement differed widely. The slopes of these curves at the end of one minute are probably equal in importance to the actual values of resistance at that time.

Transformer insulation also has considerable dielectric absorption. The curve for a 5-kw, 6900-volt transformer is shown in Figure 5-B.

Curves *A* and *C* in Figure 5 are for two rubber-insulated cables. These curves illustrate the difference that can occur in cables designed for different applications. Apparently the corona-resistant design of the cable of curve *C* results in a lower insulation resistance and a correspondingly lower dielectric absorption. In spite of the large difference in insulation resistance for these two cables, the one-minute readings are very nearly equal.

FIGURE 5. Plots of insulation resistance for a transformer and two cables. *A* is a 1500-foot, 600-volt, rubber-insulated cable. *B* is a 5 kw, 6900–volt transformer. *C* is a 7-kilovolt, rubber insulated cable, 1040 feet long. This cable is designed to be ozone-resistant.



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†R. W. Wiesman, "Insulation Resistance of Armature Windings," *Electrical Engineering*, June, 1934.

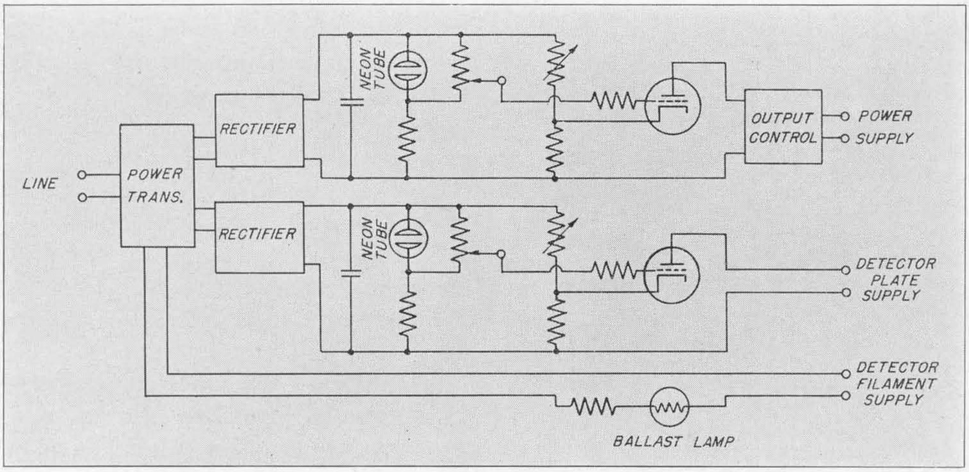

FIGURE 6. Schematic circuit diagram of the TYPE 544-P3 Power Supply.

RESISTANCE RANGE

Resistance measurements with the TYPE 544-B Megohm Bridge can be carried up to 10,000 MΩ with no loss in sensitivity of setting. Over the next decade to 100,000 MΩ the scale reading is crowded, while a resistance of 1,000,000 MΩ can just be distinguished from an infinite resistance.

500-VOLT POWER SUPPLY

The most important requirement of an a-c power supply for a megohm bridge is that it maintain a constant d-c voltage output in the face of the small rapid fluctuations which occur in any line voltage. While the balance of a d-c bridge is independent of applied voltage if the unknown resistance is non-reactive, the existence of a parallel capacitance immediately makes apparent the changes in bridge voltage because of the resulting changes in charging current. The resulting kicks in the galvanometer deflection are larger the greater the parallel capacitance and the insulation resistance.

Both the power supply to the bridge and to the detector tube are stabilized by series triodes whose varying grid bias is referred to a constant voltage obtained from a small neon tube. A diagrammatic representation of the circuits is shown in Figure 6. The filament supply of the detector tube is also stabilized by an iron-wire-type ballast tube. Means are provided on the small panel at the top of the power supply for obtaining either 100 v or 500 v for the bridge. Any intermediate voltage values can be obtained by adjustment of one of the resistors mounted on this panel.

— ROBERT F. FIELD

Specifications for the TYPE 544-B Megohm Bridge and TYPE 544-P3 Power Supply are given on the next page. For the convenience of users of the megohm bridge who may wish to replace existing 90-volt power supplies with the 500-volt unit, the TYPE 544-P3 Power Supply is also listed separately.

SPECIFICATIONS

Range: 0.1 megohm to 10,000 megohms, covered by a dial and a 5-position multiplier switch. A resistance of 1,000,000 megohms can be detected.

Accuracy:

Resistance	*Error*
.1 MΩ– 100 MΩ	± 3%
100 MΩ– 1000 MΩ	± 6%
1000 MΩ–10,000 MΩ	±10%

Above 10,000 megohms, the error is essentially that with which the scale on the MEGOHMS dial can be read.

Terminals: The terminals for connecting the unknown resistor include connections for guard electrodes so that either two- or three-terminal resistors can be measured.

Controls: Megohms dial, with multiplier; zero adjustment; CHECK-OPERATE-CHARGE switch; power ON-OFF switch.

Power Supply: The TYPE 544-P3 a-c power supply unit operates from a 105- to 125-volt, 40- to 60-cycle a-c line, and supplies either 500 volts or 100 volts to the bridge.

Operating Voltage: Terminals are provided so that the bridge voltage can be obtained from an external source if desired. Up to 500 volts can be applied.

Vacuum Tubes: The TYPE 544-P3 Power Supply uses a 6K7G detector, a 6X5G rectifier, a 5U4G rectifier, and, in the voltage regulators, a 6J5G, a 6K6G, and two CD-2005 neon lamps. All tubes are supplied.

Mounting: Shielded oak cabinet.

Dimensions: Cabinet with cover closed, (width) 8½ x (length) 22½ x (height) 8 inches, over-all.

Net Weight: With battery power supply, 30¼ pounds; with a-c power supply, 25¼ pounds.

Type	*Description*	*Code Word*	*Price*
544-B	A-C Operated (500 volts)	AGREE	$235.00
544-P3	500-volt Power Supply Only	AGREEAPACK	75.00

PROPERTIES OF SOLID INSULATING MATERIALS

• ON THE FOLLOWING TWO PAGES is presented a table of the mechanical and electrical properties of some of the more common insulating materials. The mechanical properties given are those which enable the user to determine the suitability of a material for a given application. The electrical properties listed are those which are most important at the frequencies used in electrical communication, namely dielectric constant and power factor.

Many of the plastics listed are manufactured under a variety of trade names. Different products of the same general type will often differ widely in some characteristics, such as tensile strength, softening point, etc. For these materials, an attempt has been made to list representative values, or, wherever possible, a range of values.

These data have been compiled at General Radio over a period of several years. They are taken from a number of sources, including scientific publications, handbooks and manufacturers' literature. In spite of this, there are a number of blank spaces in the table, and there are undoubtedly some inaccuracies. We hope that *Experimenter* readers who have more recent data than are shown here will send us additions and corrections which will enable us to complete the table.