THE General Radio EXPERIMENTER

VOLUME XVIII No. 3 AUGUST, 1943

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

THE EFFECT OF HUMIDITY ON ELECTRICAL MEASUREMENTS

● IT IS AT THIS TIME of year that complaints come in regarding the erratic behavior of electrical measuring equipment, particularly precision impedance bridges. The various stories conflict. Sometimes the bridge seems to read high, sometimes low; the balance may drift badly or suddenly jump to a new value; it may show increasing errors as the frequency is lowered, or the balance may shift with applied voltage. At first glance it seems that there must be as many causes as kinds of error. Actually, there is just one cause, high relative humidity. Testing laboratories and research workers in the northern latitudes are experiencing for a few months what their brothers to the South contend with for half the year and what the few in the tropics fight the year around.

High relative humidity affects insulation in two ways. If the insulation is porous, moisture will be absorbed into the volume of the material while, if moisture wets the surface, a thin film of water is formed

The new Rohm and Haas physics laboratory is one of the most complete plastics testing laboratories in the country. This photograph shows two General Radio bridges set up to measure the dielectric properties of discs of Plexiglass.

covering the whole surface. Water distributed throughout the interior of an insulator produces interfacial polarization which causes an increase in capacitance, dissipation factor, and volume conductivity. The amounts of these increases vary with the relative humidity and inversely with the frequency.[1] At 100% relative humidity and a frequency of 60 cycles, increases of as much as 50% in capacitance, of a million-fold in conductivity, and up to a dissipation factor of 1.0, are quite possible for such porous materials as filled and laminated thermosetting plastics, many thermoplastics and natural fibers like cotton, wool, and silk. The rate at which a porous material absorbs water and the tenacity with which it holds it depend greatly on the cross section of the pores. When these approach molecular dimensions, as in silica gel, which is a silicate having microscopic pores produced by suitable heat treatment, the material acts as a desiccant, and the absorbed water can be removed only by heating above the boiling point. Mica and some ceramics act in this manner. Only quartz and most glasses, some steatites, polystyrene, and a few other polymers are free from volume absorption and the accompanying deterioration of dielectric properties.

The formation of a surface film of water on an insulator is determined by the ease with which water wets the surface, which in turn is measured by the contact angle between the surface and a drop of water on the surface.[2] Most of the porous materials that show large volume absorption also wet very easily. A microscopic roughness of the surface helps film formation. Quartz, glass, and steatite also wet easily. Only wax, polystyrene, and some other polymers successfully prevent the formation of a continuous film. The condition of the surface is also important. Dust and particularly acid perspiration from handling greatly aid wetting. The conductivity of even a thin film is enormous. Merely breathing on the surface of a good insulator like quartz will lower the insulation resistance between terminals spaced ¾ inch apart from above 10 MM Ω to below 1 M Ω. A film so formed will vanish rapidly if the surface is chemically clean and the relative humidity low. On a dirty surface, however, the film persists and can be removed only by thorough cleaning or by heating.

Because there are no rigid stable insulators which are unaffected by moisture, it is customary to impregnate them or at least to coat their surfaces with one of the water-repellent substances such as wax, polystyrene, or the newer silicon resins. Any of these materials operates successfully on the non-porous insulators, such as glass and steatite, so long as perfect adhesion is maintained. Large changes in temperature, particularly toward freezing, will produce cracking and chipping of the surface material because of the differences in temperature coefficients of linear expansion, and because most coatings, the waxes in particular, become brittle at the lower temperatures. Any moisture film which then forms between the insulation and the coating persists and can be removed only by complete cleaning of the surface or by heating.

On porous materials a thin protective coating is of no value because even the waxes are themselves somewhat porous.

[1] R. F. Field, "Frequency Characteristics of Decade Condensers," General Radio *Experimenter*, Vol. XVII, No. 5, Oct., 1942, pp. 1-7.

[2] On the well waxed surface of an automobile during a rain, large drops stand with a small re-entrant angle, the area of contact being smaller than the maximum section of the drop.

Such a coating decreases the rate at which moisture penetrates to the inner material, but continued exposure to high relative humidity will eventually result in the same equilibrium conditions. For reasonable success, wax coatings must be heavy, the result of multiple dippings, and of the order of 0.1 inch.

In all General Radio instruments great care has been taken to provide adequate protection against high relative humidity. All solid dielectric condensers are hermetically sealed or heavily waxed. All high-valued resistors are waxed or similarly protected. All steatite insulation is protected by a surface coating by the manufacturer. Mica-filled phenolic or polystyrene is used as insulation for mounting all high impedances. All wires for cables are rubber covered with an identifying braid wax - impregnated. These precautions are sufficient to allow normal operation under 90% relative humidity at 90° F. of all instruments except the 0.1% impedance bridges. An even more severe test occurs when, at 90% relative humidity, the temperature fluctuates sufficiently to reach the dew point and cause direct moisture condensation. Under these conditions the operation of an instrument may not meet catalog specifications. If power is dissipated inside the instrument, the heat generated will quickly evaporate the conducting moisture films. Otherwise some time must elapse to allow natural evaporation. A 40-watt lamp or other resistive load maintained inside the case will usually prevent condensation. It will have, however, little effect on moisture absorption.

The Type 716-B Capacitance Bridge is probably as greatly affected by moisture as any of our instruments. All steatite insulated terminals are wax coated, the input transformer is wax sealed, and the bridge wiring is open bus. Only the Type 722 Precision Condenser, used on the capacitance standard, is affected by moisture, and that only in its dielectric losses, not in its capacitance. Its own dissipation factor is defined by its figure of merit $F = DC = 0.04\ \mu\mu f$, corresponding to a dissipation factor of the steatite stator support of 0.004. At about 60% relative humidity, moisture absorption through the wax coating on these bars causes their dissipation factor to rise. A tenfold increase at 90% relative humidity must be expected. This will produce a negative error in the direct reading of dissipation factor exactly equal to the increase in dissipation factor of the precision condenser. No error will appear in parallel substitution measurements.

Another dielectric loss occurs in aluminum-plate air condensers under high humidity conditions from the absorption of moisture by the aluminum oxide on the surface of all the plates. In its dry state aluminum oxide has a small dissipation factor and imparts to the whole condenser a dissipation factor of only 0.0000001, since its contribution is proportional to the ratio of the thickness of the oxide film, about 10 millionths of an inch, to the plate spacing of 30 mils. When exposed to moisture the dissipation factor of the oxide is an exponential function of the relative humidity,[3] increasing a decade of dissipation factor for every 15% rise in relative humidity. At 90% the air condenser has a dissipation factor of about 0.01. Since the dielectric loss occurs on the surfaces of all the plates, the air condenser behaves like a variable solid dielectric condenser, and

[3]A. V. Astin, "Nature of Energy Losses in Air Capacitors at Low Frequencies," *Journal of Research of the National Bureau of Standards*, Vol. 22, No. 6, June, 1939, pp. 673-695.

its dissipation factor does not cancel out even in parallel substitution measurements. As before, the error in the bridge reading is negative.

Both of these kinds of moisture absorption in steatite and in aluminum oxide are troublesome when the relative humidity stays at 60% throughout the day, since at this level only a half day is required to attain equilibrium. A relative humidity of 40% causes no appreciable error, and even a rise to 60% followed by a drop back to 40% within six hours will cause little trouble. The time needed to attain equilibrium increases with the relative humidity and is at least three days at 90%.

Every laboratory should be equipped with some type of hygrometer in order that the possibility of errors in bridge measurements may be anticipated. The ordinary hair hygrometer is very useful in spite of its large errors because it is of the indicating type. A wet and dry bulb hygrometer should be available as a check under extreme conditions. Regular readings of relative humidity during the summer months are fully as important as are those of temperature, for the units being measured are in many cases more liable to be affected by high humidity than the measuring equipment itself. This fact indicates that the bridge readings of dissipation factor may appear to be high or low dependent upon the relative rates at which the unknown condenser and the standard condenser in the bridge change their dissipation factors with humidity. Without a hygrometer this situation cannot be definitely recognized except as the reading of dissipation factor becomes ridiculously low or actually negative. A certain instability of bridge balance will appear at relative humidities above perhaps 70%, as indicated by a more or less steady drift of both capacitance and dissipation factor balance points.

There is little that can be done with existing measuring instruments to eliminate this type of error, short of air conditioning. This should preferably apply to the entire room containing measuring equipment. Then the unknown unit is measured under standard conditions. It is also possible to dry out the measuring instrument by placing a desiccant, such as silica gel, inside its case. However, the amount of moisture which can seep through the joints between panel and case and around the control shaft is amazing. Unless unusual care is taken, it will be necessary to renew the desiccant each working day whenever the relative humidity is above 70%.

— Robert F. Field

ERRATA IN THE TYPE 716-B INSTRUCTION BOOK

Two errors in the Operating Instructions for Type 716-B Capacitance Bridge have recently been discovered.

In Equation 9, page 5, the expression for C_{XP} should be

$$C_{XP} = \Delta C \frac{1 - (\Delta D)^2 \dfrac{C}{\Delta C}}{1 + (\Delta D)^2}$$

and in Equation 10, page 6, the expression for C_{XP} should read

$$C_{XP} = \Delta C \frac{1 + D\left(D' - \Delta D \dfrac{C}{\Delta C}\right)}{1 + D^2}.$$

The latter correction has been made in books currently being shipped.

CHECKING THE ACCURACY OF AIRCRAFT TACHOMETERS

● **THE CURRENT PROBLEM** in checking aircraft engine tachometers is one of handling the increased number of tachometers and of making sure that the individual tachometer takes advantage of the full tolerance allowed by the acceptance specification.

If the tachometer tolerance is ±25 rpm and if the checking standard has an error of ±10 rpm, the tachometers must each read within ±15 rpm to be accepted. If the checking standard accuracy can be improved to ±2 rpm, the tachometers need only read within ±23 rpm to be accepted. With the increased accuracy more tachometers are accepted at no increase in testing time. The extra time required for handling rejections is eliminated.

The General Radio Type 631-B Strobotac bears the approval of the Civil Aeronautics Administration for the checking of aircraft tachometers. This certificate is earned by the rated accuracy of the Strobotac, which measures speeds between 900 and 14,400 rpm with an error of less than ±1% of the measured value. This statement assumes that the supply from which the Strobotac is operated is a power line tied in with one of the main frequency-regulated power systems of the country. The instantaneous error in the frequency of a regulated 60-cycle power line seldom exceeds ±0.2%, and is usually much less than this figure. A telephone call to the local power company's Dispatcher's Office will give a check on the frequency accuracy to be expected of the local power system.

Engine tachometers are driven from the engine cam shaft which turns at one-half the crankshaft speed. In the instrument laboratory, therefore, the tachometer is checked by comparing its reading with twice the measured speed of the test-stand drive shaft.

There are usually three steps in the tachometer-testing procedure.

(a) The Strobotac calibration is adjusted against the line-controlled synchronous vibrating reed mounted within the instrument reflector, and the Strobotac scale is then set to one-half the desired tachometer test speed.

(b) The speed of the test-stand drive motor is adjusted until the drive shaft appears to stand still.

(c) The scale reading of the tachometer is recorded.

Steps (a) and (b) may be combined, and the possible calibration errors of Step (a) may be eliminated by using a stroboscopic disc and by flashing the Strobotac at the power-line frequency under LINE control. This method permits reduction of possible errors from the ±1% rated Strobotac maximum error to the power-line frequency error of usually less than ±0.2%.

The stroboscopic disc of Figure 1 may

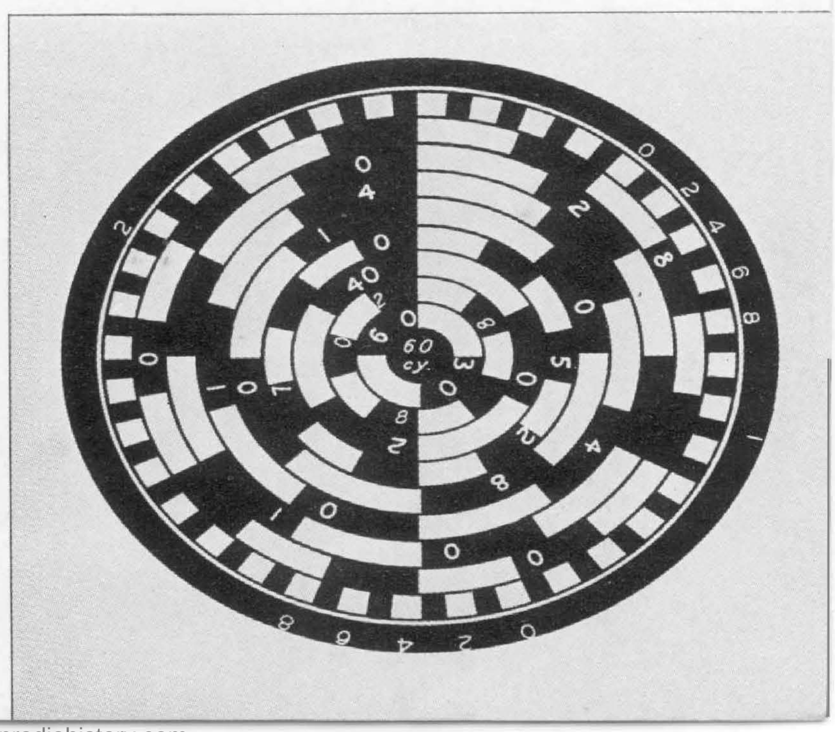

Figure 1. Tachometer test disc for Strobotac. Copies are available on request.

be cut out and mounted on light cardboard or metal. The center should be carefully located and drilled to fit on the drive shaft, the free-end shaft extension of the drive motor, or, most convenient, on a dummy tachometer to be plugged into one of the positions of a multiple-unit tachometer test stand. The face of the disc should be shaded from direct daylight or artificial illumination and should be placed within the beam from the Strobotac.

When the Strobotac control is turned to the LINE position and when the speed of test-stand drive motor is gradually increased, the rings of the disc will appear successively to stand still. Each ring when standing still shows the correct tachometer reading because correction has been made for the half-speed drive from the cam shaft. The outside ring will appear to stand still at each even hundred rpm on the tachometer scale. The actual rpm in hundreds will be readable intermittently by stroboscopic combination of the outside ring figures.

There is always a reading error inherent in observing the indication of any calibrated instrument. For most engine tachometers this error appears to be set at approximately ±1% by the scale size and design. A series of readings taken by a consistent method by one observer will largely eliminate this error, but the possibility of its presence should not be overlooked in setting up the inspection accuracy limits.

The following table shows, for the test points of the stroboscopic disc, the error corresponding to the ±1% rated accuracy of the Strobotac, and the ±0.2% normal maximum deviation of the power-line frequency. The table also gives the acceptable deviations for a typical tachometer under the two conditions of test. These deviations show the increased tolerances acceptable with the increased accuracy of checking. The typical tachometer for which the deviations are shown is assumed to be an instrument reading to 3500 rpm and expected to have an absolute error of less than ±70 rpm at any point on its scale. This corresponds to an expected accuracy of ±2% of full-scale reading.

On tachometer stands where the Strobotac will be kept in service, the instrument can be kept at operating temperature without continuous flashing of the Strobotron tube by turning the control switch to the CONTACTOR LOW position between tachometer tests. This keeps all internal parts at operating temperature and ready for operation, but does not exhaust needlessly the limited life of the Strobotron.

— FREDERICK IRELAND

TEST POINT rpm	±1% ERROR rpm	±0.2% ERROR rpm	STANDARD TOLERANCE* rpm	ACCEPTABLE DEVIATION ±1.0% TEST rpm	ACCEPTABLE DEVIATION ±0.2% TEST rpm
800	8	1.6	70	62	68.4
1200	12	2.4	70	58	67.6
1440	14.4	2.9	70	55.6	67.1
1800	18	3.6	70	52	66.4
2057	20.6	4.1	70	49.4	65.9
2400	24	4.8	70	46	65.2
2880	28.8	5.8	70	41.2	64.2
3600	36	7.2	70	34	62.8

*See text for conditions of standard tolerance.

TORSIONAL VIBRATION ANALYSIS WITH THE TYPE 736-A WAVE ANALYZER

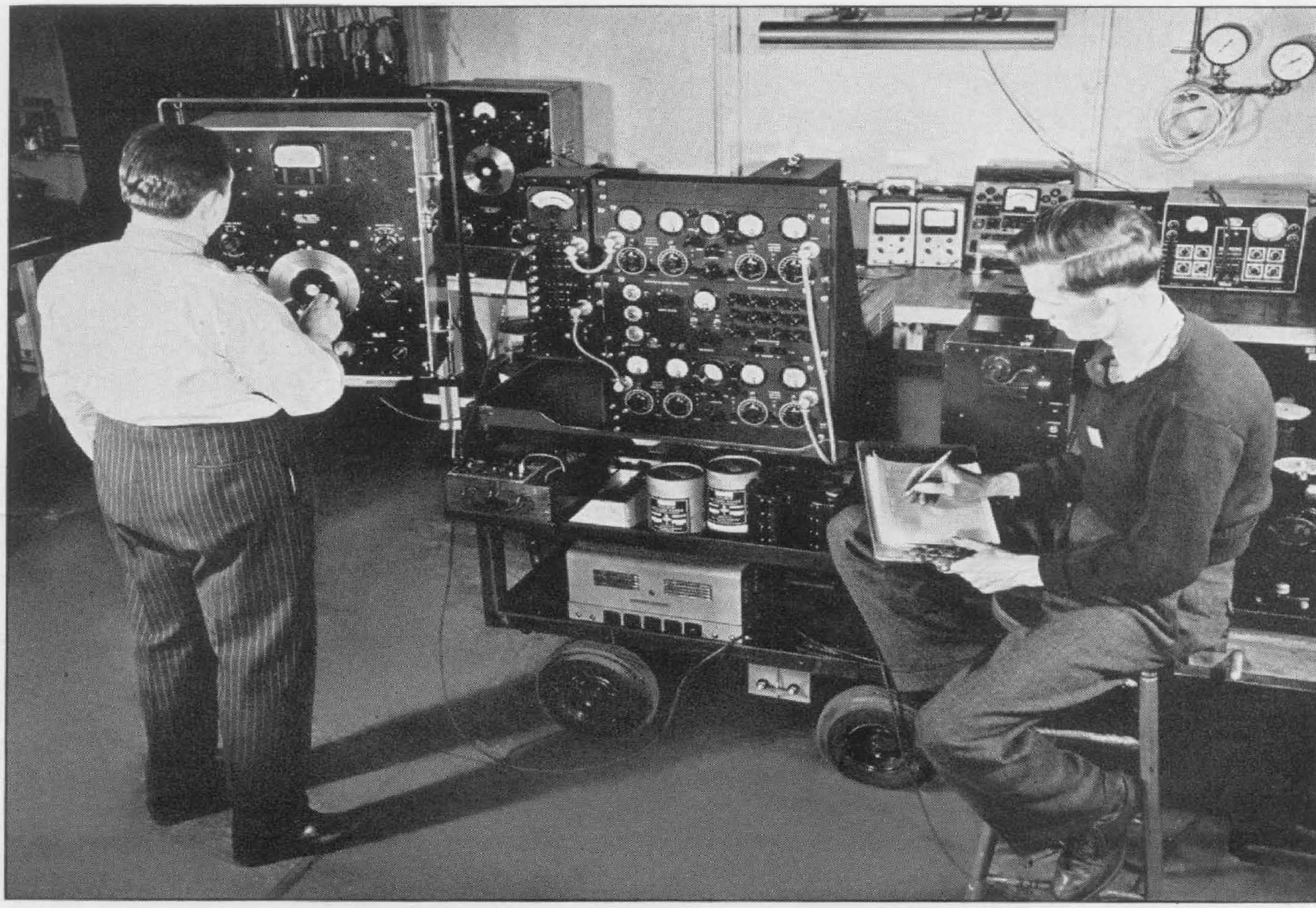

FIGURE 1. Test setup for measuring torsional vibration at the Lycoming laboratories.

● **ALTHOUGH** the TYPE 760-A Sound Analyzer and the TYPE 762-A Vibration Analyzer are recommended for general purpose sound and vibration analysis, there are specific applications where the use of the TYPE 736-A Wave Analyzer leads to certain operating conveniences and somewhat better accuracy. In Figure 1 is shown a test setup in the laboratories of the Lycoming Division, the Aviation Corporation, using the wave analyzer for the analysis of torsional vibrations in aircraft power plants.

At the lowest frequencies, the resolving power of the wave analyzer is not adequate for satisfactory separation of

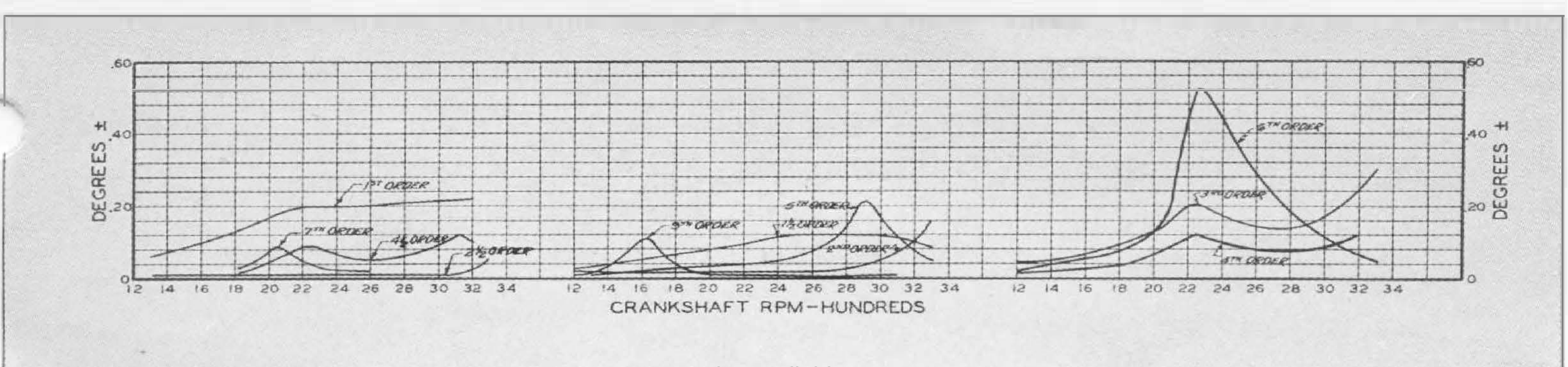

FIGURE 2. Plots showing the amplitudes of various orders of vibration as measured with the wave analyzer.

closely spaced non-harmonic components, but for vibration frequencies directly related to the fundamental engine speed, the selectivity is adequate. For instance, at a fundamental (first-order) vibration of 20 cycles (per second), the ½ order and 1½ order components fall at 10 and 30 cycles, respectively. The discrimination of approximately 30 db between such components is adequate for most torsional vibration analysis.

At extremely high frequencies the TYPE 736-A suffers somewhat in comparison to the TYPE 760-A, because the relatively sharper response curve makes tuning difficult when the frequencies under observation are not stable. For the range of frequencies normally encountered (fundamental speeds in the range 1000-3000 rpm) in torsional studies on aircraft engines, however, the selectivity characteristics of the wave analyzer are satisfactory.

A series of plots typical of the amplitude of various orders of vibration, as the driving speed is varied over a wide range, is shown.

— IVAN G. EASTON

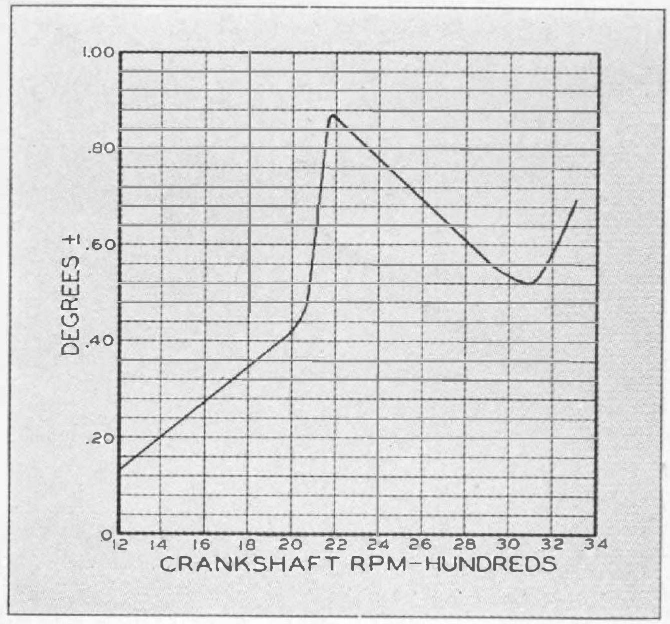

FIGURE 3. Maximum amplitudes of the resultant recorded vibration wave measured from oscillograms.

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 name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE 39, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY 6

1000 NORTH SEWARD STREET, LOS ANGELES 38, CALIFORNIA

PRINTED IN U.S.A.