THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

A PORTABLE MEGOHMMETER

● IN THE FOUR YEARS since the TYPE 487-A Megohmmeter was introduced, its use has spread to many different fields of application. This instrument, giving readings up to 50,000 megohms, was the first to extend the operating range of the ordinary direct-indicating ohmmeter to really high resistances. Since this instrument was introduced, many requests have been received for a similar meter not requiring a-c power for its operation and consequently better adapted to field use. The TYPE 729-A Megohmmeter is a new battery-operated design particularly intended for applications where portability is required.

An extremely compact arrangement has been worked out so that, even with cover and batteries, the volume and weight are both less than for the a-c operated TYPE 487-A instrument. Design improvements, including the sealing in vacuum of the highest-value resistance standard, insure that accurate indications will be obtained regardless

FIGURE 1. View of the TYPE 729-A Megohmmeter showing the compact portable construction. The cover, shown folded back, is removable.

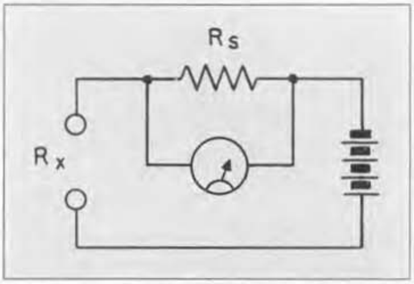


FIGURE 2. Simplified schematic of modified ohmmeter circuit, using a vacuum-tube voltmeter as the indicating element.

of adverse humidity conditions, which are particularly likely to be encountered in field use of the instrument.

The circuit employed both in the TYPE 729-A Megohmmeter and in the earlier TYPE 487-A instrument is the same as that of the ordinary ohmmeter used for testing relatively low-resistance circuits, except that a vacuum-tube voltmeter, having extremely high input resistance, replaces the simple d-c milliammeter of the latter.

In the simplified schematic shown in Figure 1, the battery voltage divides between the unknown resistance R_x and the standard resistance R_s depending on their relative values, and the reading of the voltmeter across the standard can be calibrated directly in the unknown resistance. Accuracy of the reading depends on the total circuit resistance, exclusive of the unknown, being constant in value. The contributions both of the voltage source and of the voltmeter to the total circuit resistance must either be negligible or sufficiently constant so that they can be included as part of the standard resistance determining the calibration. Variations in battery resistance affect the accuracy of the low-resistance ranges, and the grid-circuit conductance of the vacuum-tube voltmeter, on the other hand, affects only the very highest resistance measurements.

In the new TYPE 729-A Megohmmeter, the low grid-circuit conductance of the TYPE 487-A instrument has been retained, and the high-resistance limit is the same as for the latter, but with increased stability resulting from the new sealed-in-glass, high-resistance standard. An important feature of the new instrument is a tenfold extension of the range in the low-resistance direction. Five overlapping ranges are provided, so that at least a full division of deflection is obtained for resistances of all values between 2000 ohms and 50,000 megohms. The low-resistance ranges are a great convenience in testing for faults, as an indication of the nature of the trouble is afforded by the actual resistance reading in the defective part of the circuit. The improved performance results from a circuit modification in which the battery is placed directly in the measuring loop without any controlling resistances. The low-resistance limit at which readings can be made satisfactorily is thus determined by the internal resistance of the battery itself, which must not become comparable to the value of the standard resistance throughout normal battery life. Shift of the meter zero beyond a specified limit in switching to the low-resistance range warns the user that batteries must be replaced to avoid error from this cause.

The very wide range of resistances which can be measured makes the TYPE

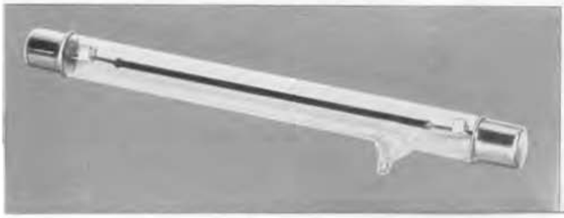


FIGURE 3. The new sealed-in-glass 1000-megohm standard resistance. In actual use the unit is coated to prevent surface leakage.

729-A Megohmmeter particularly suitable for determinations of moisture content of various materials by the electrical conductivity method. In testing lumber for moisture content, for example, using the standard pin electrodes recommended by the Forest Products Laboratory of the U. S. Department of Agriculture, a range of resistances from 460,000 ohms to 22,400 megohms must be covered to determine moisture percentages between 7 per cent and 25 per cent in Douglas fir. A similar relationship appears to hold generally between the electrical resistance and the moisture content of other semiconducting materials such as paper, moist powdered chemicals, shoe leather, etc. With such materials the range of moisture content normally encountered corresponds to a relatively enormous variation in the electrical resistance. In the TYPE 729-A Megohmmeter, however, the resistance range which is covered, over twenty million to one, is more than sufficient for such applications.

As with the TYPE 487-A Megohmmeter, a limitation of the circuit employed is that the standard resistance is of the same order of magnitude as the unknown being measured. This is a handicap when large-value paper condensers having low leakage are tested, as the time constant of the circuit results in equilibrium being reached very slowly. For example, a condenser of 1 μf capacitance, having a leakage resistance of 1000 megohms, could be shown in a few seconds to have a resistance greater than 500 megohms, but perhaps a minute would be required to obtain the resistance within 10 per cent.

Errors in the resistance standards and errors from grid current in the vacuum-tube voltmeter, which have been referred to, both affect measurements in the high-resistance ranges of the instrument. Except for errors in the mechanical system and calibration of the meter itself, amounting to a maximum of about one per cent at center-scale reading, these are the only appreciable sources of error. The vacuum-tube voltmeter is made linear in its calibration, independently of the tube characteristics, by cathode-circuit degeneration, which has proved so advantageous in the TYPE 726-A Vacuum-Tube Voltmeter as well as in the TYPE 487-A Megohmmeter. The actual deflection of the voltmeter circuit, also, is stabilized by this connection, but this is unimportant as the sensitivity is adjusted when the zero is set each time the instrument is used. Actually, as the battery voltage drops during normal life the sensitivity of the voltmeter is increased, in the process of setting the zero, so that the correct resistance readings are obtained throughout the life of the batteries. Inability to set the zero indicates that the batteries need to be replaced.

—W. N. TUTTLE

FIGURE 4. View of the meter scale. Except at the low end of the lowest range and at the high end of the highest range, only the center decade of the scale needs to be used.

SPECIFICATIONS

Range: 2000 ohms to 50,000 megohms in five overlapping ranges.

Scale: The standard direct-reading ohmmeter calibration is used: center scale values are .01, .1, 1, 10, 100, and 1000 megohms. Length of scale, 3¼"; central decade, 1⅝".

Accuracy: Within 2 per cent of the indicated value over the 30,000-ohm to 300,000-ohm range and within 5 per cent over the 300,000-ohm to 3000-megohm range when using the central decade for each multiplier. Outside the central decade, the accuracy is decreased because of the compressed scale.

Voltage on Unknown: The voltage applied on the unknown does not exceed 22½ volts and varies with the meter indication.

Tube: The tube, a type 1E5-GP, is supplied.

Batteries: The batteries required are two Burgess W30BP or equivalent and one Burgess 2F2H or equivalent. A compartment is provided in the case of the instrument for holding all batteries. A set of batteries is supplied with the instrument.

Mounting: The instrument is supplied in a walnut case with cover and is mounted on an engraved black crackle-finish aluminum panel.

Dimensions: With cover closed: (length) 11 x (width) 6⅝ x (height) 5⅞ inches, over-all.

Net Weight: 8¾ pounds, including batteries.

Type	*Description*	*Code Word*	*Price*
729-A	Megohmmeter...........	PIOUS	$85.00

THE STROBOSCOPE IN STRUCTURAL RESEARCH

● **ENGINEERS** have grown gray over problems difficult of exact solution by mathematics. In structural mechanics, although the laws governing the behavior of structural members are completely known, the exact operating conditions seldom are, and, consequently, the solutions of structural problems are necessarily empirical.

Professor Philip Bucky of the School of Mines, Columbia University, has developed in his laboratory a method of solving some of these problems in mining, hydraulics, aerodynamics, and civil engineering by means of small scalar models.

This particular application of the theory of models has been made possible by stroboscopic methods of observation and measurement, and is one of

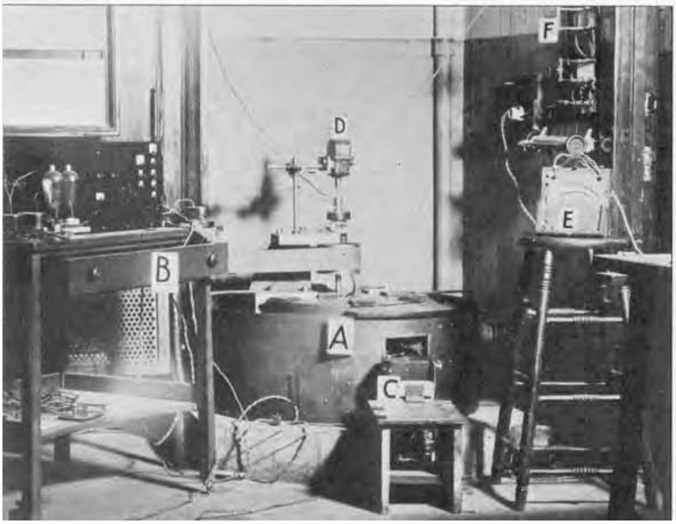


FIGURE 1. Photograph of the apparatus used for the centrifugal testing of models. The stroboscopic light source and power supply (B) was replaced, for later work with a General Radio TYPE 548-B Edgerton Stroboscope.

the most interesting uses of the electronic stroboscope which has come to our attention.

Professor Bucky has formulated the principle of similitude applying to the relation between a model and its prototype. He reduces an original structure of unwieldy proportions to a scalar model of more convenient size, and he artificially increases the pull of gravity on each particle in the same proportion as the linear dimensions have been decreased. This increased pull of gravity is simulated by spinning the model in a centrifuge and so substituting the centrifugal field for the gravitational field. When spun at such a speed that the centrifugal force is increased in the same ratio as the linear dimensions of the prototype have been decreased, the model behaves exactly like its prototype. Unit stresses at similar points in the model and prototype are the same, and the displacement or deflection of any point in the model represents to scale the displacement of a corresponding point in the prototype.

An early experiment was the testing of a model beam ten inches in span, one inch in depth, and two inches in width, which corresponded to an original beam one hundred times its size, or roughly, eighty-three feet in span, eight feet in depth, and sixteen feet in width. Spun in the centrifuge at a rate to obtain one hundred times the pull of gravity, observed with the stroboscope, and photographed by the camera, the model showed a deflection of one one-hundredth of an inch. This meant that the original two hundred and sixty-five ton beam, then, would sag one inch under its own weight.

The apparatus for centrifugal testing of models is illustrated in Figure 1. In the case (A) is mounted a rotating box. Models are placed in that box and observed through an observation port (C) where a mirror or camera is placed. Speed is measured by a generator (D) geared to the shaft, and can be read at (E), a voltmeter. The stroboscope on the table (B) furnishes a single light pulse each time the model comes to a selected position in front of the camera. The duration of the light pulse is so short (less than six millionths of a second) that the model does not have time to move and so to blur the picture. In stroboscopic light, accurate photographic records may be taken while the model rotates at any desired speed to give the required force upon the model.

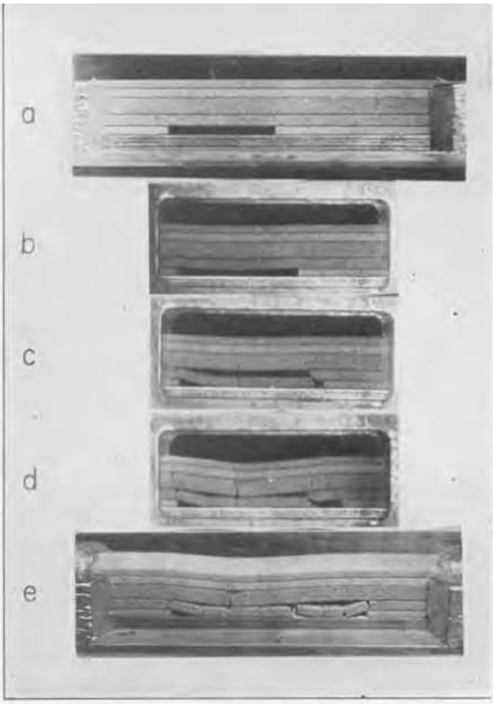


FIGURE 2. Photograph of successive stages of failure in a model face wall of a mine. The scale of the model is 1:480.

One of the present successful applications of this method is in the field of mining, where the engineer can determine with these models what length of face wall can be worked and how far

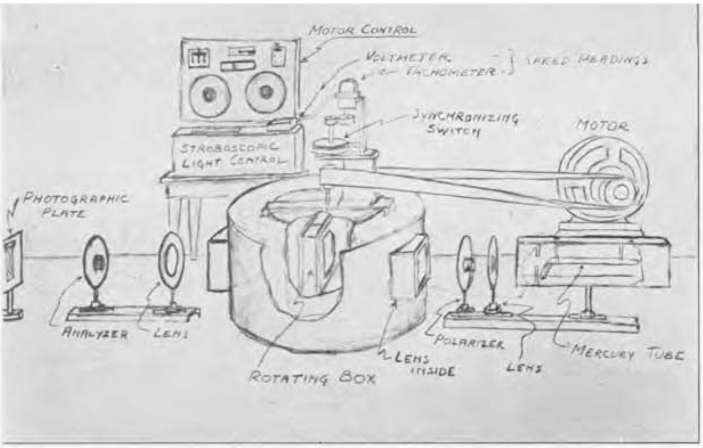


FIGURE 3. Sketch showing the arrangement of the combined centrifugal and photo-elastic apparatus.

the face wall may retreat before the structure caves in.

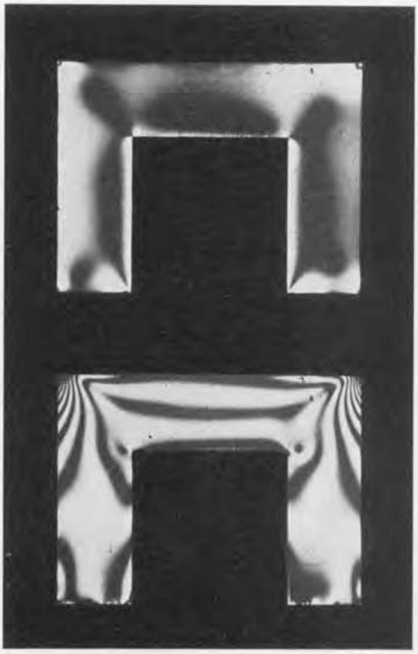
Figure 2 is a series of photographs illustrating experiments with a model face wall of a mine. The various strata of overweight and underweight are built to a scale of 1:480. In a beginning step (a) the model is shown outside of the centrifuge. While the model rotates in the centrifuge at a rate to produce a force 480 times that of gravity (b, c, and d), the roof is visibly caving. In (e), when the model has been removed from the centrifuge, the failure of the structure is plain. It is an interesting fact that the time scale, both in the model and in the field, is exactly the same.

The difficulty of determining the actual stress at any point in a structure has motivated a new development in the method. Professor Bucky is now using the photo-elastic technique to study the behavior of isotropic, transparent models in the centrifuge.

It has long been known that if a piece of transparent bakelite is stressed under static loading, and if that bakelite is then viewed by polarized light, the strain becomes visible as bands of colored light — yellow, green, and red, depending upon the intensity of the stress. In the photo-elastic set-up, a scalar model of transparent bakelite is placed in a centrifuge and the pattern and progress of its deflection under centrifugal force are photographed by means of the stroboscope.

Figure 3 shows the photo-elastic apparatus. Light from a tube source

FIGURE 4. Photographs of a bakelite model by polarized light. The upper photograph shows the model unstressed, while the lower shows the bands produced by static loading.



passes through a condensing lens and reaches the polarizer where the light is plane polarized. The light then passes through the inside lens and the stressed model in the centrifuge. The image of the model is focused by the lens through the analyzer and on to the screen.

Figure 4 (top) is a photograph of an unstressed model of bakelite. Below, static loading is shown clearly in the series of strain lines, or fringes, which can be counted and analyzed for engineering purposes.

The use of the centrifuge to simulate operating conditions, the stroboscope for observing displacements while the model is rotated at high speed, and the photo-elastic technique for analyzing the results have made possible accurate predictions of the performance of mechanical structures. The future of this method of analysis in applied mechanics seems assured.

The work being carried on is a research project of The Engineering Foundation and of Columbia University.

—F. Ireland

USING THE VARIAC WITH AUXILIARY TRANSFORMERS

● AMONG THE MANY AND VARIED LABORATORY USES of the Variac there are the occasional ones where currents or voltages exceeding the Variac rating must be obtained. When high currents are to be obtained at low voltages, or high voltages with low currents, an auxiliary transformer can be used, as indicated in Figure 1. An arrangement similar to that of Figure 1(a) is available commercially as the Type 90-B Variac.*

The 230-volt models of the Variac have a center tap, 6,† which is not furnished on the 115-volt model. In Figure 2 a 115-volt line is connected to the center tap and terminal 1, and the output is taken from terminal 1 and the brush. The Variac then acts as a 2–1 step-up transformer whose output is continuously variable from 0-230 volts. The current which can safely be drawn at the highest voltage is ½ rated current in this case.

When it is necessary to draw full rated current from a 230-volt Variac and when only a 115-volt line is available, the connections of Figure 3(a) may be used. Here an auxiliary step-up autotransformer is used so that the actual input to the Variac is equal to its rated voltage. In this case maximum current

Fig. 1a

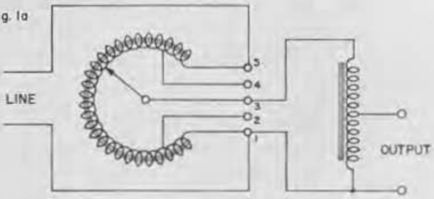


Fig. 1b

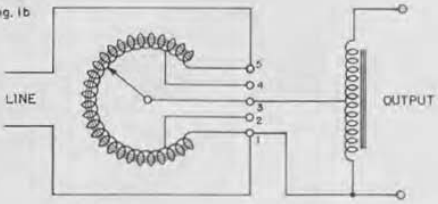
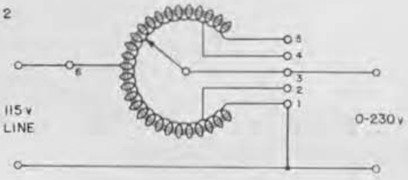


Fig. 2



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*"A Variac with Low-Voltage Output," General Radio *Experimenter*, Volume XIV, No. 2, July, 1939.

†Terminal numbers in this article are those used on Type 50 Variac. Other types are numbered differently.

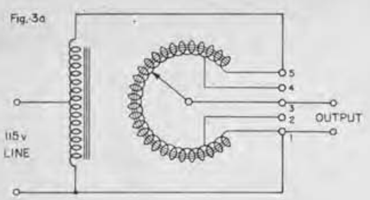

Fig. 3a

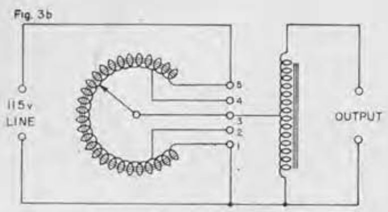

Fig. 3b

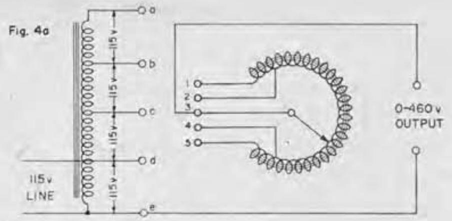

Fig. 4a

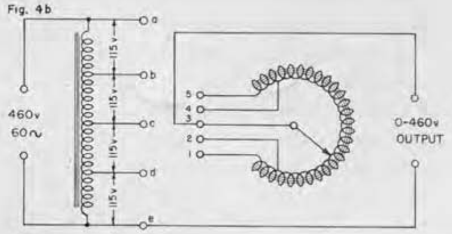

Fig. 4b

may be drawn at maximum output voltage.

Figure 3(b) is an obvious variation of the method of Figure 3(a). The auxiliary step-up transformer is used on the output instead of the input side of the Variac. This system is particularly useful when the output voltage is too high to be handled directly by a standard Variac. In this case, the output power available for a resistive load will be the volt-ampere rating of the Variac multiplied by the efficiency of the auxiliary transformer.

With the circuits shown in Figure 4, it is possible to draw rated current from the Variac at voltages considerably above the rated output voltage. An auxiliary step-up transformer is used to give the maximum voltage desired. The secondary is tapped to give voltages, between adjacent taps, not greater than the rated voltage of the Variac.

By means of suitable switching of the Variac from tap to tap, the output voltage can be varied from zero to maximum without interruption of the circuit. With terminal 1 connected to tap *e* and terminal 5 connected to tap *d*, rotation of the brush of the Variac increases the output voltage from 0 to 115 volts. Terminal 1 is then switched to tap *c* and the brush rotated in the opposite direction, raising the output from 115 to 230 volts. Terminal 5 is next switched to tap *b* and the brush rotated to vary the output from 230 to 345 volts. Finally, switching terminal 1 to tap *a* permits the output to be raised from 345 to 460 volts. When the output voltage is high, it is advisable to insulate the Variac from ground in order to eliminate the danger of voltage breakdown.

The auxiliary step-up and step-down transformers are shown in the diagrams as autotransformers. Inductively coupled transformers can, of course, also be used.

— S. A. Buckingham

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