INSTRUCTIONS

GEH-1769B
SUPERSEDES GEH-1769A AND GEI-25360B

DIRECTIONAL DISTANCE (REACTANCE) RELAYS

Type GCX17

LOW VOLTAGE SWITCHGEAR DEPARTMENT

GENERAL ELECTRIC

PHILADELPHIA, PA.

CONTENTS

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DIRECTIONAL DISTANCE (REACTANCE) RELAYS TYPE GCX17

INTRODUCTION

The Type GCX17 relay is a high-speed directional distance relay intended for the protection of transmission lines. It contains two basic units, the ohm unit and the mho directional unit. The ohm unit operates on reactance and is therefore particularly applicable to short lines because it is unaffected by arc resistance. This relay is used to protect transmission lines, either single or parallel, from phase-to-phase, three-phase, or double-phase-to-ground faults.

APPLICATION

For three-step distance protection of transmission lines, the Type GCX17 relay is used in conjunction with a Type RPM11 timing relay. Fig. 16 shows a stepped time-impedance characteristic for several transmission line sections. The instantaneous or first zone operates with no intentional time delay while the second or intermediate zone and the third zone operate through the Type RPM11 timing relay. Typical external connections for such a protective system are shown in Fig. 4. The Type RPM11 timing unit uses the power from a discharging spring which is wound by a rotary solenoid. The time is regulated by an induction drag element. The device contains two time-delay momentarily-closing contacts which close in two independently adjustable times. These contacts provide the necessary time delay for the second and third steps of transmission-line protection.

The Type RPM11 timing unit also contains an auxiliary element (TX) whose contacts control the timing unit rotary solenoid. This auxiliary element is a telephone-type relay and two of its normally-open contacts in series are used to control the solenoid.

Instruction book GEI-25364 gives detailed information on the Type RPM11 timing relays.

The Type GCX17 relay is also readily applicable to the three step distance protection of transmission lines using carrier current relaying.

The average operating times, both with and without bus side PT's for the 0.25 ohm, 0.5 ohm and 1.0 ohm relays are shown in Figs. 18, 19, 20, 21, 22 and 24.

OPERATING CHARACTERISTICS

Both the mho and ohm units are supplied with current from two phase conductors and the potential between them. The schematic connections for these two units are shown in Fig. 3. The mho unit has its side poles energized by the potential to produce the polarizing flux. The front pole is energized by current to produce a directional torque dependent upon the phase angle between this current and the polarizing voltage. The back pole provides the restraining torque.

In the ohm unit, the front and back poles produce the polarizing flux by means of current coils. The flux in the right hand or current pole is made to lag its current by about 90 degrees and, in conjunction with the polarizing flux, produces an operating torque. The left hand or potential pole flux acting in conjunction with the polarizing flux produces a restraining torque. The potential coil produces a restraining torque only when the voltage on its circuit is leading the polarizing current.

MHO UNIT

The mho unit has a circular impedance characteristic that passes through the origin and has its center on the line of the angle of maximum torque (see Fig. 1). The ohmic reach of the mho unit can be adjusted to a minimum of 2.5 ohms phase-to-neutral. The ohmic reach can be extended by reducing the percentage of the voltage supplied to the restraint circuit through the E^2 taps (see Fig. 10). The diameter of the mho unit circular characteristic is the ohmic reach of the unit and can be determined from the equation:

$$\text{Ohmic reach at line angle} = \frac{250 \cos (\phi - \theta)}{E^2 \text{ tap setting } (\%)}$$

where θ is the angle of maximum torque of the unit and ϕ is the angle of the line. For an E^2 tap setting of 100 per cent, the ohmic reach is 2.5 ohms when the angles ϕ and θ are equal.

The primary purpose of the mho unit in the Type GCX relay is to provide directional discrimination which is necessary since the ohm unit is inherently nondirectional. The mho unit directional characteristic is such that it will operate correctly for both forward and reverse faults at voltages down to 2 per cent of rated voltage over a current range of 6-60 amperes. A secondary purpose of the mho unit is to measure fault impedance for the third zone of protection.

The operating time of the mho unit is a function of fault current, fault impedance, and reach. Operating time characteristics for the mho unit are shown in Fig. 2.

OHM UNIT

The ohm unit is located near the top of the relay, directly beneath the ohm unit transfer auxiliary, OX, (see Fig. 7). It is an induction-cup type unit with one circuit-closing contact. The purpose of the ohm unit is to measure the distance to the fault and to close its contacts if the fault is within the zone protected by the relay.

The ohmic reach or zone protected by the ohm unit is adjustable by means of taps on the tap block.

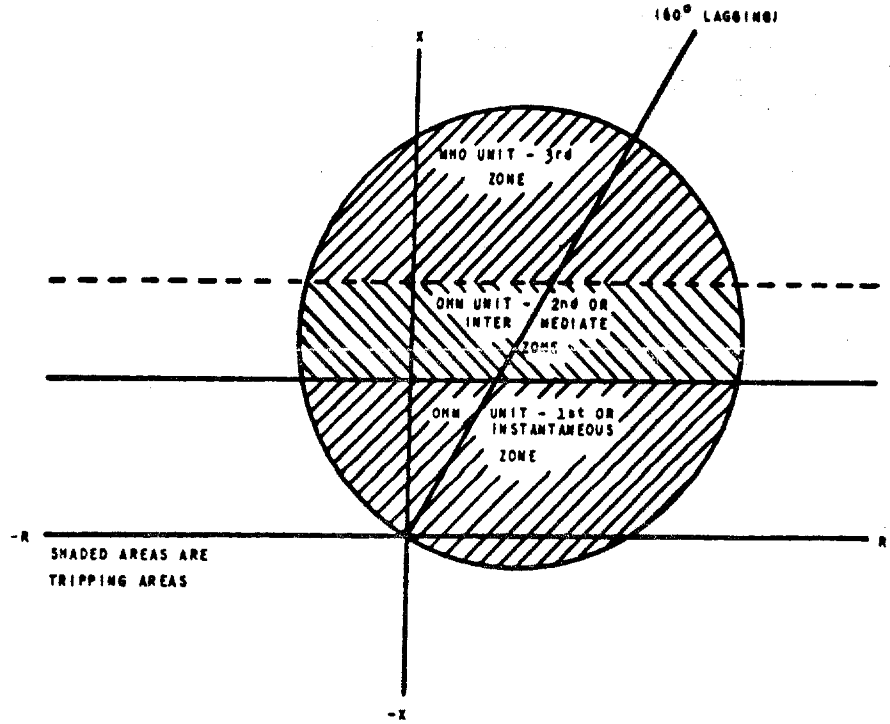

Fig. 1 Impedance Characteristics Of Ohm And Mho Units

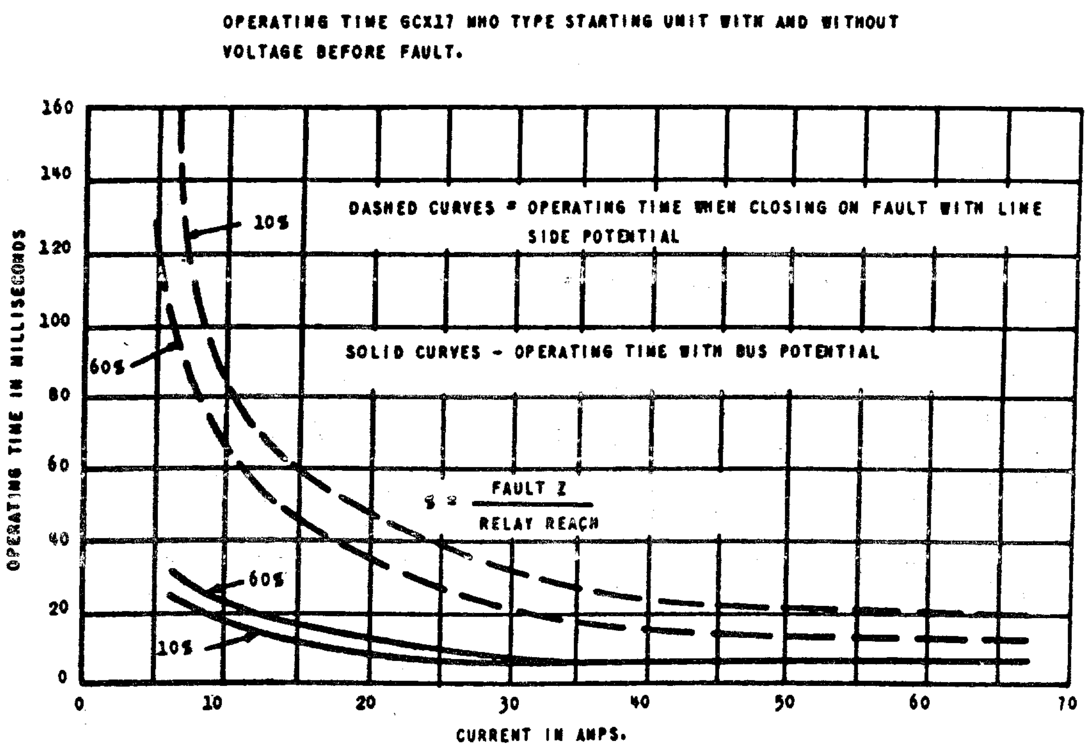

Fig. 2 Operating Time Characteristic Of Mho Unit

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The tap setting of the two taps marked No. 1 determine the instantaneous zone and the tap setting of the two taps marked No. 2 determine the intermediate zone.

The tap setting required to protect a zone X ohms long, where X is the positive-phase-sequence (phase-to-neutral) reactance expressed in secondary terms, is determined by the following equation:

$$\text{Output Tap Setting} = \frac{\text{(Input tap Setting) (Min. Ohms)}}{X}$$

The minimum ohms of the ohm unit can be found on the relay nameplate. The input tap setting is discussed below. The input tap leads (see Fig. 10) are located under the hexagonal tapped head screws in the 90 per cent and 10 per cent tap. In late model relays only the lead in the 10 per cent tap may be moved.

If X is not known it can be calculated as follows if the primary phase-to-neutral reactance (X_{pri}) is known:

$$X = X_{pri} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

or as follows if the three-phase (line-to-neutral) reactance in per cent, X%) is known.

$$X = \frac{10(KV)^2\, X\%}{KVA} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

where KV = line-to-line voltage in kilovolts and KVA = base upon which X% is given.

VERNIER ADJUSTMENT FOR LOW TAP SETTINGS

The input is usually set at 100 per cent but with a high secondary reactance, where the No. 1 taps would be a low percentage, the input may be varied by the vernier method to obtain closer settings. For instance, with a 1.2 ohm line and a 1.0 ohm minimum relay, the input would be 100 and the output tap setting would be 100/1.2 or 83.3 which can be set within 0.4 per cent. But in the case of a 12 ohm line the output setting should be 100/12 or 8.33. The nearest output setting would be 8 which is 4 per cent off. To correct this, the input can be changed to 96 in which case the output tap setting should be 96/12 or 8, which can be set exactly. Setting the relay taps by calculations will give operation on the desired ohmic values within 4 per cent. For closer settings the relay should be set by test under the desired conditions.

For a numerical example of the relay settings, together with a discussion of potential transformer connections, refer to the Appendix of this book.

The impedance pick-up characteristic of the ohm unit is shown in Fig. 1. Since the characteristic is a straight line and parallel to the R axis, the unit responds to a constant component of line impedance. This component is the reactance component. During normal conditions when load is being transmitted over a transmission line, the voltage and current supplied to the relay present an impedance which lies rather close to the R axis since load will be very near unit power factor as compared with the reactive KVA which flows during fault condition. Reference to Fig. 1 indicates that an impedance near the R axis will lie in an area of the ohm unit characteristic where its contact will close. No harm can result from this since to cause

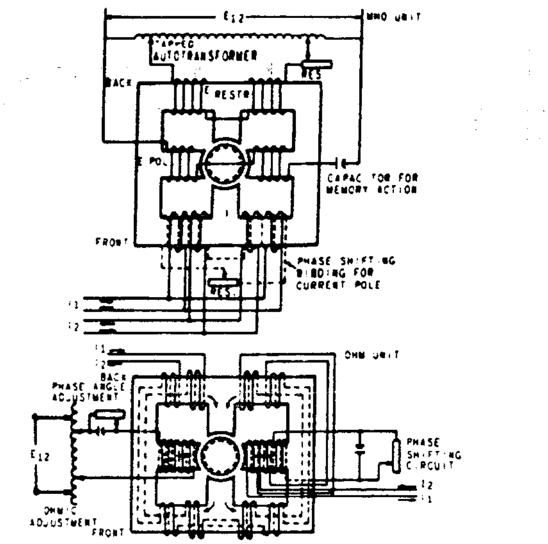


Fig. 3 Schematic Connections For Mho And Ohm Units

tripping the directional unit must also be closed (See Fig. 4).

The operating time of the ohm unit is, as with the mho unit, a function of fault current, fault impedance, and relay reach. Time characteristics are shown in Fig. 5.

On lines which have highly lagging impedances there is a small tendency for the ohm unit to overreach owing to the transient offset of the current. Fig. 6 shows the overreach characteristic of the ohm unit for maximum transient offset. This of course, assumes the inception of the fault will be at a point, in the voltage cycle where transient offset is a maximum. From Fig. 6 it is seen that the overreach is not objectionable for most lines.

OHM UNIT TRANSFER AUXILIARY

The ohm-unit transfer auxiliary, OX, is a telephone-type relay whose coil and contacts are shown in the internal connection diagram of Fig. 10. The unit is mounted at the top of the relay and is used to change the setting of the ohm unit to provide a second step of transmission-line protection. Its operation is controlled by the Type RPM timing unit as shown by the external connection diagram of Fig. 4. The normally-closed contacts of the transfer auxiliary provide the circuit for instantaneous tripping used for faults in the first step of line protection. If the fault is beyond the first zone of protection, the transfer auxiliary changes the setting of the ohm unit by switching to the No. 2 taps on the autotransformer from which a smaller potential is supplied to the ohm-unit potential restraint windings. This extends the ohmic reach of the ohm unit and enables it to operate for faults in the second zone of transmission-line protection.

CONTACT CO-ORDINATION

Since the mho unit is polarized by the fault voltage, it may reset somewhat slowly when a second or third zone fault is cleared beyond the protected line section. To prevent incorrect tripping

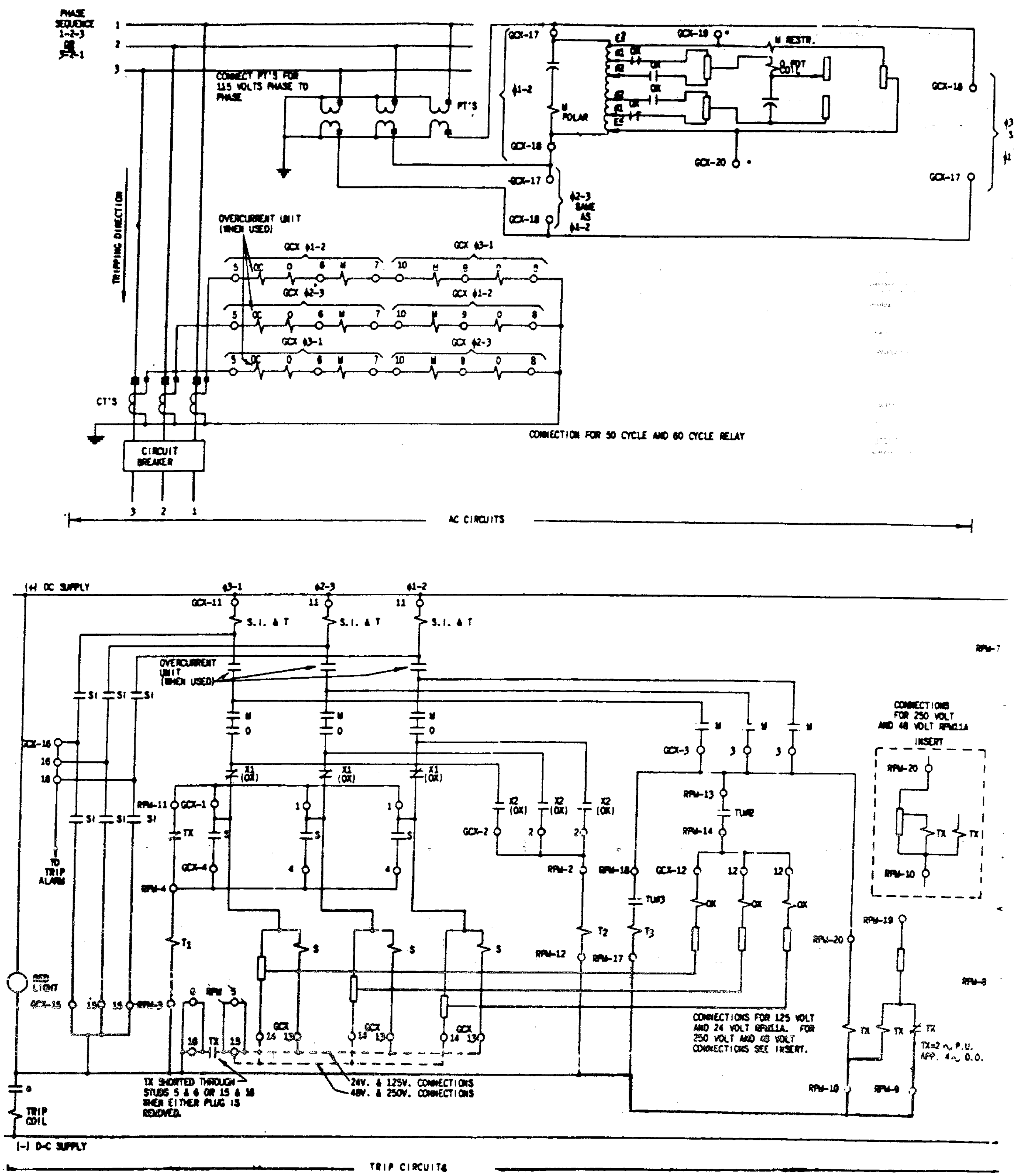
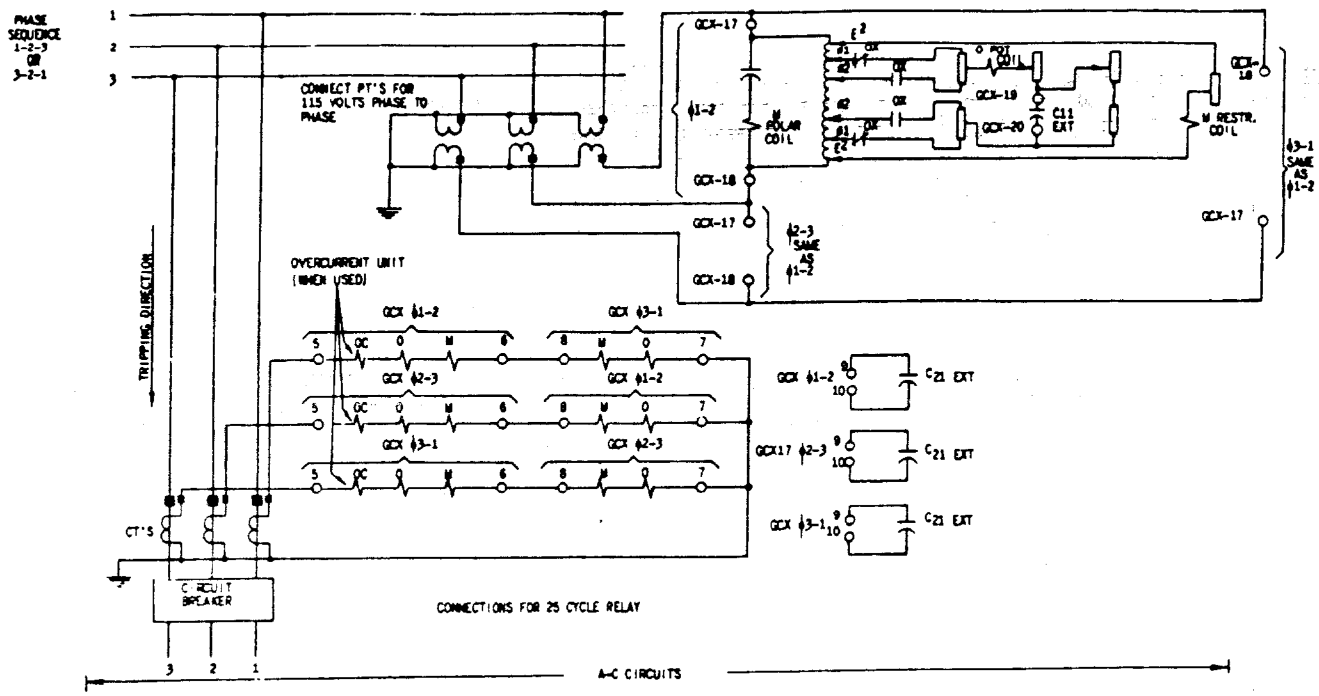


Fig. 4 Three Step Distance Protection For A Transmission Line Using Three Type GCX Distance Relays And One Type RPM11A Timing Relay



LEGEND		
SYMBOLS	ON DEVICE	DESCRIPTION
a		AUXILIARY SWITCH ON CIRCUIT BREAKER
M	GCX	MHO UNIT (DIRECTIONAL AND 3RD ZONE)
O	GCX	OHM UNIT (1ST AND 2ND ZONES)
OX	GCX	OHM UNIT TRANSFER AUXILIARY
S	GCX	AUXILIARY CO-ORDINATING ELEMENT
S.I.	GCX	SEAL-IN UNIT
T		TARGET
TU	RPM	TIMING UNIT
TX	RPM	AUXILIARY FOR TIMING UNIT
ϕ		PHASE

* = NOT USED IN THIS APPLICATION

DRAWING REFERENCES		
DEVICE	INT. CONNS.	OUTLINE
GCX	K-6375826	K-6209276
RPM 250V & 48V	K-6400680	K-6209272
RPM 125V & 24V	K-6209282	K-6209272

Fig. 4 Three Step Distance Protection For A Transmission Line Using Three Type GCX Distance Relays And One Type RPM11A Timing Relay

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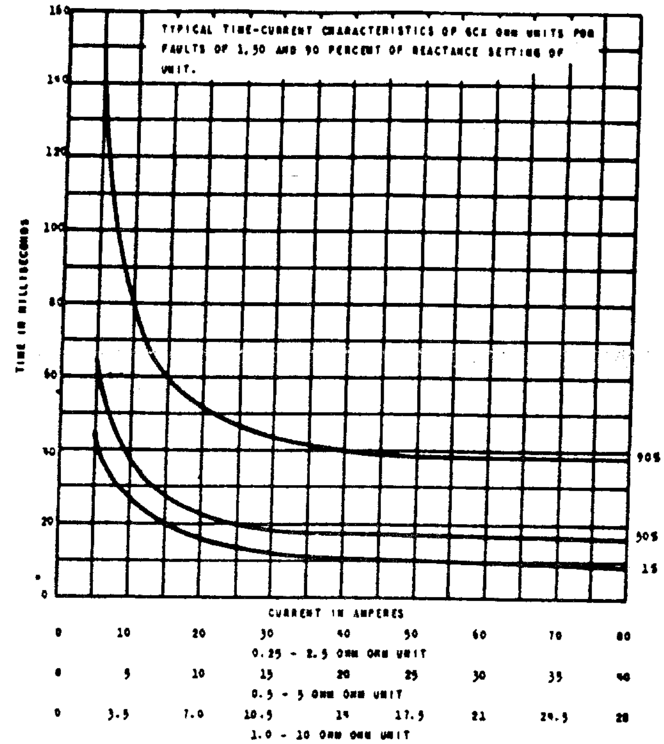

Fig. 5   Operating Time Characteristics For Ohm Units

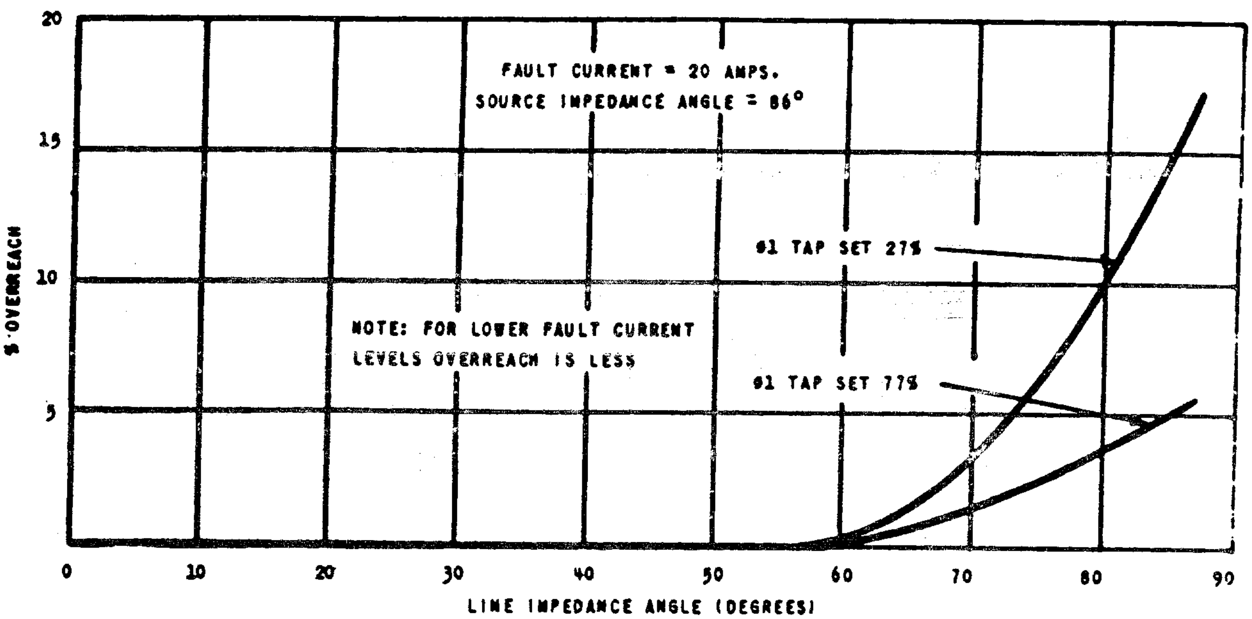

Fig. 6   Over-Reach Characteristic Of Ohm Units

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on such occurrences, an auxiliary co-ordinating element (S) is supplied on the GCX relay. This co-ordinating element operates in conjunction with the auxiliary for the timing unit (TX) as shown by the external connection diagram of Fig. 4. The TX contact opens the first zone trip circuit about 0.030 second (2 cycles) after the mho unit has operated. To restore first zone tripping for faults near the end of the ohm unit reach, the S contact closes if the mho unit remains closed for 0.015 second (1 cycle) after the ohm unit has closed. The one cycle delay in clearing first zone faults is only incurred in cases where the tripping time would normally be three cycles or more.

RATINGS

The Type GCX17 relay is available for 115 volts, 5 amperes rating with d-c control voltage of 24/48 or 125/250 volts, d-c. The ohm-unit minimum ohmic setting is available in 0.25, 0.5, or 1.0 ohm phase-to-neutral. The maximum relay reach would be 10 ohms phase-to-neutral. The mho unit is available in a minimum ohmic setting of 2.5 ohms at an angle of maximum torque of 60 degrees lag.

The contacts of the relay will close and carry momentarily 30 amperes, d-c. The breaker trip circuit, however, should always be opened by an auxiliary switch or other suitable means; it cannot be opened by the tripping relay contacts, or by the contacts of the units. The combination target and seal-in element has a dual rating of 0.6/2.0 amperes for 125/250 volt d-c control circuits. For 24/48 volt d-c control circuits, the target and seal-in element has a rating of 2.0 amperes. The lower d-c control voltage should be connected to the lower numbered stud. See Fig. 4.

The tap setting used on the target and seal-in element is determined by the current drawn by the trip coil. The 0.6 ampere tap is for use with trip coils which operate on currents ranging from 0.6 to 2.0 amperes at the minimum control voltage, while the 2.0 amperes tap should be used when trip currents are greater than 2.0 amperes. It is not good practice to use the 0.6 ampere tap when the trip current is greater than 2.0 amperes since the 0.6 ohm resistance of the 0.6 ampere tap will cause an unnecessarily high voltage drop which will reduce the voltage at the circuit-breaker trip coil. If the tripping current should exceed 30 amperes it is recommended that an auxiliary tripping relay be used.

Amperes to close first contact at 1% voltage
- at maximum torque.............. 4-5
- Resistance fault (in phase)....... 8-9
- Reactance (80 to 90 degrees)..... 4.5-6

TARGET SEAL-IN UNIT

FUNCTION	Amperes, A-c or D-c	
	2.0 A. Tap (0.3 ohms)	0.6 amp tap (0.6 ohms)
Carry for tripping duty	30	15
Carry continuously	4	0.8
Min. Target Operating Current	2	0.6

BURDENS

The current burdens at 5 amperes for the ohm and mho units are given in Table I.

TABLE I

CURRENT BURDENS PER PHASE					
Unit	Freq.	Amps	Imp.	P.F.	VA
Mho	60	5	0.32	0.62	8.03
Ohm					
(0.5 or 1.0 ohm)	60	5	0.74	0.61	18.5
(0.25 ohm)	60	5	0.19	0.58	4.75
Total Relay					
(0.5 or 1.0 ohm)	60	5	1.06	0.61	26.5
(0.25 ohm)	60	5	0.51	0.61	12.8
Mho	50	5	0.27	0.62	6.69
Ohm					
(0.5 or 1.0 ohm)	50	5	0.62	0.61	15.4
(0.25 ohm)	50	5	0.16	0.59	3.96
Total Relay					
(0.5 or 1.0 ohm)	50	5	0.89	0.61	22.09
(0.25 ohm)	50	5	0.43	0.61	10.65
Mho	25	5	0.19	0.62	4.85
Ohm					
(0.5 or 1.0 ohm)	25	5	0.54	0.63	13.5
(0.25 ohm)	25	5	0.22	0.61	5.4
Total Relay					
(0.5 or 1.0 ohm)	25	5	0.73	0.62	18.3
(0.25 ohm)	25	5	0.41	0.61	10.25

The potential burdens will vary with the tap settings used for the ohm and mho unit potential coils; therefore, potential burdens should be calculated from the following formulae. All burdens are at 115 volts.

Ohm Unit:

$$VA = (a + jb)\ (\text{No. 1 tap}/100)^2$$

where (a + jb) varies with frequency rating of the relay and is given in Table II. No. 1 tap is the first zone setting in per cent.

Mho Unit:

$$VA = (E^2\ \text{tap}/100)^2\ (c + jd) + (e + jf)$$

where (c + jd) and (e + jf) vary with the frequency rating of the relay and are given in Table II. E^2 tap is the third zone setting in per cent. The term (c + jd) represents the burden of the mho-unit restraint-coil circuit while the term (e + jf) represents the burden of the mho-unit polarizing-coil circuit.

TABLE II

POTENTIAL BURDEN CONSTANTS			
Frequency Rating	60	50	25
Ohm Restraint a+jb	23+j0	24.2+j0	13.9+j0
Mho Restraint c+jd	6.3-j7.0	6.11-j6.81	7.0-j6.62
Mho Polarizing e+jf	7.68+j.945	6.48+j1.98	10.3+j0

The maximum potential burdens will exist when both the No. 1 taps and the E^2 taps are in the 100 per cent setting. At 115 volts the maximum potential burdens are given in Table III.

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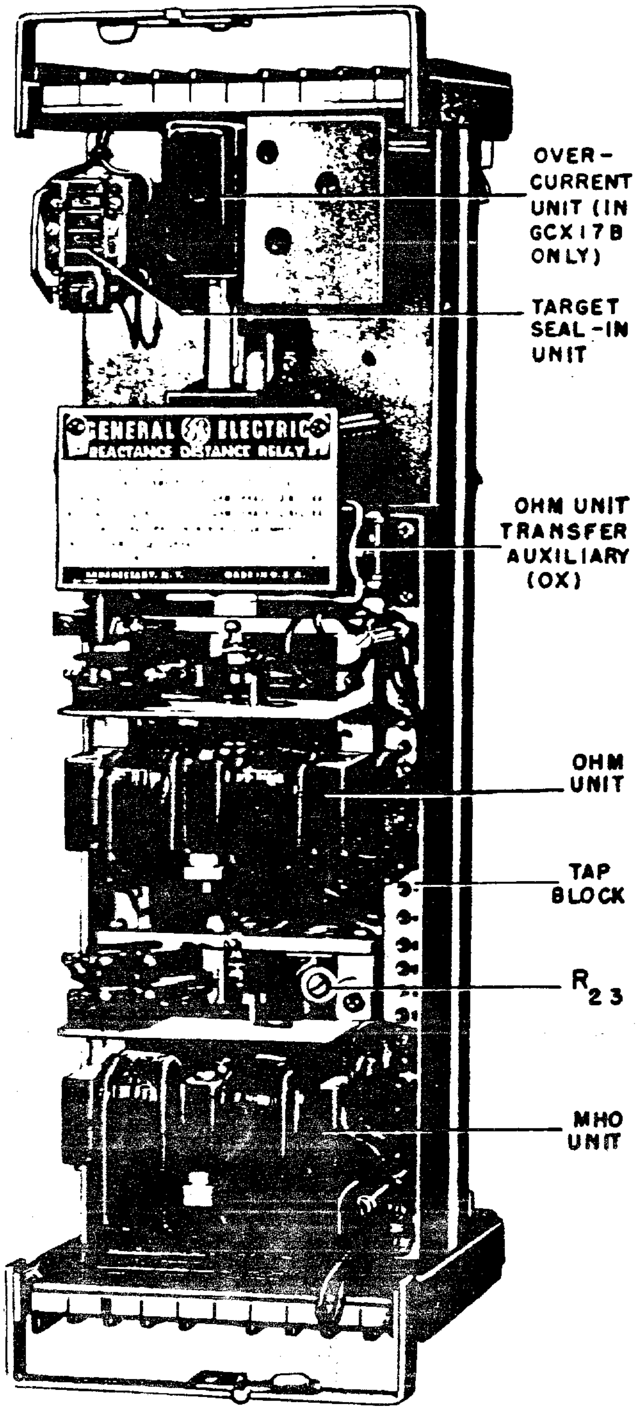

Fig. 7 Type GCX17 Relay Removed From Case
(Front View)

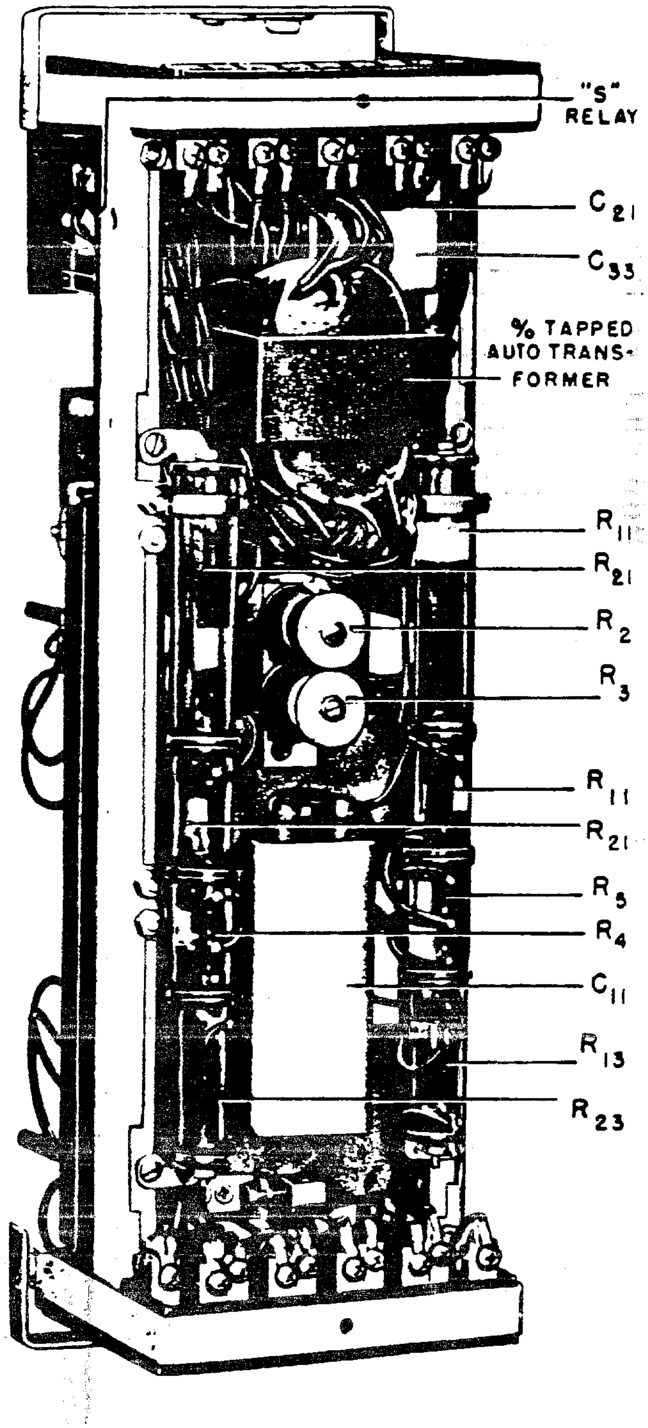

Fig. 8 Type GCX17 Relay Removed From Case
(Back View)

TABLE III

MAXIMUM POTENTIAL BURDENS						
	FREQ.	VOLTS	IMPEDANCE	P.F.	WATTS	VA
Ohm Restraint	60	115	575 + j 0	1.0	23	23
Mho Restraint	60	115	940 + j 1043	0.67	6.3	9.4
Mho Polarizing	60	115	1692 - j 208	0.99	7.6	7.7
Total Relay	60	115	351 + j 56.9	0.98	36.8	37.5
Ohm Restraint	50	115	547 + j 0	1.00	24.2	24.2
Mho Restraint	50	115	963 + j 1073	0.67	6.2	9.2
Mho Polarizing	50	115	1864 - j 570	0.96	6.5	6.8
Total Relay	50	115	354 + j 46.3	0.99	36.8	37.1
Ohm Restraint	25	115	952 + j 0	1.00	13.9	13.9
Mho Restraint	25	115	943 + j 997	0.69	6.6	9.6
Mho Polarizing	25	115	1285 + j 0	1.0	10.3	10.3
Total Relay	25	115	407 + j 86.5	0.98	31.1	31.8

RECEIVING, HANDLING AND STORAGE

These relays, when not included as a part of a control panel will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Apparatus Sales Office.

Reasonable care should be exercised in unpacking the relay in order that none of the parts are injured or the adjustments disturbed.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed and cause trouble in the operation of the relay.

DESCRIPTION

The Type GCX17 relay is of standard construction. Its drawout case has studs at both ends for the external connections. The electrical connections between the relay units and the case studs are made through stationary molded inner and outer blocks between which nests a removable connecting plug which completes the circuits. The outer blocks attached to the case have the studs for the external connections, and the inner blocks have the terminals for the internal connections.

The relay mechanism is mounted in the steel framework called the cradle and is a complete unit with all leads being terminated at the inner block. This cradle is held firmly in the case with a latch at both top and bottom and by a guide pin at the back of the case. The connecting plug, besides, making the electrical connections between the respective blocks of the cradle and case, also locks the latch in place. The cover, which is drawn to the case by thumbscrews, holds the connecting plug in place.

To draw out the cradle, the cover must first be removed. Then the plug can be drawn out. In so doing, the trip circuit is first opened, then the current transformer circuits are shorted and finally the voltage circuits are opened. After the plug has been removed, the latch can be released and the cradle easily drawn out. To replace the cradle, the reverse order is followed.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel either from its own source of current and voltage, or from other sources. Or, the relay can be drawn out and replaced by another which has been tested in the laboratory.

The relay contains three major units; the mho starting unit, at the bottom, which is directional and which detects the presence of faults within the zone covered by the relay; the ohm unit, in the center, which measures the distance to the fault; and the ohm unit transfer auxiliary, at the top, which changes the setting of the ohm unit for the longer distance for back-up protection.

A combination target and seal-in element is also mounted at the top of the relay and is connected in series with the tripping circuits. The target is reset by a button at the bottom of the cover at the left.

The auxiliary co-ordinating element (S), a telephone-type relay, is mounted at the top of the relay on the front right-hand side.

Figs. 7 and 8 show the relay removed from its drawout case and the locations of the major and auxiliary units.

RELAYS WITH EXTERNAL CAPACITORS FOR 25 CYCLES

When external capacitors are furnished with relays they are identified by means of serial numbers. The purpose of these numbers is to insure that each relay, when installed, will be provided with the same auxiliaries with which it was calibrated at the factory.

The reason for this precaution is to eliminate the variation in calibrations of the relays which would otherwise result from the variation in electrical properties of the auxiliaries.

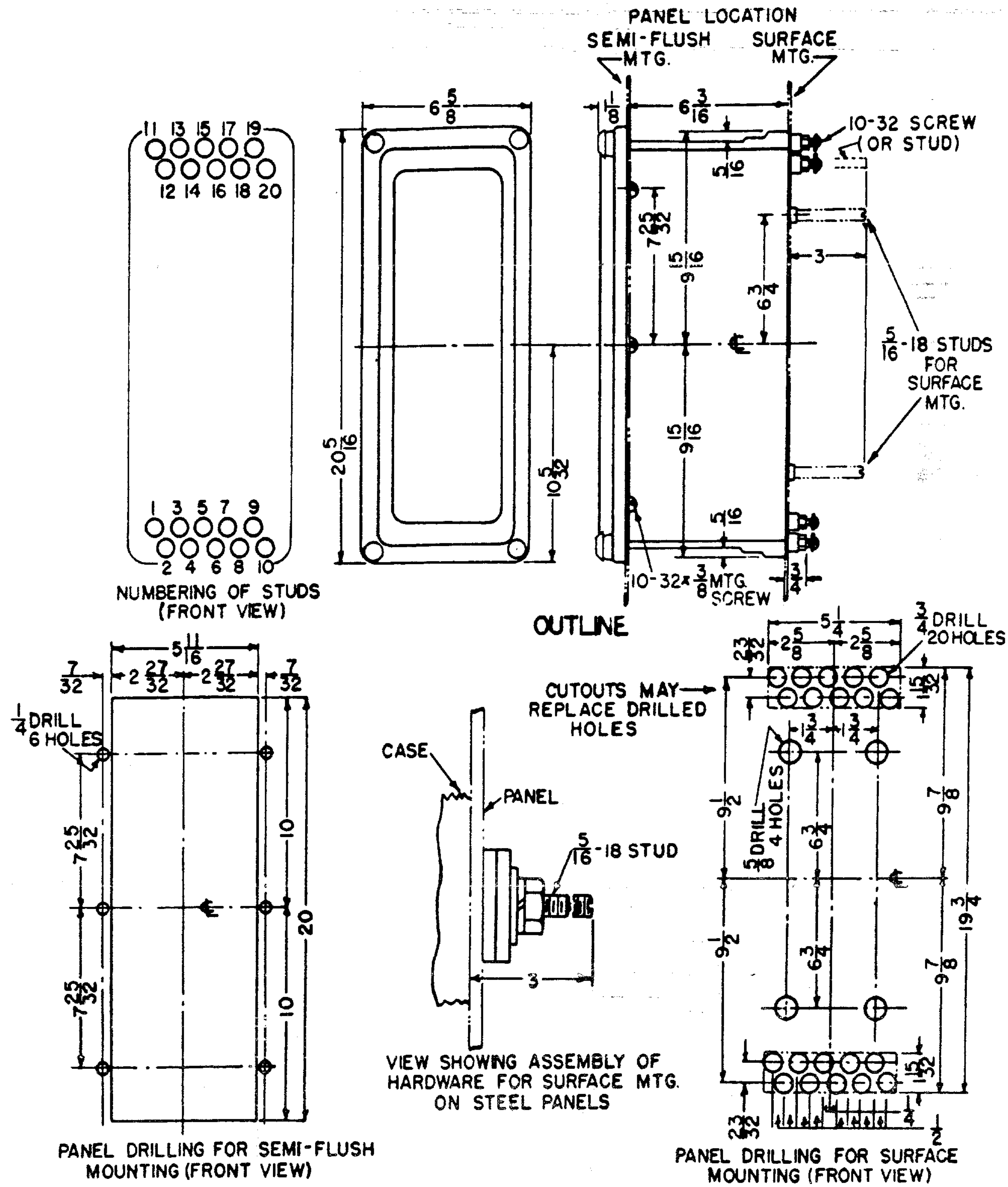

Fig. 9 Outline And Panel Drilling Dimensions For The Type GCX17 Relays

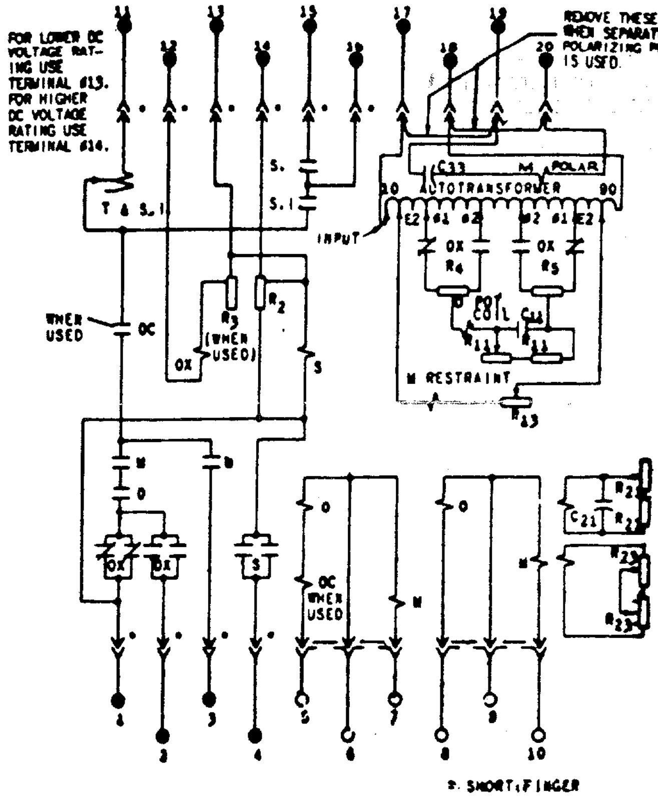

Fig. 10 Internal Connections For The Type GCX17A or B Relay (60 Cycle)

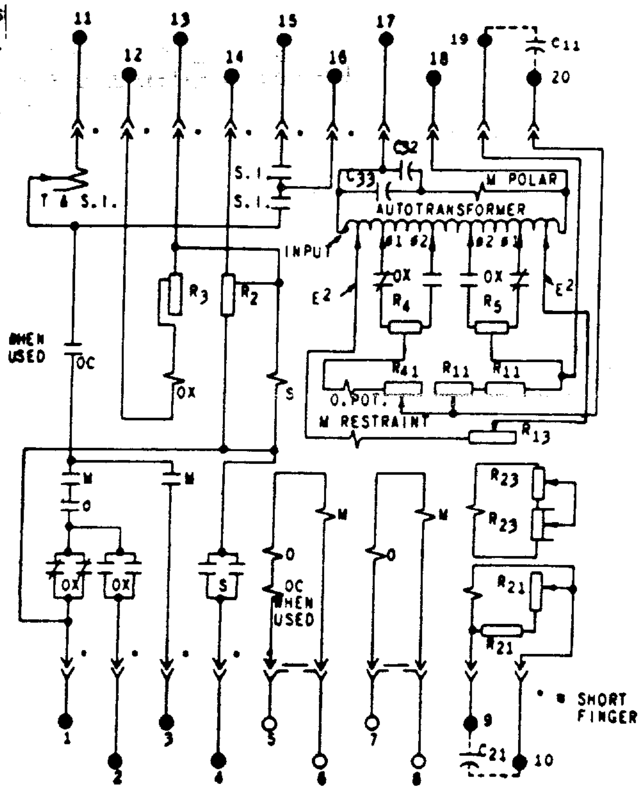

Fig. 11 Internal Connections For The Type GCX17A or B Relay (25 Cycle)

INSTALLATION

LOCATION

The location of the relay should be clear and dry, free from dust, excessive heat and vibration, and should be well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Fig. 9.

CONNECTIONS

Internal connections for the 50 cycle and 60 cycle relays are shown in Fig. 10. Internal connections for the 25 cycle relay are shown in Fig. 11. Typical external connections are shown schematically in Fig. 4. For exact external connections reference should be made to the drawings for the particular requisitions on which the relays were furnished.

One of the relay mounting studs or screws should be permanently grounded by a conductor not less than No. 12 B&S gage copper wire, or its equivalent.

ADJUSTMENTS AND TESTS

The following adjustments and tests are those which we suggest at the time the relay is first put into service. The purpose of these tests is to satisfy the purchaser that no changes in calibration or adjustments have occurred since the relays left the factory and to insure that the relay characteristics are correct for the particular settings and conditions under which they will operate in the field. The electrical tests in this section may also be made at six month intervals to insure continued satisfactory operation of the relays.

ADJUSTMENTS ON INDUCTION UNITS

1. The lead-in spring of the ohm unit should barely hold the contact against the backstops. The lead-in spring of the mho unit should hold the contacts definitely open.

2. See that the cup assembly moves without noticeable friction.

3. The ohm-unit stationary contact and the upper contact of the mho unit should rest against their felt backstops.

4. The mho-unit lower stationary-contact stop should be slightly behind the upper stationary felt contact stop.

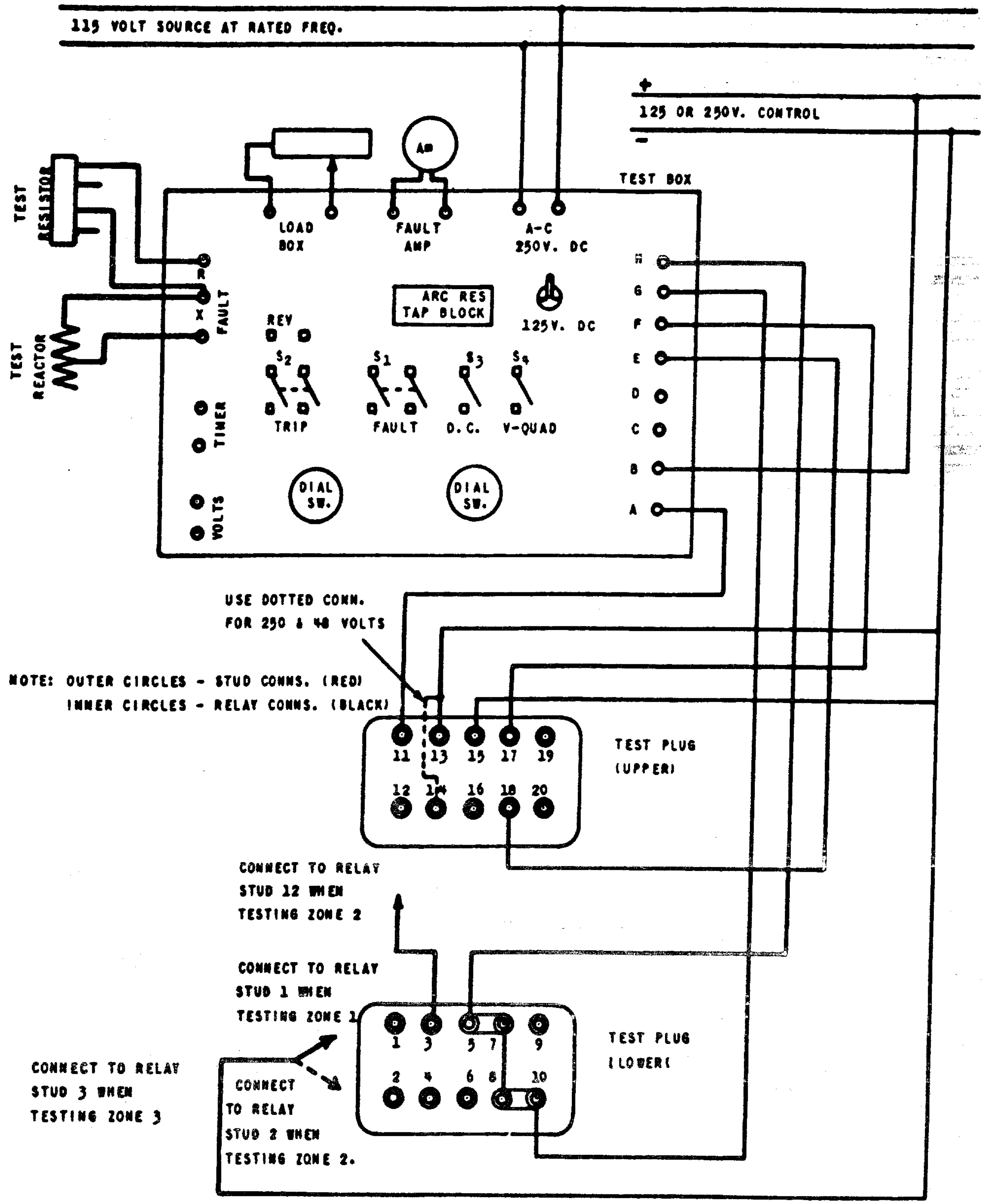

Fig. 12 Test Connections For The Type GCX17 Relays

5. The mho-unit lower stationary contact should have approximately 1/32 inch wipe. The contact gap as measured from the lower stationary contact should be 0.1 inch.

6. The ohm-unit contact gap should be 1/16 inch.

ELECTRICAL CHECK TESTS ON INDUCTION UNITS

The manner in which reach settings are made for the ohm and mho unit is briefly discussed in the introduction of these instructions. Examples of calculations for typical settings are given in the Appendix. It is the purpose of the electrical tests in this section to check the ohm and mho-unit ohmic pickup at the settings which have been made for a particular line section.

To eliminate the errors which may result from possible instrument inaccuracies a test circuit has been selected which requires no instruments. Such a circuit is shown in Fig. 13. In Fig. 13 $R_S + jX_S$ is the source impedance, S_F is the fault switch and $R_L + jX_L$ is the impedance of the line section for which the relay is being tested. The autotransformer, T_A, which is across the fault switch and line impedance is tapped in 10 per cent and 1 per cent steps so that the line impedance $R_L + jX_L$ may be made to appear to the relay very nearly as the actual line on which the relay is to be used. This is necessary since it is not feasible to provide the portable test reactor, X_L, and the test resistor with enough taps so that the combination may be made to match any line.

For convenience in field testing the fault switch and tapped autotransformer of Fig. 13 have been arranged in a portable test box, Cat. No. 6052978, which is particularly adapted for testing directional and distance relays. The box is provided with terminals to which the relay current and potential circuits as well as the line and source impedances may be readily connected. For a complete description of the test box the user is referred to GEI-8370.

a. Testing the Ohm Unit

To check the calibration of the ohm unit, it is suggested that the portable test box, Cat. No. 6052978; portable test reactor, Cat. 6054975; and test resistor, Cat. 6158546 be arranged with Type XLA test plugs according to Fig. 12. The circuit of the test box and connected equipment is similar to that shown in Fig. 13 except that the source impedance, $R_S + jX_S$ is replaced with a load box which serves to give the source voltage drop and to control the level of the fault current.

Use of the source impedance, $R_S + jX_S$, is only required when the relay is being tested for overreach and contact co-ordination. Such tests are not considered necessary at the time of installation or during periodic testing. Tests of this nature are described later in the section on SERVICING.

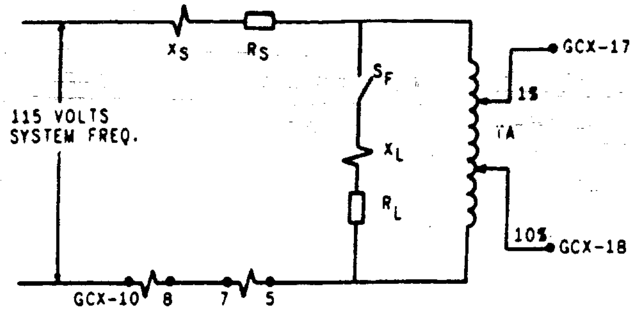

Fig. 13 Test Circuit

Connected between terminals A and B of the test box is an auxiliary relay and resistor which are arranged in such a way that, when the contacts of the ohm and mho units close, sufficient trip current will be drawn to operate the Type GCX target seal-in. After the Type GCX seal-in has had an opportunity to operate, the auxiliary relay opens the resistor circuit which draws the trip current. Since the seal-in is operated it will be necessary to open the test-box switch, S_3, which opens the d-c supply and allows the seal-in to reset. This arrangement eliminates the necessity of providing an indicating lamp and also checks the operation of the target seal-in element.

Since the relay is to be tested for the ohmic reach that it will have when in service, the value of X_L to select will be the portable test-reactor tap nearest above twice the relay phase-to-neutral ohmic reach. Explanation of the twice factor is as follows: The relay as normally connected (V_{1-2} potential and $I_1 - I_2$ current) measures positive sequence phase-to-neutral reactance. For a phase-to-phase fault, the fault current is forced by the phase-to-phase voltage through the impedance of each of the involved phases. In the test circuit, the line impedance, Z_L, is in effect the sum of the impedance of each of the phase conductors and must be so arranged in order to be equivalent to the actual fault condition. Since the impedance of each phase must be used to make up the line impedance in the test circuit its value will be twice that of the phase-to-neutral relay reach. The per cent tap of the test box autotransformer, which should cause the ohm unit to just close its contacts with the fault switch closed is given by:

$$\% = \frac{2\,(X_{Relay})}{X_L}\,(100)$$

For this test the value of R_L may be made zero since the ohm unit responds only to a reactance quantity. The load box however may be adjusted to give a fault current of approximately 10 amperes or whatever fault current is expected during three-phase and/or phase-to-phase fault conditions.

To illustrate the above the 1.0 minimum ohm phase-to-neutral relay, set zone 1 at 86 per cent and zone 2 at 58 per cent, used in Example 1 of the Appendix will be used.

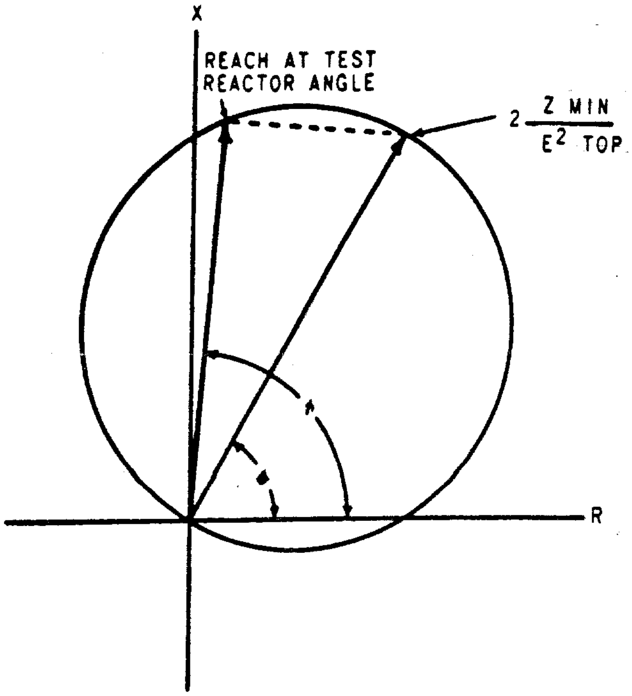

Fig. 14 Reach Of Mho Unit At Angle Of Test Reactor

$$2X_{Relay} = 2\left(\frac{1.0}{.86}\right) = 2.3 \text{ ohms.}$$

Therefore use reactor nominal 3.0 ohm tap. Assume now that the reactor calibration curve has been referred to and that reactance of the 3.0 tap at the current level to be used is 3.2 ohms. From this and the above, the test-box autotransformer percent tap at which the ohm-unit contact will close is:

$$\% \text{ tap} = \frac{2.3}{3.2}\ (100) = 72\%$$

The ohm unit should therefore close its contact with test-box autotransformer taps set at 72 per cent and remain opened with the percent taps at 73 per cent.

To determine the phase angle of the ohm unit's reactance characteristic, it is only necessary to observe the effect of adding resistance in series with the line reactance. This is the resistance, R_L, which should be noninductive and in magnitude 5 to 8 times as large as the line reactance, X_L. Either the calibrated test resistor Cat. No. 6158546 or the tapped fault resistor included in the test box may be used as the line resistor, R_L. When the pick-up test is made with this line resistance in the circuit, the load box used as source impedance should be readjusted such that approximately the same fault current flows as did in the first test. With the fault switch closed, the ohm unit should close its contacts at the same test-box autotransformer per cent tap as before. For phase angle meter readings see Fig. 25.

A check of the ohm unit's second zone reach may be made in the same manner except that the transfer relay, OX, should be energized by connecting a jumper between relay studs 3 and 12 and by connecting the negative return lead to relay stud 2 rather than stud 1. (See Fig. 12). For polarity test see Fig. 24.

b. Testing The Mho Unit

The mho unit is tested in a manner very similar to the ohm unit above, the major difference being in the manner in which the test-box autotransformer per cent tap setting for pickup is determined. This difference results from the fact that unlike the ohm unit, the impedance pick-up characteristic of the mho unit on an R-X diagram is a circle passing through the origin. The diameter of the circle which is the relay angle of maximum reach is at an angle of 60 degrees with the R axis. (See Fig. 1).

Since the reactance of the test reactor may be very accurately determined from its calibration curve, it is desirable to check relay pickup with the fault reactor alone, due account being taken of the angular difference between the line reactance, X_L, and relay angle of maximum reach. As in the case of the ohm unit, the line reactance, X_L, selected, should be the test reactor tap nearest above twice the mho unit reach with account being taken of the difference in angle of the test reactor tap impedance and the relay angle of maximum reach. From Fig. 14 it is seen that twice the relay reach at the angle of the test reactor impedance is:

$$2Z_{Relay} = 2\ \frac{Z_{min\ ohms}}{E^2 \text{ tap set}} \cos(\phi - \theta) \text{ where}$$

ϕ is the angle of the test reactor impedance and θ is the relay angle of maximum reach. The test-box autotransformer percent tap for the mho-unit pick up is given by:

$$\% \text{ tap} = \frac{2Z_{Relay}}{Z_L}\ (100)$$

To illustrate the above the relay setting in Example 1 of the Appendix will again be used. Reference to the example shows the E^2 tap setting to be 61 per cent. The minimum ohmic reach of all Type GCX17 mho units is 2.5 ohms with the relay angle (θ) of maximum reach at 60 degrees. In determining the reactor tap setting to use, it may be assumed that the angle (ϕ) of the test reactor impedance is 80 degrees. From the above twice, the relay reach at the angle of the test-reactor impedance is:

$$2Z_{Relay} = 2\ \frac{2.5}{.61} \cos(80-60) = 7.7 \text{ ohm}$$

Therefore, use the reactor 12 ohm tap. Twice the relay reach at the angle of test reactor impedance should be recalculated using the actual angle of the reactor tap impedance rather than the assumed 80 degrees. Table IV shows the angles for each of the reactor taps.

TABLE IV

Tap	Angle	cos ϕ-60
24	88	0.883
12	87	0.891
6	86	0.899
3	85	0.906
2	83	0.921
1	81	0.934
0.5	78	0.951

From the table it is seen that the angle of the impedance of the 12 ohm tap is 87 degrees. Therefore:

$$2Z_{Relay} = 2\frac{2.5}{.61} \cos (87-60) = 7.3 \text{ ohms}$$

The calibration curve for the portable test reactor should again be referred to in order to determine exact reactance of the 12 ohm tap at the current level being used. For the purpose of this illustration assume that the reactance is 12.2 ohms. Since the angle of the impedance of the 12 ohm tap is 87 degrees, the impedance of this tap may be calculated as follows:

$$Z_L = X_L/\cos 3 = \frac{12.2}{.9986} = 12.22 \text{ ohms}$$

From this calculation it is seen that the reactance and the impedance may be assumed the same for this particular reactor tap. Actually the difference need only be taken into account on the reactor 3, 2, 1 and 0.5 ohm taps.

The test-box autotransformer tap setting required to close the mho-unit contacts with the fault switch closed is:

$$\% = \frac{7.3}{12.2} (100) = 59.7\%$$

If the ohmic pickup of the mho unit checks correctly according to the above, the chances are that the angle of the characteristic is correct. The angle may, however, be very easily checked by using the calibrated test resistor in combination with various reactor taps. The calibrated test resistor taps are pre-set in such a manner that when used with 12 and 6 ohm taps of the specified test reactor, impedances at 60 degrees and 30 degrees respectively will be available for checking the mho-unit reach at the 60 degree and 30 degree positions. The mho-unit ohmic reach at the zero-degree position may be checked by using the calibrated test resistor alone as the line impedance. The calibrated test resistor is supplied with a data sheet which gives the exact impedance and angle for each of the combinations available. The test-box autotransformer per cent tap for pickup at a particular angle is given by:

$$\% \text{ Tap} = \frac{2(2.5) \cos (60-a)}{(E^2 \text{ tap}) \quad Z_L} 100$$

where a is the angle of the test impedance (Z_L), Z_L is the 60 degree, 30 degree or zero degree impedance value taken from the calibrated resistor data sheet and E^2 is mho unit restraint tap setting expressed as a decimal. As in the case of the previous tests, the load box which serves as source impedance should be adjusted to allow approximately 10 amperes to flow in the fault circuit when the fault switch is closed.

When checking the angle of maximum reach of the mho unit as indicated above, there are two factors to keep in mind which affect the accuracy of the results. First, when checking the mho unit at angles of more than 30 degrees off the maximum reach position, the error becomes relatively large with phase angle error. This is apparent from Fig. 14 where it is seen, for example, at the zero-degree position that a two or three degree error in phase angle will cause a considerable apparent error in reach. Secondly, the effect of the control spring should be considered since the mho unit can only have a perfectly circular characteristic when the control-spring torque is negligible. For any normal level of polarizing voltage, the control spring may be neglected but in testing the unit as indicated above it may be necessary to reduce the test-box autotransformer tap setting to a point where the voltage supplied to the unit may be relatively low. This reduces the torque level since the polarizing as well as the restraint will be low with the result being that the control-spring torque will no longer be negligible. The result of the control spring at low polarizing voltages is to cause the reach of the mho unit to be somewhat reduced.

In order to see the affect of the above in their true proportion, it is suggested that reach characteristic as determined from testing be plotted on an impedance diagram such as the mho characteristic shown in Fig. 1. Obviously, the apparent error in reach resulting from phase angle error at angles well off the maximum-reach position, are in a region where a fault impedance vector will not lie. Concerning the spring torque error, it is pointed out that the mho unit is not the measuring unit for primary protection but rather is only a directional unit and, therefore, its directional response is the most important consideration. For the third-zone back-up protection, the mho unit is the measuring unit, but for the remote faults, the voltage at the relay is not apt to be low. Furthermore the accuracy of a third-zone back-up unit is not as important as that of a first-zone unit.

In addition to the above tests on the mho unit, it may also be checked for directional action with the test-box circuit as shown in Fig. 12. The fault resistor, R_2, may be zero, the test reactor should be set on the 0.5 ohm tap. With the test-box switch, S_2, in the trip position, the mho-unit contact should remain closed for a current range of 6-60 amperes with 2 per cent rated voltage applied. A voltmeter should be used to read the voltage at studs 17-18 of the relay. The voltage over the 6-60 ampere-current range is adjustable by means of the test-box autotransformer tap switches. When switch, S_2, of the test box is thrown to the reverse position, the mho unit contacts should remain open for the same conditions as above described.

c. Other Check Tests

In addition to the calibration checks for ohm and mho units as described above, it is desirable to make the following additional tests on the relay in general:

1. Use the test circuit as shown in Fig. 12 except connect the negative return lead to relay stud 4 rather than 1, 2 or 3 for the zone 1, zone 2 or zone 3 tests. Then close the ohm and mho-unit contacts manually. The target seal-in element of the relay should operate. Reference to the Type GCX internal connection diagram (Fig. 10) indicates that tripping in this test is through the "S" relay contact and therefore the test serves as a check on the operation of the "S" relay.

2. If the relay being tested is a Type GCX17B relay which includes an overcurrent unit, its pickup may be checked by adjusting the fault current level by means of the load box. Calibration points of the overcurrent unit are marked on the relay nameplate. Normally, the overcurrent unit is set at the factory on its lowest pickup.

INSPECTION

Before placing the relay into service, inspection of miscellaneous items should be made to insure that no change has taken place in mechanical adjustment during shipment or storage period. It is suggested that the following items be examined.

The armature and contacts of the target-seal-in element should operate freely by hand.

There should be a tap screw in only one of the taps above the right-hand stationary contact of the target-seal-in element. A spare tap screw is provided in the tap hole above the left-hand stationary contact which should be used when it is necessary to change the tap. When it is desirable to change the target-seal-in tap, the spare tap screw should be inserted in the new tap and tightened before the existing tap screw is removed. This procedure will maintain the right-hand stationary contact position, since it is held fixed only by the tap screw.

The target should reset promptly when the reset button at the bottom of the cover is operated, with the cover on the relay.

There should be no noticeable mechanical friction in the rotating structure of the units and the moving contacts should return to their backstops when the relay is de-energized.

There should be approximately 1/64 inch end play in the shafts of the rotating structures. The lower-jewel screw bearing should be screwed firmly into place and the top pivot locked in place by its set screw.

If there is reason to believe that the jewel is cracked or dirty, the screw assembly may be removed from the bottom of the unit and examined under a microscope, or the surface of the jewel may be explored with the point of a fine needle. When replacing the jewel screw, care should be taken to engage the upper pivot in the shaft before screwing in the jewel screw.

All nuts and screws should be tight with particular attention being paid to tap plugs.

CAUTION: Examine the tap block with great care to make sure the tap lead terminals do not come in contact with adjacent terminals, tap-hole shoulders, mounting screw heads or other grounded parts. Even on those relays provided with tap lead-sleeve insulation, it is possible to mechanically puncture the sleeve insulation by forcing the tap lead terminal against some nearby part. The punctured insulation may cause a portion of the tapped autotransformer to be shorted or grounded, the result from this being eventual failure of the transformer. As a good general practice, it is recommended that the tap leads be placed horizontally on the tap block with the leads coming out rather than in toward the relay.

The felt gasket on the cover should be securely cemented in order to maintain an effective dust seal.

The contact surfaces should be clean.

MAINTENANCE

PERIODIC INSPECTION

At six month intervals an inspection of the relay should be made covering those items listed under INSPECTION in the preceding INSTALLATION section.

PERIODIC TESTING

At the same time the periodic inspection is made, the check tests described in the INSTALLATION section should be made. These tests may be made very quickly if the test-box autotransformer settings for each relay terminal are determined ahead of time in which case it is only necessary to insert the test plugs in each relay in succession and observe relay contact operation when the fault switch is closed. Frequent calibration tests are not considered necessary since the calibration of this relay does not change appreciably with time. If it is found that the relay does not test correctly according to the above, readjustment may be made according to the procedure set forth under SERVICING in this section.

CONTACT CLEANING

Silver contacts should never be handled or touched by bare hands because dampness on the hands may cause the formation of silver salts which have high resistance.

For fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface resembling in effect a superfine file. The polishing action is so delicate that no scratches are left, yet it will clean off any corrosion thoroughly and rapidly. Its flexibility insures the cleaning of the actual points of contact. Sometimes an ordinary file cannot reach the points of contact because of obstruction offered by some relay part, but the flexible burnisher can be drawn through the contacts while they are held together, thus cleaning both simultaneously and at the correct contact points.

Knives, files, and abrasive paper or cloth, etc., produce scratches on fine silver and, of course, the abrasive medium may be left imbedded in the surface of the silver and prevent subsequent contact. A contact cleaned with one of these devices may arc and require cleaning again in perhaps one-tenth of the time taken by a new contact to deteriorate to the same condition. This is because the minute raised sides of the fine scratches, made in cleaning the contact, form tiny arcing points which melt, become sticky and get bigger with each contact operation; a new contact has a smooth surface and there is no place where the current density is great enough to melt the silver and roughen the surface, thereby starting the process of deterioration.

SERVICING

If it is found that the calibrations do not check during installation tests or periodic tests, recalibration should be made by adjusting as necessary elements normally called factory adjustments. The adjustments are listed below. These may be located from Figs. 7 and 8.

R_{11} - Ohm Unit Characteristic Phase Angle Adjustment
R_{21} - Ohm Unit Characteristic Reach Adjustment
R_{13} - Mho Unit Characteristic Reach Adjustment
R_{23} - Mho Unit Characteristic Phase Angle Adjustment
Core Adjustments - Stray Torque

LABORATORY TESTS

Should it ever be necessary to replace an ohm or mho unit or if the basic factory adjustments have been for some reason disturbed, it is advisable to make the following tests which are of a laboratory nature.

a. Ohm Unit

To compensate for slight manufacturing dis-symmetries, the iron core inside the induction cup of the ohm unit has been machined to have a flat surface on one side. By loosening the core position locknut on the bottom of the unit, the core may be rotated until the desired position is reached. The usual position for the flat, as assembled by the factory, is toward the rear left-hand corner of the unit. The exact position for the flat may be determined as well as other adjustments from the following tests:

1. Pickup, Phase Angle, Core Position

Use the test circuit shown in Fig. 12. Adjust the control spring so that the moving contact just rests against the backstop. With the number 1 taps in 100 per cent and the fault switch open, loosen the core locking screw slightly and rotate the core clockwise (viewed from the top) until the contacts close. Then rotate the core counterclockwise until the moving contact just rests against the backstop. This adjustment tends to compensate for any stray torques which might cause the contacts to close on voltage alone. Note that it should be unnecessary to rotate the core more than 30 degrees in either direction.

Before making pickup or phase-angle adjustments, the unit should be allowed to heat up for approximately 15 minutes, energized with voltage alone. Determine the test-box autotransformer setting for pickup and the test reactor tap as described in the section covering installation tests. With the fault switch closed and the source impedance (R_S) set to allow approximately 10 amperes to flow, adjust (R_{21}) so that the contacts just close. Then insert line resistance (R_L) approximately three times the line reactance (X_L) in the test circuit, readjust the source impedance (R_S) to again allow 10 amperes to flow, and adjust (R_{11}) so that the ohm-unit contacts just close at the same test-box autotransformer tap setting as before. This procedure presents an impedance to the relay whose angle is approximately 20 degrees. If the relay pickup is the same for the 20 degree impedance as it is with reactance alone, the relay angle of maximum reach will be at 90 degrees or the unit will measure reactance alone. The pickup and phase-angle adjustments of the ohm unit are to a slight extent interdependent. For this reason it is necessary to go back and check the pick-up adjustment (R_{21}) after the phase-angle adjustment (R_{11}) has been made and alternately set each until each is correct.

TABLE V

Min. Ohms	Calibration Range	Clutch Adjustment	
		Grams	Amps with Zero Restraint
0.25	5-75 Amps	17-21	23-30
0.50	3-60 Amps	27-33	14-20
1.00	2-40 Amps	27-33	10-15

Table V shows current calibrating ranges for ohm units of different minimum ohmic ratings. With the test circuit arranged as above, the ohmic pickup may be checked at different current levels by changing the amount of source impedance (R_S).

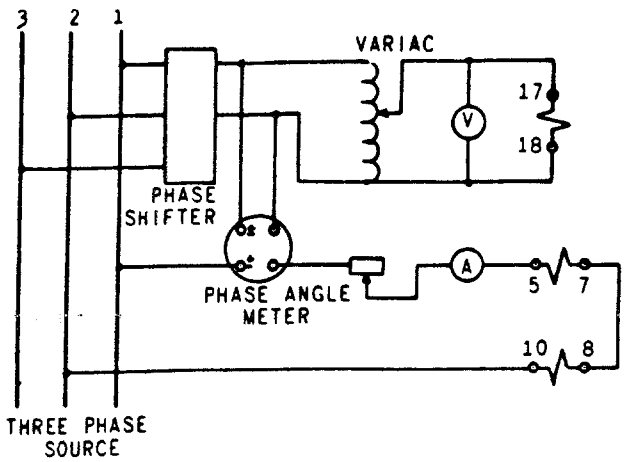

Fig. 15 Laboratory Test Connections

The pickup should not vary more than 3 per cent above or below the set value over the calibrating range. If it is higher at high currents, the core may be shifted slightly in a counterclockwise direction but the pickup and phase-angle adjustments should be repeated if it is necessary to shift the core. If the pickup is lower than 3 per cent of the set value at low values of current, the control spring tension may be slightly decreased although not to such an extent that the contacts close when the relay is de-energized.

2. Overreach

Overreach is the tendency of a distance relay to operate on an impedance greater than that for which it has been set during the transient stage of the fault. Reference to Fig. 6 indicates that the percent overreach varies with fault current magnitude and angle of the line impedance. To check the overreach of the ohm unit, the test circuit shown in Fig. 12 may be used except the source impedance which has heretofore been a load box should now be a reactor. This is necessary in order to obtain the full offset which can be expected during field conditions. The test-box autotransformer tap setting are determined as before. The reactor which replaces the load box as the source impedance may be a standard test reactor, Cat. 6054975. The angle of the line impedance, $R_L + jX_L$ should be set by varying R_L, since X_L is fixed on the basis of the relay setting and relay minimum ohmic rating. The angle should be set by means of a phase-angle meter and should of course be the same as the line angle since that is the condition under which the relay will operate. Accordingly, the fault current level now adjusted by X_S should be in the same order of magnitude as the maximum fault current expected. Since maximum overreach occurs when the inception of the fault is at a point in the voltage cycle where the transient offset is greatest, the fault switch should be closed ten successive times in determining the test box autotransformer setting above that calculated fo pickup. One of the ten trials will be near the poin where maximum transient offset occurs. The dif ference between the test-box autotransformer ta setting required to keep the contacts open on transient basis and the tap setting which will kee the contacts open on a steady state basis expresse as a percentage of the latter is the per cent tran sient overreach of the ohm unit.

b. Mho Unit

The mho unit in the Type GCX17 relay is primarily intended as a directional unit since the ohm unit is inherently nondirectional. It also serves as the third-zone backup distance-measuring element. The mho unit may be tested using the test circuit shown in Fig. 15. The correct directional action on a mho unit may be adjusted by varying the position of the iron core within the induction cup. Unlike the core of the ohm unit, the mho unit core is perfectly round. However, it is mounted in the mho unit in such a way that it may be moved from side to side within the structure. Adjustment is made by first loosening the lamination clamping screw at the back of the unit one full turn and then by turning the core-bracket adjusting screw which is located at lower rear side of the mho unit. Access to the adjusting screw head is from the right-hand side of the unit. Make sure the lamination clamping screw is tightened one full turn before measuring electrically the correctness of the adjustment. The directional action is checked at a high current and low voltage both at the relay angle of maximum reach and at 180 degrees from the relay angle of maximum reach. This simulates a fault just off the bus on the protected line and a fault on the bus. With the test circuit arranged as shown in Fig. 15, apply 1 per cent rated volts (1.15 volts) and 60 amperes at 60 degrees lag. This test is made with the E^2 taps in 100 per cent. At the 60 degree lag position the mho unit contacts should close. With the phase angle shifted to 240 degrees lag, the contacts should remain open when current and voltage are applied. By turning the adjusting screw clockwise a torque will be introduced in the contact closing direction.

The suggested way of determining the mho unit angle of maximum reach is by approaching the characteristic from either side until the points are found where the contacts just close. Half way between the two angles where the contacts just close is the mho-unit angle-of-maximum reach. This test may be made by the test circuit shown in Fig. 15 with the voltage adjusted to 55 volts and the current at 15 to 20 amperes. The phase angle of the mho unit is adjusted by two resistors designated R_{23} one of which is tapped and the other variable. These may be located from Figs. 7 and 8. For the 60 degree position of the mho unit characteristic the tapped resistor is not used. If the relay application is such that it is desirable to have the mho characteristic at a more lagging angle, it may in some instances be necessary to insert a portion of the tapped resistor. This is done by moving the bolted connection on R_{23} fixed from the lower to the middle tap. The relay is adjusted at the factory to have a 60 degree lagging characteristic. Note that the ohmic reach of the mho unit is not independent of the phase-angle adjustment. Where the reach is adjusted for 2.5 ohms phase-to-neutral at 60 degrees lag, it will be approximately 3.2 ohms phase-to-neutral at 75 degrees lag.

The reach of the mho unit is adjusted by R_{13} which may be located in Fig. 8. With the test circuit as shown in Fig. 15, set the phase angle of 60 degrees lag and the voltage at 55 volts. The mho-unit contacts should close when the current is increased to 11.0 amperes. After the pickup of the mho unit has been set, it is desirable to again check its directional action and angle of maximum reach.

c. Ohm and Mho Unit Contact Co-ordination

In the section headed OPERATING CHARACTERISTICS, the "S" relay was described as the co-ordinating element which prevents tripping if the mho and ohm unit contacts were closed at the same time after an external fault is cleared. For the reverse situation i.e., where the ohm unit is closed on load and a fault occurs just beyond the protected section, no auxiliary element is required to obtain satisfactory co-ordination. The contact co-ordination for this condition may be checked by arranging the test circuit as shown in Fig. 12 except that a resistor and capacitor series connected should be placed across the fault switch. The capacitor should be of such magnitude that it cancels the inductive reactance of the line impedance. The resistor should allow approximately 4.5 amps to flow with the fault switch open. The line impedance, $R_L + jX_L$ should be slightly greater than that of the protected section and should be selected such that the impedance presented to the relay by virtue of the test-box autotransformer tap setting will be done so, with the tap settings as high as possible. This will make the potential on the relay before the fault switch is closed nearly 115 volts, which is of course a normal operating condition. The source impedance should be made up of reactance as in the case of the ohm-unit overreach test and again should be of such magnitude that maximum anticipated-fault current will flow when the fault switch is closed. The ohm and mho unit settings are those which will be used in service. For successive closures of the fault switch with the d-c circuits energized, the seal-in unit should not set up if co-ordination is satisfactory.

d. Clutch Adjustment - Ohm and Mho Units

To improve contact action, ohm and mho units are provided with friction clutches which slip when the contacts are closed with high torque and prevent contact bounce. The tension on the clutch spring, which is concentric with the shaft, may be varied by loosening the set screw in the clutch spring collar which may then be rotated to increase or decrease the clutch spring tension. Clutch settings for ohm units are given in both grams and amperes at zero restraint in Table V. The mho-unit clutch should slip with approximately 50 grams force applied. This corresponds to approximately 30 amperes at the angle of maximum reach and E^2 tap settings at zero per cent.

RENEWAL PARTS

It is recommended that sufficient quantities of renewal parts be carried in stock to enable the prompt replacement of any that are worn, broken, or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company, specifying the quantity required and describing the parts by catalogue numbers as shown in Renewal Parts Bulletin No. GEF-2508.

APPENDIX

CALCULATION OF RELAY SETTINGS

Following is a discussion of and examples of calculations of relay settings. Factors affecting relay settings such as infeed and potential transformer connections will be considered.

Proceed as follows in determining relay settings:

1. Calculate the primary phase-to-neutral reactance in ohms of the line to be protected from the formula

$$X_{pri} = \frac{10\overline{KV}^2\ X\%}{KVA}$$

where X_{pri} = primary phase-to-neutral reactance in ohms.

$\overline{KV}$ = line-to-line voltage in kilovolts
$X\%$ = phase-to-neutral line reactance in per cent
KVA = KVA base upon which $X\%$ is given.

2. Calculate the secondary phase-to-neutral reactance

$$X_{sec} = X_{pri}\ \frac{\text{CT ratio}}{\text{PT ratio}}$$

3. The instantaneous zone (zone 1) is set by the two tap leads on the tap block marked No. 1 and usually covers 80 per cent to 90 per cent of the line section. If it is assumed that 90 per cent of the line section is to be covered, the No. 1 tap setting is given by:

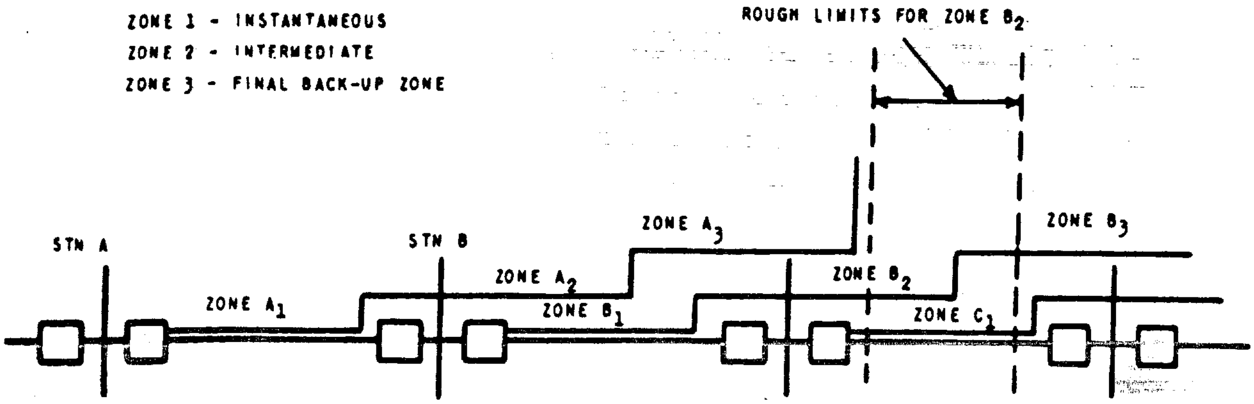

Fig. 16 Zone Setting Diagram, 2nd And 3rd Zone Reach

$$\text{No. 1 Tap} = \frac{(\text{input tap})\ X_{min.}}{.90\ X_1}$$

where No. 1 tap = Number 1 tap setting in percent
Input tap = Input tap setting in percent
X_{min} = Minimum phase-to-neutral reactance reach of the relay the value of which is given on the relay nameplate.
X_1 = Phase-to-neutral secondary reactance of the first line section.

4. The tap settings for the second zone (No. 2) and the third zone (E^2) depend upon system configuration and the amount of infeed fault current supplied from the bus at the end of first line section.

Referring to Fig. 16, the second zone of the relay at A must reach beyond B and yet must not reach far enough to overlap the second zone of the relay at B. Similarly, the third zone of the relay at A should not overlap the third zone of the relay at B and yet should not overlap the third zone of the relay at B and yet should reach beyond station C.

The second zone should reach to cover the last 10 percent of zone one to provide back-up protection. Thus, with the first zone of the following section set to cover 90 percent of its section, ideally this zone 2 setting could be fixed at 80 percent of the section. This can be regarded as the upper limit for zone 2. The lower limit for zone 2 is around 20 percent of the second section which assumes that the third zone setting for the preceding station can be set to fall within this 20 percent.

The major factor which determines the accuracy with which the zone 2 and zone 3 can be set is the determination of infeed current from the buses at the ends of the protected-line sections. For example, in Fig. 16 current infeed at stations B and C cause voltage drops in the line between their respective buses and the fault. These drops cause the elements at A to underreach for faults in the backup zones unless the infeed currents are taken into consideration when the settings are made. To better understand these drops, we must picture current I_A at station A and current I_B, infeed at station B. Now if we imagine a fault somewhere between stations B and C we can set up an equation to show what the relay sees at station A.

I_A = Current at station A.

Z_A = Impedance of line A.

I_B = Current infeed at station B.

Z_B = Impedance from station B to fault.

$$\text{Relay sees} = \frac{I_A Z_A + (I_A + I_B)\ Z_B}{I_A}$$

$$= Z_A + Z_B + \frac{I_B Z_B}{I_A}$$

As we can see, the relay will see the true impedance Z_A and Z_B but will be falsely misled by $\frac{I_B Z_B}{I_A}$. This is the section that has to be taken into consideration when settings are made. It has been shown that the impedance of the section beyond B as it appears to the back-up elements at A is increased by the ratio of fault current in the second section to the fault current in the first section.

However, the primary functions of zone 2 is to obtain end-zone protection for the remainder of the line section protected by zone 1. Unless this is a tapped line with infeed from the tap, there should be no necessity for considering infeed for end-zone protection.

As a rough guide in determining back-up settings, set zone 2 to cover 50 per cent of the adjacent line section under conditions of maximum infeed. Set zone 3 ten per cent beyond the end of the adjacent section.

The phase-to-neutral secondary reactance of zone 2 is calculated in the same manner as for zone 1. Assuming reach is to be 50 per cent into the second section the No. 2 tap setting can be calculated from

$$\text{No. 2 tap} = \frac{(\text{input tap})\ X_{min}}{X_1 + 0.50\ K_2 X_2}$$

where No. 2 tap = Number 2 tap setting in per cent
Input Tap = Input tap setting per cent
X_{min} = Minimum phase-to-neutral reactance reach of the relay
X_1 = Phase-to-neutral secondary reactance of the first line section
K_2 = ratio of fault current in second section to the fault current in the first section for a fault 50 per cent into the second section
X_2 = Phase-to-neutral secondary reactance of the second line section

The third zone is protected by the mho unit which as seen from Fig. 1 is responsive to an impedance at an angle. This is unlike the ohm unit which is responsive to reactance alone. Since the reach of the mho unit varies with the angle of the fault impedance the determination of the E^2 tap setting which controls the mho unit reach must take into account the difference between the angle of the fault impedance and the angle of maximum reach of the mho unit. The angle of maximum reach of the mho unit, as set at the factory, is 60 degrees lag and the minimum phase-to neutral ohmic reach is 2.5 ohms. Impedance rather than reactance alone are used in calculating the reach required for the third zone. The impedance of the sections to be protected is determined in a manner similar to the determination for zones 1 and 2 except that impedance rather than reactance quantities are used.

Assuming the reach of the third-zone element is to be 10 per cent beyond the end of the second section, the E^2 tap setting may be calculated from

$$E^2 \text{ tap} = \frac{(\text{Input Tap})\ 2.5 \cos (\phi - 60)}{1.1\ (Z_1 + K_3 Z_2)}$$

where
E tap = E tap setting in per cent
Input tap = Input tap setting in per cent
ϕ = Angle of protected line impedance
Z_1 = Phase-to-neutral secondary impedance of the first line section
Z_2 = Phase-to-neutral secondary impedance
K_3 = Ratio of fault current in second line section to fault current first line section for a fault of the end of the second line section.

Example 1

As an example let us consider a 154 KV line with 1.61 + j 6 per cent impedance on a 50,000 KVA base and an adjoining section of 2.68 + j 10 per cent impedance with 300/5 CT's.

$$\text{CT ratio} = \frac{300}{5} = 60/1$$

$$\text{PT ratio} = \frac{154{,}000}{115} = 1340/1$$

$$X_{pri} = \frac{10\ KV^2\ X\%}{KVA}$$

$$= \frac{10\ (154)^2 \times 6}{50{,}000} = 28.5 \text{ ohms } \phi\text{-N}$$

$$X_{sec} = X_{pri}\ \frac{\text{CT ratio}}{\text{PT ratio}} = 28.5 \times \frac{60}{1340} = 1.3 \text{ ohms.}$$

It will be assumed that no current is fed into the second section at the intervening station. (i. e. $K_2 = K_3 = 1$).

Use a relay with 1.0 ohm minimum phase-to-neutral reach and set zone 1 to cover 90 per cent of the protected section,

No. 1 tap $= \frac{100 \times 1.0}{0.9 \times 1.3} = 85.5$ per cent so that the 86 per cent tap should be used.

The second or intermediate time zone is usually set to cover about one-half of the next section. The reactance of the second section is 10 per cent or 10/6 x 1.3 = 2.17 ohms secondary.

$$\text{No. 2 Tap} = \frac{100 \times 1.0}{1.3 + (0.5)\ 2.17} = \frac{100}{2.38} = 42.0\%$$

Zone 2 taps should therefore be set on 42 per cent, covering the protected section and approximately 50 per cent of the next adjacent section. The time setting should be the tripping time of the next breaker plus say 10 cycles margin.

To set the third zone of protection, the line characteristic angle must be known. These are determined from the impedances of the two sections to be protected.

1st section 1.61 + j 6% = 6.22% at 75 degrees lag
2nd section 2.68 – j 10% = 10.35% at 75 degrees lag

The total impedance for the two sections is 16.6 at 75 degrees lag. The primary impedance in ohms

$$Z_{pri} = \frac{(10)\ 154^2\ (16.6)}{50{,}000} = 78.8 \text{ ohms at } 75^\circ$$

The secondary impedance in ohms is

$$Z_{sec} = 78.8\ \frac{60}{1340} = 3.53 \text{ ohms at 75 degrees}$$

The third zone is set by the E^2 tap settings and is 10 per cent greater than the first and second line sections.

$$E^2 \text{ tap set} = \frac{100\ (2.5) \cos (75-60)}{1.1\ (3.53)} = 62.1\%$$

The E^2 taps should therefore be set on 62 per cent.

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RELAY SETTINGS WHEN POTENTIAL IS TAKEN FROM LOW SIDE OF POWER TRANSFORMER

When a line is terminated in a transformer and no source of potential for line relaying is available on the line side, it is necessary to use low side potential and take into account the power transformer ratio, the phase shift which occurs in a delta-wye power transformer and the impedance of the transformer itself. The 30 degree phase shift in the delta-wye power transformer may be compensated for by selecting phase-to-neutral rather than phase-to-phase voltage from the secondary of the wye-wye connected potential transformer or by using an auxiliary wye-delta potential transformer. The latter method is preferred since the phase-to-neutral voltage of the former method is affected by ground faults on the low voltage system. When the auxiliary potential transformer is required, Cat. YT1557M may be used. Using low side potential means the relay will see the transformer reactance as a part of the protected section. Since the relay first zone is to be set to cover 80-90 per cent of the protected section which includes the transformer, it will cover a relatively small section of the line if the transformer reactance is high compared to the line reactance. If instantaneous tripping is required over a greater portion of the line section than can be covered by the Type GCX relay, some form of pilot relaying not using the distance principle should be investigated. When the potential transformer ratio has been properly selected from the application standpoint, the overall PT ratio may be considered as:

$$\frac{\text{High side line-to-line voltage}}{\text{relay voltage (115)}}$$

Example 2

Consider a 154 KV line with two adjoining sections of 12 per cent and 10 per cent reactance respectively on a 50,000 KVA base. Line angles are 70 degrees. A power transformer at the end for which relay settings are being determined is 13.8 KV delta connected on the low side and 154 KV wye connected on the high side. CT's on the line side are connected in wye and have a ratio of 150/5. Three PT's connected wye-wye on low side of the power transformer have PT ratios of 120/1. An auxiliary potential transformer connected for a rating of 115 volts wye primary to 115 volts delta secondary. The power transformer has 5 per cent reactance on a 40,000 KVA base. Assume that for a fault in the middle of the second section $K_2 = 1.7$ and for a fault at the end of the adjacent section that $K_3 = 1.5$.

The relay settings are determined as follows:

Line Reactances:

1st Section $\frac{10\,(154)^2\;12}{50{,}000} = 57.0$ ohms

2nd Section $\frac{10\,(154)^2\;10}{50{,}000} = 47.5$ ohms

Transformer Reactance:

$$\frac{10\,(154)^2\;5\%}{40{,}000} = 29.6 \text{ ohms}$$

Overall PT ratio:

$$\frac{154{,}000}{115} = 1340/1$$

CT Ratio:

$$\frac{150}{5} = 30/1$$

Secondary Reactances:

$$X_1 = 57.0\left(\frac{30}{1340}\right) = 1.27 \text{ ohms}$$

$$X_2 = 47.5\left(\frac{30}{1340}\right) = 1.06 \text{ ohms}$$

$$X_T = 29.6\left(\frac{30}{1340}\right) = 0.66 \text{ ohms}$$

Secondary Reactances and Impedances:

Assume transformer has 85 degree phase angle.

$$R_1 = \frac{X_1}{\tan\phi} = \frac{1.27}{\tan 70} = 0.46,$$

$$Z_1\;0.46 + j\,1.27 = 1.35 \text{ ohms at } 70^\circ$$

$$R_2 = \frac{X_2}{\tan\phi} = \frac{1.06}{\tan 70} = 0.38,$$

$$Z_2 = 0.38 + j\,1.06 = 1.13 \text{ ohms at } 70^\circ$$

$$R_{Trans} = \frac{X_{Trans}}{\tan\phi} = \frac{0.66}{\tan 85^\circ} = .058,$$

$$Z_{Trans} = 0.058 + j\,0.66 = 0.66 \text{ ohms at } 85^\circ$$

Zone 1 Setting Assuming 90 Per cent Coverage and One Ohm Relay

$$\text{No. 1 tap} = \frac{100 \times 1}{(1.27 + .66)\;.90} = 57\%$$

Zone 2 Setting Assuming 50 Per cent Coverage of Adjacent Section

$$\text{No. 2 tap} = \frac{100 \times 1}{(1.27 + .66) + 0.5 \times 1.7 \times 1.06} = 35\%$$

Zone 3 Setting

$$Z_1 + Z_{Trans} = 0.518 + j\,1.93$$

$$K_3\,Z_2 = 1.5\,(0.38 + j\,1.06) =$$

$$\frac{0.57 + j\,1.59}{1.088 + j\,3.52} = 3.69 \text{ ohms at } 73^\circ$$

$$E^2 \text{ tap} = \frac{100 \times 2.5 \cos(73-60)}{1.1 \times 3.69} = 60\%$$

There are occasions when the backup cannot be satisfactorily obtained with the three zone method as outlined above. This can occur when a large generating station feeds power to an intermediate point in a line.

In Fig. 17 for a fault as shown, if breaker 2 fails to operate, normally breaker 1 would operate on backup. If, however, the generators at A supply a large amount of current to the fault there may be many times as much current in line 2 as in line 1. To provide backup, the relay at B would require a third zone setting correspondingly large compared with the first zone setting. Such settings will make the relay susceptible to power swings.

A solution is to use an auxiliary timing unit in conjunction with the tripping circuits for the line breakers at the station A. If these breakers fail to open in a definite time after their trip coils have been energized, the timing unit operates an auxiliary relay to trip all the breakers connected to the bus.

In short line sections it may be difficult to prevent the third zones from overlapping, since the minimum reach of the mho unit is 2.5 ohms. It will be necessary to grade the time settings to obtain selectivity.

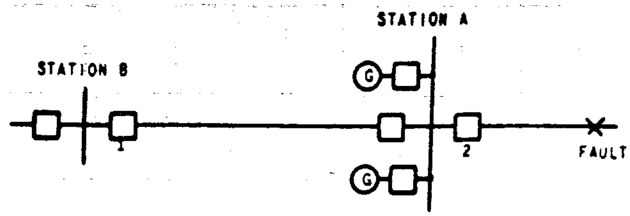


Fig. 17 Zone Setting, Effective Of Infield

Where a protected line terminates in a bus from which a number of lines are radiating it is common to set the backup steps for the longest line. This will result in overreaching on backup for faults in the shorter lines. Selectivity may be obtained by grading the time settings.

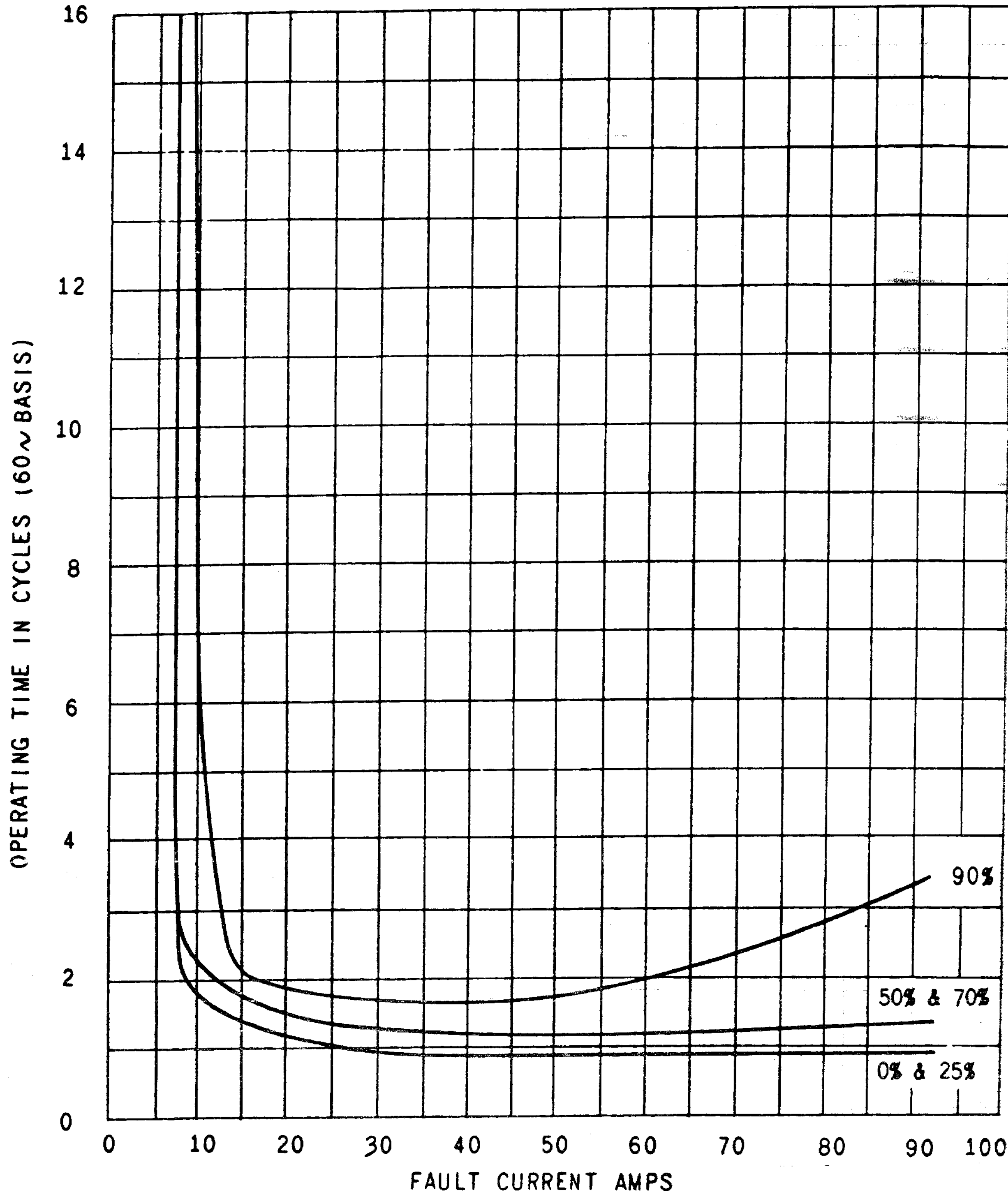


Fig. 18 Average Operating Time Curves (With Bus Side PT's) For Type GCX17 0.25 Ohm Relay

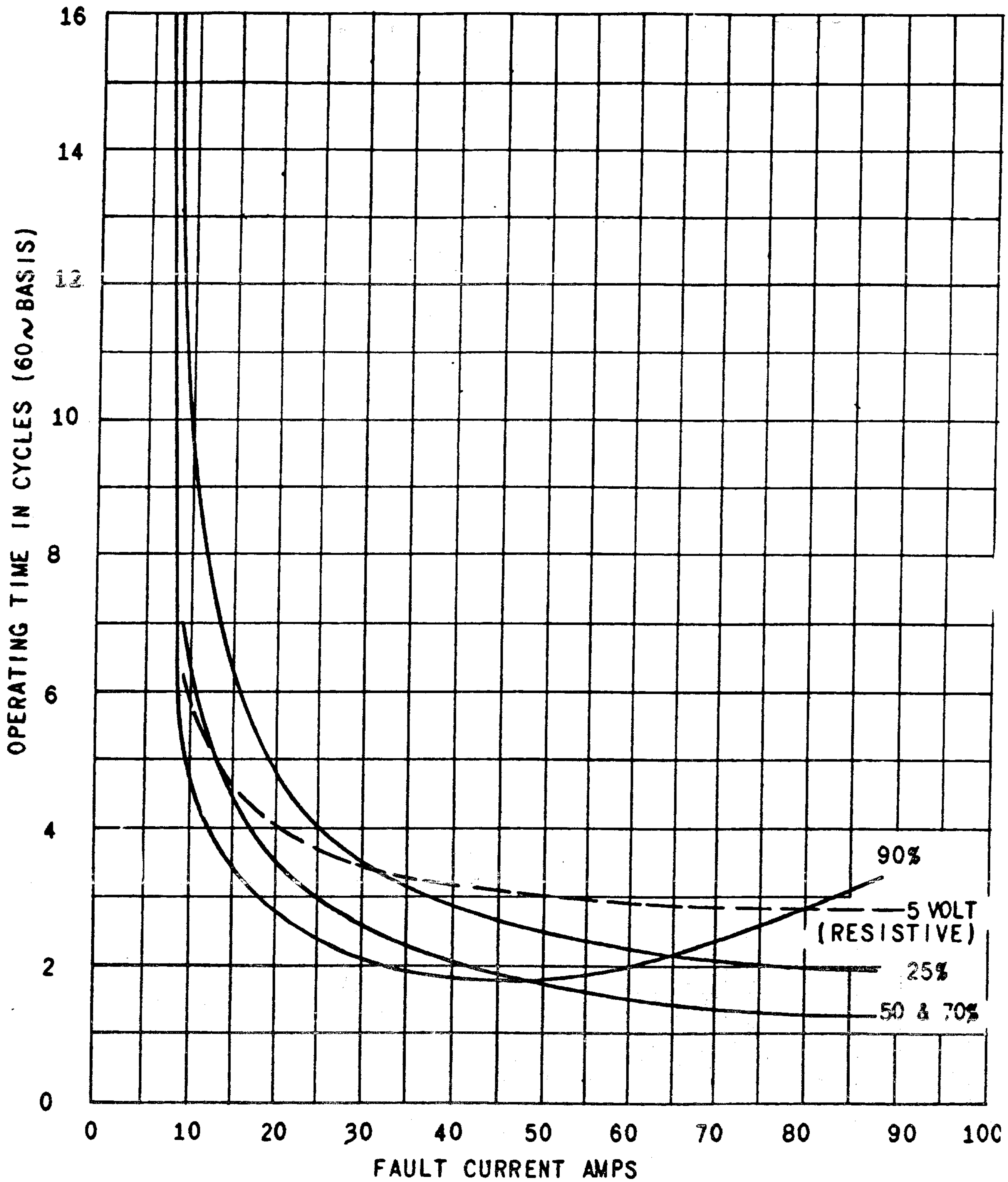


Fig. 19 Average Operating Time Curves (Zero Voltage Before Fault) For Type GCX17 0.25 Ohm Relay

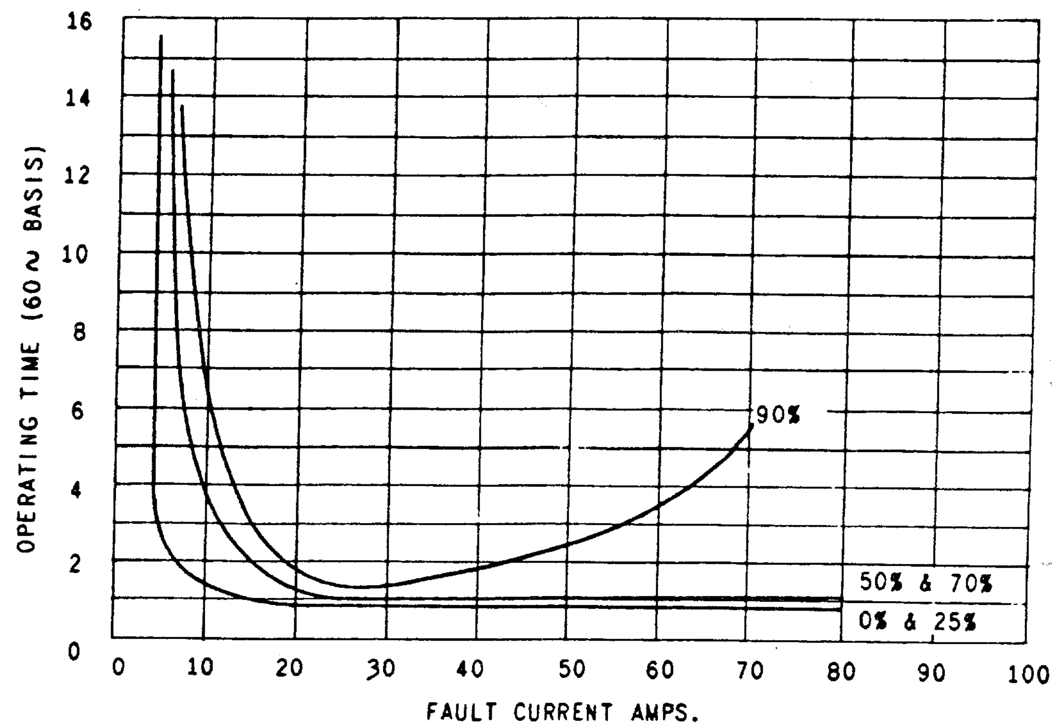


Fig. 20 Average Operating Time Curves (With Bus Side PT's) For GCX17 0.5 Ohm Relay

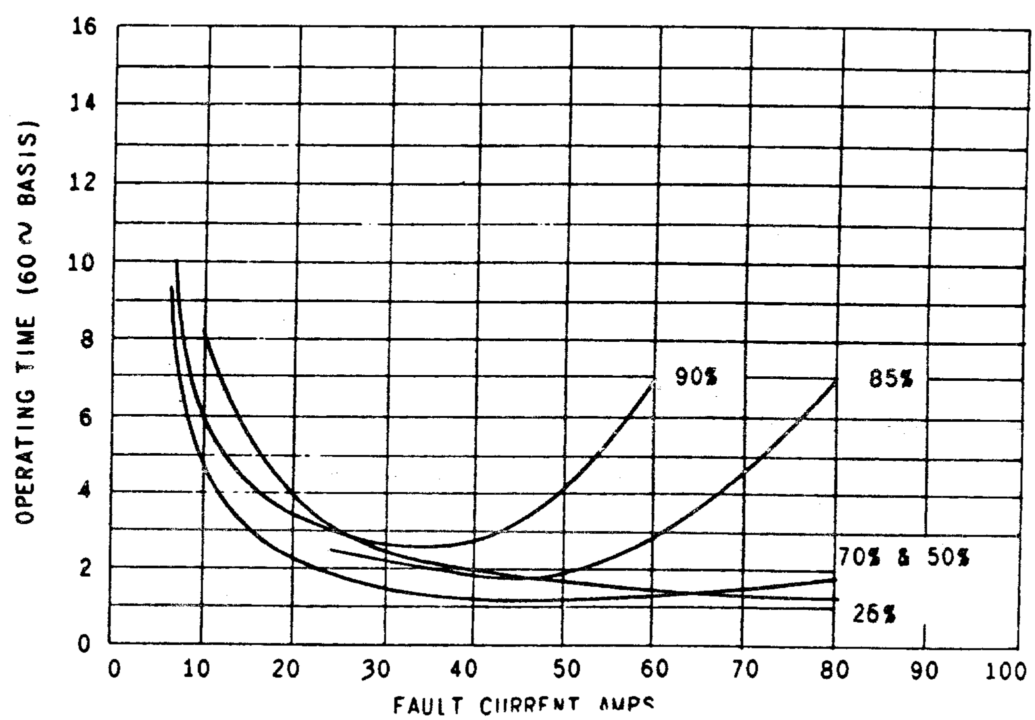


Fig. 21 Average Operating Time Curves (Zero Voltage Before Fault) For GCX17 0.5 Ohm Relay

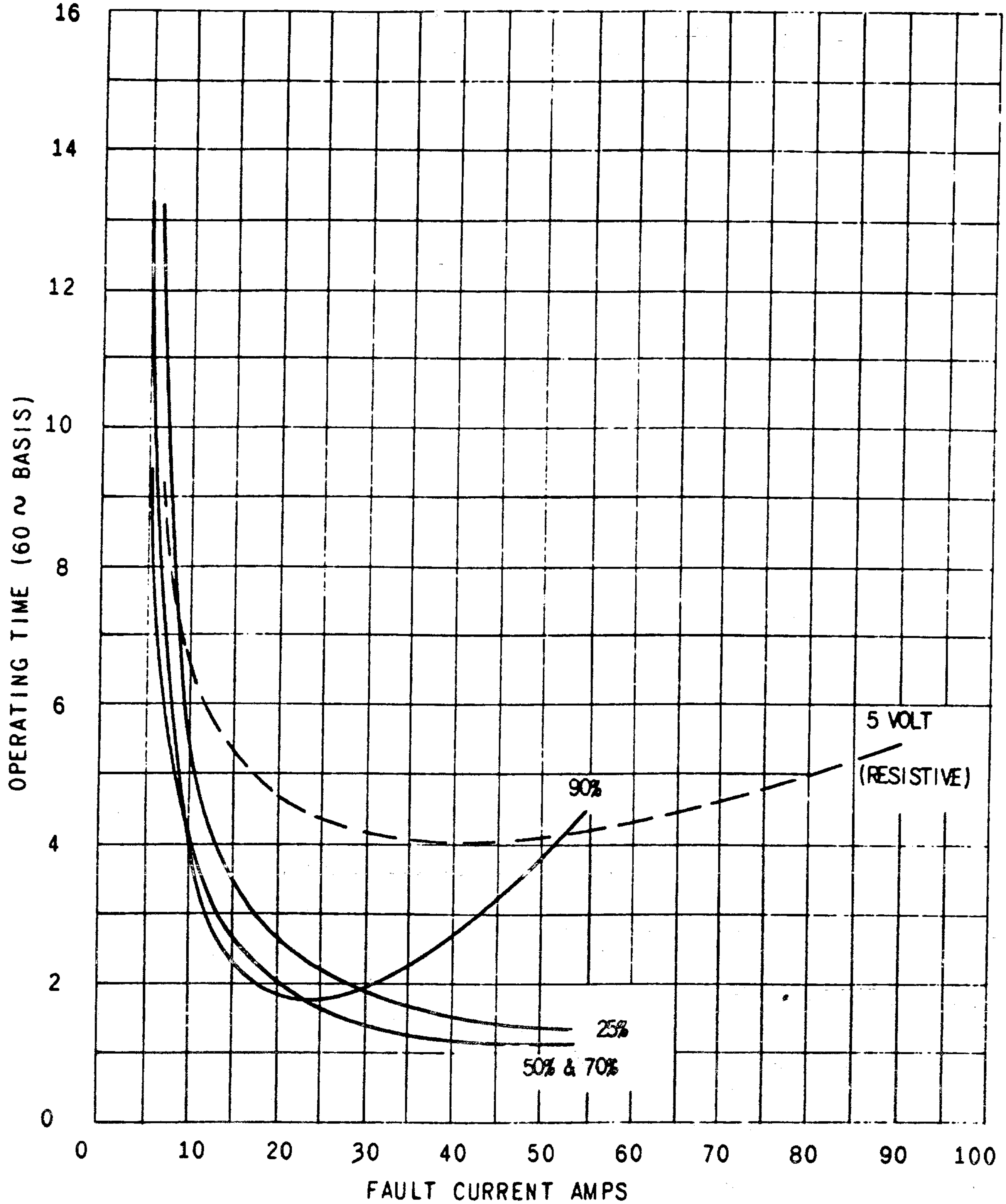


Fig. 22 Average Operating Time Curves (Zero Voltage Before Fault) For GCX17 1.0 Ohm Relay

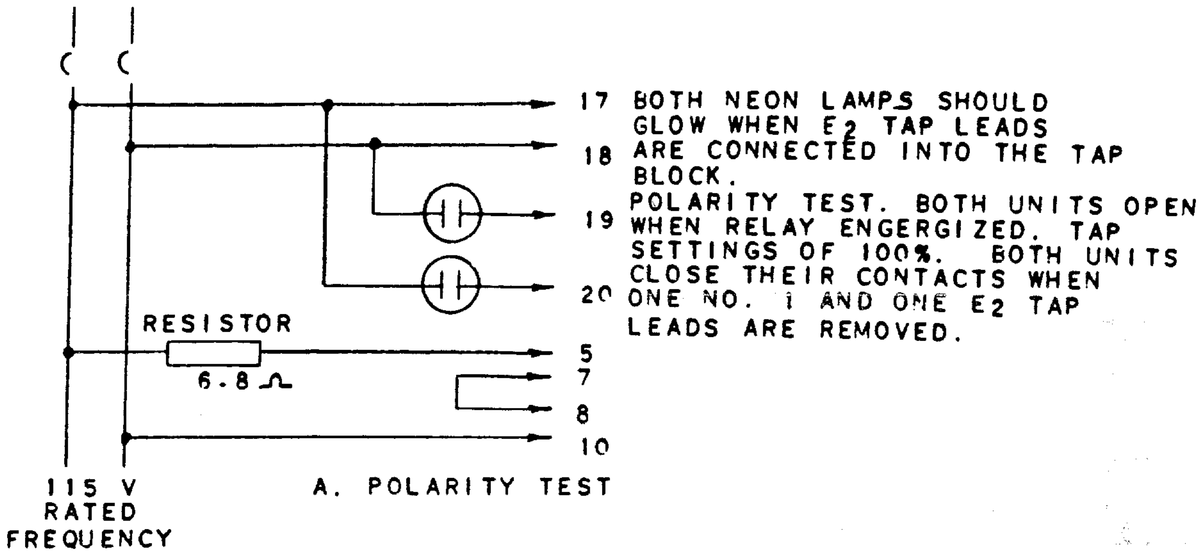


Fig. 23 Average Operating Time Curves (With Bus Side PT's) For GCX17 1.0 Ohm Relay

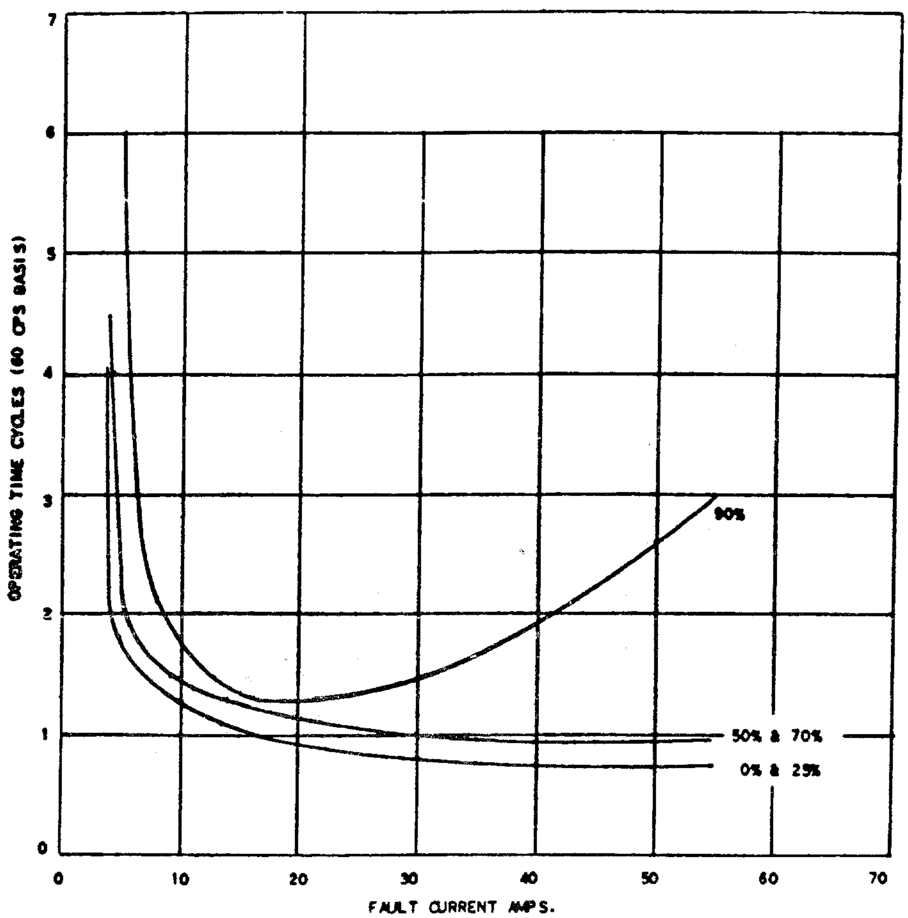
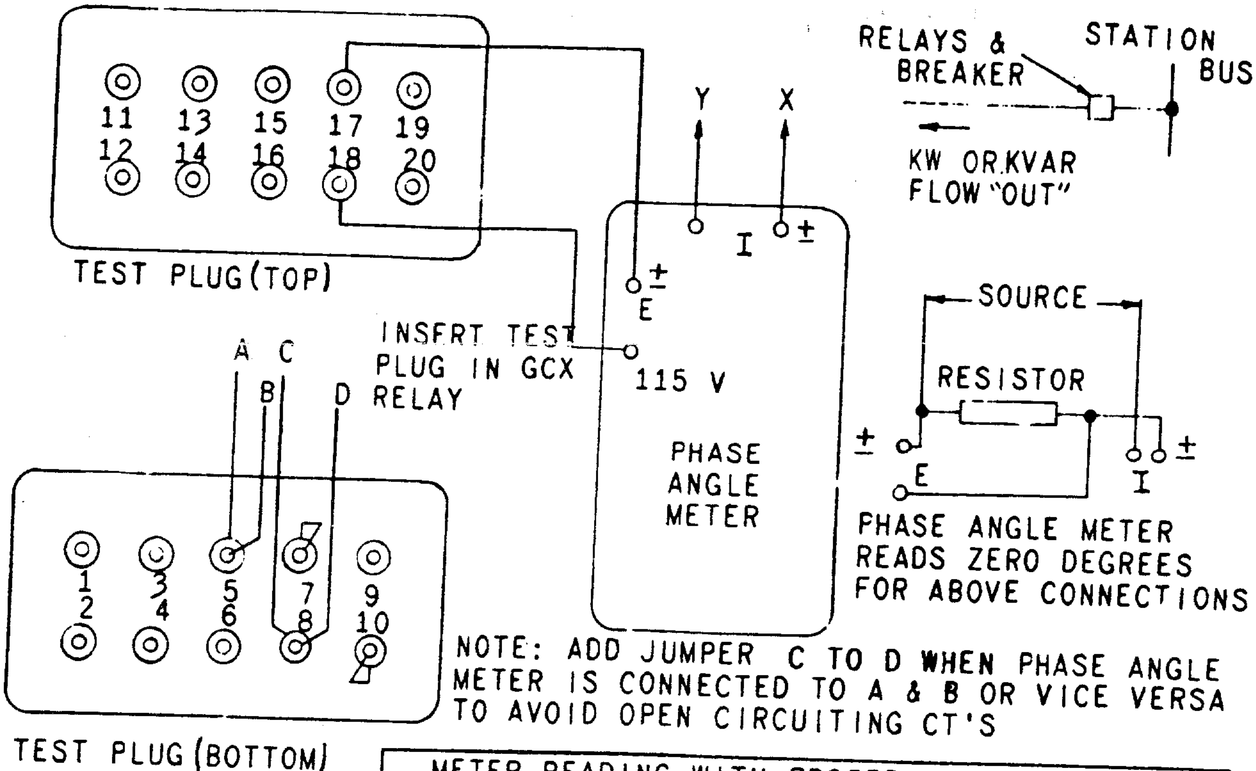


Fig. 24 Polarity Test Connections For GCX17 Relay



NOTE: ADD JUMPER C TO D WHEN PHASE ANGLE METER IS CONNECTED TO A & B OR VICE VERSA TO AVOID OPEN CIRCUITING CT'S

		METER READING WITH PROPER EXTERNAL CONNECTIONS							
		PHASE SEQUENCE 1-2-3							
	POWER FACTOR ANGLE (DEG. LEAD) →	0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360
	KW & KVAR DIRECTIONS WITH RESPECT TO THE BUS	KW OUT > KVAR IN	KVAR > IN KW OUT	KVAR IN > KW IN	KW IN > KVAR IN	KW IN > KVAR OUT	KVAR > OUT KW IN	KVAR > OUT KW OUT	KW OUT > KVAR OUT
RELAY CONNECTIONS	X TO A Y TO B	330-15	15-60	60-105	105-150	150-195	195-240	240-285	285-330
	X TO C Y TO D	30-75	75-120	120-165	165-210	210-255	255-300	300-345	345-30
		PHASE SEQUENCE 1-3-2							
	X TO A Y TO B	30-75	75-120	120-165	165-210	210-255	255-300	300-345	345-75
	X TO C Y TO D	330-15	15-60	60-105	105-150	150-195	195-240	240-285	285-330

THE ABOVE RANGES OF PHASE ANGLE METER READINGS ARE THE ANGLES BY WHICH THE CURRENT LEADS THE VOLTAGE WITH THE DESCRIBED CONDITIONS OF POWER (KW) AND REACTIVE POWER (KVAR) FLOW WITH THE STATION BUS CONSIDERED AS THE REFERENCE IN ALL CASES.

CAUTION: MAKE CORRECTIONS FOR METER ERRORS ON LOW CURRENTS, INHERENT IN SOME PHASE-ANGLE METERS.

Fig. 25 Connections And Reading For Phase Angle Test

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