Automatic Machine for Testing Capacitors and Resistance-Capacitance Networks

By C. C. COLE and H. R. SHILLINGTON

(Manuscript received May 8, 1956)

The modern telephone system consists of a variety of electrical components connected as a complex network. Each year, millions of relays, capacitors, resistors, fuses, protectors, and other forms of apparatus are made for use in telephone equipment for the Bell System. Each piece of apparatus must meet its design requirements, if the system is to function properly. This article describes an automatic machine developed by the Western Electric Company for testing paper capacitors and resistance-capacitance networks used in central office switching equipment.

INTRODUCTION

The capacitors discussed in this article are the ordinary broad limit units made with windings of paper and metal foil, packaged in a metal case. They include both single and double units in a package, connected to two, three, or four terminals. The networks consist of a capacitor of this same type connected in series with a resistor.

The testing requirements for capacitors include dielectric strength, capacitance, and insulation resistance. These same tests plus impedance measurements are specified for networks. In general, requirements of the kind involved here could be adequately verified by statistical sampling inspection. However, in equipment as complex as automatic telephone switching frames, even the minor number of dielectric failures that would elude a properly designed sampling inspection would result in an intolerable expense in the assembly and wiring operations. While engineering considerations thus called for a detailed inspection for dielectric breakdown, it was recognized that detailed inspection of the other electrical requirements could be obtained at no additional expense for labor with automatic testing machines.

DESIGN CONSIDERATIONS

In the development of this machine, the designer was faced with the same problems that obtain in the conception and design of any unit of complex equipment. These included the economic feasibility, reliability, simplicity, and versatility of such a machine.

Economic Feasibility

This can be determined by comparing the cost of performing the operations to be made by the proposed machine with the cost by alternative methods. Estimates indicated that the cost of the machines could be recovered within two years by the saving in labor that would be effected.

Reliability

Reliability has two connotations, (1) freedom from interruptions of production because of mechanical or electrical failure and (2) consistent reproducible performance. A rugged mechanical design combined with the use of the most reliable electrical components available is necessary. In addition, safeguards are required to protect the equipment from mechanical or electrical damage. To achieve consistent reproducible performance, it is important that testing circuits of adequate stability be used. Besides, it was recognized that each circuit should be so arranged that in case of a circuit failure, there would be immediate and positive action by the machine to prevent acceptance of defective product. All circuits are designed to provide positive acceptance. This means that the machine must take action to accept each item of product at each test position. In the case of the dielectric strength tests, a self-checking feature is included.

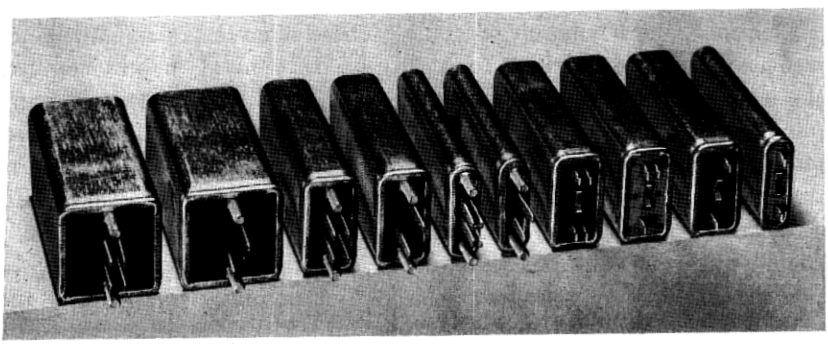

Fig. 1 — Types of capacitors and networks tested.

Simplicity

This type of equipment is operated by non-technical personnel. To minimize the possibility of improper operation of the equipment, it is important that adjustments and judgment decisions by the operator be minimized. From a production standpoint, it is important that the machine be designed to permit quick changes to handle the variety of product to be tested. All "set-ups" are made by the operator and the switching of circuits and changing of contact fixtures are simply and easily done.

Versatility

The product tested by this machine includes a variety of physical sizes and terminal arrangements with a wide range of electrical test requirements (Fig. 1).

a. *Physical Sizes.* The aluminum containers for this type of capacitors and R.C. Networks all have the same nominal length and width but are made in three different thicknesses.

b. *Terminals.* The product is made with terminals of two different lenths, two different spacings, and four different patterns connected in eight combinations. It is necessary to provide contact fixtures and switching facilities to handle all of these combinations.

c. *Electrical Tests*

(1) Dielectric strength tests are made between terminals, and between terminals and can, on single unit packages. Two-unit packages require an additional test between units.

(2) Capacitance: The capacitance of the product to be tested ranges from 0.02 mf to 5.0 mf or any combination within this range in one- or two-unit packages with no series resistance in the case of capacitors, but with a series resistor from 100 ohms to 1,000 ohms in the case of networks. This problem is discussed in more detail in the description of the capacitance test circuit.

(3) Insulation Resistance: The minimum requirements vary from 375 megohms to 3,000 megohms.

(4) Impedance: The RC networks have impedance requirements at 15 kc that range from 100 ohms to 1,000 ohms.

MECHANICAL ASPECTS OF TESTING MACHINE

Packaging of the product precludes a magazine type of feed because the variety of terminal combinations associated with two-unit packages necessitates orientation in the contact fixtures that can not be done by

1. HANDWHEEL FOR POSITIONING TEST FIXTURES.
2. ROTARY FEED MECHANISM.
3. PRODUCT PASSING ALL TESTS EJECTED FROM FIXTURE.
4. INSULATION RESISTANCE TEST PANEL AND TERMINAL COMBINATION "SETUP" SWITCHES.
5. CABINET HOUSING TEST CIRCUITS.
6. CONTAINERS FOR REJECTED PRODUCT.

Fig. 2 — Testing machine in operation.

mechanical means. A turret type construction is used to permit one operator to perform both the loading and unloading operations.

Fig. 2 shows this machine in operation. The networks or capacitors are fed into the fixtures by an operator and as the turret carries the fixtures past the feed mechanism, rollers on the feed mechanism are synchronized with the fixtures and the roller forces the unit under test into the contact fixture against a spring loaded plunger to make contact with the fixture contact springs. Also, synchronized with the feed mechanism is the closing of the gripper hook on the bottom end of the can containing the unit under test.

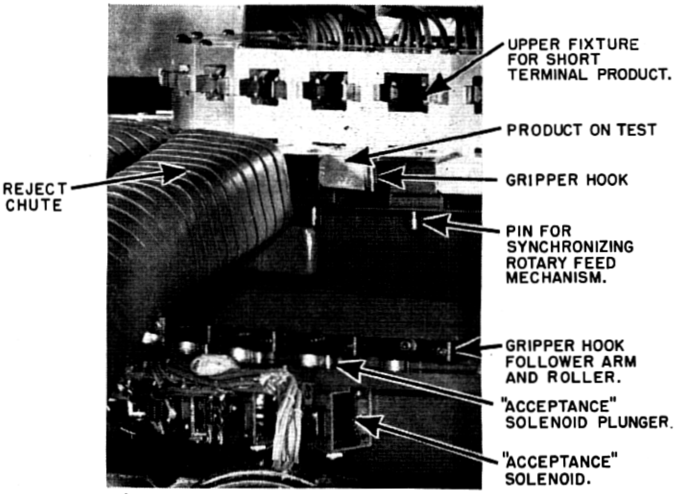

Fig. 3 — View of rejection and acceptance mechanisms.

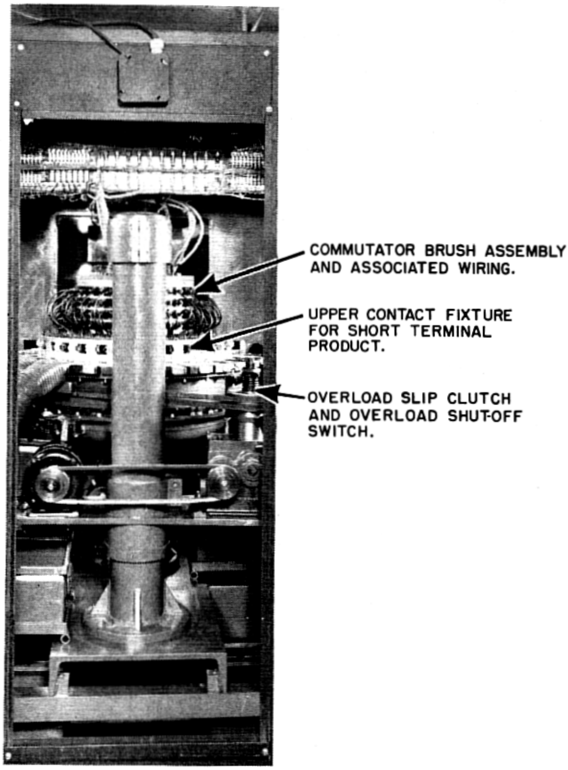

Fig. 4 — View of turret.

The acceptance or rejection of a unit under test at any one of the six test positions depends on whether the test on the unit energizes the "acceptance" solenoid associated with that test position. The gripper hook, which locks the unit under test in the contact fixture, is connected to a release shaft, follower arm, and roller (see Fig. 3). The roller rides in a track in which the plunger of each "acceptance" solenoid lies unless removed by energizing the solenoid from its associated test circuit. In the case of a defective unit, the acceptance solenoid is not energized and the roller in passing over the plunger of the "acceptance" solenoid trips the gripper hook and the spring loaded plunger in the contact fixture ejects the defective unit. Units that pass all tests are ejected on a turntable to the left of the operator from which they are stacked in handling trays by the operator.

The turret assembly includes the test fixtures, the gripper hooks and associated release shaft, follower arm and roller, and the brush assembly

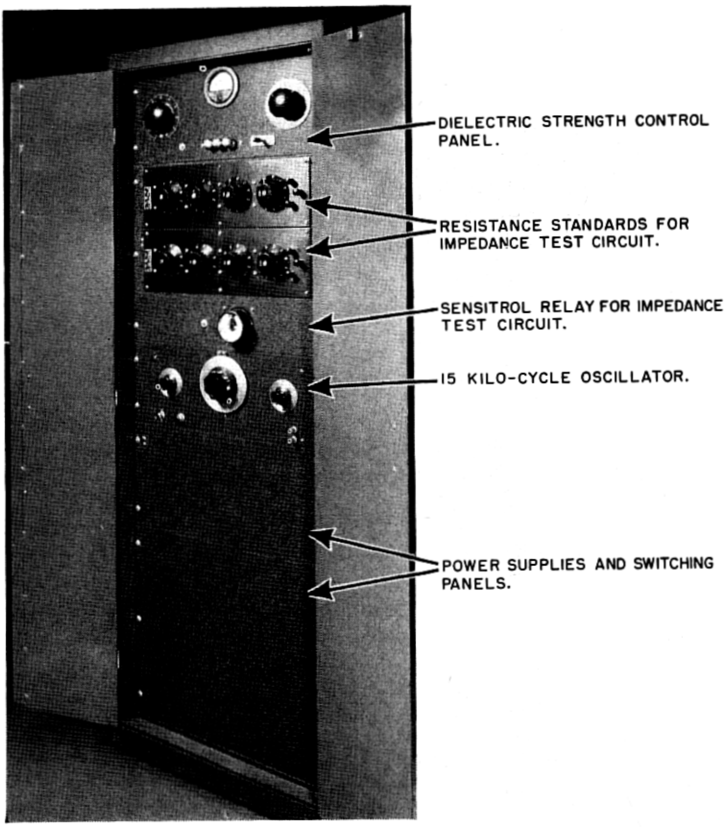

Fig. 5 — Control panels for dielectric strength and impedance tests.

connected to the test fixtures. The commutator is stationary and its segments are connected to the test circuit through permanent wiring. Fig. 4 shows the turret. Each fixture has two sections, one above the other, with the contacts wired in parallel. The lower section is designed for making contact to stud mounted units with long terminals and the upper section for strap mounted units with short terminals. To change the machine "set-up" from one fixture to the other, the turret assembly is raised or lowered by means of the hand wheel, shown on Fig. 2, located at the right of the operator. This feature was incorporated in this machine to facilitate rapid "set-up" which is essential for testing small lots. An overload clutch is incorporated in the driving mechanism to prevent mechanical damage to the machine in case of a "jam".

Fig. 5 shows the control panels for dielectric strength and impedance and Fig. 6 shows the control panels for the capacitance circuits.

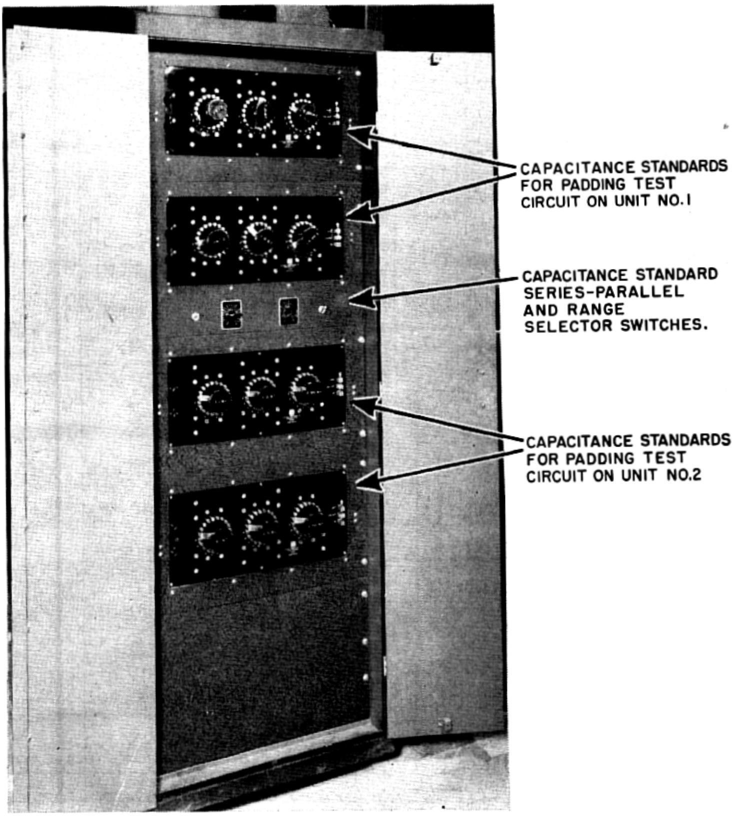

Fig. 6 — Control panels for capacitance circuits.

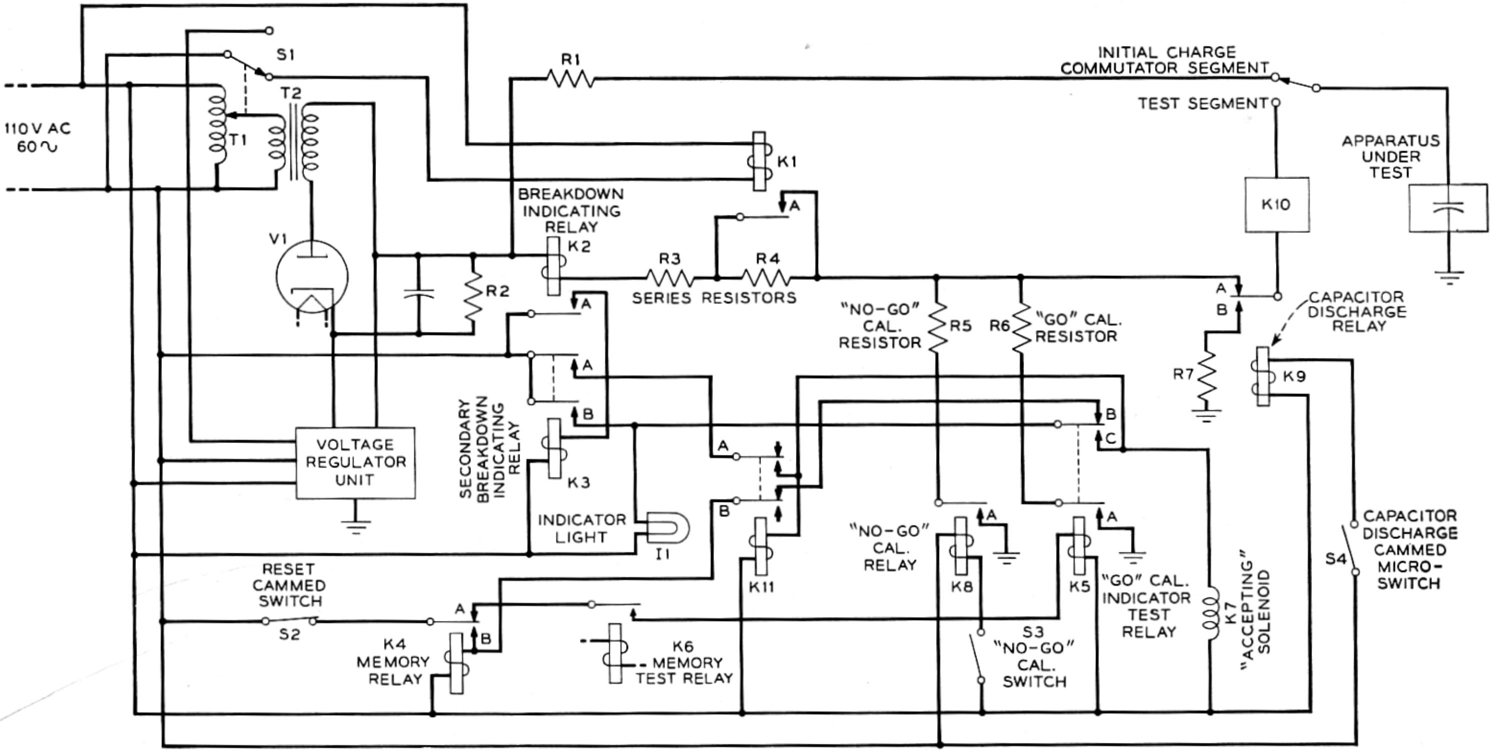

Fig. 7 — Simplified schematic of dielectric strength test circuits.

ELECTRICAL ASPECTS OF TESTING MACHINES

Tests are applied to the product in sequence during one revolution of the turret.

1. Dielectric strength test between terminals and can, and between terminals and studs.
2. Dielectric strength test between units in the same can when the can contains two units.
3. Dielectric strength test between terminals of each unit.
4. Impedance test.
5. Capacitance test.
6. Insulation resistance test.

Dielectric Strength Test Circuit Operation

Since the three dielectric strength tests are made on similar circuits, the operation of one of these circuits is described using the nomenclature and circuit designations shown in Fig. 7. A graphic interpretation of the circuit operations shown in Fig. 7 is given in Fig. 8.

The "heart" of each circuit is a calibrated current sensitive relay K2 that operates on minute values of current resulting when a defective unit under test attempts to charge on the "test" commutator position.

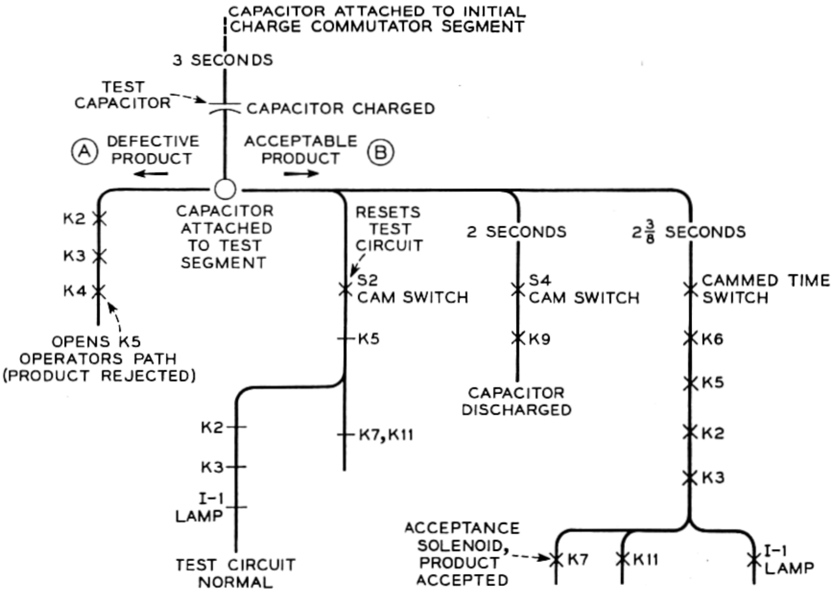

Fig. 8 — Sequence chart for dielectric strength test circuit operation.

Two commutator segments are required to make a dielectric strength test. These segments are known as "initial charge" and "test". After the unit under test has been charged at the test voltage for three seconds on the "initial charge" segment, it passes to the "test" segment in which the unit is again connected to the test voltage through relay K2, current limiting and calibrating resistors R3 and R4 and the contacts on the preset terminal selecting relays K10.

One of the two conditions (under heading A and B below) may be encountered in making this test and the circuit operation for each will be discussed separately.

A. Circuit Operation for Acceptable Product. An acceptable product retains the charge received on the "initial charge" segments and when this unit reaches the "test" segment, no further charging current of a magnitude great enough to operate relay K2 will flow through the unit. Two seconds after the unit under test has been connected to the test segment, a cammed timing switch S4 closes to operate discharge relay K9 to discharge the unit under test to ground through R7. The "self-checking" feature mentioned earlier in this article under "Design Considerations" functions as follows: After the unit under test has been on the "test" segment for approximately 2⅜ seconds, a cammed timing switch (not shown) closes the memory test relay K6 which in turn closes the "go" calibration indicator relay K5 and the "A" contacts on this relay grounds the high voltage test circuit through resistor R6. This resistor is of such a value as to permit sufficient current to operate relay K2. The contacts on relay K2 are not adequate to carry much current, so an auxiliary relay K3 is closed through contacts "A" on relay K2. Contacts "B" on relay K3 closes the indicator light circuit I1 and operates relay K11 and the acceptance solenoid K7. Contacts "A" on the same relay lock relay K11. The circuit is reset for the next unit to be tested by momentarily opening the reset cammed switch S2. Relay K11 was added to the circuit to eliminate a "sneak circuit" that occurred occasionally following the reset when relay K5 opened faster than relay K3. This would result in relay K4 operating to reject the next unit tested. Relay K1 is controlled by switch S1 operated by the manual control T1 on the test voltage power supply. The function of this relay is to add calibrating resistor R4 to the test circuit for voltages above 1,000 volts. Resistor R5, relay K8, and switch S3 control the manual calibrating "No Go" circuit for breakdown indicating relay K2.

B. Circuit Operation for Defective Product. Defective product will not retain the charge it received on the "initial charge" segment and when it reaches the "test" segment, current will flow through the breakdown indicating relay K2 in an attempt to charge the defective unit, but this current will close relay K2 which in turn closes relay K3. This completes the circuit through the "B" contacts of relays K3, K5, and K11 to close memory relay K4. The closure of relay K4 prevents the memory test relay K6 from closing the "go" calibration indicator relay K5, thereby leaving contact "C" open on relay K5 and no power is applied to the "acceptance solenoid" K7 circuit, which rejects the unit under test.

IMPEDANCE — TEST CIRCUIT OPERATION

The impedance test is made with a 15-kc circuit (see Fig. 9). One arm of the circuit, composed of resistor R12 paralleled by capacitor C5 and the unit under test, is compared with another arm, composed of resistor R11, paralleled by capacitor C4 and either one of two resistance boxes, R13 and R14 respectively, representing maximum and minimum impedance limits. The detector consists of a balanced diode V2 with a 1–0–1 microampere sensitrol relay K24 connected between the diode cathodes. If the impedance of the unit under test falls within the limits for which the resistance boxes were set, the acceptance solenoid will be energized to accept the unit under test. A product outside the preset limits is rejected because the acceptance solenoid is not energized.

The circuit operation is discussed for the following four conditions under A, B, C, and D.

A. Impedance Test on Dual Unit Capacitors

This test is made on capacitors to prevent shipment of resistance-capacitance networks mislabeled as capacitors. Fig. 9 shows dual unit networks connected to the test terminals. Capacitors to be tested are connected to these same terminals. The greater than minimum test cutout relay K18 is preset closed by the switching circuit K23. The cammed memory reset timing switch S14 (normally closed) is opened momentarily to clear relay K19, K20, and K21 at the start of the test.

The sensitrol relay reset switch S16 is cammed shut momentarily to reset the contactor on the sensitrol relay K24. With relay K26 open, the "less than maximum" resistance box R13 is connected to the test circuit. If unit "A" of the dual unit capacitor under test is acceptable product, the contactor on sensitrol relay K24 will close on contact "A", which applies power to close and lock test No. 1 "less than maximum" memory relay K19. Cam operated switch S13 applies power to close relay K26 to connect the "greater than minimum" resistance box R14 into the test circuit. This resistance box is set on zero ohms when capaci-

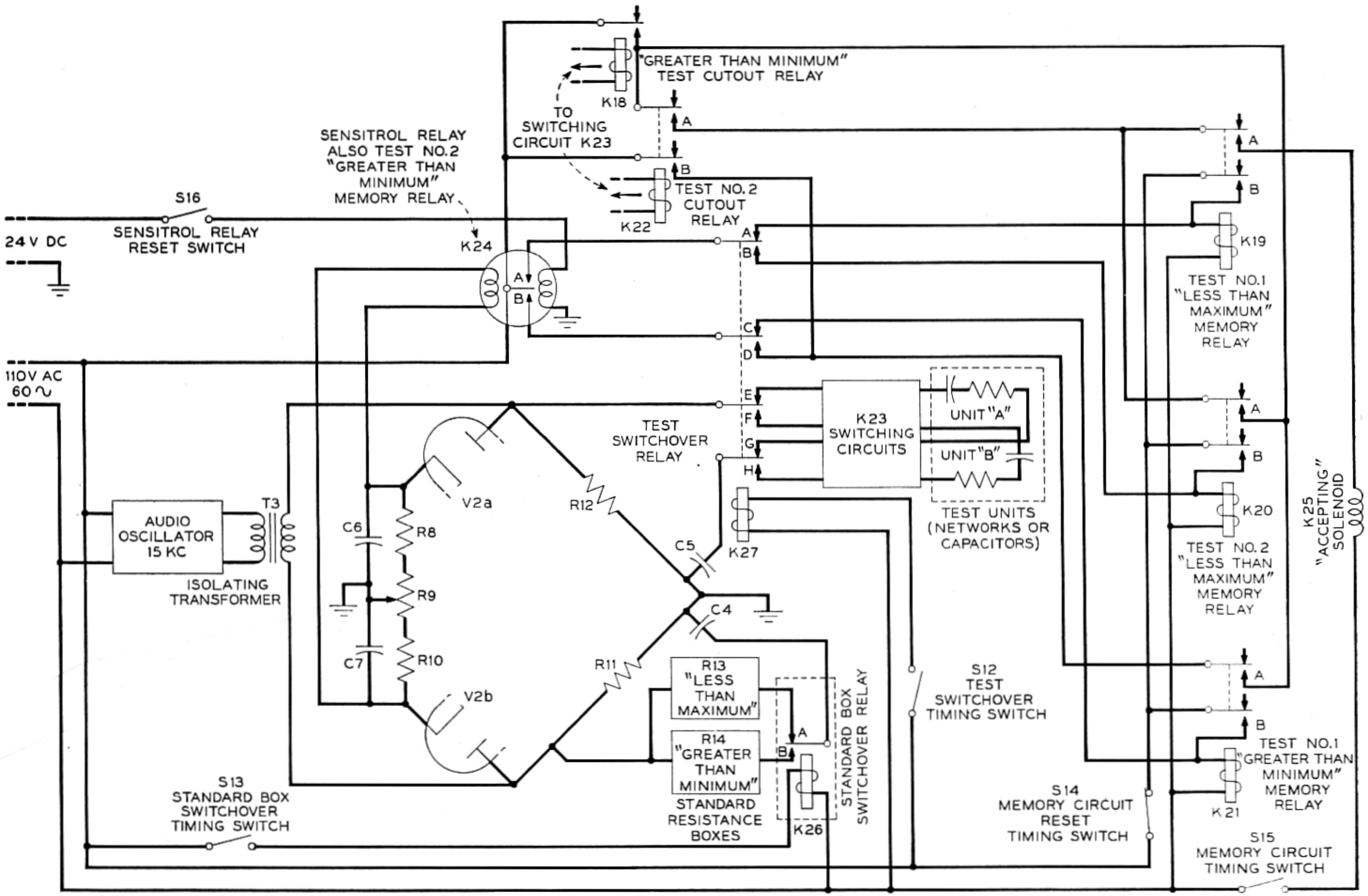

Fig. 9 — Simplified schematic of impedance test circuits.

tors are tested. Sensitrol relay reset switch S16 is cammed shut momentarily to reset sensitrol relay K24, after which the sensitrol relay contactor closes on its "B" contact, thereby applying power to close and lock test No. 1 "greater than minimum" memory relay K21.

Switch S13 is cammed open which opens relay K26 and connects the "less than maximum" resistance box R13 into the test circuit. At the same time switch S12 is cammed shut to close relay K27 which disconnects unit "A" from test and connects unit "B" to the test circuit. Switch S16 is cammed shut momentarily to reset the sensitrol relay contactor. If the unit "B" on test is an acceptable product, the sensitrol relay contactor will close on its "A" contacts and applies power to close and lock test No. 2 "less than maximum" memory relay K20 through contacts "B" of relay K27.

Switch S13 is cammed shut to close relay K26 and connect the "greater than minimum" resistance box R14 into the test circuit. Switch S16 is cammed shut momentarily to reset the sensitrol relay K24 after which its contactor closes on the "B" contact for acceptable product. Memory circuit timing switch S15 is cammed shut and power from one side of the 110 volt ac line flows through the acceptance solenoid, contacts "A" on relay K19, contacts "A" on relay K20, the closed contacts on relay K18 to the other side of the 110-volt ac line to close K25 and to accept the dual unit capacitor under test. The failure of either relay K19 or K20 to operate because of defective product tested opens the acceptance solenoid circuit and rejects the capacitor tested.

B. Impedance Test on Single Unit Capacitors

The impedance test on a single unit capacitor is identical with the testing of dual unit capacitors, except test No. 2 cutout relay K22 is preset closed and test No. 2 "less than maximum" memory relay K20 is not operated since only a single unit is tested.

C. Impedance Test on Dual Unit Networks

The impedance test on dual unit networks is identical with the test for dual unit capacitors, except the "greater than minimum" test cutout relay K18 is not preset closed and the resistance boxes R13 and R14 are set to represent maximum and minimum limits.

D. Impedance Test on Single Unit Networks

The impedance test on single unit networks is identical with the test of dual unit networks except test No. 2 cutout relay K22 is preset closed for the same reason given above for the test of single unit capacitors.

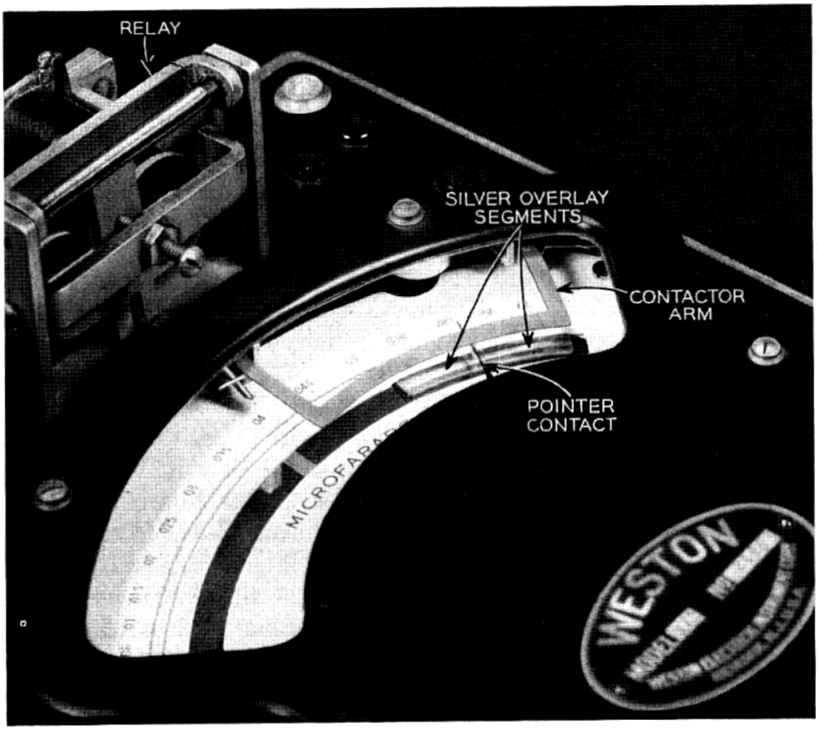

Fig. 10 — Details of modified microfarad meter.

CAPACITANCE TEST CIRCUIT OPERATION

The wide range of capacitance values to be measured, both with and without the series resistance in resistance-capacitance networks, and the one and two-unit construction of the product imposed limitations on the type of capacitance measuring circuits that could be used in this machine. The method selected consists of modified Weston Model 372 microfarad meters that automatically set up external circuits associated with the meters to accept or reject the product as determined by limits preset into the machine.

Two decade capacitance boxes, having a range from 0.001 to 1.0 mf in steps of 0.001 mf are connected in series or parallel with the capacitor on test to make the resultant capacitance fit the range of the meter and control the maximum and minimum limits. This procedure increases the number of capacitor codes that may be tested on a given meter. Capacitors from 0.02 to 5 microfarads are tested on this machine to an accuracy of ±2 per cent.

The modified microfarad meters are equipped with two brass segments, covered with an overlay of silver (Fig. 10). These segments are mounted end to end in a predetermined cutout portion of the meter scale, representing maximum and minimum capacitance conditions. The physical distance between the adjacent ends of these two segments is as small as possible without the two segments touching. A small silver contact is mounted on an insulated portion of the meter pointer, directly above but not touching the segments while the meter pointer traverses its arc of rotation. The armature of the relay, mounted on the meter, actuates a contactor arm which forces the silver contact on the pointer down against the silver overlay segment, thus closing external circuits connected to the segments and contactor.

The testing machine is equipped with three ranges of the special microfarad meters as follows:

1. Suppressed scale from 1.2 to 1.8 mf, with the dividing point between the two segments at 1.60 mf.
2. Suppressed scale from 0.25 to 0.75 mf, with the dividing point between the two segments at 0.63 mf.
3. Suppressed scale from 0.051 to 0.075 mf with the dividing point between the two segments at 0.062 mf.

Two meters for each of the above ranges are necessary in each testing machine, one for each unit in a dual unit. Likewise, four capacitance boxes are necessary, two for each unit in a dual unit.

The discussion that follows, which is divided into two headings, A and B, is a detailed description of the capacitance test circuit. The circuit component designations are those shown in Fig. 11.

A. *Capacitance Test on Dual Unit Capacitors or Networks*

The cammed switch S5 is opened momentarily at the beginning of the test to restore the test circuit to normal; following this, the cammed switch S8 closes and operates relay K14, which applies power and closes the power supply circuit through the microfarad meters and the capacitor on test.

The capacitance decade box "less than maximum" C2 is shown in series with test capacitor No. 1 by the preset series-parallel switch S10, and in a like manner a capacitance box is connected in series with test capacitor No. 2.

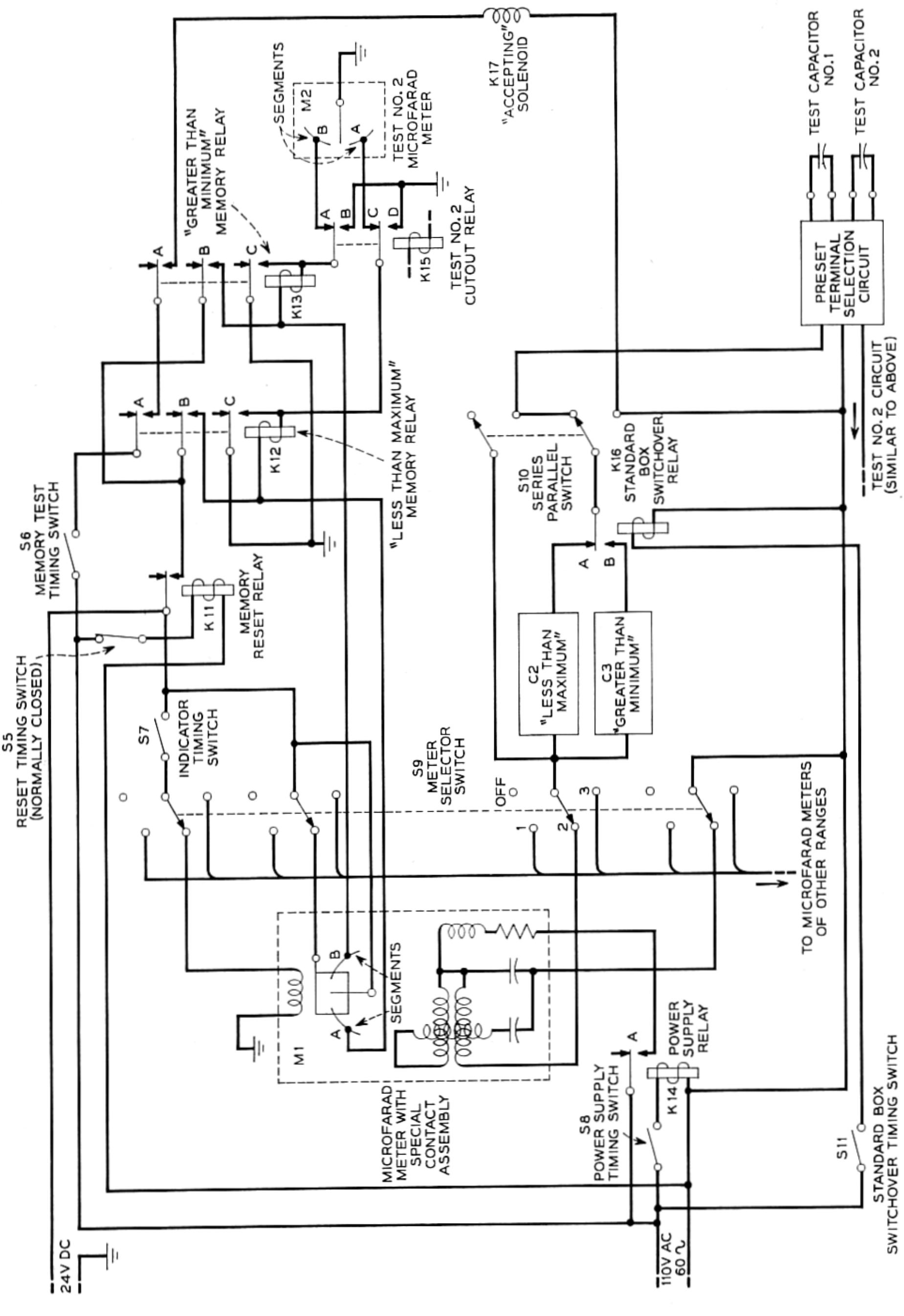

Fig. 11 — Simplified schematic of capacitance test circuits.

Note: The capacitance decade box for Test No. 2 is not shown in Fig. 11. Also, only the segments for M2 Test No. 2 microfarad meter are shown.

If capacitor units No. 1 and No. 2 under test are acceptable product, the pointer on the microfarad meters M1 and M2 will both swing to segment "A". The cammed switch S7 will close and energize the relay on the microfarad meters (not shown on meter M2) which will operate the meter contactor and close the circuit through segments "A" of meters M1 and M2 and apply 24 volts dc to close and lock the "less than maximum" memory relay K12.

The cammed switch S7 is opened to release the meter pointer from segments "A" on M1 and M2. Cammed switch S8 is opened momentarily to release relay K14 which removes the test voltage from the capacitors on test and from meter M1 and M2. During this interval cammed switch S11 is closed to energize relay K16 which connects the "greater than minimum" capacitance box C3 in series with capacitor unit No. 1 on test and meter M1. In a like manner a second "greater than minimum" capacitance decade box (not shown on Fig. 10) is connected in series with capacitor unit No. 2 and microfarad meter No. 2. If the capacitor units No. 1 and No. 2 under test are acceptable product, the microfarad meter pointers will swing to segments "B". The cammed switch S7 will close and energize the relay on the microfarad meters M1 and M2 which will operate the contactor that depresses the M1 and M2 meter pointers against segments B and closes and locks the "greater than minimum" memory relay K13. With relays K12 and K13 closed as described above, the cammed switch S6 is closed which operates the acceptance solenoid K17 through the "A" contacts on relays K12 and K13 to accept the dual unit capacitor under test.

It may be readily observed that in case either or both of the capacitor units on test are out of limits, the circuit will not close either or both relays K12 and K13, which would leave the acceptance solenoid K17 circuit open, and the product would be rejected.

B. Capacitance Test of Single Unit Capacitors or Networks

The capacitance test of single unit capacitors is the same as for dual unit capacitors, except test No. 2 circuit and test No. 2 microfarad meter M2 are not used. Test No. 2 cutout relay K15 is closed to apply ground to its contacts B and D.

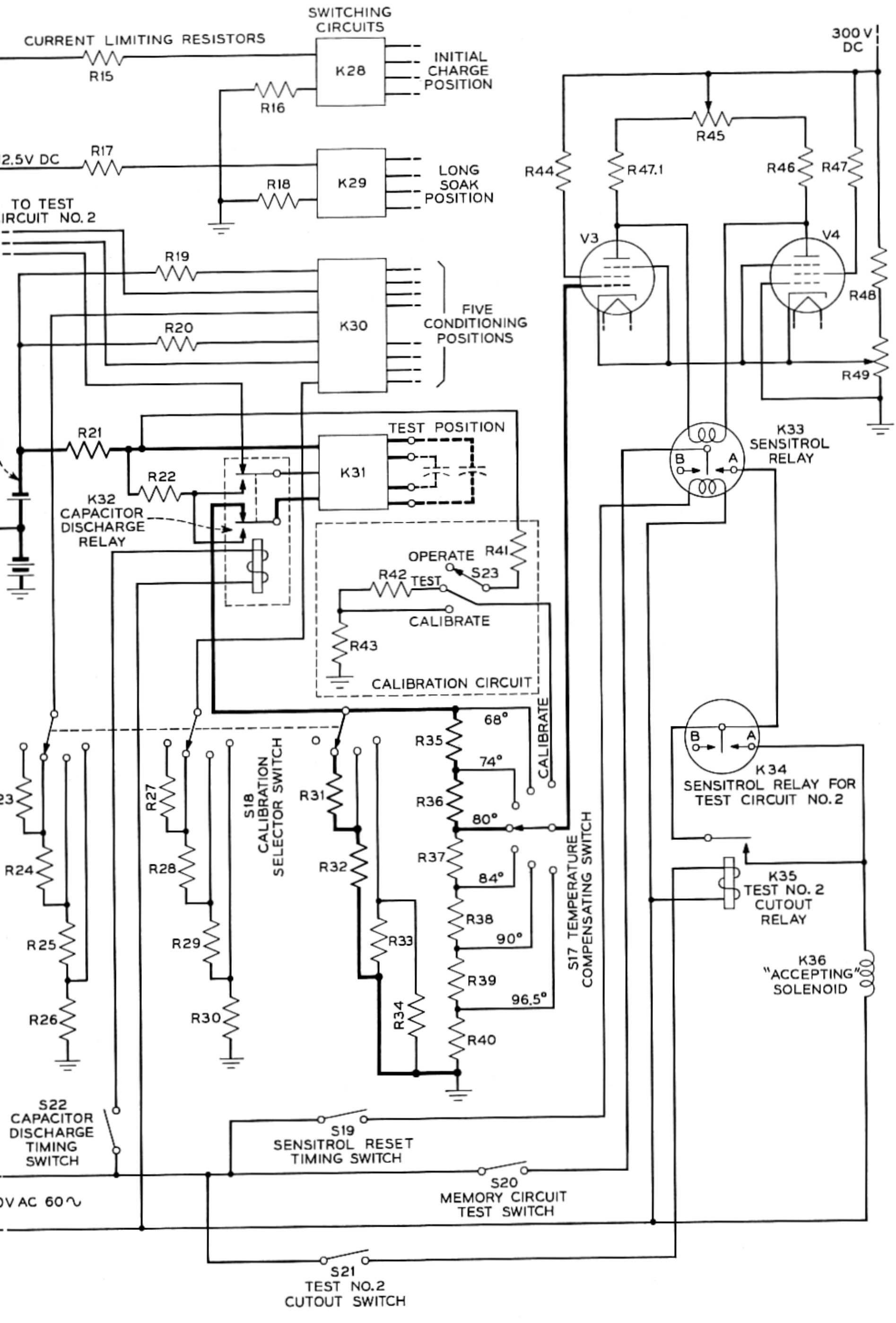

Fig. 12 — Simplified schematic of insulation resistance test circuits.

INSULATION RESISTANCE TEST CIRCUIT OPERATION

In general, the insulation resistance test consists of a charging period and a test period. The charging of the unit under test requires 10 positions or 30 seconds time to insure that the unit is thoroughly charged before it reaches the test position. At the test position the capacitor or network on test is connected to form part of a voltage divider in the grid circuit of a sensitive balanced detector. This sets up relays to accept or reject the unit under test depending on whether the unit meets the limits for which the circuit was preset and calibrated. Two insulation resistance circuits are required, one for each unit in a dual unit capacitor or network. A calibrating circuit is provided by switch S23 and resistors R41, R42, and R43.

The discussion that follows is a detailed description of the sequence of operation of the insulation resistance test circuit. The component designations are those shown on Fig. 12. The discussion is divided into two headings A and B as follows:

A. Insulation Resistance Test on Dual Unit Capacitors or Networks

The capacitor or network on test is automatically connected in succession to the INITIAL CHARGE POSITION, the LONG SOAK POSITION and FIVE CONDITIONING POSITIONS which assures that the acceptable product is thoroughly charged before it reaches the test position. The switching circuits K28, K29, K30, K31 switch S18, and the temperature compensating switch S17 are manual preset switch circuits for the particular code on test.

For the sake of simplicity, the balanced detector and the reset solenoid for sensitrol relay K34 for test circuit No. 2 are not shown. If the insulation resistance of the units on test meets the limits for which the circuit was calibrated and preset, the contactor on K33 and K34 both close on the "A" contacts. Switch S20 is then cammed closed to apply power through the "A" contacts on the sensitrol relays to energize the acceptance solenoid K36 to accept the units on test. At the close of the test, capacitor discharge timing switch S22 is cammed closed, thereby closing the capacitor discharge relay K32 which discharges the units on test before they are ejected as acceptable product. It may be readily observed from the schematic that a unit or units defective for insulation resistance will fail to close either or both of the "A" contacts on the sensitrol relays K33 and K34, which leaves the acceptance solenoid circuit K36 open, thereby rejecting the units tested.

B. Insulation Resistance Test on Single Unit Capacitors or Networks

The insulation resistance test on single unit capacitors or networks is the same as for dual units, except the second test circuit is not required and test No. 2 cutout switch S21 is closed to operate test No. 2 cutout relay K35 which eliminates the second test circuit and its sensitrol relay K34.

CONCLUSION

This machine has been in successful operation on a multishift basis for several years and has proven itself economically. Inspection of the product tested shows that the machine's performance, quality wise, is highly satisfactory. Difficulties that have been encountered were largely those associated with product handling, contact fixtures, etc. Machines of this type that are planned for the future will make use of circuitry developed since this machine was built, but many of the features described will be incorporated.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions to the development of this machine of G. E. Weeks of the Western Electric Company S. V. Smith and S. E. Frisbee of the Electric Eye Company.