Electronic Relay Tester

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An electronic relay tester has been developed to gauge the contacts of a relay while it is pulsing. The device provides a visual presentation of the gauging position of up to 16 contacts at one time. The equipment has been developed primarily as a means for rapid inspection and concurrent adjustment (when needed) in relay manufacture. It may also be used as a laboratory instrument for studies of timing, chatter, and other performance characteristics of relays.

INTRODUCTION

Electronic equipment has been developed to gauge up to 16 relay contacts simultaneously as the relay operates or releases in pulsing. The system provides a visual presentation on an oscilloscope of the gauge points where the relay armature opens or closes the contact. The position of the armature is shown by the horizontal position of the scope beam. Each particular contact is represented on the scope by one of 16 horizontal lines generated by the motion of the armature. A vertical step on a line indicates the gauge point at which the contact operates.

The device consists of three main parts: (1) An electrostatic gauge to indicate the position of the relay armature, (2) An electronic scanner that continually switches across all the contact pairs, and (3) A brightness control circuit to intensify the beam of the scope when the armature is moving. Fig. 1 shows a schematic diagram of this equipment.

As shown on Fig. 2 the scope, test relay jack and electrostatic gauge are mounted on a bench. The scanner, power supplies and control circuits are mounted underneath the bench.

ELECTROSTATIC GAUGE

As the relay armature moves, its position is indicated at all times by the horizontal position of the scope beam in response to the output voltage of the electrostatic gauge, which is applied to the horizontal plates.

This output voltage varies with the position of the armature which serves as one plate of an air capacitor controlling the frequency of an oscillator. The voltage across a coupling impedance in the plate circuit of the oscillator is rectified to provide the output voltage of the gauge.

The gauge which is shown schematically on Fig. 3 may be divided functionally into three main parts: (1) An oscillator which operates in the region of 100 megacycles; (2) A detector sensitive to the frequency of the oscillator and consequently also sensitive to the position of the armature; and (3) A "zero set" cathode follower which connects the detector output to the input of a dc amplifier. The dc amplifier has suffi-

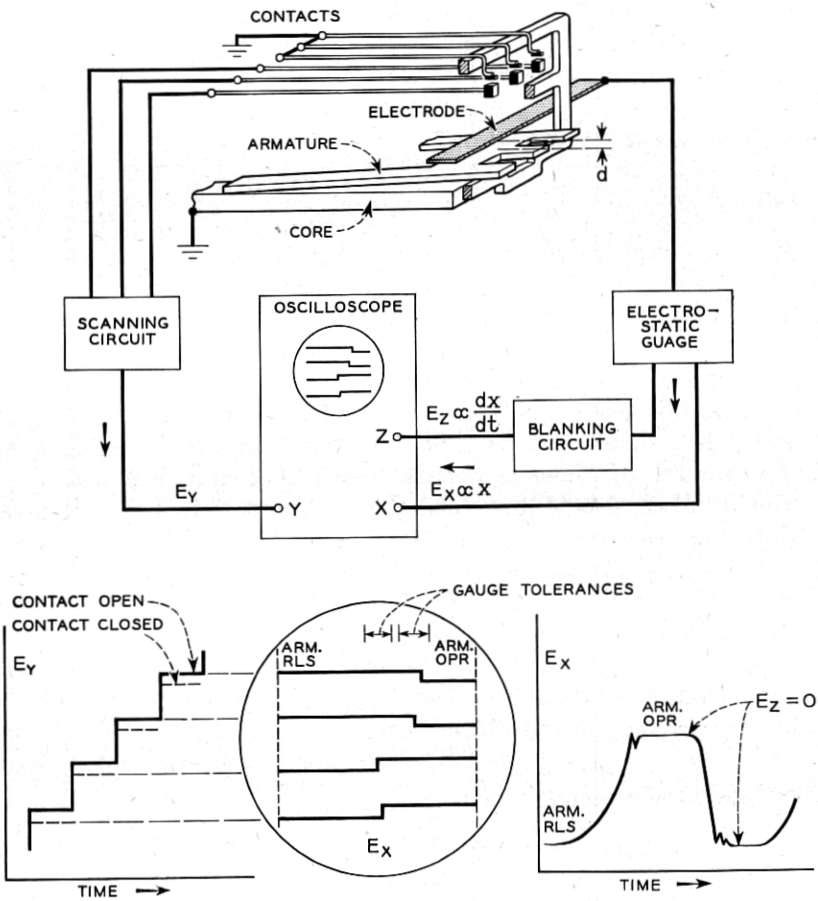

Fig. 1 — Schematic diagram of electronic relay tester.

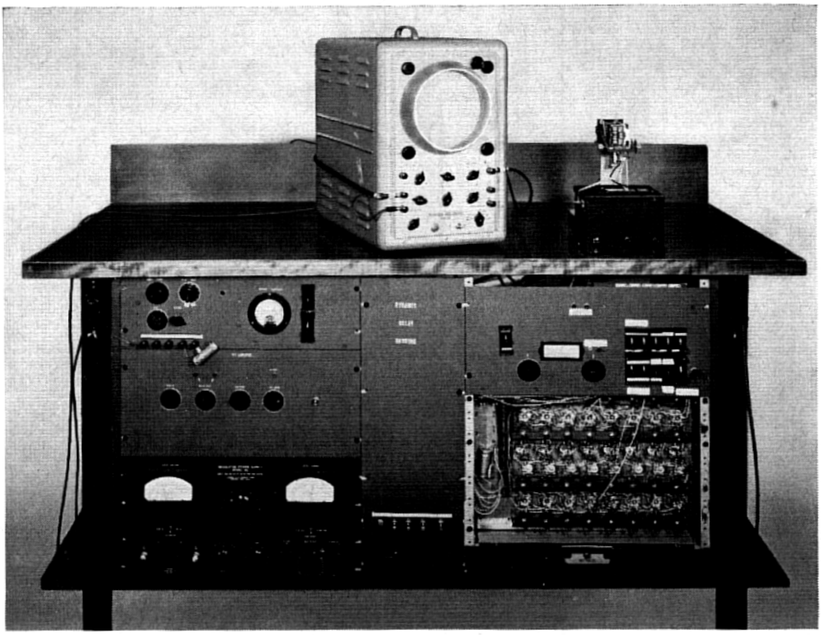

Fig. 2 — Photograph showing arrangement of equipment.

cient gain to provide adequate deflection voltage to the horizontal plates of the scope.

The oscillator comprises a 6AU6 pentode tube and an associated tank circuit. The tube is connected as an electron coupled oscillator with the energy for the oscillations being supplied by the screen circuit. The plate output is a modulated current that passes through the screen and suppressor grids. Considerable isolation of the coupling circuit from the oscillator is obtained by this arrangement.

An antiresonance circuit similar to the tank circuit is used to couple the plate of the oscillator tube to the rectifier. Since the electron coupled oscillator acts as a high impedance generator or constant current source the voltage across the coupling impedance is proportional to the value of the impedance. Hence as the oscillator frequency is shifted by a change in the position of the armature a corresponding shift occurs in the ac voltage across the coupling impedance and rectifier tube (6AL5). The output voltage of the rectifier also shifts with the input to the rectifier since the changes are slow compared with the time constant of the output circuit of the rectifier.

In normal operation the output of the rectifier may vary from 6 volts

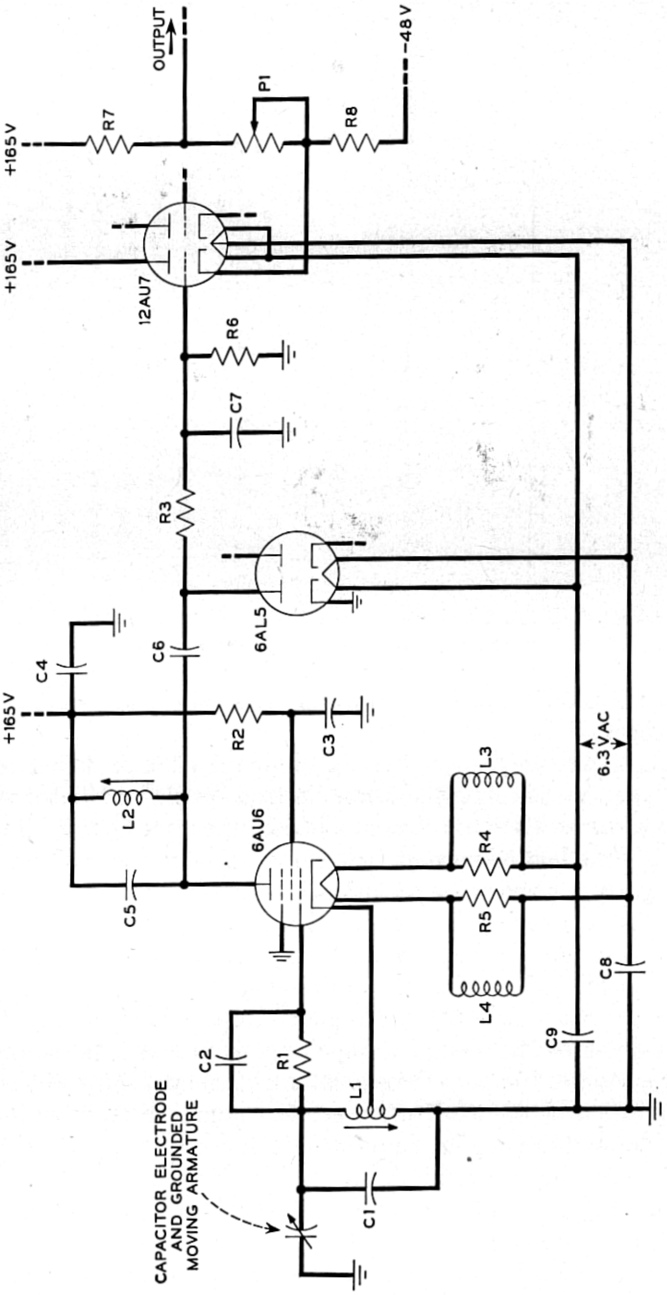

Fig. 3 — Schematic circuit of electrostatic gauge.

to 10 volts with 10 volts appearing when the armature is operated. A typical voltage-displacement curve is shown on Fig. 4. This output is applied to the grid of the "zero set" cathode follower and its bias is set so the output will be from approximately -2 volts to $+2$ volts. This voltage is applied to the horizontal dc amplifier of the scope.

Theory of Operation of Gauge

Since the capacitance probe is in the tank circuit the frequency of the oscillator changes with variations in the separation of the probe electrodes. Hence a displacement of the moving electrode causes a change in the frequency but no change in the amplitude of the alternating current through the pentode plate. The radio frequency voltage that appears across the coupling impedance is the product of the plate current and the coupling impedance.

Since the current is constant in amplitude:

$$E = I_0 Z,$$

where E = *rf* voltage applied to rectifier, I_0 = *rf* plate current from oscillator, and Z = coupling impedance.

Since a change in E is due to a change in the oscillator frequency and the resultant change in Z;

Let

$$f = \frac{\omega}{2\pi} = \text{oscillator frequency},$$

$$f_2 = \frac{\omega_2}{2\pi} = \text{resonance frequency of coupling circuit},$$

$$Q = \frac{\omega_2 L_2}{R},$$

and

$$Y = 1 - \frac{f^2}{f_2^2}.$$

where L_2 = inductance of coupling circuit, and R = resistance of coupling circuit.

The coupling impedance can be written:

$$Z = \frac{\omega L_2 Q}{\sqrt{Q^2 Y^2 + 1}} \tag{1}$$

At resonance $Z_{\text{max.}} = \omega_2 L_2 Q$.

Since the maximum value of E is obtained when Z is at a maximum:

$$\frac{E}{E_{\max}} = \frac{Z}{Z_{\max}} = \frac{1}{\sqrt{Q^2Y^2 + 1}}, \tag{2}$$

provided ω/ω_2 is near unity.

Probe and Grid Circuit of Oscillator

The oscillator frequency is determined by the resonant frequency of the tank circuit. Fig. 3 shows that the tank comprises the capacitance of the probe plus a fixed capacitance and an inductance. The probe which is assumed to be a parallel plate condenser has a capacitance which is inversely proportional to the plate separation.

Let: d be plate separation of probe, d_1 be separation at resonance (where $f = f_2$),

$$x = \frac{d}{d_1}.$$

Then the variable capacitance of probe is given by:

$$C_p = C_1 \frac{d_1}{d} = \frac{C_1}{x}$$

and the total capacitance of the tank by:

$$C_0 + C_p = C_0 + \frac{C_1}{x},$$

where C_0 = fixed capacitance of tank including fixed part of probe capacitance.

Let:

$$\frac{C_1}{C_0} = K,$$

then

$$\omega^2 = \frac{1}{L_1 C_0 \left(1 + \frac{K}{x}\right)} \quad \text{and} \quad \omega_2^2 = \frac{1}{L_1 C_0 (1 + K)},$$

where ω and ω_2 are radian frequencies of the oscillator at probe separations d and d_1 respectively and L_1 is the effective inductance of the tank circuit. It follows that:

$$\frac{\omega^2}{\omega_2^2} = \frac{1 + K}{1 + \frac{K}{x}},$$

and therefore:

$$Y = 1 - \frac{\omega^2}{\omega_2^2} = 1 - \frac{x + Kx}{K + x},$$
$$= \frac{1 - x}{1 - \frac{x}{K}}. \tag{3}$$

This expression for Y may be substituted in (2) giving:

$$\frac{E}{E_{\max}} = \frac{1}{\sqrt{Q^2Y^2 + 1}} = \frac{1}{\sqrt{1 + Q^2\left(\frac{1 - x}{1 + \frac{x}{X}}\right)^2}}. \tag{4}$$

For $x/K \gg 1$ (4) may be written:

$$\frac{E}{E_{\max}} \frac{1}{\sqrt{1 + K^2Q^2\left(\frac{1 - x}{x}\right)^2}}. \tag{5}$$

Equation (5) gives the voltage across the rectifier as a function of probe separation and the product KQ. It can be used to determine the optimum values of: (1) K the ratio of variable to fixed oscillator capacitance, (2) the Q of the coupling impedance, and (3) the range of probe

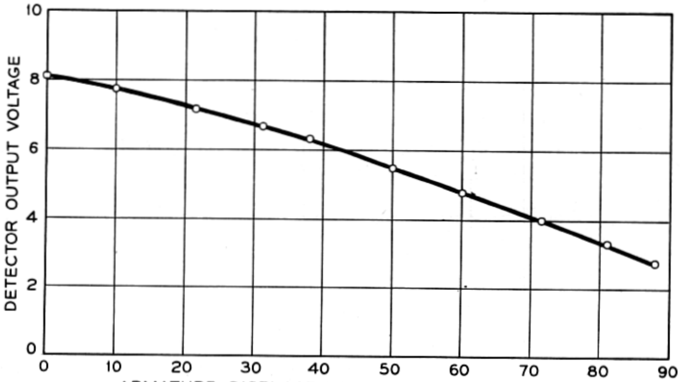

Fig. 4 — Typical output voltage versus displacement curve of the electrostatic gauge.

separations over which a prescribed degree of linearity can be obtained. It can be shown that the maximum range of linearity is obtained with $(KQ)^2 = 2$ and that the center of this range is at $x = \frac{1}{2}$. Fig. 5 is a graph of (5) against x with $(KQ)^2$ set at 2.

SCANNING CIRCUIT

The scanning circuit is a high speed electronic switching and detecting device which rapidly selects successive contacts, checks whether the contact is opened or closed, and displays this information on the vertical plates of the scope. Each contact is assigned a particular vertical reference level. When gauging, each level appears as a horizontal line with a vertical step on the line indicating the armature position for the contact operation.

Electron tubes designated "C" on Fig. 6 serve as switches to connect one contact at a time to the vertical plates of the scope. Each contact is connected to the grid circuit of a C tube. In order to test a contact its

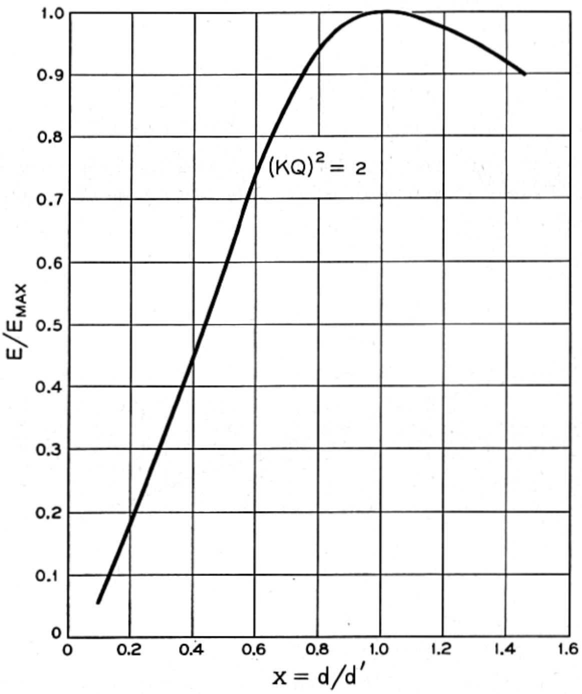

Fig. 5 — Curve showing E/E_{max} versus x with $(KQ)^2 = 2$ computed from equation (5).

associated C tube is made to conduct by shifting the grid voltage. All of the C tube cathodes are connected together to a common cathode resistor which couples the voltages from the contacts to the vertical amplifier of the scope. The plate current that flows when a C tube is fired causes a voltage drop through the common cathode resistor which deflects the scope beam to the proper vertical level. The level is set to the desired value by adjusting the plate circuit resistance. Since the contact under test is connected to the grid circuit, the grid voltage and the cathode voltage are shifted a small amount by opening or closing the contact. That is, when a C tube is fired the vertical plate voltage jumps to one value when the contact is open and it jumps to another slightly different value when the contact is closed. The 16 C tubes corresponding to the 16 contacts under test are fired one at a time in succession by 16 associated multivibrator stages. The multivibrators are connected in a ring so that each stage is fired by the preceding stage. When a stage is fired it holds its C tube in a conducting condition for two microseconds.

Fig. 6 is a detailed schematic of the single stage multivibrator (tubes A and B) with an associated modulator (C) tube. The multivibrators are normally in a stable waiting state and go into a temporary unstable state only when a transient is applied. Normally the A tube is cut off and the B tube is conducting. When a pulse is applied to the A tube grid the A tube conducts and the B tube is cut off. After two microseconds the A tube reverts back to its waiting state and sends a pulse to the next stage. When the B tube is cut off it provides a flat two microsecond pulse through the coupling circuit to the associated C tube.

Each multivibrator stage consisting of the A and B tubes with other circuit elements is mounted on a plug-in turret which may easily be changed in case of trouble.

BRIGHTNESS CONTROL CIRCUIT

When pulsing a relay the armature remains on the operated and released positions for a relatively long time interval. If the intensity of the scope beam is allowed to remain constant the spots at the ends of the traces are bright enough to fog the entire scope face. This makes it difficult to see the relatively weak lines that are caused by the motion of the armature. Therefore a control circuit is provided to brighten the scope trace only when the relay armature is in motion. The circuit shown on Fig. 8 provides the voltage required to intensify the cathode beam of the scope. This voltage is obtained by differentiating the output voltage of the electrostatic gauge. As the latter is proportional to the

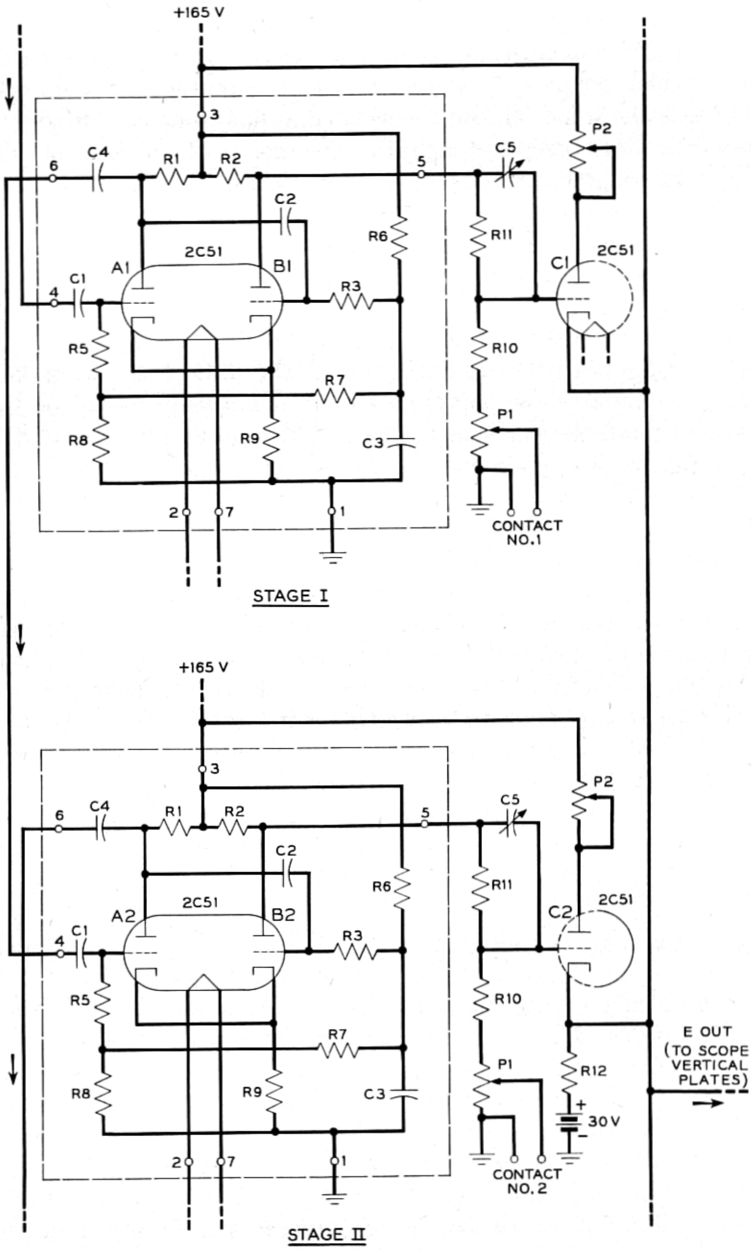

Fig. 6 — Schematic circuit of two switching stages showing modulator tubes (C) and their associated multivibrator tubes (A and B).

armature position, the differentiated voltage is proportional to the armature velocity. After amplification the voltage from the gauge is applied to a tube with a transformer in the plate circuit. The voltage across the secondary coil of the transformer is the differentiated voltage, proportional to the armature velocity. It is applied to a germanium diode bridge, which may be connected as a half-wave or full-wave rectifier by the selector switch. The rectified voltage is amplified and clipped and then applied to the Z axis terminals of the scope. The scope trace is brightened during operate, during release, or during both in accordance with the setting of the bridge selector switch.

GAUGING A RELAY

The relay is plugged into a holding fixture with a jack for the coil and contact terminals. The jack connects the relay coil to the circuit which provides power for operating the relay. It also connects the relay contact terminals to the scanning circuit.

The electrostatic transducer electrode is mounted on a bracket which is attached to the front end of the fixture by means of a hinged bracket.

After the relay is plugged into the jack, it is clamped and the gauge electrode is rotated into position near the armature. Then the "zero set" potentiometer on the dc amplifier is used to align the operated armature position with the zero marking on the calibrated horizontal scale of the scope.

The contact selector switch is used to select the combination of contacts to be scanned such as: all contacts, all breaks, or all makes. For convenience in checking relays with 8 contacts or less a switch on the scanning circuit is used to connect 8 of the multivibrators in a ring instead of 16 so that only 8 lines appear on the scope. These 8 lines may be shifted to obtain greater spacing for easier reading. A typical gauging pattern on an oscilloscope screen is shown on Fig. 7.

This also improves the gauging accuracy which depends upon the amount of armature motion between successive scanning dots. For 16 horizontal lines on the screen the time interval between successive dots is 32 microseconds. For an armature velocity of 30 inches per second the corresponding distance between successive dots on one line is about 1 mil-inch. If 8 lines are used this distance is about 0.5 mil-inches. The gauging error resulting from this dot definition is actually less than indicated because successive operations of the armature give a small random variation in the dot locations.

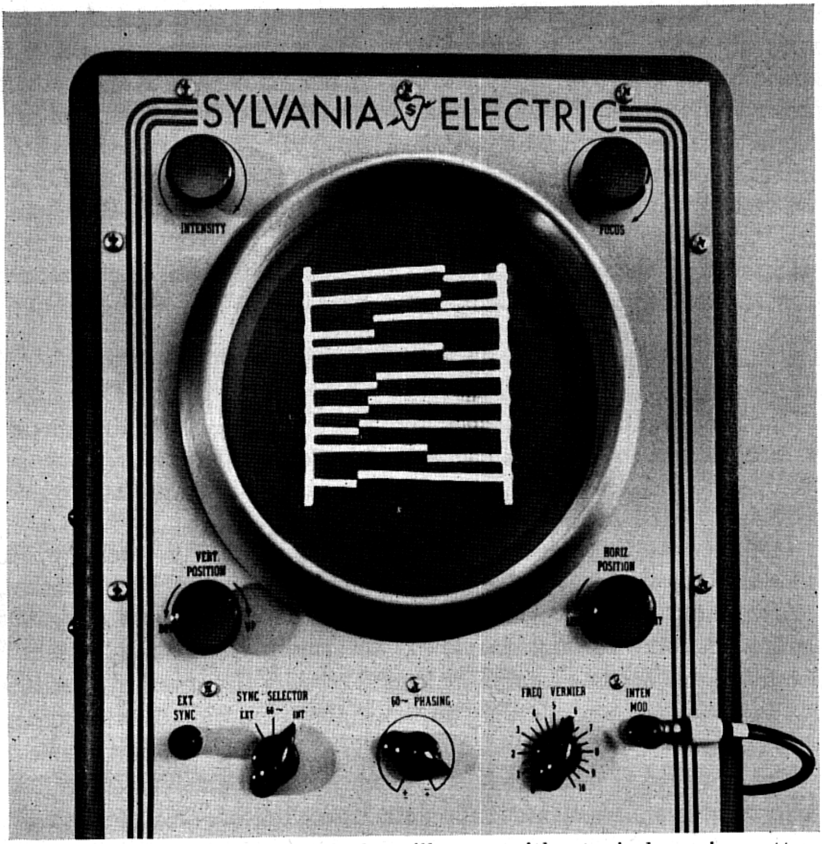

Fig. 7 — Photograph of the 7-inch oscilloscope with a typical gauging pattern on the screen.

The brightness control switch is used to compare gauging when the relay is operating with the corresponding gauging when it is releasing. An apparent difference of 2 to 3 mil-inches is noticed between the operating gauge point of a contact and the releasing gauge point. This measurement change is ascribed to the tip flexure or follow of the contact wire. Contact closure occurs when the contacts first touch, in advance of the short follow travel during which the tension of the contact wire is transferred from the card to the contact. In dynamic operation, the contact opens when it is first struck by the card, before the tension would be transferred statically from the contact to the card. Thus the dynamic contact closure points agree with the static gauging, and differ from the dynamic opening point by the amount of contact follow. Good correlation is obtained between the static and dynamic gauge measurements if make contacts are gauged on operate and break contacts on release.

OTHER RELAY CHARACTERISTICS

Switches are provided to permit other relay charcateristics to be observed on the scope such as armature motion, contact chatter, and the contact operate and release times. The contact gauging is obtained with the horizontal plates connected to the electrostatic gauge. With this setting, the time for a dot to move across the screen may be less than 3 milliseconds (depending on the armature transit time) and contact chatter may be observed during this time.

With a time base sweep on the horizontal plates, the armature motion

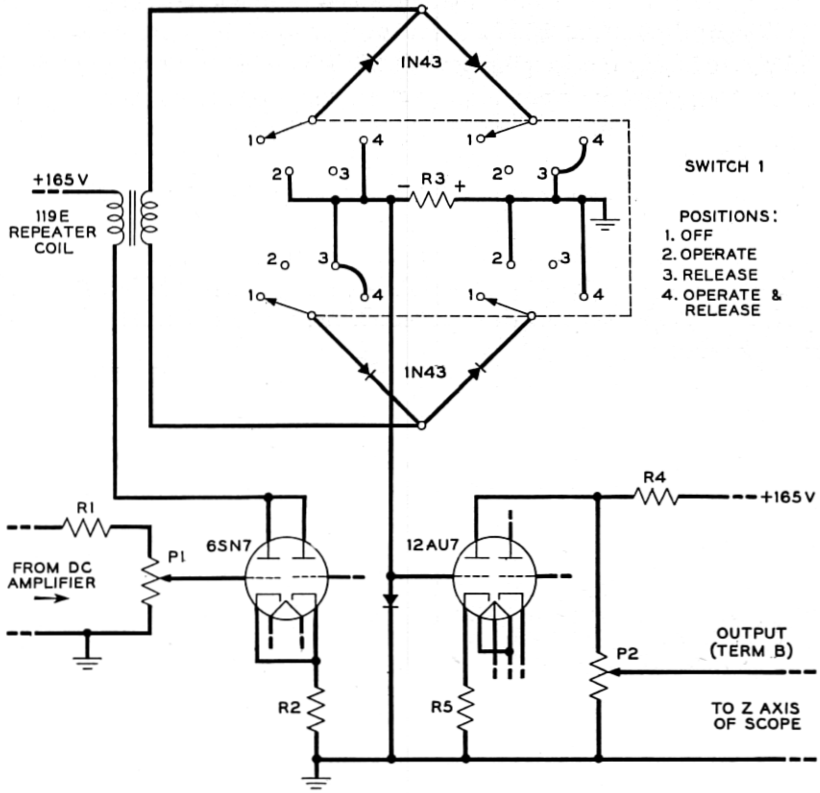

Fig. 8 — Schematic of oscilloscope brightening circuit.

may be put on the vertical plates. The chatter of 16 contacts may also be observed at one time to obtain a quick check of the contact performance. Operate and release times of the contacts may be read directly from the scope if a pip is put on the vertical axis when the test relay coil is energized. The front end of the relay is clamped for all measurements.

Switches are provided to select different combinations of contacts to be checked with either a time base horizontal sweep or with the armature displacement as the horizontal sweep.

DISCUSSION

The electronic relay tester was designed primarily for rapid inspection of wire spring relays. It provides a means for observing the position of the armature for the operation of all contacts simultaneously while the relay is pulsing. This method has several advantages over thickness gauges which are frequently used: (1) The contacts are gauged under conditions of use, that is, the armature moves as in normal operation without touching the gauging device; (2) Inspection is more rapid since the go-no-go positions are displayed on the scope face. Relay spring combinations requiring a sequence of contact operation are readily observed while the relay operates in a normal way; and (3) When relay adjustments are made the results of the adjustment are shown immediately so the contact operate points are centered within the desired range giving more margin for changes that may occur with use. This device is readily changed to measure other relay characteristics that may be of interest such as operate or release time, contact chatter and armature rebound.

ACKNOWLEDGMENTS

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