THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A SAMPLE HOLDER FOR SOLID DIELECTRIC MATERIALS

Also IN THIS ISSUE

● **A KNOWLEDGE** of the dielectric properties of insulating materials is important not only to the designer who utilizes such materials for insulation structures but also to the physicist and chemist who is concerned with the internal structure of the material. From either point of view, it is important to be able to make measurements over a wide range of frequencies. If the material is to be used as insulation, it is obviously desirable to obtain data at the frequency of use, while, if the fundamental structure of the material is of interest, the variations of dielectric constant and loss factor with frequency are clues to the chemical structure.

In the accepted method of evaluating the dielectric constant and dissipation factor, a capacitor is formed by placing the material between metallic electrodes. If the configuration of the electrodes is such that the distribution of the electric field is accurately known, the

Under the recent Order M-71 of the National Production Authority, assistance is provided to technical and scientific laboratories for the procurement of needed supplies and materials.

In accordance with the order, a laboratory may apply a new rating, DO-X1, to obtain delivery of products and materials needed to carry on scientific or technological investigations, testing or development or experimentation, provided that the total amount expended does not exceed $3,000 during any one quarter.

No further authorization is needed from the National Production Authority to use this rating, but all prospective users should consult the NPA Order M-71, which may be obtained from the nearest field office of the Department of Commerce, before applying the rating, as its use is necessarily restricted.

The order also provides a means for laboratories to obtain certain amounts of controlled materials under the Controlled Materials Plan.

constants of the material can be determined from the electrical measurements. Among structures readily calculable are parallel plates and concentric cylinders. At power, audio, and radio frequencies to 100 megacycles and more, parallel plates are used whenever possible because of the relative ease of preparing a specimen. In a two-electrode plane system, a circular electrode is most widely used because the field configuration is symmetrical and most readily calculated.

At frequencies in the megacycle range, the inductance and resistance of leads connecting the electrode system to the measuring circuit can introduce error and must be considered. In a classical paper, Hartshorn and Ward* described a method of essentially eliminating lead impedance by combining the measuring capacitor and the electrode system and using a substitution method of measurement. This type of holder is generally recognized as the most satisfactory for measurements at radio frequencies. It is recognized in ASTM Specification D-150 for use in the frequency range from 0.1 Mc to 100 Mc.

*L. Hartshorn and H. Ward, *Proceedings*, I.E.E. (London), Vol. 79, pages 597 to 609.

Figure 1. View of the Type 1690-A Dielectric Sample Holder.

The Type 1690-A Dielectric Sample Holder, shown in Figure 1, is a micrometer-type holder of the Hartshorn type with several important refinements in design.

DESIGN DESCRIPTION

A cross-section view of the sample holder is shown in Figure 2. The main micrometer capacitor is formed by the two electrodes (*H*) and (*L*). The surfaces of these electrodes are optically ground to be plane within a few wavelengths. A precision-ground micrometer screw drives the movable grounded electrode with respect to the fixed insulated electrode. The screw adjustment is a convenient-size instrument-type knob, in contrast to the small thimble employed in the usual machinist's micrometer commonly employed for this purpose. The spacing of the electrodes is indicated by the large legible calibration on the drum as shown in Figure 1. The smallest division is one-half mil, with 1/10th mil easily readable. The micrometer screw is electrically shunted by a flexible copper bellows to assure low and constant resistance and inductance in the current path to the movable electrode. The lower electrode is supported in position by Vycor insulators which are well away from the field between the electrodes.

A unique feature of the design is the method of driving the movable electrode. A spring-loaded drive is used so arranged that, when the movable electrode comes into full contact with the specimen (or the bottom electrode), the drive disengages. Two important results are achieved by this design feature: (1) the movable electrode assumes the plane of the top surface of the specimen, thus assuring best possible contact even if the faces of the specimen are not rigorously parallel, and (2) straining of the micrometer screw is avoided since the drive disengages at a predetermined pressure.

A vernier capacitor with a capacitance range of 5 $\mu\mu$f is also provided, for use in determining the width of resonance curves in the susceptance variation method. This capacitor is of the cylindrical type, the movable cylinder being a precision micrometer screw. Ten turns of the screw cover the range of 5 $\mu\mu$f, and the drum attached to the screw is accurately divided into 50 divisions, each corresponding to 0.01 $\mu\mu$f.

Facilities for connecting to the electrodes and for mounting the holder are extremely flexible. Pin-type connectors on standard ¾″ spacing may be used, or completely shielded connections may be made with Type 874 Universal Coaxial Connectors. Terminal facilities and mounting bosses are provided both at bottom and side of the housing. This permits the holder to be mounted with the electrodes horizontal whether the panel of the bridge or other measuring circuit is horizontal or vertical.

The electrode assembly is mounted in a rugged aluminum casting, which shields the assembly on four sides. The shielding is completed by two aluminum side panels which can be swung out of the way to insert and remove the specimen.

LOW-FREQUENCY CONSIDERATIONS

Although the micrometer type of holder was originally conceived for use at frequencies from 1 to 100 Mc, the Type 1690-A was designed in the conviction that it will be as useful at audio and power frequencies as at radio frequencies. The use of this type of holder, properly calibrated, virtually eliminates the errors from edge capacitance and stray capacitance without resort to the complication of guarded specimens and measuring circuits. The validity of this statement is demonstrated by the following outline of the methods of calibration and use.

The total capacitance at the terminals for any spacing t of the electrodes can be considered as the sum of the following components:

C_a — the direct geometric capacitance between the electrodes.

C_e — the fringing capacitance, or "edge" capacitance, contributed by the lines of force passing directly from electrode to electrode but outside the edges.

C_g — the stray capacitance of the insulated electrode and lead to the grounded enclosure.

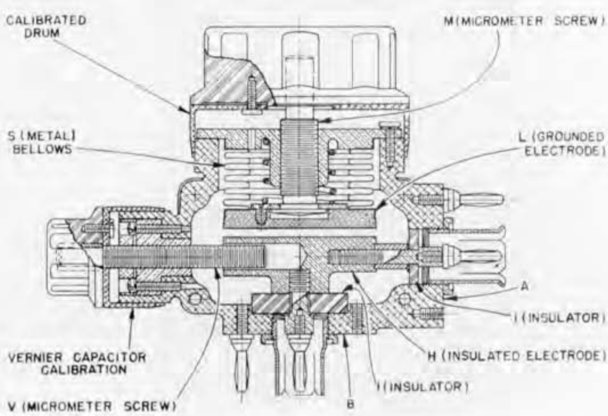

Figure 2. Cross section of the dielectric sample holder showing details of construction.

C_m — an error component caused by any mechanical imperfections in the screw thread and by any slight lack of parallelism of the electrodes.

The *difference* in capacitance between any two settings t_1 and t_2 is then the sum of the differences of the individual components

$$\triangle C = \triangle C_a + \triangle C_e + \triangle C_g + \triangle C_m$$

The direct capacitance C_a can be calculated accurately for any setting, but the error terms cannot. The calibration is made by measuring the actual $\triangle C$, taking arbitrarily a spacing of 100 mils as the reference point. The differences between the observed $\triangle C$ and the calculated $\triangle C_a$ are plotted in the form of a calibration curve as shown in Figure 3. From this curve the difference in error terms between any two settings can be determined.

In the normal method of use, an observation of the measuring circuit is made with the sample in place, at a setting t_1. The total capacitance is then

$$C_x + C_{e1} + C_{g1} + C_{m1}$$

With the sample removed, the electrode spacing is reduced until the total capacitance is restored to its original value, which then can be expressed as

$$C_{a2} + C_{e2} + C_{g2} + C_{m2}$$

Equating the two expressions, we have

$$C_x = C_{a2} + \sum \triangle C_{error}$$

But the summation of the differences in the error terms is precisely the quantity given in the calibration curve of Figure 3. Therefore the capacitance of the sample is the air capacitance at the setting t_2 after correction from the calibration data. For convenience, tables of the calculated air capacitance for 2″ electrodes are provided.

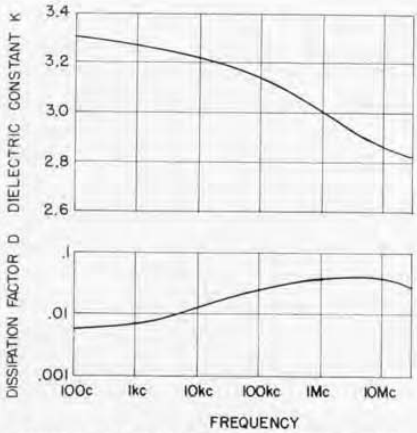

Figure 4. Dielectric constant and dissipation factor of a sample of polyvinyl butyral as measured with the Type 1690-A Dielectric Sample Holder, the Type 716-C Capacitance Bridge, and the Type 821-A Twin-T Impedance-Measuring Network.

The only assumption involved in this method is that the fringing capacitance at the setting t_1 is the same regardless of the dielectric constant of the medium between the plates. While this is not rigorously true, the error involved appears to be very small.

If the specimen is smaller in diameter than the electrodes, the expression for its capacitance is

$$C_x = C_{a2} - C_{a1}\left(1 - \frac{A_x}{A_e}\right) + \text{ corrections,}$$

where A_x is the area of the sample, A_e the area of the electrodes (3.14 square inches for 2″ electrodes).

MEASUREMENTS

Figure 4 shows typical measurements made with the new holder over the

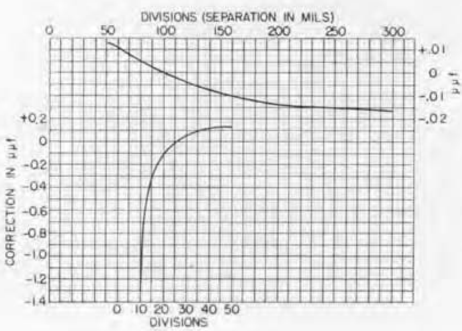

Figure 3. Typical calibration curve for the Type 1690-A Dielectric Sample Holder.

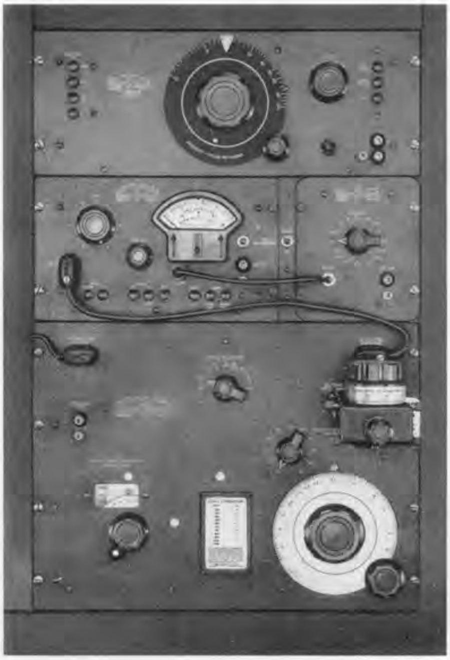

Figure 5. An assembly of equipment for dielectric measurements at frequencies between 50 cycles and 100 kilocycles, consisting of the Type 1302-A Oscillator, the Type 1231-BR Amplifier and Null Detector with Type 1231-P5R Filter, and the Type 716-C Capacitance Bridge, with the Type 1690-A Dielectric Sample Holder.

frequency range from 100 cycles to 30 Mc with the TYPE 716-C Capacitance Bridge and the TYPE 821-A Twin-T. The excellent continuity in the curves obtained with the two different measuring circuits emphasizes the advantage of using the same holder for measurements over a wide frequency range.

Sufficient measurements have been made at v-h-f and u-h-f frequencies, using the TYPE 874-LB Slotted Line and the TYPE 1602-A Admittance Meter, to establish that accurate measurement of *dielectric constant* can be made with this holder to at least 500 megacycles. Evaluation of the results for dissipation factor measurements has not been carried sufficiently far to establish performance specifications. An analysis of the high frequency performance will be presented in a later issue of the *Experimenter.*

— IVAN G. EASTON

SPECIFICATIONS

Electrodes: Diameter, 2.000 inches ±0.0025. Surfaces are ground optically flat within a few wavelengths.

Electrode Spacing: Adjustable from zero to 0.3-inch maximum. The spacing is indicated directly by the micrometer reading.

Vernier: Incremental capacitance is 5 $\mu\mu$f nominal.

Calibration: For the main capacitor a chart is provided giving the calculated air capacitance as a function of spacing. A correction chart is also provided with each holder, giving the measured deviations from calculated values over the range from 300 mils to 10 mils spacing. In accordance with recommended ASTM practice, this calibration is referred to the calculated geometric value at a spacing of 100 mils.

For the vernier capacitor a correction chart is provided, from which capacitance differences can be determined to an accuracy of ±0.004 $\mu\mu$f.

Zero Capacitance: Approximately 11 $\mu\mu$f.

Frequency: This type of specimen holder introduces no significant error at frequencies below 100 Mc. At higher frequencies the technique of its use has not been firmly established, but satisfactory results can be obtained for many types of measurements.

Accessories Supplied: TYPE 1690-P1 Adaptor Assembly for mounting to the TYPES 716-C Capacitance Bridge and the TYPE 821-A Twin-T.

Accessories Available: TYPE 1690-P2 Adaptor Assembly for connecting for TYPE 874-LB Slotted Line or TYPE 1602-A Admittance Meter.

Mounting: Supplied with a wooden carrying case. A drawer in the case provides storage for hardware, and a spring clip holds the calibration charts, which are mounted in aluminum holders.

Dimensions: Overall, mounted on adaptor, 6¼ x 5¾ x 4½ inches.

Net Weight: 3¾ pounds.

Type		*Code Word*	*Price*
1690-A	**Dielectric Sample Holder***	LOYAL	**$395.00**
1690-P2	**Adaptor Assembly (for Type 874-LB Slotted line)**	LOYALMOUNT	**30.00**

*U. S. Patents Nos. 2,125,826 and 2,548,457.

WHY RHEOSTAT BURNOUTS?

Because of the nature of the circuits in which rheostats are generally employed, the current through the rheostat usually varies in a direction inverse to the amount of resistance inserted in the circuit. Oftentimes this fact is overlooked when choosing a wire-wound rheostat for use in a certain circuit position. The result may be that too small a rheostat is used and that the localized overload, when small values of resistance are in circuit, either burns out the rheostat in short order or, if it does not burn the rheostat out, gradually embrittles the phenolic mandrel until it breaks. Either condition, unfortunately, takes the rheostat out of service.

Probably there are other reasons than oversight for using too small a rheostat. The specifier of components may confuse the behavior of the usual low-operating-temperature wire-wound rheostats with that of the ones especially designed for high-power use. Many of these latter have insulated aluminum or other metal as a mandrel; many, in addition, have an aluminum housing. The metal tends to conduct the heat away from the section actually carrying the current, producing a so-called "end effect" which is quite large. The amount of energy that can be dissipated in a very small proportion of the rheostat is only slightly reduced from the over-all energy rating of the rheostat when all the resistance is in.

The generally encountered low-operating-temperature wire-wound rheostat has insulating parts made from phenolic materials, paper-based or cotton-cloth-based for the laminated materials, and wood-flour-based for the molded materials. The longitudinal conductivity of these phenolic materials away from a small area in which the energy is being dissipated is very small compared to the conductivity of metals. However, it isn't completely negligible. There *is* a small "end effect."

Advantage may be taken of this "end effect," if it is done with care, to enable one to use a somewhat smaller rheostat than he might otherwise use in cases where the circuit current goes up as rheostat resistance goes down with shaft rotation. Measurements have been made on one of our TYPE 214 Rheostats to discover the magnitude of the "end effect." These rheostats have rated currents which will produce a 60°C. rise at the hot spot. It was found, for instance, that if only one per cent of the resistance of a linear rheostat was in circuit, it could carry two times rated current without exceeding the allowable 60°C. rise. This and other figures for larger rotation percentages are given in the table.

Rotation	*Current for 60° C. Rise*
1%	2 × rated current
2%	1.65 × rated current
5%	1.3 × rated current
10%	1.1 × rated current
20%	1.03 × rated current

It will be noted that the allowable increase in current rating at 20 per cent rotation is essentially negligible. Even that at 10 per cent rotation is not very significant.

The information in the table has been plotted up in two ways and displayed in Figure 1. The variation of allowable current with percentage rotation is shown on the lower curve. The upper curve shows the amount of energy which can actually be dissipated (I^2R) as a function of rotation. If there were no "end effect," this latter curve would follow the course of the dotted 45°

line. The departures above the 45° line are the beneficial results of the "end effect."

Some discretion should be exercised in making use of these figures. It should be remembered that they represent data actually taken on a particular design of rheostat. Change of geometric proportions, materials, and so on will change the values of the current-multiplying factors for small rotations. Change in resistance value should have negligible effect. The real criterion should, of course, be a direct and not a derived one. If one wishes to get all one possibly can out of a rheostat, he should do it by actually measuring the temperature rise under his own proposed current conditions to be sure that the safe operating temperature of the unit isn't exceeded under any conditions. There is no substitute as good as a test under actual conditions of use.

Of course there are ways to improve the current-carrying capacity of a rheostat at low rotation angles, but so far this article has dealt with the performance capabilities of a standard linear rheostat. One way to increase low-rotation current-carrying capacity is to wind the low end with lower resistance per unit angle (larger wire, lower resistivity alloy, or both). Another way would be to include between the phenolic mandrel and the winding one or two thin pieces of copper or aluminum to conduct the heat away from the over-

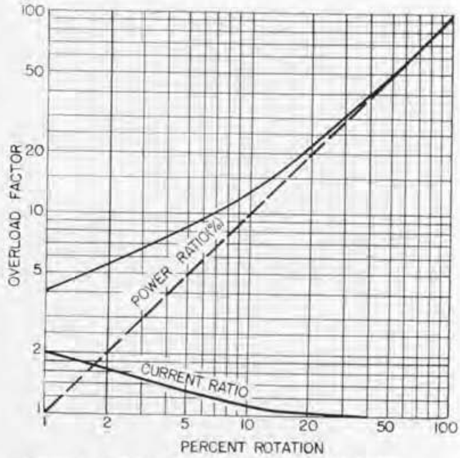

Figure 1. Plot of the allowable overload factor for Type 214 Rheostats, resulting from the "end effect" at small angles of rotation.

loaded section. The conducting pieces need not necessarily be the full length of the mandrel. Beyond the complication of manufacture, this expedient does not degrade the performance of the rheostat on d.c. However, it would seriously limit the usefulness of the rheostat at audio frequencies through the capacitance which the metal conducting piece would introduce across all or part of the rheostat winding.

It is hoped that this information may be found useful in some marginal applications of rheostats, to enable one to reduce the rheostat size without losing the advantages of specifying a standard rheostat normally carried in stock.

— P. K. McElroy

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

View of the General Radio booth at the 1950 Pacific Electronic Exhibit.

SEE US AT THE PACIFIC ELECTRONICS EXHIBIT

Be sure to see the General Radio booth at the Pacific Electronic Exhibit, August 22, 23, and 24, at the Civic Auditorium in San Francisco, California. In booths 418 and 419 the General Radio Company will have on display a number of new instruments, some of which have already been described in the *Experimenter* and others that will be described in forthcoming issues. Among the new instruments exhibited will be the following:

Type 1021-A U-H-F – V-H-F Standard-Signal Generator
Type 1602-A U-H-F Admittance Meter
Type 1330-A Bridge Oscillator
Type 1390-A Random Noise Generator
Type 1862-A Megohmmeter
Type 1652-A D-C Limit Bridge
Type 1550-A Octave-Band Noise Analyzer
Type 71-A Variac® Transformer
Type 874 Coaxial Elements
New Unit Instruments,
and standards of resistance, capacitance, and inductance.

The Pacific Electronic Exhibit is sponsored by the West Coast Electronic Manufacturers' Association and is held jointly with the Western Convention of the Institute of Radio Engineers. In conjunction with the Exhibit, two business conferences will be held, one on "Government Procurement Procedure," Wednesday, August 22, and another on "Where the Electronic Industry Stands in the National Preparedness Program," Thursday, August 23.

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