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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A PRECISION TUNING FORK WITH VACUUM-TUBE DRIVE

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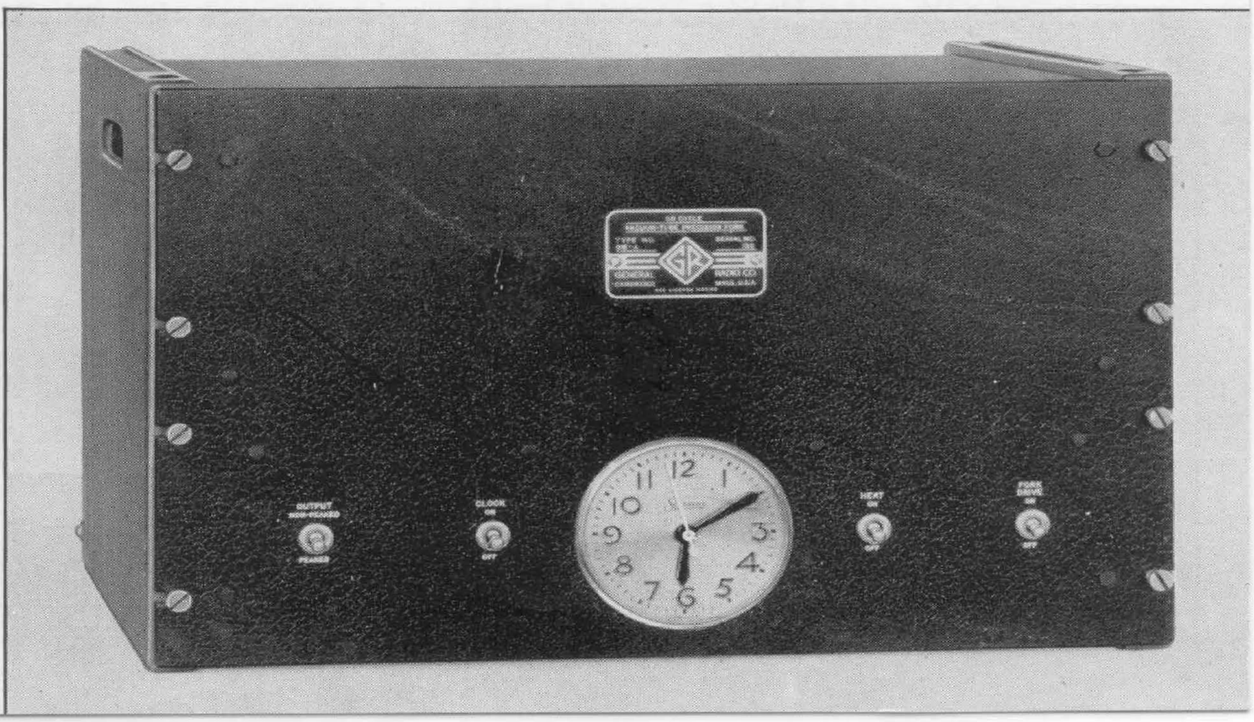
● THE LOW-FREQUENCY TUNING FORK has been widely used as a standard both for frequency measurement and control and for chronographic work. In May, 1936, the General Radio Company announced[1] the TYPE 815 Precision Fork which is supplied to operate at 50, 60, or 100 cycles per second.

This readily-portable instrument is a double-button microphone-driven fork, which is energized by a battery of from 4 to 6 volts. The fork itself is made from a stainless-steel alloy having a low temperature coefficient, so that the operating frequency remains within 0.01% of its rated value under all normal fluctuations of ambient temperature and battery

[1]General Radio *Experimenter*, Vol. X, No. 12.

FIGURE 1. Panel view of the TYPE 816 Vacuum-Tube Precision Fork.



voltage. In later tests[2] under controlled conditions of temperature and driving voltage, one of these forks stayed within 0.002% of its nominal value during a two-months' period of continuous operation.

Subsequent studies showed that the fork itself, because of its high value of Q (about 19,000), was ultimately capable of still greater precision. Accordingly, a modified form of this tuning-fork standard, designated as TYPE 816[3], was developed to minimize some of the limitations inherent in the original instrument.

Next to temperature variations, the chief source of erratic residual fluctuations in the frequency of the microphone-driven fork is the microphone button used in the driving circuit. The amplitude and phase characteristics of a loose pocket of granular carbon are not constant, but are subject to considerable random variation. Consequently, the microphones were removed, and the fork was driven by generating from the tine motion a small emf in a polarized electromagnet, L_1, amplifying this emf, and subsequently driving the fork by a second polarized electromagnet, L_2. This permitted a smaller tine motion, which itself increased the inherent stability of the fork.

Another limitation of the microphone-driven fork for some applications is the appreciable but unavoidable variation in power output, again caused by the erratic behavior of a carbon microphone. This is essentially eliminated in the new amplifier-driven fork.

In order to reduce the effect of ambient temperature fluctuations, the fork is built into a temperature-controlled box regulated automatically by a thermostat so that the actual temperature of the fork is kept to within about 0.1° Centigrade of an optimum mean value.

To provide for universal operation the circuits are so designed that power for energizing both the heater elements and the amplifier system may be obtained from either of two sources:

(1) A single-phase a-c power line supplying from 100 to 130 volts at any commercial frequency, or

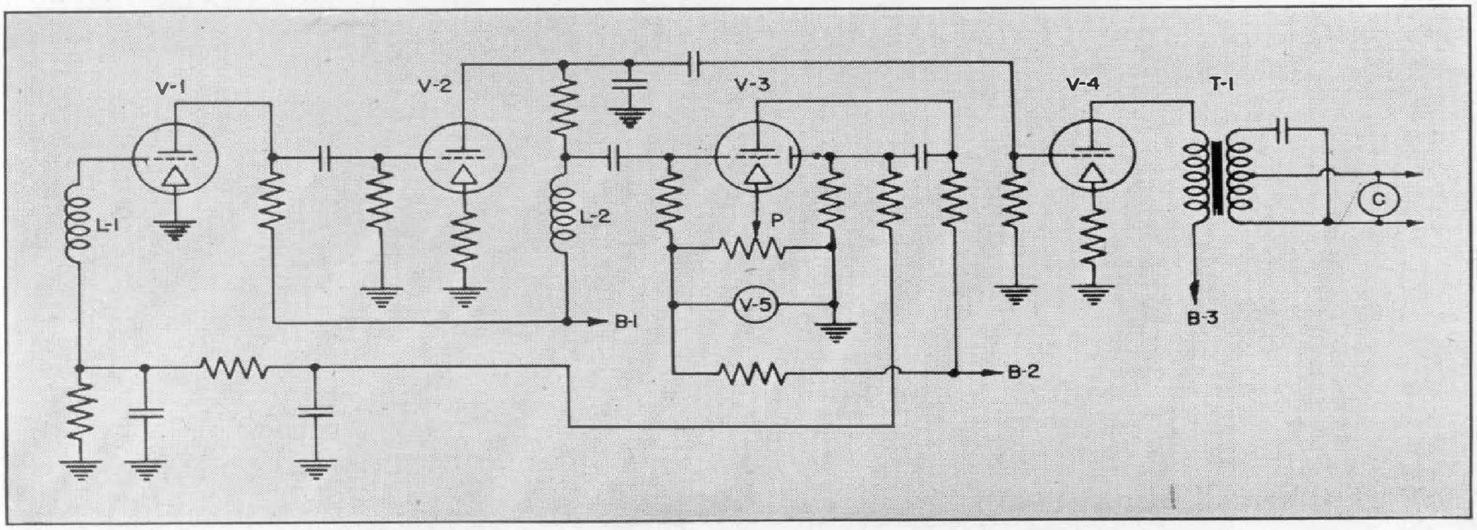
(2) A d-c power line of 100 to 130 volts.

While this method of driving a tuning fork is not basically novel, several features have been introduced into the amplifier system, all of which contribute to the ultimate stability. The input tube, V_1, of the amplifier is heavily

[2]General Radio *Experimenter*, Vol. XIII, Nos. 4, 5.

[3]Although the TYPE 816 Vacuum-Tube Precision Fork has been available for war use for some time, it has not hitherto been described in the *Experimenter*.

FIGURE 2. Schematic circuit diagram of the TYPE 816-A Vacuum-Tube Precision Fork.



biased by means of an a-v-c tube, V_3, whose control potential is regulated in turn by a gaseous discharge tube, V_5, thus providing a rigid control of tine amplitude, independent of supply line fluctuations. The amplifier design is such that phase shifts in the output of the driving tube, V_2, are reduced to a very low minimum. These features, combined with the high Q of the fork and its low temperature coefficient, produce a tuning-fork standard whose residual variations, when temperature controlled, aggregate less than 0.001%, and can, to a considerable degree, be attributed directly to diurnal fluctuations in barometric pressure.

If a less precise standard will suffice for any particular application, the heater power source may be omitted, and the frequency stability of the fork will be determined chiefly by ambient temperature fluctuations.

OPERATING CHARACTERISTICS

Because of the high thermal capacity of the fork, the actual temperature remains within 0.1° Centigrade of the optimum controlled value of about 60° Centigrade during successive cycles of thermostat operation. At 60° the temperature coefficient of frequency is less than two parts per million per degree. When the temperature control is not used, the effective temperature of the fork will follow, with considerable time lag, the fluctuations of ambient temperature, and the frequency will be subject to a negative temperature coefficient[4] of the order of 10 to 20 parts per million per degree Centigrade.

The a-v-c bias potential, and hence the fork amplitude, is adjustable by means of the potentiometer, P, thus permitting an electrical control of the fork frequency over a range of about 0.001%. With a minimum value of this bias potential the supply-line-voltage coefficient of frequency is positive and is less than 0.03 parts per million per volt change of line voltage. At the mid-value of this bias potential, the coefficient is less than 0.01 parts per million per volt; while at the maximum bias potential the coefficient is negative and less than 0.1 parts per million per volt change.

When one of these forks was checked against a piezo-electric primary standard having a still higher degree of precision, it was found that the major part of the minute fluctuations of the fork frequency could be attributed to variations in barometric pressure. Increase of pressure caused a greater effective loading on the tines of the fork and a corresponding reduction in frequency. The resultant negative coefficient is about 2.5 parts per million per inch of mercury change in the barometer reading. Since the fork is maintained at a fixed temperature above ambient, it would appear that fluctuations in ambient humidity would have no appreciable effect upon its frequency.

These coefficients are each so small that under all normal variations encountered in practice the unmonitored

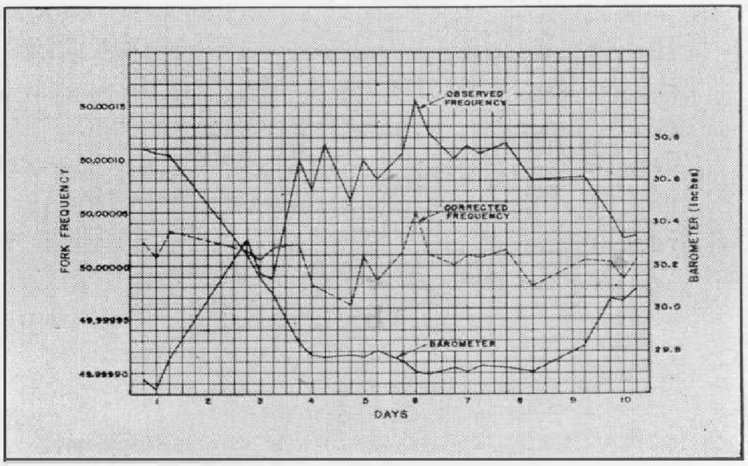


FIGURE 3. Typical frequency variation for a nine-day interval. Note that when corrected for barometric pressure the frequency remained within one part in a million of its nominal value.

[4] The measured temperature coefficient is supplied with each fork.

frequency will remain stable within conservative limits of 10 parts per million or 0.001% which, as a chronometer, means an error of less than one second per day. If corrections for barometric pressure are applied by adjustment of the potentiometer, *P*, a precision of better than five parts per million may be expected for this standard when set up and run continuously.

The data plotted in Figure 3 were taken on a 50-cycle fork during a typical nine-day interval of continuous operation and show how the residual variation of the frequency of one of these tuning-fork standards follows inversely the variation of barometric pressure. The observed frequency values were measured with a precision of one part in five million. The second curve gives these data corrected to a mean barometer value of 30.2 inches. It will be seen that, during this interval, the *corrected* data did not depart by more than one part in a million from the nominal value of 50 cycles per second.

CONSTRUCTIONAL FEATURES

The Type 816 Precision Fork and its associated circuits are completely housed in a metal cabinet. The instrument is adapted either for relay-rack mounting or for standing upon a laboratory bench and, if kept approximately horizontal, is readily portable for field use. Input and output leads are attached through plugs on the rear of the cabinet.

The fork and associated magnets are mounted on a spring-supported sub-panel to minimize damping. This assembly, in turn, is contained in a metallic box carrying the heater units and is surrounded by a balsa wood box for thermal insulation. The box and the amplifier tubes are mounted upon a horizontal shelf beneath which are the various elements of the amplifier circuits. If desired, a thermometer may be inserted through the side wall of the cabinet into the fork box. The instrument panel carries various control switches and a synchronous clock, *C*, which can be driven from the fork-controlled output and used for calibrating the standard over long-time intervals in terms of radio time signal observations. This clock may be reset by a knob on the rear of the cabinet.

The necessary circuit changes for accommodating the two different sources of power supply are made at the input power jack.

Coarse adjustments of the fork frequency may be made by setscrews in the extremities of the fork tines, and fine adjustments by means of the a-v-c bias control, *P*.

OUTPUT

Output power at the controlled frequency is obtained by the use of a separate output tube, V_4, furnishing about two watts without and one watt with the synchronous clock in operation. This output power may be obtained at three different generator impedance values. The output voltage may be nearly sinusoidal or, for certain chronographic uses, may be sharply peaked in character, as selected by a switch on the panel. This peaked waveform being rich in harmonics is frequently useful in measuring unknown frequencies of higher value than the standard. The use of an output transformer, *T*, permits the output signal circuit to be ungrounded and free from d-c polarization.

The original Type 815 Precision Fork still retains its advantage of being light in weight and of minimum bulk, together with its ability to be driven by three small dry cells, and possesses an accuracy which makes it reliable to 0.01%. On the other hand, the new TYPE 816-A Vacuum-Tube Precision Fork has at least a tenfold higher precision, better than 0.001%, gives a higher and an unvarying output power, is equipped with a synchronous clock for time keeping and calibration, and may be operated either from an a-c or a d-c power line. Each instrument therefore has a field of application in which it proves most advantageous. — HORATIO W. LAMSON

SPECIFICATIONS

Frequency: 50 or 60 cycles per second.

Calibration: The frequency is adjusted within 0.0005% of its rated value and is measured to 0.0001% in our standardizing laboratory.

Stability: When the temperature-control system is operated, the frequency is within one part in 100,000 (0.001%) of its mean value thus timing to better than one second per day. Without temperature control, the frequency will follow (with a considerable lag) variations in ambient temperature. At ordinary room temperatures, the temperature coefficient of frequency is negative and is between − 10 and − 20 parts in 10^6 per degree Centigrade. Frequency changes with supply voltage and atmospheric pressure are usually negligible in comparison to the rated accuracy of the fork.

Power Supply: The amplifier circuit and the heaters for temperature control are arranged to operate on either of two types of power supply, selection being made by plug and jack terminals:
(1) a-c line, 100 to 130 volts, 50 to 60 cycles.
(2) d-c line, 100 to 130 volts.

Power Input: For temperature control, 30 watts; for fork and amplifier, 45 watts.

Output: Peaked or sinusoidal, as selected by a switch. When the synchronous clock is operated, maximum output is 1 watt. When clock is not used, maximum output is 2 watts. Output circuit is not grounded and is free from any d-c polarization. Various output impedances between 200 and 30,000 ohms are provided.

Maximum peaked open-circuit output voltage is 350 volts.

Vacuum Tubes: Supplied with Instrument,
2 — 6A7G 1 — 6Q7G
1 — 25L6GT 1 — 25Z6
1 — 139-949A

Accessories Supplied: Spare fuses; 2 Multipoint Connectors; 1 line connector cord.

Mounting: The entire assembly is mounted on a standard 19-inch relay-rack panel, which can be adapted for table mounting by the use of the wooden end frames supplied. The instrument is readily portable in an operating condition if kept in approximately its operating position.

Dimensions: Panel, 19 x 12¼ inches; depth, 12½ inches.

Net Weight: 49½ pounds.

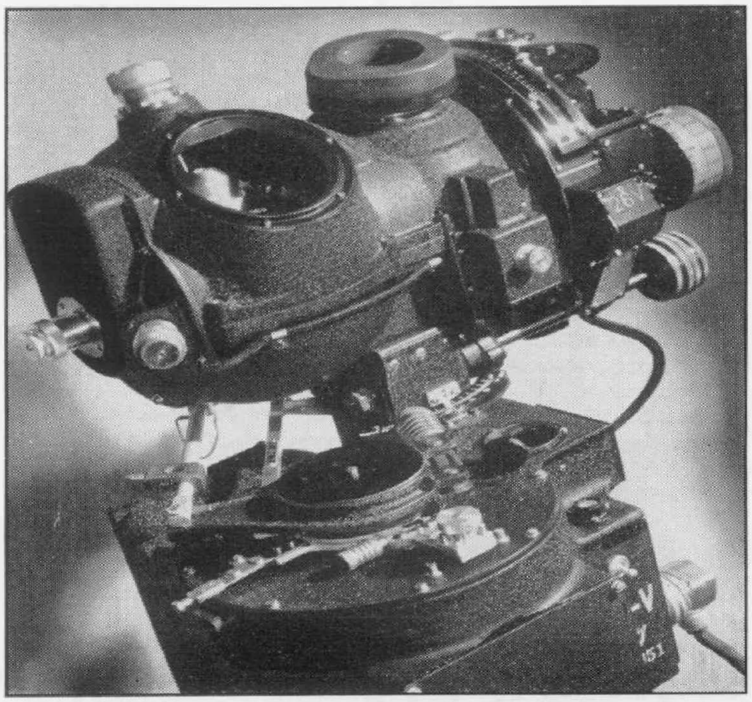
Type		*Code Word*	*Price*
816-A	Vacuum-Tube Precision Fork.....	FERRY	$385.00
816-B	Vacuum-Tube Precision Fork.....	FABLE	385.00

[6]Licensed under patents of the American Telephone and Telegraph Company.

BUSMAN'S HOLIDAY

● **EVEN WHEN ON VACATION,** the engineer seldom loses interest in research. Mr. Robert F. Field of the Engineering Staff, while vacationing at his Meredith, New Hampshire, summer home, recently conducted an investigation of the variations in water depth and temperature over parts of Winnepesaukee and Squam lakes. The results were reported to the Meredith Rotary Club at their weekly luncheon on August 15.

BALANCING TO 0.000070 INCH WITH THE AID OF THE STROBOTAC



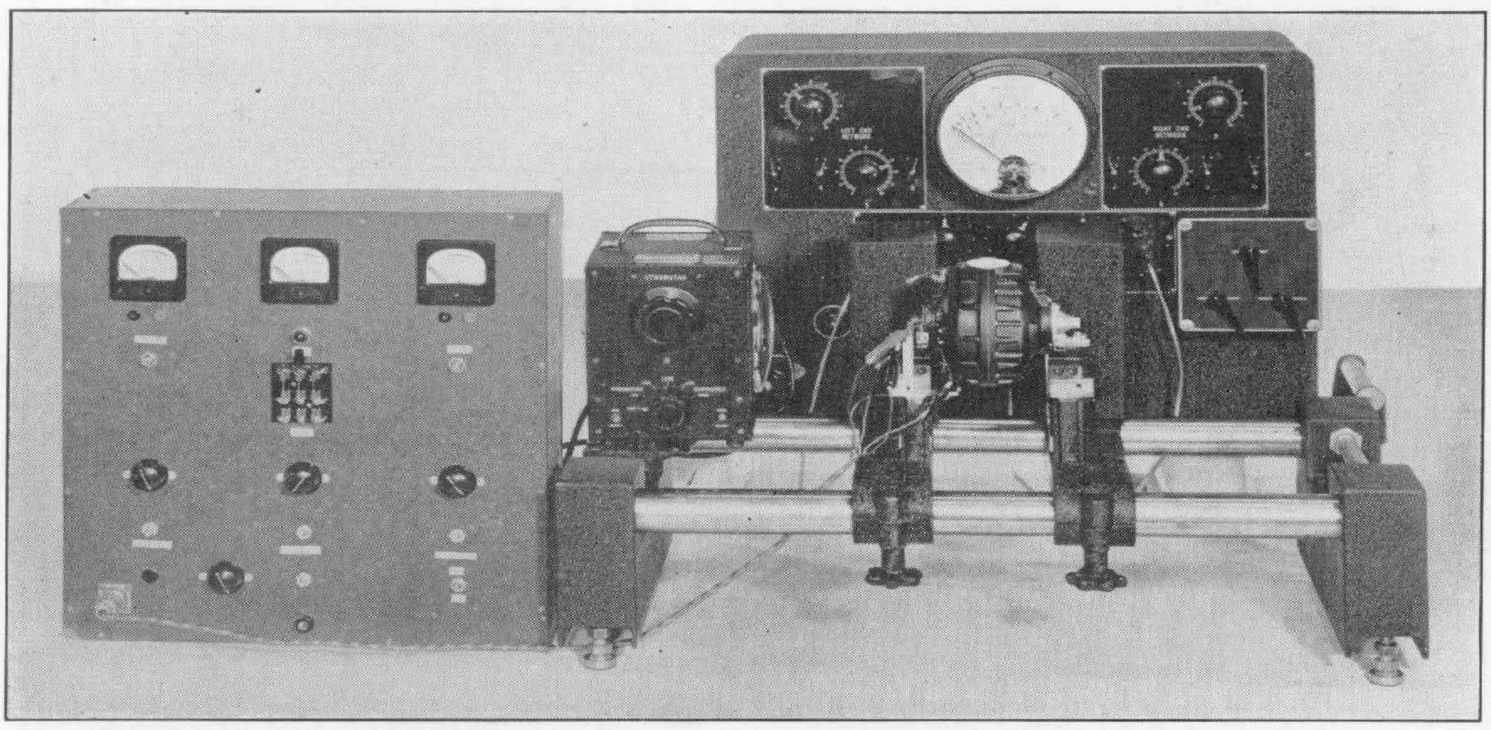
(*Above*) The famous Norden Bombsight.

(*Below*) The Dynetric balancing machine showing the Strobotac and a gyro in test position.

● **THE FAMOUS NORDEN BOMBSIGHT**, until recently a complete military secret, is probably one of the most precise instruments made by man, yet it is being built in mass production by a number of manufacturers.

The bombsight consists of two main units: the stabilizer, which controls the horizontal flight of the plane during the bombing run; and the sighting mechanism, which contains the telescope and computer. Each of these main units contains a gyro, which must be balanced to the unheard-of accuracy of 70 millionths of an inch. At the plant of the Victor Adding Machine Company, one of the manufacturers of the Norden bombsight, this balancing is accomplished on a "Dynetric" balancing machine, manufactured by the Gisholt Machine Company. This machine uses as one of its elements a General Radio Strobotac.

The accompanying photograph shows the balancing machine with a gyro and its housing in the test position. The Strobotac, which is shown at the left of



the gyro, has two functions: first, to determine the rotational speed of the gyro wheel; and second, to indicate the angular position of unbalance.

The Strobotac is set to the desired speed, and the gyro is then brought up to this speed by means of the electronic speed controller in the cabinet at the extreme left. When the desired speed is reached, the rotor, as viewed in the light from the Strobotac, appears stationary. A precise setting and control of the speed is necessary because the balancer includes a sharply tuned filter.

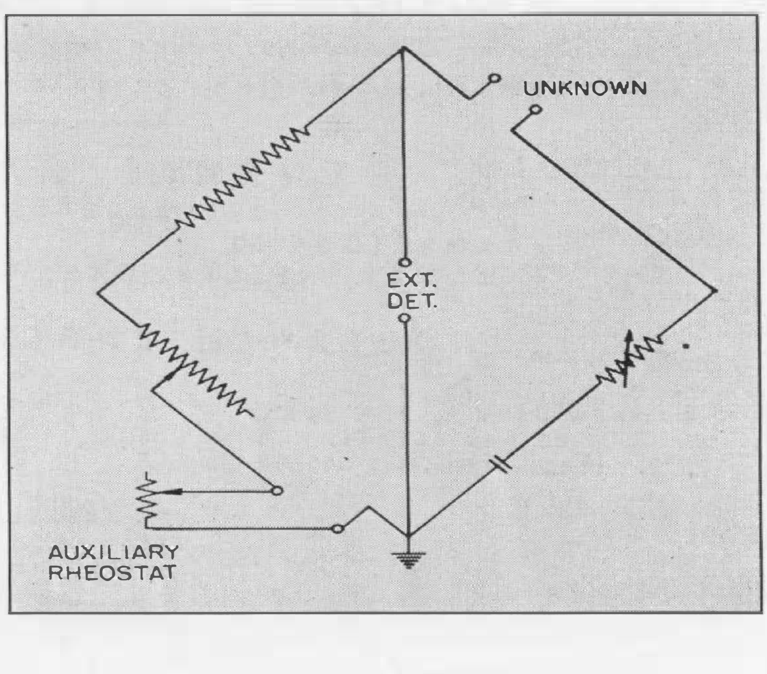
In the balancing operation itself, the machine determines the amount and angular position of the unbalance in each of two planes, which are the faces of the gyro wheel. The angular position at which unbalance occurs is shown opposite a stationary pointer when the Strobotac flashes. On the meter behind the gyro is shown directly the weight that must be removed at the indicated position to remove the unbalance. The sequence of these operations is selected by switches, shown at the right of the gyro rotor. One switch selects the plane of observation, i.e., left or right; another selects either the meter indication of amount of unbalance, or the Strobotac indication of angular position; while a third provides two orders of meter sensitivity.

PRODUCTION TESTING WITH IMPEDANCE BRIDGES

● **WHEN THE TYPE 740-B CAPACITANCE BRIDGE** and the Type 650-A Impedance Bridge are used for the production testing of capacitors, inductors, and resistors, uneven wear of the potentiometers in the bridges may occur as a result of continued operation over narrow ranges of the dials. This can be avoided by connecting in series with the potentiometer an external unit covering the tolerance range necessary for the measurement, and making balances entirely on this unit. The calibration of the auxiliary potentiometer can be made experimentally by comparison with the bridge dial, or can be calculated from the bridge constants. Our Type 471, 371, or 314 and 214 Potentiometers will be found quite satisfactory for this application.

As an example, consider the measurement on the Type 650-A Impedance Bridge of 500-$\mu\mu$f capacitors with an acceptance tolerance of $\pm 5\%$. With the CRL Multiplier set at 100 $\mu\mu$f, the balance point for 500 $\mu\mu$f is at 5 on the CRL dial, corresponding to a resistance of 5000 ohms on the CRL rheostat. At the balance point for the lower limit of 475 $\mu\mu$f (500 $\mu\mu$f less 5%), the resistance of the CRL dial is 4750 ohms, and at the upper limit is 5250 ohms.

Consequently, a 500-ohm rheostat



can be used, with its dial marked zero at the center and marked +5% and —5% at the ends. The CRL dial should be set at 4750 ohms, or 4.75 on the scale, to make the auxiliary rheostat balance at center scale for 500 $\mu\mu$f.

To connect the auxiliary rheostat, it is necessary to break the connection between the arm of the CRL rheostat and ground, and to insert the auxiliary at this point.

ATTENTION: MIDWEST

● **MR. ROBERT F. FIELD** of our Engineering Department will present a paper entitled "The Behavior of Dielectrics over Wide Ranges of Frequency, Temperature, and Humidity" at the following local sections of the Institute of Radio Engineers:

Cedar Rapids	September 19
Chicago	September 21
Kansas City	September 24
Minneapolis	September 25
Milwaukee	September 26
South Bend	September 27

A Technical Conference on r-f coil design is being arranged by our Chicago office. At this meeting Mr. Field will lead the discussion and present the results of some of his recent work on this subject. This meeting will be held the afternoon of September 18 and engineers interested in attending and participating are invited.

Mr. Kipling Adams of the Service Department will be in Chicago during the last two weeks of September and the first week of October. The purpose of his visit is to offer owners of General Radio equipment in the Chicago area greater assistance in service and maintenance problems than would be possible by correspondence. Mr. Adams will be available for consultation, and arrangements are being made by our Chicago office.

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.

GENERAL RADIO COMPANY
275 MASSACHUSETTS AVENUE
CAMBRIDGE 39 MASSACHUSETTS
TELEPHONE: TROWBRIDGE 4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WORTH 2-5837

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WABASH 3820

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
TEL.—HOLLYWOOD 6321

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