GEI-98328J

INSTRUCTIONS

DIRECTIONAL DISTANCE

(REACTANCE RELAY)

TYPES

GCX51A Forms 11 and up
GCX51B Forms 11 and up

GENERAL ELECTRIC

TABLE OF CONTENTS

	PAGE
DESCRIPTION	3
APPLICATION	3
RATINGS	4
OPERATING PRINCIPLES	6
MHO Unit	6
OHM Unit	6
CHARACTERISTICS	7
MHO Unit	7
OHM Unit	8
Operating Time	9
Vernier Adjustment for Low Tap Settings	10
OHM Unit Transfer Auxiliary	10
BURDENS	11
CALCULATION OF SETTINGS	12
CONSTRUCTION	14
ACCEPTANCE TESTS	15
Visual Inspection	15
Mechanical Inspection	16
Electrical Checks	16
MHO Unit Checks	16
Control Spring Adjustment	16
Ohmic Reach	17
Angle-of-Maximum-Torque Check	17
OHM Unit Checks	18
Control-Spring Adjustment	18
Ohmic Reach and Angle of Maximum Torque	18
Other Checks and Tests	18
OHM-Unit Transfer Relay (OX)	18
Target/Seal-in Unit	19
INSTALLATION PROCEDURE	19
Location	19
Mounting	19
Connections	19
Visual Inspection	19
Mechanical Inspection	19
Electrical Check Tests on Induction Units	20
Testing the OHM Unit	20
Testing the MHO Unit	21
Other Checks and Tests	24
Overall Tests	25
PERIODIC CHECKS AND ROUTINE MAINTENANCE	26
Contact Cleaning	26
SERVICING	26
MHO UNIT	26
Control-Spring Adjustment	26
Ohmic Reach Adjustment	27
Angle of Maximum Torque	27
OHM UNIT	28
Control-Spring Adjustment	28
Reach and Angle-of-Maximum-Torque Adjustment	28
RENEWAL PARTS	29
LIST OF FIGURES	30
APPENDIX I	48

DIRECTIONAL DISTANCE (REACTANCE) RELAYS

TYPE GCX51

DESCRIPTION

The Type GCX51A and GCX51B relays are single-phase, three-zone phase-distance relays. The first- and second-zone distance measurements are made by a unit having a reactance (or OHM) type of characteristic, while the third zone has a directional MHO characteristic. The GCX51A and 51B relays are identical except that the GCX51B contains an instantaneous overcurrent fault detector while the GCX51A does not. Three type-GCX51 relays plus a suitable RPM or SAM timing relay will provide three-step directional distance protection against three-phase, phase-to-phase, and double-phase-to-ground faults on a transmission line. They are also used in conjunction with other relays and pilot channels to provide high-speed protection in transferred-tripping and directional-comparison schemes. Each GCX51 has one target seal-in unit and comes in an L2 case. The R-X characteristics of these relays are shown in the R-X diagram of Figure 5.

APPLICATION

The type GCX51A and GCX51B relays, because of the reactance characteristics of their first and second zones, are particularly well suited for the protection of circuits where arc resistance is apt to be a problem. Since the arc resistance in a fault is directly related to the length of the arc and inversely to the current, arc resistance is independent of line length. Thus, arc resistance becomes a more significant part of the total impedance from the relay to the fault as the protected line length gets shorter. It is for this reason that the GCX type of characteristic is ideally suited for the protection of short transmission lines. However, the GCX51 relays may also be applied on longer lines if the range of the relay permits the required reach settings.

It will be noted in the section on **RATINGS** that the reactance unit in each GCX51 relay provides three basic minimum-reach settings, readily selected by means of a tap link at the front of the relay. In general, when setting these units for a given reach, it is desirable to use the highest basic reach tap that will accommodate the required first-zone reach setting. For example, if a 0.75 ohm setting is required for the first zone of a standard reach relay, the 0.5 ohm basic reach tap should be used rather than the 0.25 ohm tap. It is not recommended that the OHM unit tap leads be set for less than 10%.

The third zone MHO unit of these relays is adjusted at the factory to have an angle of maximum torque of 60°. Athough this can be adjusted up to 75°, it is desirable to retain the 60° setting to obtain maximum arc resistance accommodation for first zone faults close to the relay location. It is not recommended that the MHO unit tap leads be set for less than 25%. The MHO unit reach setting may be subject to further limitations as described in Appendix I.

Table I shows the minimum currents required in the relay for three-phase faults at the remote end of the protected line. These values of current were determined by tests of all conditions of fault locations, of MHO and OHM unit coordination, and of proper unit contact action to determine the final limitation for positive relay operation for any multi-phase fault on the line.

TABLE I

Basic Tap Setting	Min. Three-Phase Fault Current Secondary Amperes
Short-Reach Relay	
0.1 ohms	16 - Amperes
0.2 ohms	10 - Amperes
0.4 ohms	10 - Amperes
Standard-Reach Relay	
0.25 ohms	6 - Amperes
0.50 ohms	5 - Amperes
1.00 ohms	4 - Amperes

Because they have no significant transient overreach, the first-zone units of the GCX51 relays may be set for 90% of the distance to the nearest remote terminal. The second-zone units should be set to reach at least 110% of the distance to the farthest remote terminal (including the effects of infeed if present). The third-zone MHO units should be set to reach sufficiently farther than the second-zone units to provide for accommodating arc resistance at the second-zone balance point. The third-zone MHO units sometimes are used to obtain back-up protection for faults on remote line sections. However, it is not good practice to set the MHO unit to reach any farther than is necessary.

The overcurrent fault detector in the GCX51B relays should always be set to pick up no lower than 115% of maximum load current. These fault detector units are not designed to operate continuously in the picked-up position.

For information on settings see the section on **CALCULATIONS OF SETTINGS.**

For typical external connections in a three-step distance scheme see Figure 3.

RATINGS

The Type GCX51A and GCX51B relays covered by these instructions are available for 120 volts, 5 amperes, 50/60 cycle rating. The 1-second current rating is 225 amperes. The DC control voltage of 48/125/250 is selected by a link setting on the front of the relay.

The basic minimum reach and adjustment range for the OHM and MHO units of the standard-reach and short-reach forms of the relay are given in Table II.

TABLE II

RELAY	OHM UNIT BASIC MIN. REACH * (ø-N OHMS)	OHM UNIT RANGE (ø-N OHMS)	MHO UNIT BASIC MIN. REACH (ø-N OHMS)	MHO UNIT RANGE (ø-N OHMS)	**ANGLE OF MAX. TORQUE
Short Reach	0.1/0.2/0.4	0.1/4	1	1/4	60°
Standard Reach	0.25/0.5/1.0	0.25/10	2.5	2.5/10	60°

* Adjustment link is set at the 0.2 or 0.5 basic min. reach prior to shipment.

** The angle of maximum torque of the MHO unit can be adjusted up to 75° with resulting increase in reach to approximately 120% of the reach at the 60° angle of maximum torque.

It will be noted that for each relay three basic minimum reach settings are listed for the OHM unit. Selection of the desired basic minimum reach is made by means of two captive tap screws on a tap block at the front of the relay.

The reach settings of the OHM and the MHO units can be adjusted in one percent (1%) steps by means of auto-transformer tap leads on the tap block at the right side of the relay. First-zone reach of the OHM unit is determined by the No. 1 leads, second-zone reach by the No. 2 leads, and the reach of the MHO unit, by the E_2 leads.

The GCX51B relay includes an instantaneous overcurrent unit identified as OC on the internal-connection diagram, Figure 8. The short-reach form of the GCX51 is normally furnished with an OC unit having a 4-16 ampere calibration range. The standard-reach form is available with OC calibration ranges of 4-16, 2-8 or 1-4 amperes.

The contacts of the GCX51 relays will close and carry momentarily 30 amperes DC. However, the circuit-breaker trip circuit must be opened by an auxiliary switch contact or other suitable means, since the relay contacts have no interrupting rating.

The 0.6/2 ampere target seal-in unit used in the GCX51 relays has ratings as shown in Table III.

TABLE III

TARGET SEAL-IN UNIT		
	0.6 Amp Tap	2.0 Amp Tap
Minimum Operating	0.6 amps	2.0 amps
Carry Continuously	1.5 amps	3.5 amps
Carry 30 Amps for	0.3 secs.	4 secs.
Carry 10 Amps for	4 secs.	30 secs.
DC Resistance	0.6 ohms	0.13 ohms
60 Cycle Impedance	6 ohms	0.53 ohms

OPERATING PRINCIPLES

MHO Unit

The MHO unit of the Type GCX51 relays is of the four-pole induction cylinder construction (see Figure 14) with schematic connections as shown in Figure 4. The two side poles, energized with phase-to-phase voltage, produce the polarizing flux. The flux in the front pole, energized with a percentage of the same phase-to-phase voltage, interacts with the polarizing flux to produce restraint torque. The flux in the rear pole, energized with the two line currents associated with the same phase-to-phase voltage, interacts with the polarizing flux to produce the operating torque.

The torque at the balance point can therefore be expressed by the following equation:

$$T = 0 = EI \cos(\phi - \theta) - KE^2$$

where:

E = The phase-to-phase voltage (E_{12})
I = The delta current ($I_1 - I_2$)
θ = Angle of maximum torque of the unit
ϕ = Power factor angle of fault impedance
K = Design constant

Dividing through by E^2 and transposing, the equation reduces to the following expression in terms of impedance:

$$\frac{1}{Z} \cos(\phi - \theta) = K \quad \text{or} \quad Y \cos(\phi - \theta) = K$$

Thus the unit will pick up at a constant component of admittance at a fixed angle, depending on the angle of maximum torque. Hence the name MHO unit.

OHM Unit

The OHM unit of the GCX51 relays is also of the four-pole induction cylinder construction (see Figure 14) with schematic connections as shown in Figure 4. The front and back poles, energized with delta current, produce the polarizing flux. The side poles are energized with a voltage equal to the difference between the operating quantity, IZ_T, and the restraint voltage, E, where I is the delta current and Z_T is the transfer impedance of the transactor. Torque on the unit results from interaction between the net flux in the side and the polarizing flux in the front and rear poles, and at the balance point can be expressed by the following equation:

$$T = 0 = KI\,(IZ_T - E) \sin \beta$$

where:

E = phase-to-phase voltage (E_{12})
I = delta current ($I_1 - I_2$)
Z_T = transfer impedance of transactor (design constant)
β = angle between I and ($IZ_T - E$)
K = design constant

By means of trigonometric relations, the above equation can be reduced to:

$(KI)\ (IZ_T) \sin \phi - KI\ (E) \sin \theta = 0$

where:

ϕ = angle between I and IZ_T (i.e. the transactor angle, a design constant)
θ = angle between E and I (i.e. angle of fault impedance)

Since Z_T for a particular transactor tap setting is also a design constant, the equation becomes:

$K'I^2 = K\ IE \sin \theta$

$$\frac{K'}{K} = K'' = \frac{E}{I} \sin \theta$$

$$K'' = Z \sin \theta = X_F$$

Thus the unit will operate when the fault reactance X_F is less than a constant determined by the transactor characteristics and tap setting.

CHARACTERISTICS

The operating characteristics of the OHM and MHO units in the GCX51 relays are best shown as impedance characteristics on an R-X diagram. (See Figure 5).

MHO Unit

The MHO unit has a circular impedance characteristic which passes through the origin and has its center on the angle-of-maximum-torque line of the unit. The basic minimum reach of the unit at the angle of maximum torque (see Table II under **RATINGS**) is obtained when the E^2 restraint taps are on 100%. The ohmic reach can be extended by reducing the percentage of the fault voltage applied to the restraint circuit, that is by setting the E^2 restraint taps on a lower percentage position on the tap block. The ohmic reach of the unit at the transmission line angle, which will usually differ from the angle of maximum torque, can be determined from the following equation:

Ohmic Reach at Line Angle =

$$\frac{(\text{Input Tap})\ Z_{min}\ \cos(\theta - \phi)}{E^2 \text{ Tap Setting } (\%)}$$

where:

θ = Angle of maximum torque of the unit
ϕ = The angle of the line
Z_{min} = The basic minimum phase-to-neutral ohmic reach of the unit

Input Tap = Input tap setting in Percent (normally is 100 except as explained under "Vernier Adjustment" on page 10).

E^2 Tap Setting (%) = the E^2 or Voltage Restraint Tap Setting in percent

For E^2 tap and input tap settings of 100% the phase-to-neutral ohmic reach will be equal to the basic minumum reach shown in Table II under **RATINGS** when the angles ϕ and θ are equal.

The primary purpose of the MHO unit in the type-GCX51 relays is to provide the directional discrimination that is necessary since the OHM unit is inherently nondirectional. The MHO unit directional characteristic is such that it will operate correctly for either forward or reverse faults at voltages down to 1% of rated voltage over a current range of 5 to 60 amperes. A secondary purpose of the MHO unit is to measure fault impedance for the third zone of protection.

At reduced voltage, the ohmic value at which the MHO unit will operate may be somewhat lower than its calculated value. This "pullback" or reduction in reach is shown in Figure 6 for the 1.0 ohm MHO unit used in the short-reach relay, or in Figure 7 for the 2.5 ohm MHO unit used in the standard-reach relay. The percentage of relay reach for a constant tap setting is expressed as a function of the three-phase fault current, $I_{3\phi}$, for various ohmic reach settings. The MHO unit will operate for all points to the right of the curves. The static curves of Figures 6 and 7 were determined by tests performed with no voltage supplied to the relay before the fault was applied. The dynamic curves were obtained with full rated voltage of 120 volts supplied to the relay before the fault was applied. These dynamic curves illustrate the effect of the MHO unit memory action, which maintains the polarizing voltage on the unit for a few cycles after the inception of the fault.

This memory action is particularly effective at low voltage levels where it enables the MHO unit to operate for low fault currents. This can be most forcefully illustrated for a zero-voltage fault by referring to Figure 7. A zero-voltage fault must be right at the relay bus and therefore, to protect for this fault, it is imperative that the relay reach zero percent (0%) of its setting. Figure 7 shows that the MHO unit, under static conditions, will not see a fault at zero percent (0%) of the relay setting regardless of the tap setting. However, under dynamic conditions when the memory action is effective, Figure 7 shows that a 2.5-ohm MHO unit with a 100% tap setting will pick up if $I_{3\phi}$ is greater than 2.5A. This is of course a marginal condition. The minimum fault currents considered safe are listed in Table I in the **APPLICATION** section.

OHM Unit

The OHM unit impedance characteristic when represented on the R-X diagram (Figure 5) is a straight line parallel with the R axis. The unit will operate for fault impedances lying below its characteristic, and hence is non-directional.

During normal conditions when load is being transmitted over the protected line, the voltage and current supplied to the unit present an impedance that lies close to the R axis since load will be very near unity power factor in contrast with the reactive KVA that flows during fault conditions. An impedance near the R axis will lie below the OHM unit characteristic (see Figure 5) and hence the OHM unit contact will be closed. This will cause no trouble, however, since the directional MHO unit contact will not be closed for this condition (see Figure 3).

The basic minimum reach of the OHM unit as listed in Table II under **RATINGS** is obtained when the restraint tap leads are on 100%. The ohmic reach can be extended by setting the restraint tap leads on a lower percentage position on the tap block. The setting of the two tap leads marked No. 1 determines the reach of the instantaneous or first zone, and the setting of the two tap leads marked No. 2 determines the reach of the intermediate or second zone.

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

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

For a numerical example of the determination of the OHM and MHO unit settings, refer to the section on **CALCULATIONS OF SETTINGS.**

The purpose of the OHM unit in the GCX51 relays is to provide an accurate measurement of the distance to a fault and to close its contacts if the fault lies within the first or second zone protected by the relay.

The overreach of the OHM unit from transient offset of the fault current is very small, even with highly lagging line impedances, and can be neglected for relay settings within the recommended ranges.

Operating Time

The operating time of the Type GCX51 relay is determined by a number of factors such as basic minimum reach of the OHM and MHO units, fault-current magnitude, ratio of fault impedance to relay reach, and whether relay voltage prior to the fault is at rated 120 volts or is zero (0). A series of figures is included at the rear of the book showing operating time of the MHO unit and overall operating time of the relay for a number of typical conditions. The operating time of the MHO unit is given separately because this unit is frequently used for the carrier-stop function in directional comparison carrier schemes.

The time-curve figures are listed in Table IV for the MHO unit alone and in Table V for the relay.

TABLE IV

Time Curves for MHO Unit Alone

Relay	Basic Min. Reach (MHO Unit)	Volts Prior to Fault	Figure #
Short	1.0 ohm	120	15
Reach	1.0 ohm	0	16
Stand.	2.5 ohm	120	17
Reach	2.5 ohm	0	18

In each figure it will be noted that time curves are given for three ratios of fault impedance to relay reach setting. In the case of the figures for the zero-voltage condition, an additional curve (shown dotted) is also given for a 4-volt resistive fault condition. In all cases, the E^2 and/or the No. 1 taps were in the 100% position and the MHO unit angle of maximum torque was set at 60° lag.

TABLE V

Overall Time Curves for Relay

Relay	Basic Min. Reach (MHO Unit)	Volts Prior to Fault	Figure #
Short Reach	0.1	120	19
	0.1	0	20
	0.2	120	21
	0.2	0	22
	0.4	120	23
	0.4	0	24
Standard Reach	0.25	120	25
	0.25	0	26
	0.5	120	27
	0.5	0	28
	1.0	120	29
	1.0	0	30

Vernier Adjustment for Low Tap Settings

The input leads are normally set at 100% but with a high secondary-line reactance, where the No. 1 tap leads would be set at a low percentage, the input connections may be varied by a vernier method to obtain a closer setting. For example, if the desired first zone reach is 1.2 ohms and the basic minimum reach of the OHM unit is 1.0 ohm, with the input on 100% the output tap setting would be 100/1.2 or 83.3%, which can be set within 0.4%.

However, if the desired first zone reach were 9.5 ohms, the output setting would be 100/9.5, or 10.55%. The nearest output tap would be 11%, which is 4% off the desired value. To correct this, the input leads can be shifted to 95%, in which case the output setting would be 95/9.5, or 10%, which of course can be set exactly.

OHM Unit Transfer Auxiliary

The OHM unit transfer auxiliary, OX, is a telephone-type relay whose coil and contacts are shown on the right in the internal-connection diagram of Figure 8. 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 or SAM timing relay as shown by the external connections diagram of Figure 3. 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 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.

BURDENS

The maximum current burdens for the relay at 5 amperes are listed in Table VI.

TABLE VI

AMPS	CY.	R	X	P.F.	W	VA
5	60	0.32	0.12	0.94	8	8.5

These data are for the 1.0 ohm minimum basic reach tap of the standard-reach relay. The burden on the 0.5 and .25 taps, and on the 0.4, 0.2 and 0.1 ohm taps of the short-reach relay, will be slightly lower.

The potential burden will vary with the tap settings used for the OHM and MHO unit restraint circuits and can be calculated from the following formulae. All potential burdens are at 120 volts and are for 60 cycle relays:

OHM Unit:

$$VA = \left(a + jb\right)\left[\frac{\text{No. 1 Tap Setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2$$

MHO Unit:

$$VA = \left(c + jd\right)\left[\frac{E^2\,\text{Tap Setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2 + (e + jf)$$

The terms (a + jb) and (c + jd) represent the burdens of the OHM and MHO unit restraint circuits with input and output taps on 100%. The term (e + jf) represents the burden of the MHO unit polarizing circuit. The values of these terms are given in Table VII.

TABLE VIIA

POTENTIAL BURDENS

Frequency Rating		60 Cycles
OHM	(a + jb)	12.3 + j0
MHO Restraint	(c + jd)	4.6 - j5.7
MHO Polarizing	(e + jf)	10.0 + j0

TABLE VIIB

BURDENS FOR THE OVERCURRENT UNIT

Rated Amps	Calibration Range	VA at 5 Amps/60Cyc	W at 5Amps/60 Cyc
3	1-4	41	12.7
6	2-8	11.5	3.56
12	4-16	2.65	0.8

These burdens are measured with the armature in the dropped-out position. Values are for minimum pickup settings.

Complete potential burden data with No. 1 taps and E^2 taps on 100% and with the input tap on 100% are given in Table VIII:

TABLE VIII

MAXIMUM POTENTIAL BURDENS

	FREQ.	VOLTS	IMPEDANCE	P.F.	WATTS	VA
OHM	60	120	1169 + j0	1.0	12.3	12.3
MHO Restraint	60	120	1245 + j1540	0.66	4.6	7.3
MHO Polarizing	60	120	1460 + j0	1.0	10.0	10.0
Total Relay	60	120	515 + j109	0.98	26.8	29.6

The DC potential burden of the OX transfer relay circuit is given in Table IX for the 3 DC voltage taps:

TABLE IX

VOLTS	OHMS
48	800
125	2000
250	4000

CALCULATION OF SETTINGS

Table X illustrates qualitatively how to set the three zones of the relays when they are applied in straight distance schemes. For directional comparison applications, see GEK-7384.

TABLE X

UNIT	SETTINGS ON TWO TERMINAL LINES	SETTINGS ON THREE TERMINAL LINES
01	Set for 90% of the total line.	Set for 90% of the reactance to the nearest remote terminal. Do not include the effects of infeed.
02	Set for at least 110% of the total line reactance.	With all three terminal breakers closed, calculate the effective reactance seen by this unit for a three-phase fault at one of the remote terminals. Repeat for a fault at the second remote terminal. Include the effects of infeed in both cases. Select the larger of the two reactances and set this unit for at least 110% of this reactance.
M	Since the MHO unit supervises first- and second-zone tripping, it must be set to reach at least as far as the second-zone reactance unit. Actually the reach setting should be long enough to provide ample arc resistance accommodation at the balance point of the second zone. Any additional reach would only provide for additional back-up protection for faults on remote lines.	

Assume that it is desired to use GCX51B relays to protect the two-terminal, 5 mile, 69 KV transmission line shown in Figure 9.

Maximum load current = 450 amps

CT Ratio - 600/5

PT Ratio - 69,000/115

$$Z_{sec} = Z_{prim} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

$$Z_{sec} = 5(0.14 + j\ 0.80)\ \frac{120}{600} = 0.14 + j\ 0.80 \text{ ohms}$$

$$Z_{sec} = 0.813 \quad \angle 80^\circ$$

Select the standard-reach relay.

From a system fault study, determine the minimum secondary fault current at breaker #1 for a three-phase fault at bus B. Now determine the minimum secondary fault current at breaker #2 for a three-phase fault at bus A. Both these values should exceed 5 amperes for the relay selected above, when set on the 0.5 ohm base reach tap that is determined below.

The percent tap setting for the first-zone reactance unit is obtained from the following equation:

$$T = \frac{(X_{min})}{X_L} \times 100$$

where:

T = #1 tap setting in percent
X_{min} = Basic reach tap setting of reactance unit
X_L = Desired reactance reach in secondary phase-to-neutral ohms

If we assume that it is desired to set the first zone for 90% of the distance to the remote terminal, then:

X_L = 0.9 (0.80) = 0.72 Secondary ohms

For this ohmic reach use a 0.5 ohm basic reach tap setting. Thus,

X_{min} = 0.50

and

$$T = \frac{0.50}{0.72} \times 100 = 69.4\%$$

Since the 69.4% calculated from the equation above is not an integral number, use the next highest #1 tap, which is 70%.

To achieve this setting the tap lead from the lower No. 1 position would be connected to the 70% point and the tap lead from the upper No. 1 position would be connected to the 0% point.

The second-zone must be set to reach beyond the far terminal. Assume that after due consideration it is desired to set the second-zone reactance reach for 1.5 secondary ohms.

The percent tap setting required to obtain this reach is obtained from the same equation that was used for the first zone. Since the same unit is used for second-zone as is used for first zone, the same base reach tap setting is common to both zones. Thus, for the second-zone

$$T = \frac{0.50}{1.50} \times 100 = 33\%$$

To achieve this setting, the lower No. 2 tap lead would be connected to the 30% point, and the upper No. 2 tap lead would be connected to the 3% point.

The tap setting for the third-zone MHO unit is given by the following equation:

$$T = \frac{Z_{min}}{Z_L} \times 100 \cos (60 - \phi)$$

where:

T = Third zone (E^2) tap setting in percent.
Z_{min} = Minimum reach of the MHO unit as marked on the nameplate. For the standard reach relay, this is 2.5 ohms.
Z_L = Desired impedance reach in secondary phase-to-neutral ohms.
ϕ = Impedance of angle of Z_L
60° = Angle of maximum torque of the MHO unit.

Assume that in this case it is desired to set the third zone to reach 2.75 80° secondary phase-to-neutral ohms.

The percent tap setting for such a reach is:

$$T = \frac{2.5}{2.75} \times 100 \cos (60 - 80) = 85.5\%$$

Set the third zone (E^2) taps for 86%.

Note that the restraint tap setting of the MHO unit must not be set for less than 25%. Also refer to Appendix I for possible further limitations on the MHO unit reach setting. The instantaneous unit setting should be no lower than 115% of full-load current. In this case, with 600/5 CT's and a maximum load current of 450 amperes, the instantaneous overcurrent unit must be set to pick up above:

$$\frac{450}{600} \times 5 \times 1.15 = 4.3 \text{ amperes}$$

It should be noted that with such a setting the GCX relays will not operate for any faults that do not produce at least 4.3 amperes.

CONSTRUCTION

The Type GCX51 relays are assembled in the standard large-size, double-end (L2) drawout case, having studs at both ends in the rear for 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 that 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 a steel framework called a 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 plugs in place.

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 that has been tested in the laboratory.

The relay is composed of three major sub-assembly elements:

1. The bottom element includes the MHO or starting unit and associated circuit components. This unit is directional and detects the presence of faults within the zone covered by the relay. It also initiates operation of the zone timer for faults within its reach.

2. The middle element includes the OHM or reactance unit and associated circuit components. This unit provides accurate first- or second-zone distance measurement.

3. The top element includes the OHM unit transfer auxiliary (OX), the combination target and seal-in unit, the transactor associated with the OHM unit potential circuit, the tapped autotransformer that determines the reach of the OHM and MHO units, and in the case of the type GCX51B relay, the instantaneous overcurrent unit. The tap block associated with the autotransformer is mounted along the right side of the relay.

Figures 1 and 2 show the relay removed from its drawout case with all major components identified. Symbols used to identify circuit components are the same as those that appear on the internal connection diagram in Figure 8.

ACCEPTANCE TESTS

Immediately upon receipt of the relay an **INSPECTION** and **ACCEPTANCE TEST** should be made to make sure that no damage has been sustained in shipment and that the relay calibrations have not been disturbed. If the examination or test indicates that readjustment is necessary, refer to the section on **SERVICING**.

Visual Inspection

Check the nameplate stamping to make sure that the model number and rating of the relay agree with the requisition.

Remove the relay from its case and check that there are no broken or cracked molded parts or other signs of physical damage, and that all screws are tight.

Mechanical Inspection

It is recommended that the following mechanical adjustments be checked:

1.

CHECK POINTS	MHO UNIT	OHM UNIT
Rotating shaft end play	5 - 8 mils	5 - 8 mils
Contact gap	120-130 mils	35-45 mils
Contact wipe	3 - 5 mils	3 - 5 mils

2. There should be no noticeable friction in the rotating structure of the OHM and MHO units.

3. Make sure control springs are not deformed and spring convolutions do not touch each other.

4. With the relay well leveled in its upright position, the OHM unit and MHO unit contacts must be open. The moving contacts of the OHM and MHO units should rest against their backstops.

5. The armature and contacts of the seal-in unit should move freely when operated by hand. There should be at least 1/32" wipe on the seal-in contacts.

6. Make sure the armature of the telephone-type relay (OX) is moving freely.

7. Check the location of the contact brushes on the cradle and case blocks against the internal connection diagram for the relay.

Electrical Checks

Before any electrical checks are made on the OHM and MHO units, the relay should be connected as shown in Figure 10 and be allowed to **warm up** for approximately 15 minutes with the potential circuit alone (studs 17-18) energized at rated voltage and with the E^2 and No. 1 taps set at 100%. The units were warmed up prior to factory adjustment and if rechecked when cold will tend to underreach by 3% or 4%. Accurately calibrated meters are of course essential.

It is desirable to check the factory settings and calibrations by means of the tests described in the following sections. The OHM and MHO units were carefully adjusted at the factory and it is **not advisable to disturb these settings unless the following checks indicate conclusively that the settings have been disturbed.** If readjustments are necessary, refer to the section on **SERVICING** for the recommended procedures.

MHO Unit Checks

a. Control Spring Adjustment

Connect the relay as shown in Figure 10 and set the E^2 tap leads at 100%. The position of the No. 1 and No. 2 tap leads does not affect this test. Make sure that the relay is level in its upright position.

With the current set at 5 amperes and the voltage across studs 17-18 at 120 volts, set the phase shifter so that the phase-angle meter reads 300° (i.e. current lags the voltage on studs 17-18 by 60°). Now reduce the voltage to 2 volts and the current to about 2 amperes. Gradually increase the current until the MHO unit contacts just close. This should occur between 4.1 - 4.9 amperes for the 2.5 Ω mho, and 5.1 - 5.9 amperes for the 1.0 Ω mho.

b. Ohmic Reach

With the relay still connected as shown in Figure 10 and the E^2 taps in the 100% position, set the voltage at the value shown in Table XI for the relay to be checked. Increase the current until the MHO unit contacts just close. This should occur within the limits shown in Table XI:

TABLE XI

Relay	Basic Min. Reach (ø-N Ohms)	V_{17-18} Set At	Pickup Amps	Equiv. Test Reach (ø-ø Ohms)
Short Reach	1	40V	19.4-20.6	2
Standard Reach	2.5	75V	14.6-15.4	5

Note that for the test conditions the MHO unit sees a phase-to-phase fault of twice the basic minimum reach.

c. Angle-of-Maximum-Torque Check

For the angle-of-maximum-torque check, the connections of Figure 10 will still be used with the E^2 taps still at 100%, and the voltage set at the value shown in Table XI for the relay to be checked. The pickup should then be checked with the current displaced 30° from the maximum torque position in both the lead and lag direction.

Set the phase shifter so that the phase-angle meter reads 330°. Note that while the phase angle is being set the current should be at 5 amperes and the voltage on studs 17-18 should be increased temporarily to 120 volts. With voltage again at the value shown in Table XI, increase the current slowly until the MHO unit picks up. The pickup current should be 22 to 24 amperes for the short-reach relay and 16.5 to 18.2 amperes for the standard-reach relay.

Now reset the phase angle at 270° and again check the current required to pick up the MHO unit. The pickup current should fall within the same limits given in the previous paragraph.

Note that the two angles used in the previous check, i.e., 330° and 270°, are read 30° away from the angle of maximum torque. An examination of the MHO unit impedance characteristic in Figure 5 shows that the ohmic reach of the unit should be the same at both 330° and 270° and should be 0.866 times the reach at the angle of maximum torque.

OHM Unit Checks

a. Control-Spring Adjustment

Be sure that the relay is well leveled in its upright position. The moving contact should just touch its backstop.

b. Ohmic Reach and Angle of Maximum Torque

Since the OHM unit is a reactance-measuring device, its angle of maximum torque occurs at 90°, current lagging voltage.

1. To check the ohmic reach, use the connections shown in Figure 10. Set the No. 1 tap leads on 100% and set the current at 10 amperes. Set the phase shifter so that the phase-angle meter reads 270° (i.e. current lags voltage by 90°). Now vary the voltage across studs 17-18 until the point is found where the OHM unit contacts just close. This pickup point will be different for the standard- and short-reach forms of the relay, and also will depend upon the setting of the basic ohmic reach taps. Table XIV shows the pickup voltage point for the intermediate range settings in the colum headed 90°. A ±3% variation is permissible.

2. To check the angle of maximum torque use the same connections and settings as in (1) above except now set the phase shifter so that the phase angle meter reads 315° (i.e. current lags voltage by 45°). Again vary the voltage across studs 17-18 until the point is found where the OHM unit contacts just close. These points are listed in Table XII for the standard- and short-reach forms of the relay in the column headed 45°. A ± 3% variation is permissible.

Note that the relays are normally shipped from the factory with the basic minimum reach adjustment taps on the intermediate setting, that is, 0.2 ohms for the short-reach form and 0.5 ohms for the standard-reach form.

TABLE XII

OHM UNIT CHECK POINTS

RELAY	BASIC MIN REACH SETTING	NO. 1 TAP	SET CURRENT AT:	OPERATING POINTS(V_{17-18}) I LAGS V BY +∠-3% 90°	45°
Short Reach	0.2 Ohms	100%	15A	6V	8.4V
Stand. Reach	0.5 Ohms	100%	10A	10V	14.1V

Other Checks and Tests

In addition to the tests on the OHM and MHO units, it is recommended that the following general tests and checks be made as a part of the **ACCEPTANCE TEST** routine.

a. OHM-Unit Transfer Relay (OX)

The OHM-unit transfer relay, identified as OX in Figure 8, is provided with a voltage-selection link to adapt it for application on 48, 125 or 250 volt DC control. The unit should be checked for correct operation on each link position. Apply a variable source of DC voltage across studs 12-13 and check that the OX unit picks up at 80% or less of the nominal tap voltage for each link position.

b. Target/Seal-in Unit

The target/seal-in unit has an operating coil tapped at 0.6 or 2.0 amperes. The relay is shipped from the factory with the tap screw in the 0.6 ampere position. The operating point of the seal-in unit can be checked by connecting from a DC source (+) to stud 11 of the relay and from stud 3 through an adjustable resistor and ammeter back to (-). Connect a jumper from stud 15 to stud 3 also, so that the seal-in contact will protect the MHO unit contact. Then close the MHO contact by hand and increase the DC current until the seal-in unit operates. It should pick up at tap value or slightly lower. Do not attempt to interrupt the DC current by means of the MHO contact. Instead, open the circuit externally or turn off the DC source.

If it is necessary to change the tap setting, say from 0.6 to 2.0 amps, proceed as follows: Remove the tap screw from the left-hand contact strip and insert it in the 2.0 amp position of the right-hand contact strip. Then remove the screw from the 0.6 amp tap and put it in the vacant position in the left-hand plate. If this procedure is followed the contact adjustments will not be disturbed.

INSTALLATION PROCEDURE

Location

The location of the relay should be clean 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 Figure 32.

Connections

The internal connections of the GCX51A and B relays are shown in Figure 8. An elementary diagram of typical external connections is shown in Figure 3.

It will be noted in Figure 8 that as shipped from the factory, internal jumpers are connected between cradle terminals 17-19 and 18-20. If it is desired to use a separate polarizing potential, these internal jumpers can be removed. The restraint voltage would then be connected to studs 17-19 and the polarizing voltage to 19-20.

Visual Inspection

Remove the relay from its case and check that there are no broken or cracked component parts and that all screws are tight.

Mechanical Inspection

Recheck the seven adjustments mentioned under Mechanical Inspection in the section on **ACCEPTANCE TESTS.**

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 **CALCULATION OF SETTINGS** section. Examples of calculations for typical settings are given in that section. It is the purpose of the electrical tests in this section to check the OHM and MHO unit ohmic pick up at the settings that have been made for a particular line section.

To eliminate the errors that may result from instrument inaccuracies, and to permit testing the OHM and MHO units from a single-phase AC test source, the test circuit shown in schematic form in Fig. 11 is recommended. In this figure $R_S + jX_S$ 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% and 1% 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 Figure 11 have been arranged in a portable test box, Cat. No. 102L201, 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 GET-3474.

a. Testing the OHM Unit

To check the calibration of the OHM unit, it is suggested that the portable test box, Cat. No. 102L201; portable test reactor, Cat. 6054975; and test resistor, Cat. 6158546 be arranged with Type XLA test plugs according to Figure 12. These connections of the test box and other equipment are similar to the schematic connections shown in Figure 11 except that the Type XLA test plug connections are now included.

Use of the source impedance $R_S + jX_S$, simulating the conditions that would be encountered in practice, is necessary only if the relay is to be tested for overreach or contact coordination, tests which are not normally considered necessary at the time of installation or during periodic testing. Some impedance will usually be necessary in the source connection to limit current in the fault circuit to a reasonable value, especially when a short-reach unit is to be checked, and it is suggested that a reactor of suitable value be used for this purpose since this will tend to limit harmonics in the fault current.

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 thephase-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 percent 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:

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

For this test the value of R_L may be made zero (0) since the OHM unit responds only to a reactance quantity. The load box, however, may be adjusted to give a fault current of approximately 15 amperes, or whatever fault current is expected during three-phase and/or phase-to-phase fault conditions.

To illustrate the above, assume that a standard-reach relay is being tested and that the OHM unit range selection taps have been set for a basic minimum reach of 0.5 ohms. Further assume that the No. 1 taps are set at 70%, providing a zone 1 reach of approximately 0.72 ohms phase-to-neutral. These values were used in the example in the section on **CALCULATION OF SETTINGS.**

$$2X_{Relay} = 2(.72) = 1.44 \text{ ohms}$$

Therefore it will be necessary to use the 2 ohm reactor tap, since this is the nearest tap above twice the unit phase-to-neutral ohmic reach. Assume now that the calibration curve for the particular test reactor in use has been checked and that the reactance of the 2 ohm tap at the current level to be used in the test is actually 2.1 ohms. The percent tap of the test box autotransformer at which the OHM unit contact will just close can be calculated as follows:

$$\%Tap = \frac{1.44}{2.1} \quad (100) = 68.6\%$$

The OHM unit should therefore theoretically close its contact with the test box autotransformer taps set at 68% and remain open with the taps at 69%. A range of 67% to 70% is acceptable.

The phase angle of the OHM unit reactance characteristic can be readily checked by adding resistance R_L in series with the line reactance X_L in the test circuit Figure 12. This resistance, R_L, should be non-inductive and about 3 to 4 times as large as the line reactance, X_L. The source impedance should also be readjusted so that when the pickup point is checked the fault current will be approximately the same as in the previous test with reactance alone. When the fault switch is closed, the OHM unit should close its contacts at the same test box percent tap setting as in the previous test.

A check of the OHM unit second-zone setting may be made in the same manner, except that the transfer relay OX must be picked up by applying rated DC voltage between studs 12 and 13 (be sure the DC voltage selection link position agrees with the voltage to be used). It may also be necessary to use a different test reactor tap setting.

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 percent tap setting for pickup is determined. This difference results from the fact that, unlike the OHM unit, the impedance pickup characteristic of the MHO unit on an R-X diagram is a circle passing through the origin. The diameter of this circle is the reach of the unit at its angle of maximum torque, which is normally 60° with respect to the R axis.

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 selected, X_L, 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 Figure 13 it is seen that twice the relay reach at the angle of the test reactor impedance is:

$$2ZRelay = 2 \frac{Zmin}{E2\ Tap} \cos(\phi - \theta)$$

where:

ϕ = angle of test reactor impedance
θ = MHO unit angle of maximum reach

The test-box autotransformer percent tap for MHO unit pickup is then given by the equation:

$$\%\ Tap = \frac{2ZRelay}{ZL}(100)$$

As an illustration of the above, the example in the section on **CALCULATION OF RELAY SETTINGS** will again be used. In this example the E^2 tap setting was calculated to be 86%, and since a standard reach relay was used the basic minimum reach of the MHO unit is 2.5 ohms at the 60° angle of maximum torque. In determining the test reactor tap setting to use, it can be assumed as an approximation that the angle ϕ of the test reactor impedance is 80°. Based on this assumption, twice the relay reach at the angle of the test reactor will be:

$$2ZRelay = 2 \frac{2.5 \times 100}{86} \cos(80-60) = 5.6 \text{ ohms}$$

Therefore the 6 ohm tap of the test reactor should be used. 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°. Table XIII shows the angles for reach of the reactor taps.

TABLE XIII

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 6 ohm tap is 86°. Therefore:

$$2Z_{Relay} = 2\ \frac{2.5 \times 100}{86}\ \cos(86-0) = 5.22 \text{ ohms}$$

The calibration curve for the portable test reactor should again be referred to in order to determine exact reactance of the 6 ohm tap at the current level being used. For the purpose of this illustration, assume that the reactance is 6.2 ohms. Since the angle of the impedance of the 6 ohm tap is 86°, the impedance of this tap may be calculated as follows:

$$Z_L = X_L/\cos 4 = \frac{6.2}{9976}. = 6.23 \text{ ohms}$$

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 contact with the fault switch closed can now be determined as follows:

$$\%\ \text{Tap} = \frac{5.22}{6.2} = 84.3\%$$

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, impedance at 60° and 30° respectively will be available for checking the MHO-unit reach at the 60° and 30° positions. The MHO-unit ohmic reach at the zero-degree (0°) position may be checked by using the calibrated test resistor alone at 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 percent tap for pickup at a particular angle is given by:

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

where:

a = angle of test impedance Z_L

Z_L = the 60°, 30°, or 0° impedance value taken from the calibrated resistor data sheet

E^2 = MHO unit restraint tap setting

As in the previous tests the source impedance should be readjusted in each instance to maintain approximately the same fault-current level for each check point.

When checking the angle of maximum reach of the MHO unit as indicated above, there are two factors to keep in mind that affect the accuracy of the results.

First, when checking the MHO unit at angles of more than 30° off the maximum reach position, the error becomes relatively large with phase-angle error. This is apparent from Figure 13 where it is seen, for example, at the zero-degree (0°) position that a two or three degree (2° or 3°) 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 effect of the errors mentioned above in their true proportion, it is suggested that the reach characteristic, determined by test, be plotted on an R-X impedance diagram as typified by Figure 5. It is obvious that the apparent errors in reach, resulting from phase-angle error at angles well off the maximum reach position, occur in a region where the fault impedance vector will not lie. As for the error introduced by spring torque, it should be noted that the MHO unit is not the measuring unit for the primary protection but rather is only a directional unit. Therefore, its directional response is the most important consideration. For third- zone backup protection, the MHO unit is the measuring unit, but for remote faults the voltage at the relay is not apt to be low, and furthermore the accuracy of a third-zone backup 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 Figure 12. The fault resistor, R, may be zero, the test reactor should be set on the 0.5 ohm tap. With the test-box switch closed, the MHO unit contact should remain closed for a current range of 6-60 amperes with 2% 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 the connections are changed to the reverse position, the MHO unit contacts should remain open for the same conditions as described above.

c. <u>Other Checks and Tests</u>

In addition to the calibration checks on the OHM and MHO units as described above, it is desirable to make the following general tests:

1. Check that the voltage-selection link for the OX transfer unit is in the correct position for the DC voltage to be used (48, 125, or 250V). Check that the OX unit is picking up at 80% of nominal rated voltage, as determined by the link position, by applying a variable DC voltage between studs 12 and 13.

2. Check that the target seal-in unit is operating at tap value. This can be checked by means of the connections in Figure 12 if the zone-1 signal circuit is loaded with the proper by-pass resistor to draw a current of approximately tap value and the OHM and MHO contacts (and OC unit if present) are closed by hand. Be sure the seal-in unit tap screw is left in the required position (0.6 or 2.0 amps) for the application. If it is

necessary to change the tap setting, follow the procedure outlined in the section on **ACCEPTANCE TESTS** under Target Seal-In Unit.

3. If the relay being tested is a Type GCX51B, the pickup of the overcurrent unit (OC) should be checked. This can be done by adjusting the fault current level by means of the loadbox (Figure 12). Calibration points of the OC unit are marked on the relay nameplate. Normally the overcurrent unit is set at the factory for its minimum pickup. Pickup of the OC unit can be set at the desired value by changing the position of the knurled armature on the plunger rod. An approximate adjustment can be obtained by means of the etched lines on the calibrating tube. For an accurate setting, connect an adjustable source of AC current through studs 5-6 and set the armature for the exact pickup required. Note that typical pickup points of the OC unit are above the continuous rating of the OHM unit and transactor coils.

4. Clutch Adjustment

Ohm unit — Short Studs 17 & 18 (remove voltage). Place reach taps in center tap.

Rating	Clutch Action
0.5 Ohm	Slips between 34-44 amps
0.2 Ohm	Slips above 60 amps

Mho unit — Remove short - set voltage at 120V across studs 17 & 18, 19 & 20.

Rating	
2.5 Ohms	Slips between 50-57 amps
1.0 Ohm	Slips above 60 amps

The clutch on either unit can be adjusted by inserting a special flat open-end wrench underneath the green composition head directly above the spool body of the front coils, so that it engages with the flats on the molded spacer on the cup shaft. Hold this wrench and, with a 5/16" open-end wrench, loosen or tighten the clutch by turning the nut below the spring wind-up sprocket. Turn the nut clockwise (top-front view) to tighten the clutch setting; counterclockwise to loosen it.

d. Overall Tests

An overall check of current-transformer polarities, and connections to the relay, can be made on the complete installation by means of the test connections and tabulation in Figure 31. A check of the phase-angle-meter readings shown in the table for the power factor angle and phase sequence involved will indicate whether the relay is receiving the correct voltage and currents for the conventional connections shown in Figure 3.

For another overall test, remove the lower connection plug from the relay, disconnecting the current circuits. The MHO unit should develop strong torque to the right with normal voltage on the relay. Now replace the lower plug and open the E^2 taps on the main tap block. If the direction of power and reactive flow is away from the bus and into the protected line section, the MHO unit should operate. If the reactive power flow is into the station bus, the resulting phase angle may be such that the MHO unit will not operate.

PERIODIC CHECKS AND ROUTINE MAINTENANCE

In view of the vital role of protective relays in the operation of a power system, it is important that a periodic test program be followed. It is recognized that the interval between periodic checks will vary depending upon environment, type of relay, and the user's experience with periodic testing. Until the user has accumulated enough experience to select the test interval best suited to his individual requirements it is suggested that the points listed under INSTALLATION PROCEDURE be checked at an interval of from one to two years.

Contact Cleaning

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etch-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 ensures the cleaning of the actual points of contact. Do not use knives, files, abrasive paper or cloth of any kind to clean relay contacts.

SERVICING

If it is found during the installation or periodic tests that the OHM or MHO unit calibrations are out of limits, they should be recalibrated as outlined in the following paragraphs. It is suggested that these calibrations be made in the laboratory. The circuit components listed below, which are normally considered as factory adjustments, are used in recalibrating the units. These parts may be located from Figures 1 and 2.

R_1 - OHM unit reach adjustment.
R_2 - OHM unit phase-angle adjustment.
R_3 - MHO unit reach adjustment.
R_4 - MHO unit phase-angle adjustment.

NOTE: Before making pickup or phase-angle adjustments on the MHO or OHM units, the unit should be allowed to heat up for approximately 15 minutes, energized with voltage alone. Also it is important that the relay be mounted in upright position so that the units are level.

MHO UNIT

a. Control-Spring Adjustment

Connect the relay as shown in Figure 10 and set the E^2 tap leads at 100%. Make sure that the relay is level in its upright position. With the current set at 5 amperes and the voltage across studs 17-18 at 120 volts, set the phase shifter so that the phase-angle meter reads 300° (i.e., current lags voltage by 60°).

Now reduce the voltage to 2 volts and set the current at 5.5 amperes for 1Ω mho units and 4.5 amperes for 2.5Ω mho units. Insert the blade of a thin screwdriver into one of the slots in the edge of the spring-adjusting ring (see Figure 14)and turn the ring until the contacts just close. If the contacts were closing below the 4.5 ampere set point, the adjusting ring should be turned to the right. If they were closing above the set point, the adjusting ring should be turned to the left. Apply 2% of rated voltage to the relay.

Increase the current from 4.5 to 60 amperes; the contact should stay closed. Adjust the core if this test does not function. Then remove the potential, and short studs 17 & 18; the contact should remain open from 0 - 60 amperes. Both above tests will pass if the core is in the proper position.

Figure 33 shows an exploded view of the core and associated parts that lock the core in position to the unit sled.

By use of the special wrench, 0178A9455 part 1, the core can be rotated in either direction 360° without holding the locking nut "F" or having to retighten after the final position of the core has been determined.

b. Ohmic Reach Adjustment

The basic minimum reach of the MHO unit can be adjusted by means of rheostat R_3, which is identified in Figure 1. Increasing R_3, by turning the screwdriver adjustment in a counterclockwise direction, increases the reach of the unit.

Connect the relay as shown in Figure 10. Set the E^2 taps in the 100% position, and with the current at 5 amperes and voltage at 120 volts set the phase shifter so that the phase-angle meter reads 300° (i.e., current lags voltage by 60°). Now set the voltage on studs 17-18 at the value shown in Table XI (under **ACCEPTANCE TESTS**) for the relay to be adjusted, and adjust R_3 so that the MHO unit picks up at 20 ±2% amperes for the short-reach relay or 15 ±2% amperes for the standard-reach relay.

c. Angle of Maximum Torque

The angle of maximum torque of the MHO unit is controlled by means of rheostat R_4. Turning the R_4 screwdriver adjustment counterclockwise increases the angle of maximum torque.

With the relay connected as shown in Figure 10 and the E^2 taps in the 100% position, set the voltage across studs 17-18 at 40 volts for the short-reach relay, or 75 volts for the standard-reach relay (see Table XI under **ACCEPTANCE TESTS**). Then adjust R_4 so that the unit picks up at the same current level (21 to 23 amps for the short-reach relay, or 16.5 to 18.2 amps for the standard-reach relay) at phase-angle meter readings of 330° and 270°. (See MHO unit checks in the section on **ACCEPTANCE TESTS**).

NOTE: Adjustment of rheostat R_3 has a secondary effect on the angle of maximum torque, and adjustment of R_4 likewise effects the reach of the unit. Therefore, for very accurate settings it is necessary to recheck the reach after the angle of maximum torque has been set, and to continue readjustments until the reach and angle of maximum torque are both within the limits specified above.

OHM UNIT

a. Control-Spring Adjustment

Make sure the relay is well leveled in its upright position. Insert the blade of a thin screwdriver into one of the slots in the edge of the spring-adjusting ring, and set the ring so that the moving contact just touches its backstop. With the proper adjustment, if the backstop is backed off, the moving contact will not follow.

NOTE: It is recommended that the control-spring adjustments for both the OHM and MHO units be checked with the relay mounted in its final position on the panel.

b. Reach and Angle-of-Maximum-Torque Adjustment

The basic minimum reach of the OHM unit is controlled by rheostat R_1, and its angle of maximum torque (90° current lagging voltage) may be adjusted by means of rheostat R_2. It should be noted, however, that these adjustment are not independent; that is, an adjustment of R_2 will have some effect on the reach of the OHM unit, and adjustments of R_1 will affect the angle of maximum torque.

To calibrate the OHM unit, place the No. 1 taps in the 100% position and use the connections shown in Figure 10. Follow the procedure outlined below:

Step 1:

With current set at 5 amps and voltage at 120V, adjust the phase shifter so that the phase-angle meter reads 270° (i.e., current lags voltage by 90°). Then set the current for the value listed in the column headed "90°" in Table XIV. For example, for the 0.2 ohm basic minimum reach, the current would be set at 15 amps and the voltage at 6V. Adjust R_1 rheostat until the OHM unit contacts just close. Now raise the voltage and again lower it slowly until the OHM unit contacts just close. The voltage at the operating point should be within ±1% of the voltage listed in Table XIV in the column headed "90°". Readjust R_1 until the operating voltage is within the ±1% limit.

NOTE: The relay operating circuit should not be left energized with the test currents of Table XIV for more than a few seconds at a time.

TABLE XIV

RELAY	BASIC MIN. REACH SETTING	NO. 1 TAP	SET CURRENT AT:	OPERATING POINTS(V_{17-18}) I LAGS V BY: 90°	45°
	0.1 Ohms	100%	20A	4V	5.7V
Short Reach	0.2 Ohms	100%	15A	6V	8.5V
	0.4 Ohms	100%	15A	12V	17.0V
	0.25 Ohms	100%	15A	7.5V	10.6V
Stand. Reach	0.5 Ohms	100%	10A	10V	14.1V
	1.0 Ohms	100%	10A	20V	28.3V

Step 2:

Reset the phase shifter so that the phase-angle meter reads 315° (current lags voltage by 45°), and with the same current used in Step 1 set the voltage at the value listed in the column headed "45°". Then adjust R_2 until the contacts just close. Now raise the voltage and reduce it slowly until the contacts just close. The voltage at this operating point should be within ±1% of the value in Table XIV under the "45°" column. Modify the R_2 setting until the operating voltage is within this ±1% limit.

Step 3:

Recheck Step 1. The OHM unit contacts should close within ±2% of the voltage listed in the "90°" column. If the OHM unit contacts do not close within these limits, repeat steps 1 and 2 until the OHM unit contacts close within the limits specified.

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, specify quantity required, name the part wanted, and give complete nameplate data. If possible, give the General Electric requisition number on which the relay was furnished.

Since the last edition, Figure 32 has been changed.

LIST OF FIGURES

FIGURE		PAGE
1	Type-GCX51A Relay Removed from Case (Front View)	32
2	TypGCX51A Relay Removed from Case (Rear View)	32
3	Three-Step Distance Proctection for a Transmission Line Using Three Type-GCX51A or GCX51B Phase Distance Relays and One Type-SAM14B or SAM14K Timing Relay	33
4	Schematic Diagrams of MHO and OHM Units Used in Type-GCX51 Relays	34
5	Characteristics of the OHM and MHO Units on an Impedance Diagram for GCX51 Relay	35
6	Static and Dynamic Reach Data for the 1.0 Ohm MHO Unit Used in the Short-Reach GCX51 or B Relay	35
7	Static and Dynamic Reach Data for the 2.5 Ohm MHO Unit Used in the Standard-Reach GCX51A or B Relay	36
8	Internal Connections (Front View) of the Type-GCX51A or GCX51B Relay	36
9	Schematic Diagram of Typical Two-Terminal Line	37
10	Test Circuit for GCX51A and GCX51B Relays Using a Phase Shifter	38
11	Schematic Diagram of GCX Test Circuit	38
12	Connection for Field Testing the GCX51A and GCX51B Relays Using Type XLA Test Plugs	39
13	Reach of the MHO Unit at Angle of the Test Reactor	40
14	Four-Pole Induction-Cylinder Unit, Typifing Construction of the OHM and MHO Units in the GCX51 Relays	40
15	Operating-Time Curves for 1-Ohm MHO Unit in the Short-Reach Relay When the Relay Voltage Before the Fault is 120 Volts	41
16	Operating-Time Curves for 1-Ohm MHO Unit in the Short-Reach Relay When the Relay Voltage Before the Fault is Zero Volts	41
17	Operating-Time Curves for 2.5-Ohm MHO Unit in the Standard-Reach Relay When the Relay Voltage Before the Fault is 120 Volts	41
18	Operating-Time Curves for 2.5-Ohm MHO Unit in the Standard-Reach Relay When the Relay Voltage Before the Fault is Zero Volts	41
19	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.1 Ohms, Voltage Before the Fault, 120V)	42
20	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.1 Ohms, Voltage Before the Fault, Zero Volts)	42
21	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.2 Ohms, Voltage Before the Fault, 120V)	42
22	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.2 Ohms, Voltage Before the Fault, Zero Volts)	42
23	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.4 Ohms, Voltage Before the Fault, 120V)	43
24	Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.4 Ohms, Voltage Before the Fault, Zero Volts)	43
25	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.25 Ohms, Voltage Before the Fault, 120V	43
26	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM Unit Reach 0.25 Ohms, Voltage Before the Fault, Zero Volts)	43
27	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.5 Ohms, Voltage Before the Fault, 120V)	44

LIST OF FIGURES

FIGURE		PAGE
28	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.5 Ohms, Voltage Before the Fault, Zero Volts)	44
29	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 1.0 Ohm, Voltage Before the Fault, 120V)	44
30	Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 1.0 Ohm, Voltage Before the Fault, Zero Volts)	44
31	Test Connections for Overall Test of the GCX51 Relays	45
32	Outline and Panel Drilling for GCX51A and GCX51B Relays	46
33	Magnet and Coil Assembly	47
I-1	R-X Diagram Illustrating Response of GCX51 Relay to Phase-to-Phase Fault on Adjacent Phase Pair	49
I-2	Curves for Determining Maximum Safe Setting of MHO Unit in GCX51 Relay	50
I-3	Curves for Determining the Correction Factor of the GCX51 Relay	50

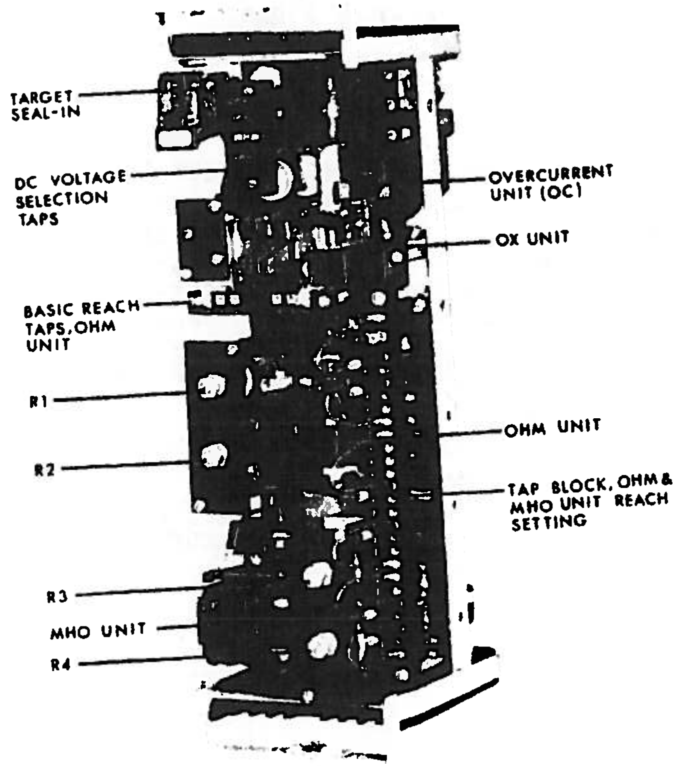


Figure 1 (8034914) Type-GCX51A Relay Removed from Case (Front View)

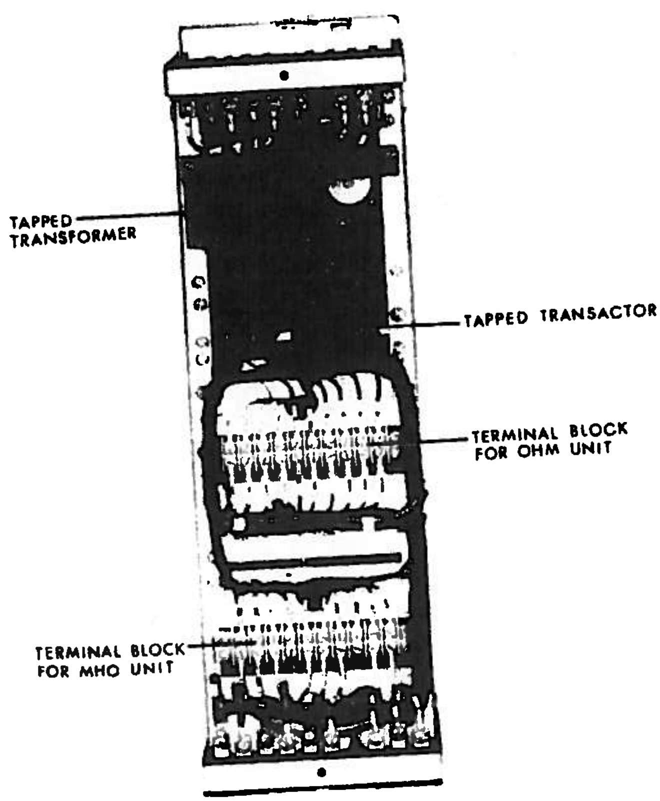
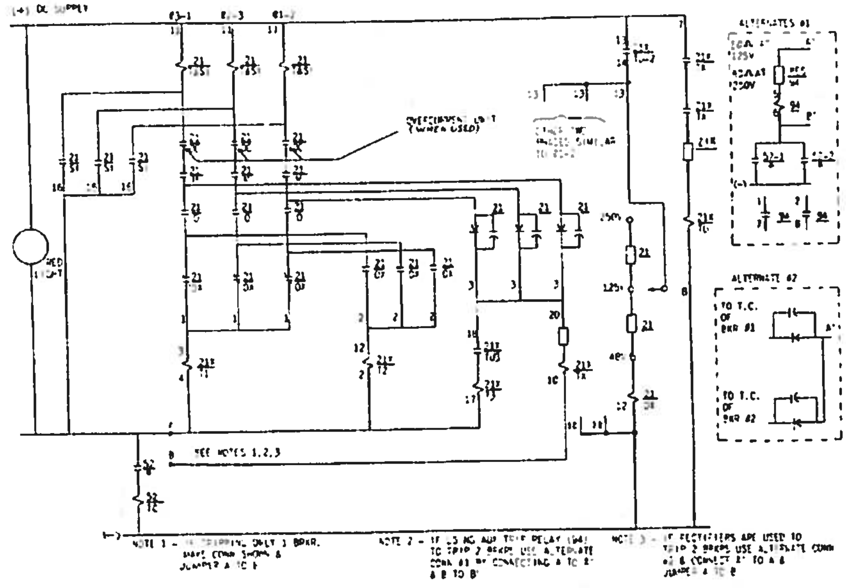


Figure 2 (8034917) Type-GCX51A Relay Removed from Case (Rear View)



LEGEND			
DEVICE NO.	DEVICE TYPE	INCL. ELEM.	DESCRIPTION
21	GCX51A,B,M,N,R		REACTANCE TYPE STEP DISTANCE RELAY
		TR	TRANSACTOR
		M	MHO UNIT
		O	REACTANCE UNIT
		OX	ZONE TRANSFER AUXILIARY FOR O
		TASI	TARGET AND SEAL-IN
21T	SAM11D & 11H*		TIMING RELAY
		T1,T2,T3	ZONE 1, ZONE 2, ZONE 3, TARGETS
		TU	TIMING ELEMENTS
		TU-2	FIRST TIMING CONTACT TO CLOSE
		TU-3	SECOND TIMING CONTACT TO CLOSE
		TX	AUXILIARY FOR TIMING ELEMENTS
52			CIRCUIT BREAKER
		a	AUXILIARY SWITCH
		TC	TRIP COIL
94	HGA14AR OR AL		AUXILIARY TRIPPING RELAY

* OR SAM14B,14K

TABULATION OF DEVICES		
DEVICE TYPE	INT. CONNS.	OUTLINE
GCX51A,B,M,N,R	0165A7706	K-6209276
SAM11D&H, OR SAM14B,14K	0171A7092	K-6209272
HGA14AR (BACK CONNS)	K-6400535	K-6400535
HGA14AL (FRONT CONNS)	377A139	377A139
TRIP RECTIFIER (102L218G-2) 125V		104A8584
TRIP RECTIFIER (102L218G-4) 250V		104A8584

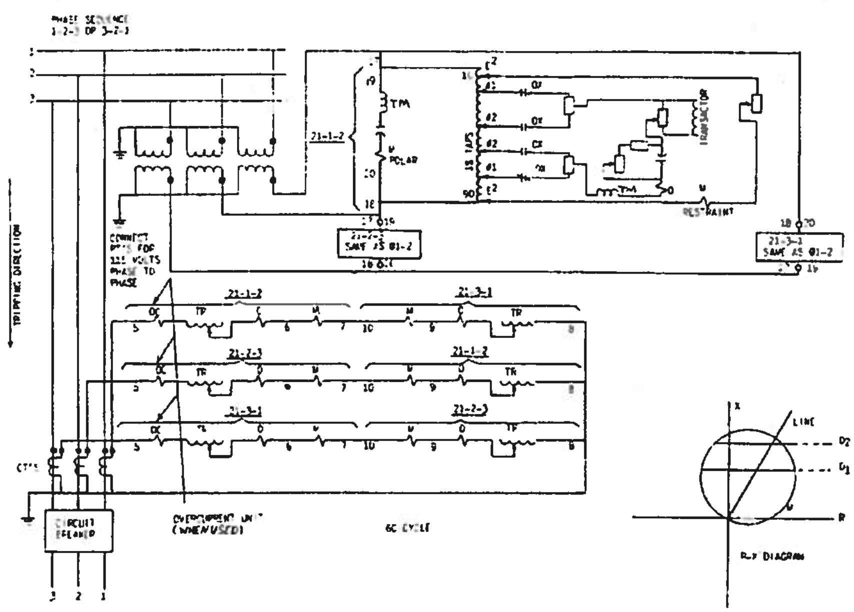


Figure 3 (7381B93-6) Three-Step Distance Protection for a Transmission Line Using Three Type-GCX51A or GCX51B Phase Distance Relays and One Type-SAM14B or SAM14K Timing Relay

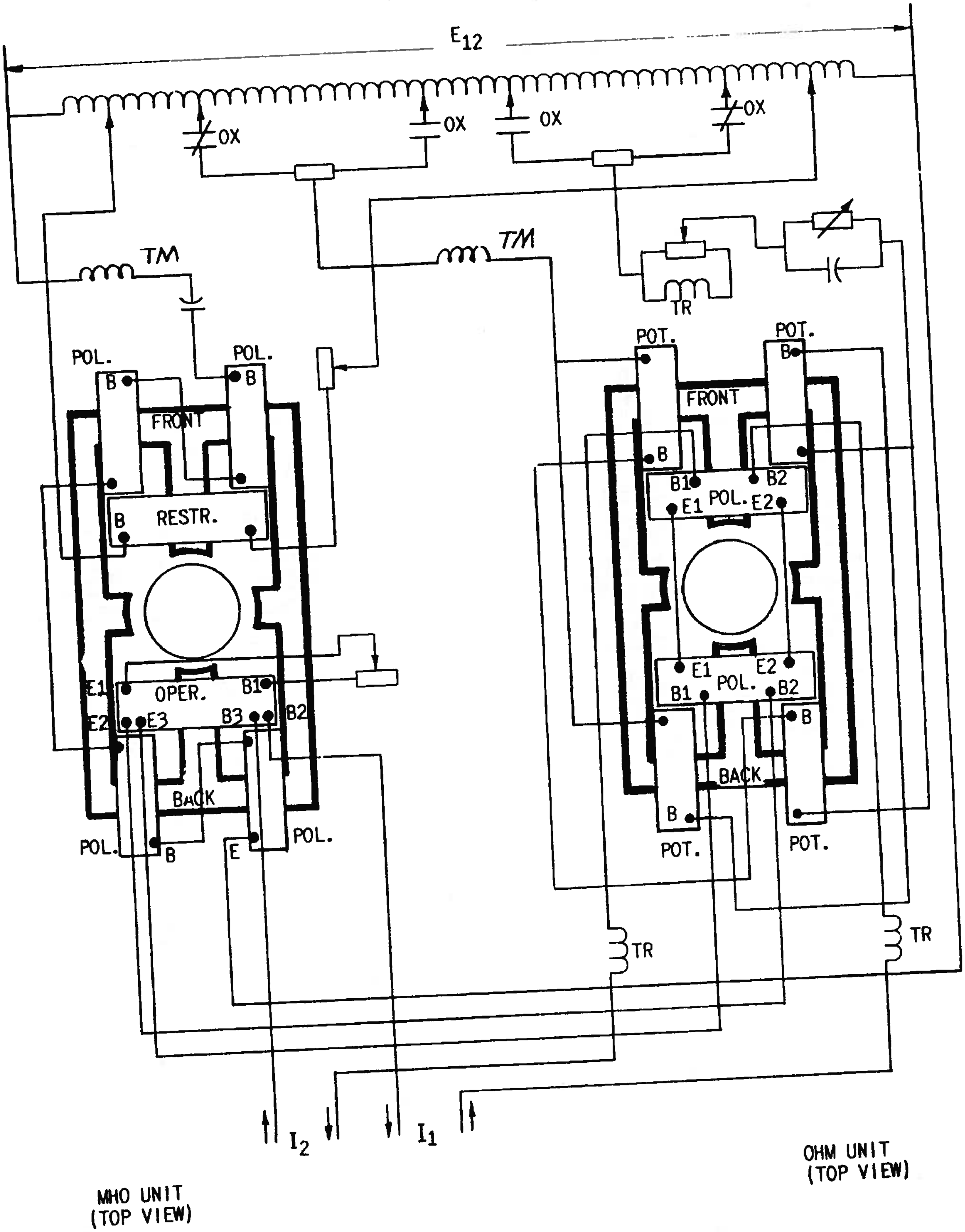


Figure 4 (0116B6856-1) Schematic Diagrams of MHO and OHM Units used in Type-GCX51 Relays

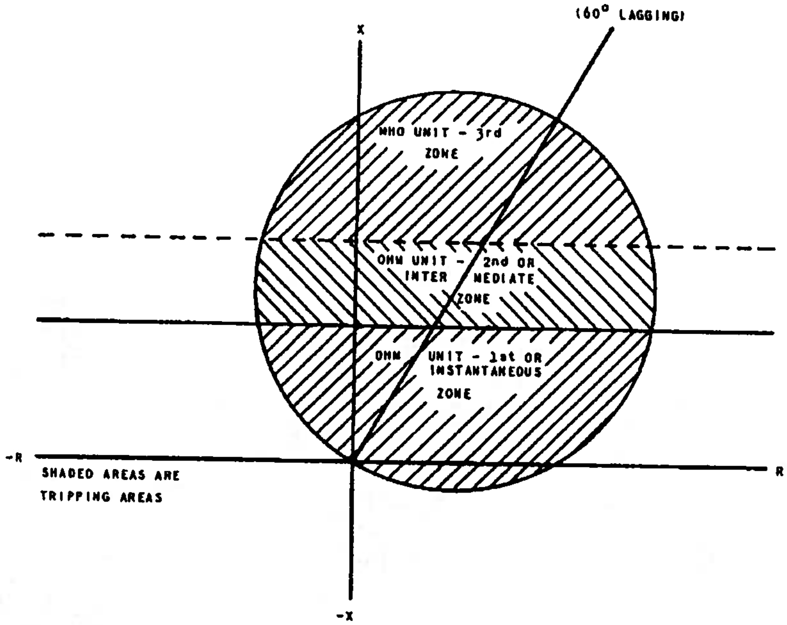


Figure 5 (6305889-4) Characteristics of the OHM and MHO Units on an Impedance Diagram for GCX51 Relay

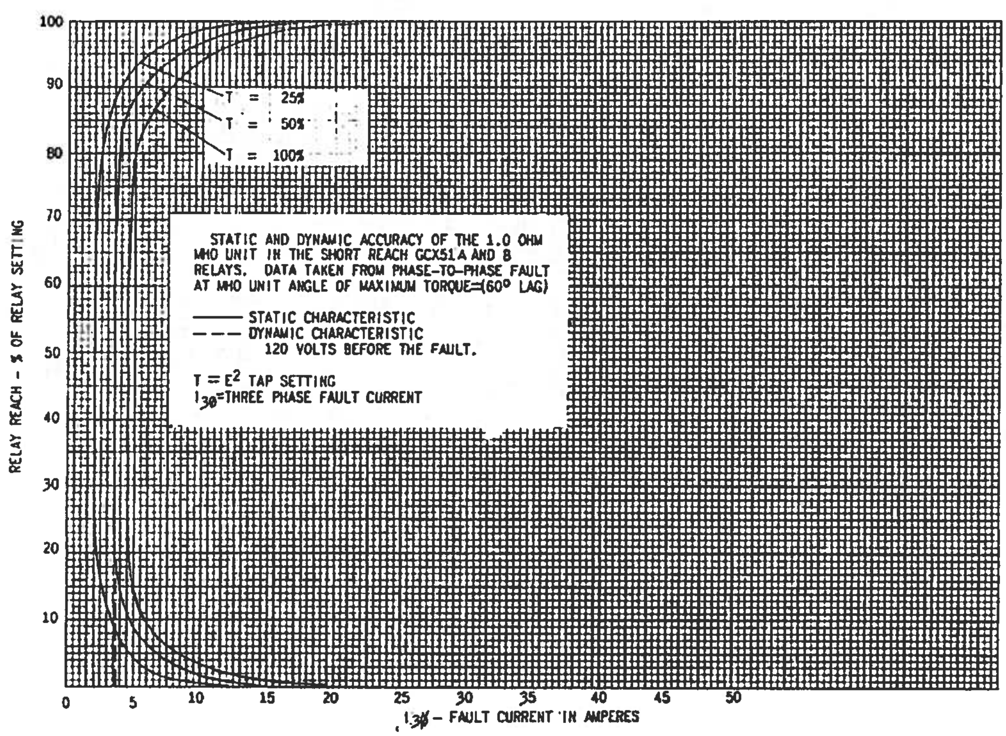


Figure 6 (0178A7144-1) Static and Dynamic Reach Data for the 1.0 Ohm MHO Unit Used in the Short-Reach GCX51A or B Relay

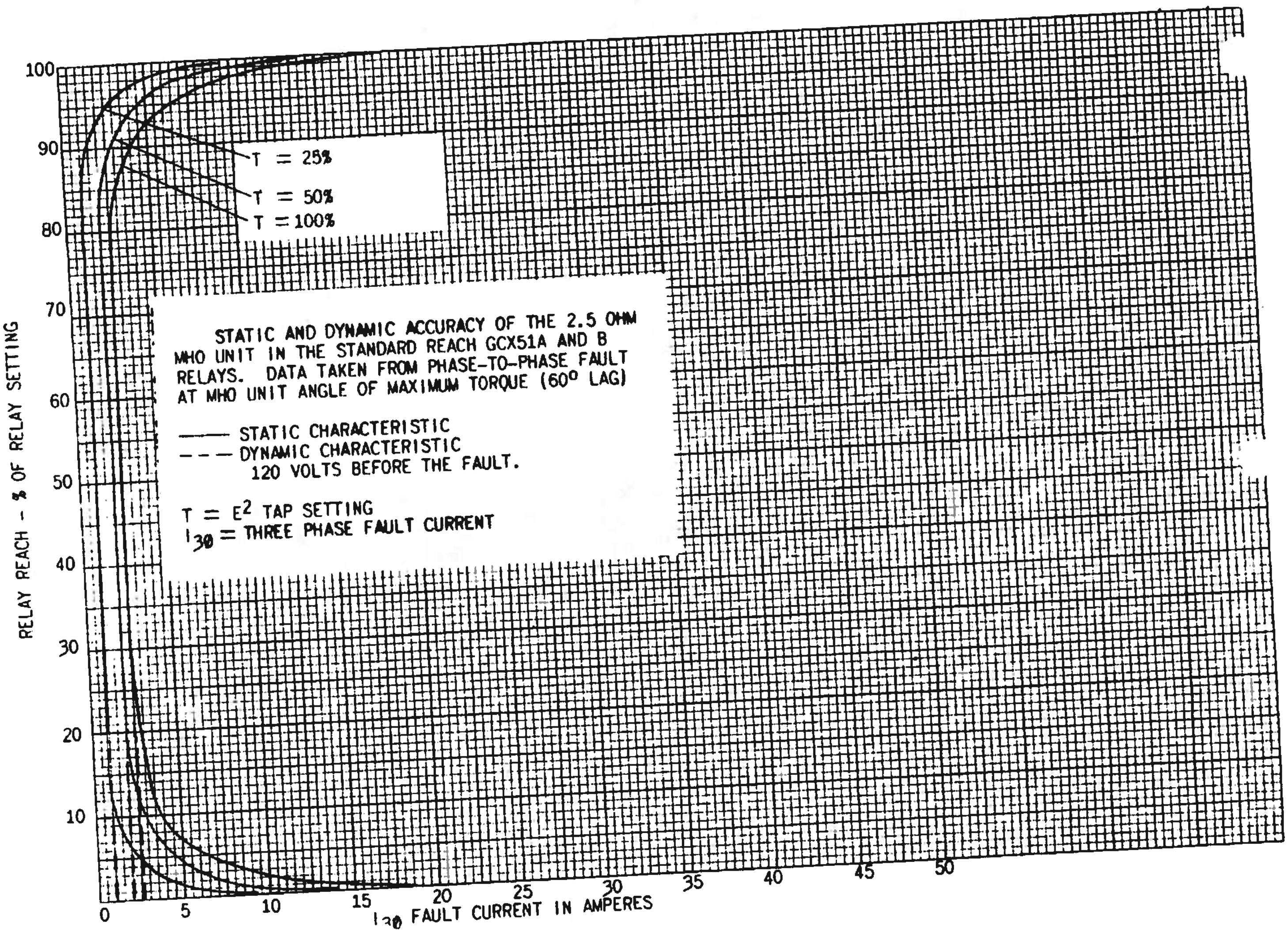


Figure 7 (0178A7145-2) Static and Dynamic Reach Data for the 2.5 Ohm MHO Unit Used in the Standard-Reach GCX51A or B Relay

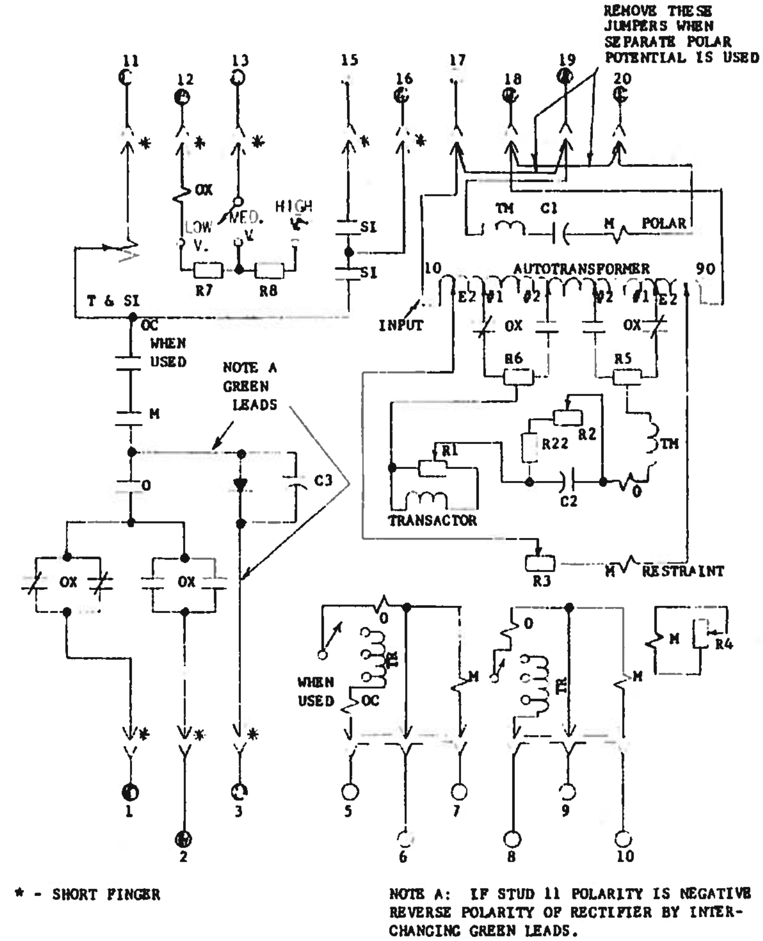


Figure 8 (0203A8583-5) Internal Connections (Front View) of the Type-GCX51A or GCX51B Relay

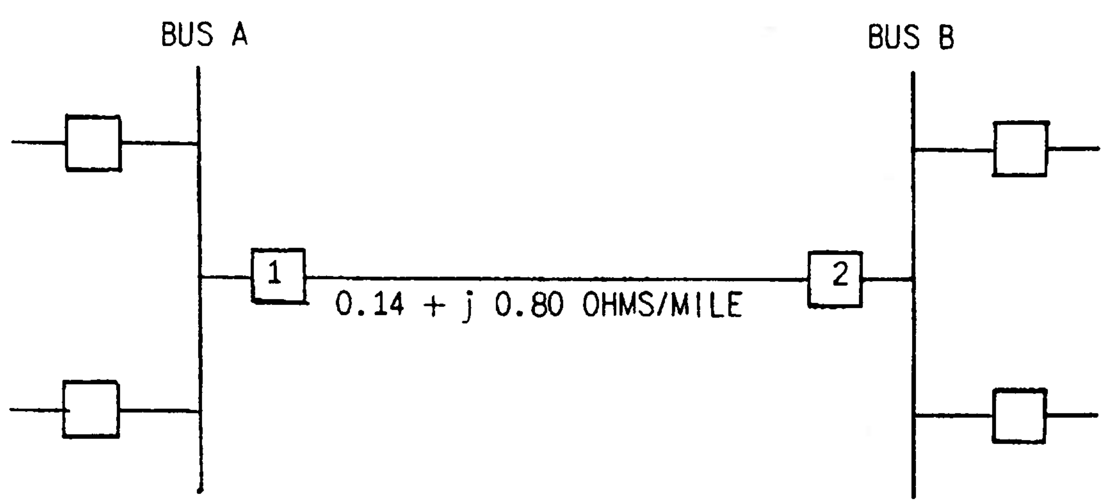


Figure 9 (0178A7169-1) Schematic Diagram of Typical Two-Terminal Line

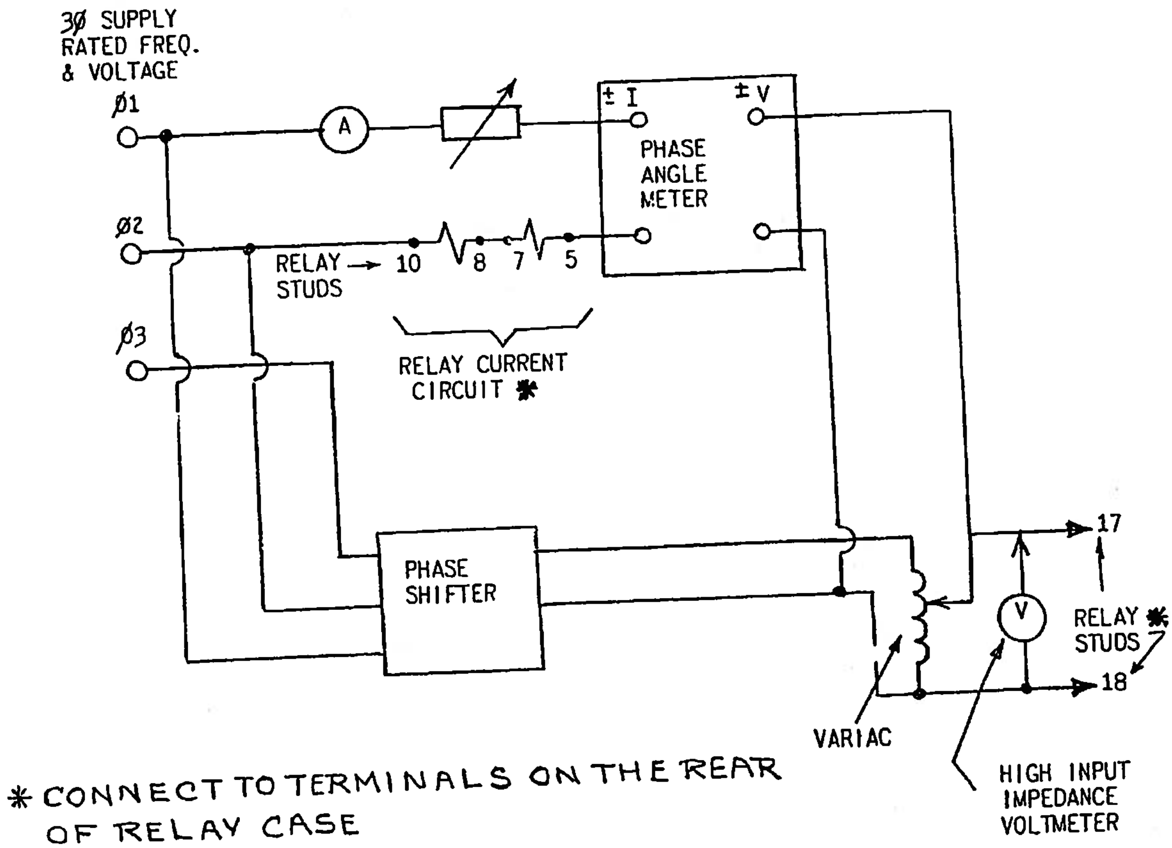


Figure 10 (0165A6069-2) Test Circuit for GCX51A and GCX51B Relays Using a Phase Shifter

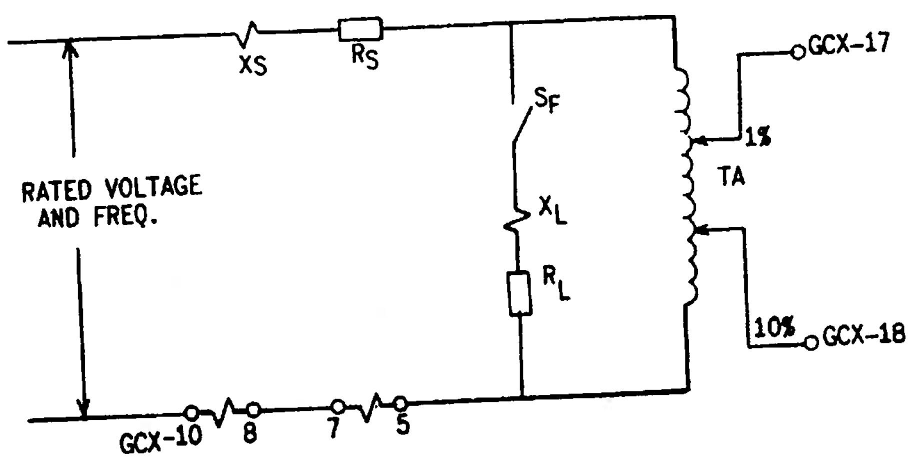


Figure 11 (362A624-2) Schematic Diagram of GCX Test Circuit

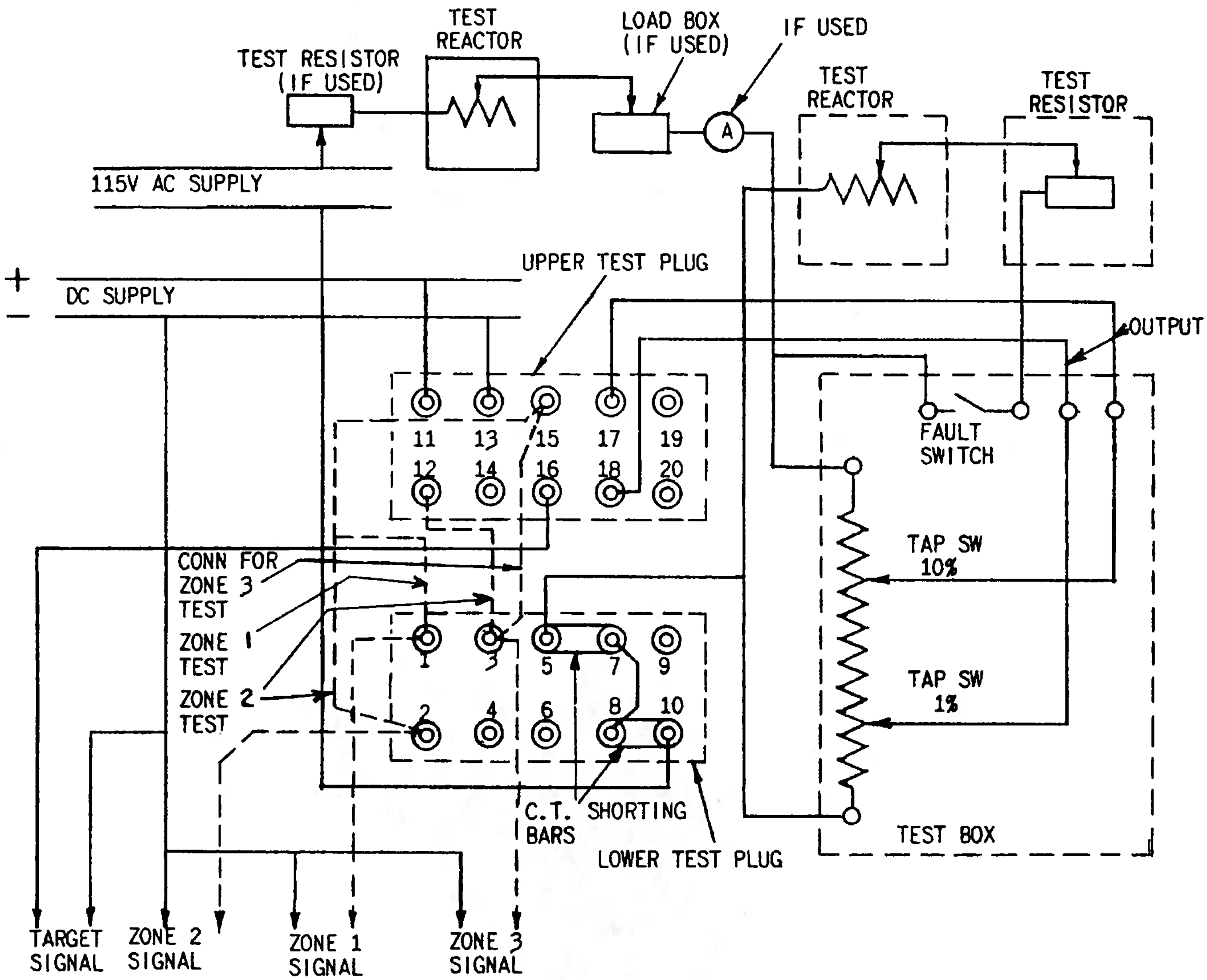


Figure 12 (0178A7162-1) Connection for Field Testing the GCX51A and GCX51B Relays Using Type XLA Test Plugs

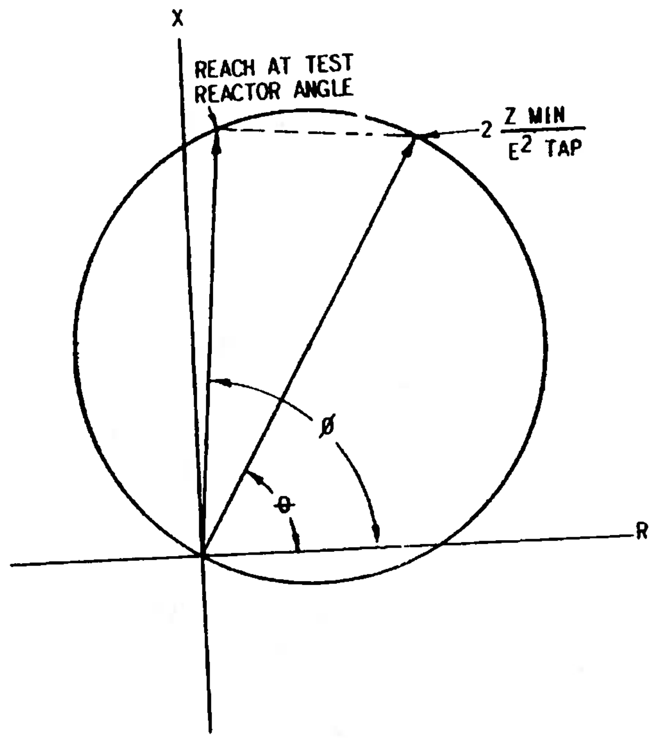


Figure 13 (362A625-5) Reach of the MHO Unit at Angle of the Test Reactor

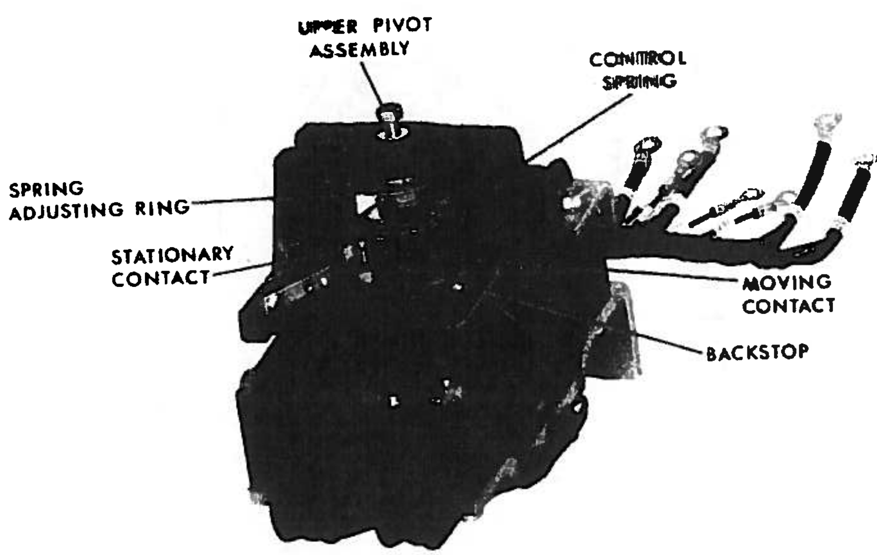


Figure 14 (8034958) Four-Pole Induction-Cylinder Unit, Typifying Construction of the OHM and MHO Units in the GCX51 Relays

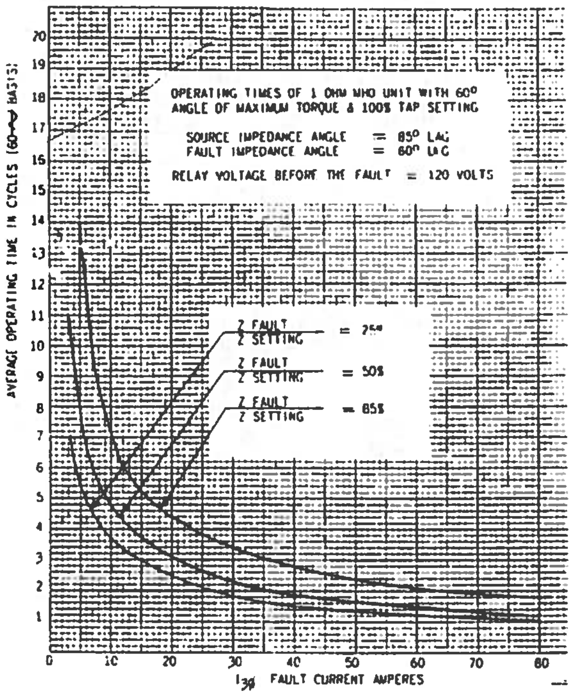


Figure 15 (0178A7155) Operating-Time Curves for 1-Ohm MHO Unit in the Short-Reach Relay When the Relay Voltage Before the Fault is 120V)

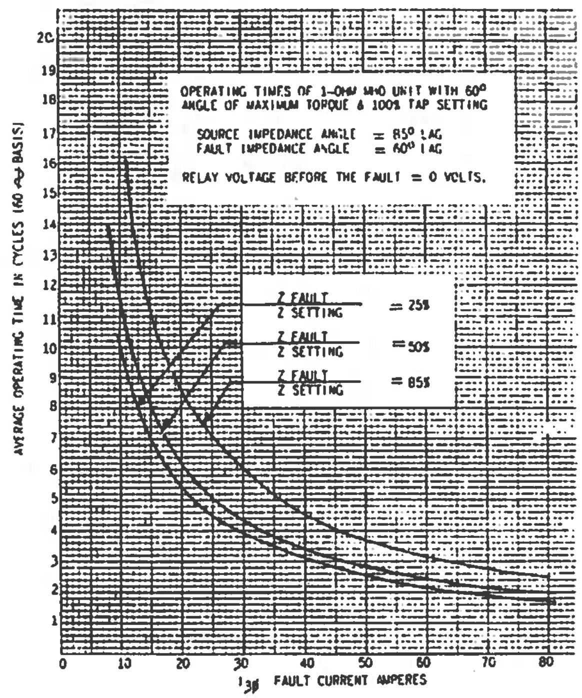


Figure 16 (0178A7154) Operating-Time Curves for 1-Ohm MHO Unit in the Short-Reach Relay When the Relay Voltage Before the Fault is Zero Volts

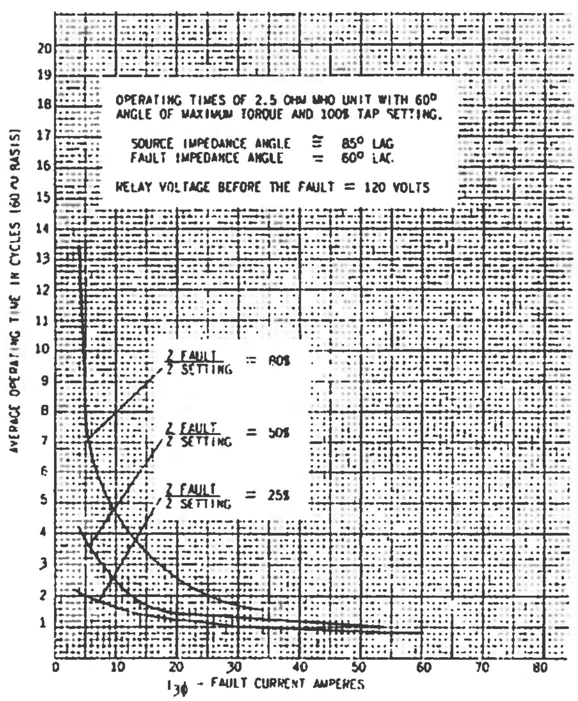


Figure 17 (0178A7142) Operating-Time Curves for 2.5-Ohm MHO Unit in the Standard-Reach Relay When the Relay Voltage Before the Fault is 120V

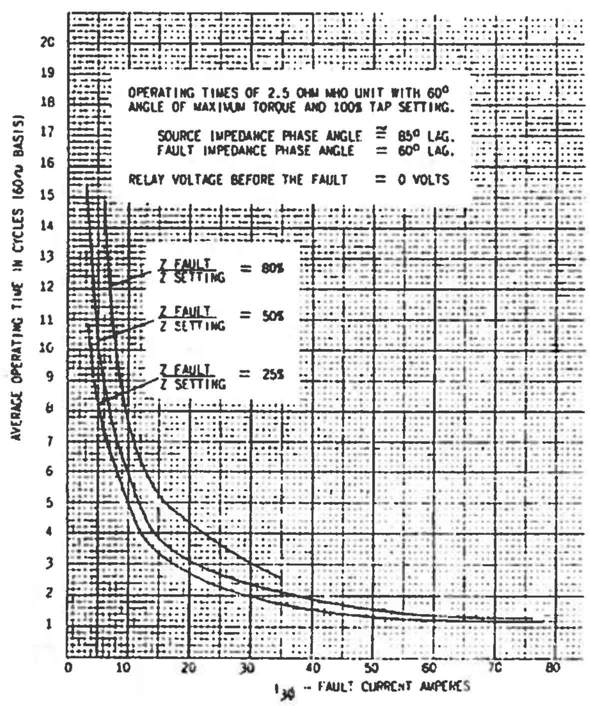


Figure 18 (0178A7143) Operating-Time Curves for 2.5-Ohm MHO Unit in the Standard-Reach Relay When the Relay Voltage Before the Fault is Zero Volts

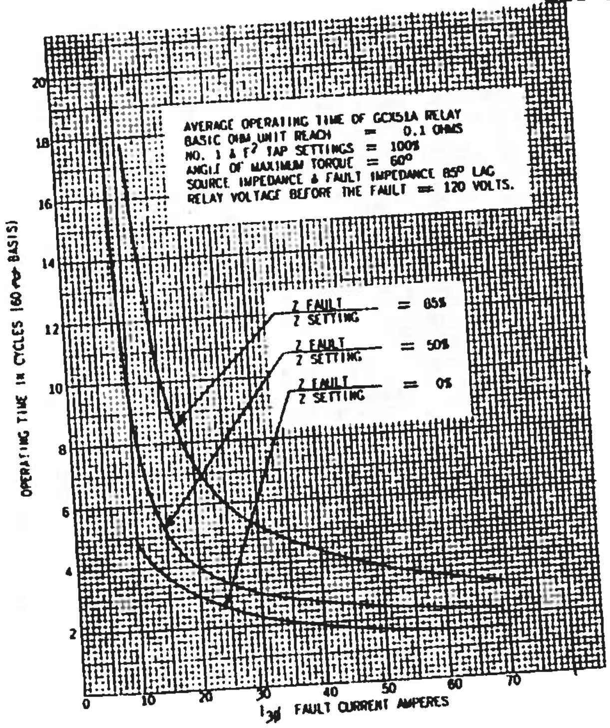


Figure 19 (0178A7156) Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.1 Ohms, Voltage Before the Fault, 120V)

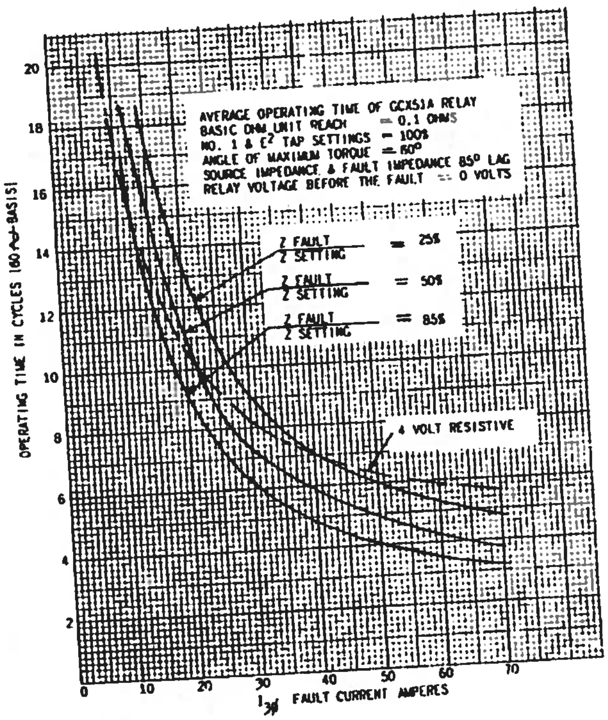


Figure 20 (0178A7159) Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.1 Ohms, Voltage Before the Fault, Zero Volts)

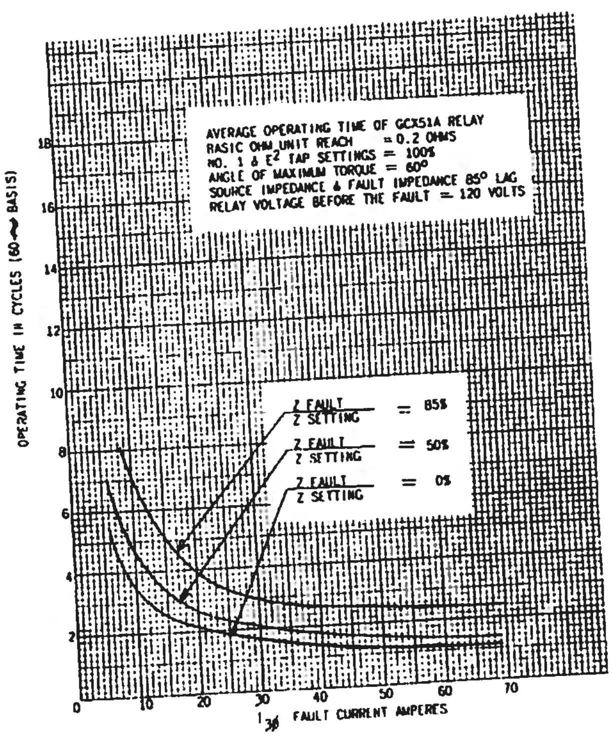


Figure 21 (0178A7157) Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.2 Ohms, Voltage Before the Fault, 120V)

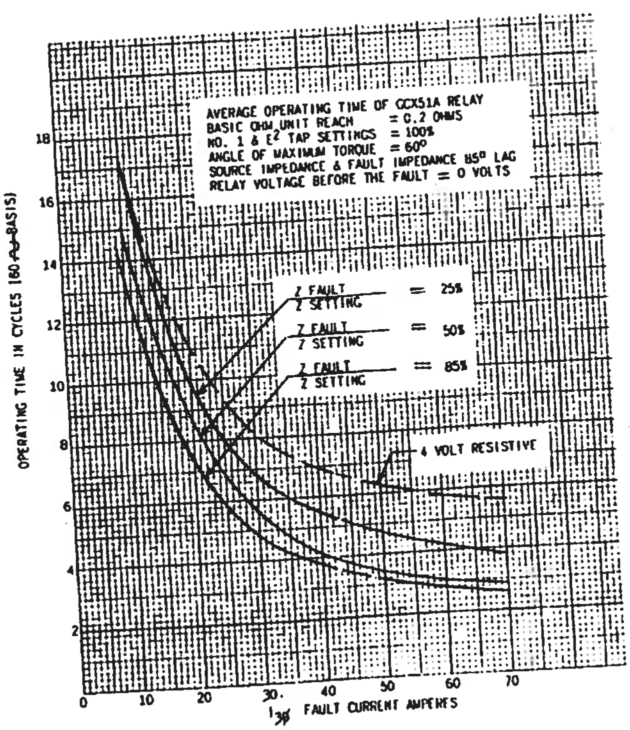


Figure 22 (0178A7158) Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.2 Ohms, Voltage Before Fault, Zero Volts)

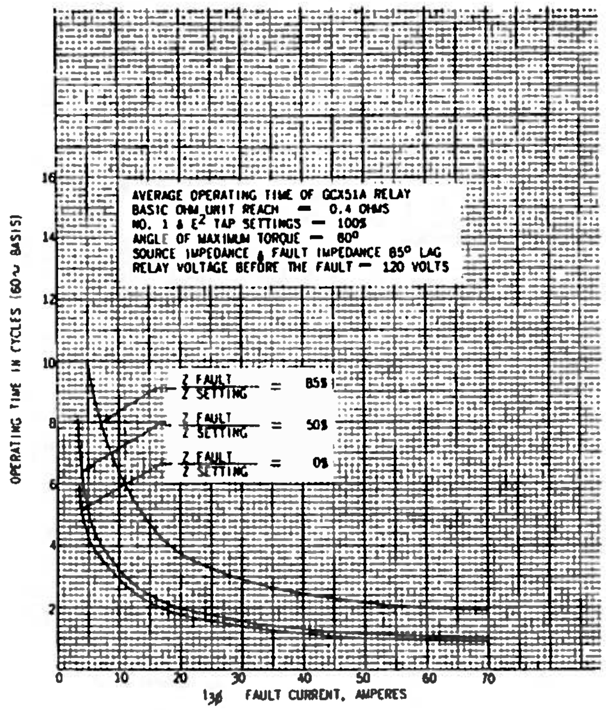


Figure 23 (0178A7149) Operating-Time curve for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.4 Ohms, Voltage Before the Fault, 120V)

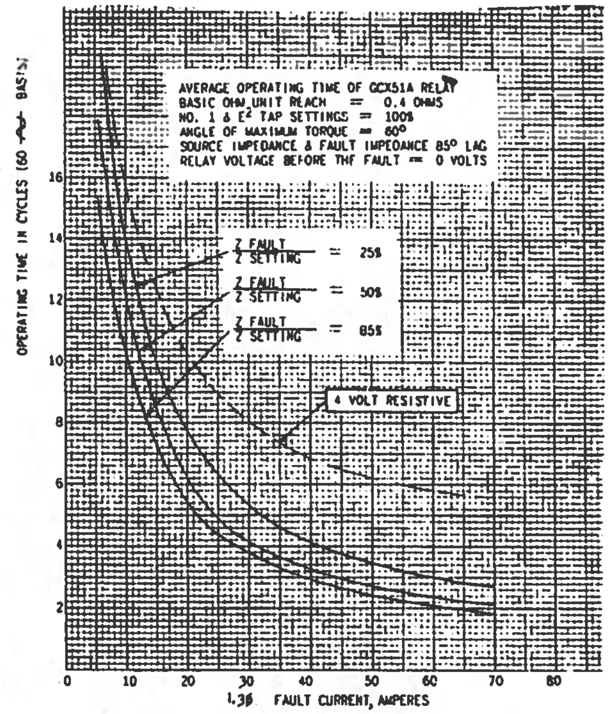


Figure 24 (0178A7148) Operating-Time Curves for Short-Reach GCX51 Relay (Basic OHM-Unit Reach 0.4 Ohms, Voltage Before the Fault, Zero Volts)

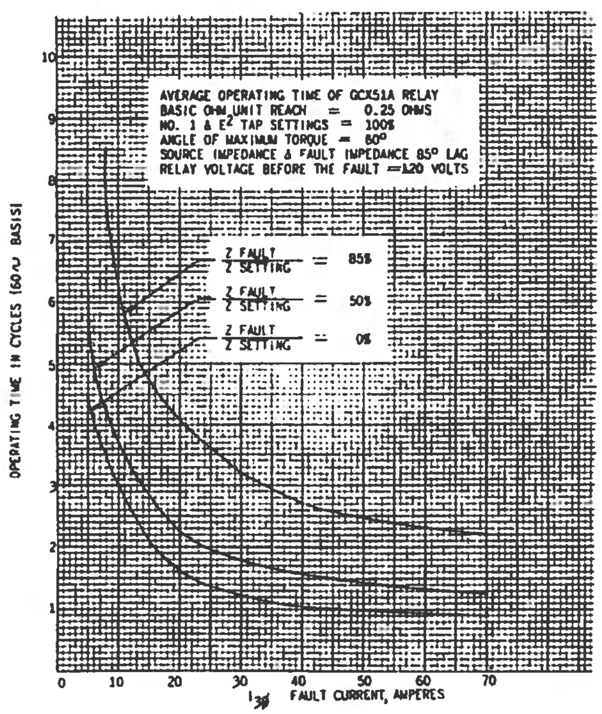


Figure 25 (0178A7150) Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.25 Ohms, Voltage Before the Fault, 120V)

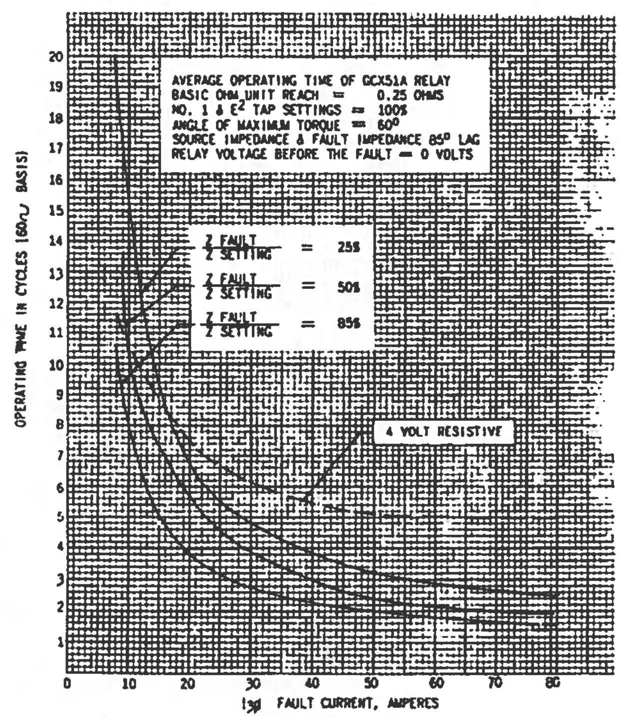


Figure 26 (0178A7151) Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.25 Ohms, Voltage Before the Fault, Zero Volts)

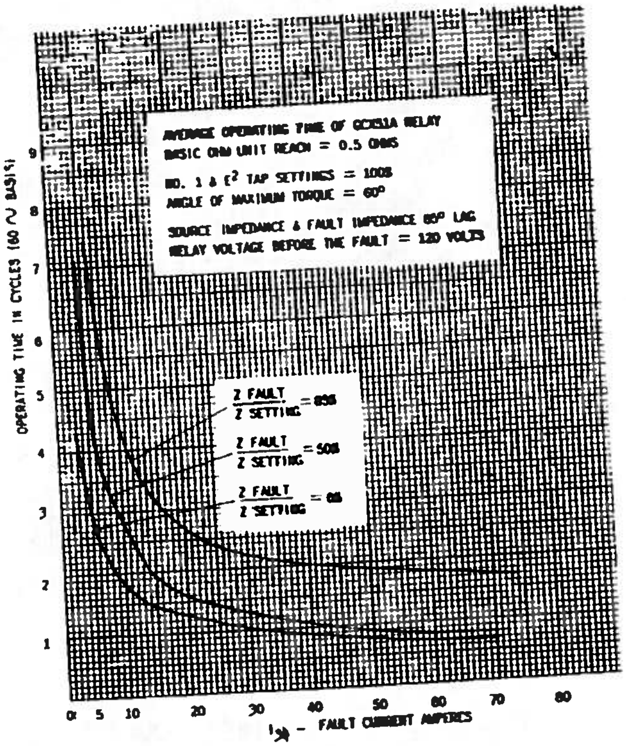


Figure 27 (0178A7146) Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.5 Ohms, Voltage Before the Fault, 120V

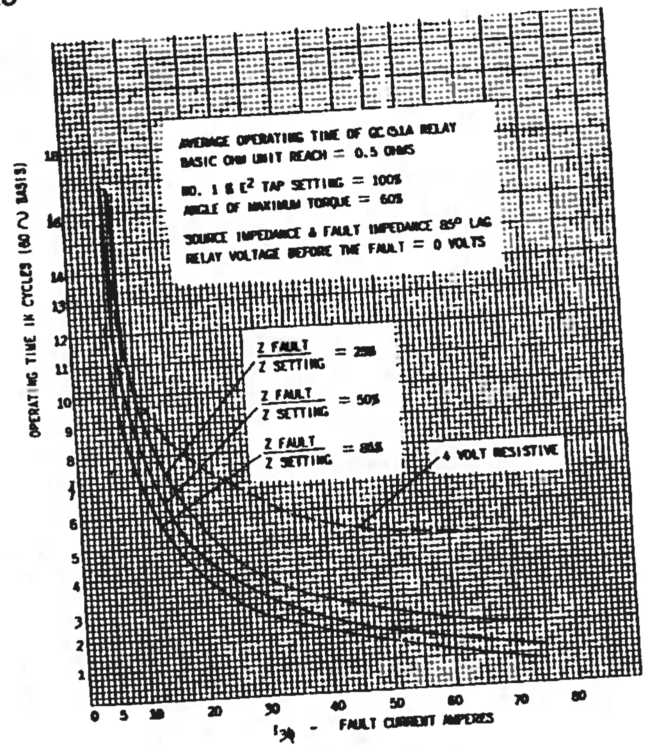


Figure 28 (0178A7147) Operating-Time curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 0.5 Ohms, Voltage Before the Fault, Zero Volts)

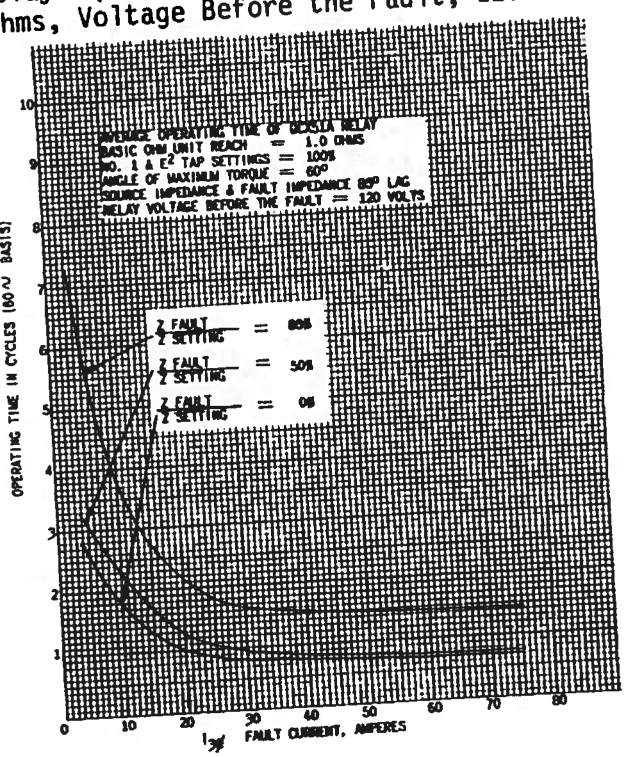


Figure 29 (0178A7152) Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 1.0 Ohm, Voltage Before the Fault, 120V)

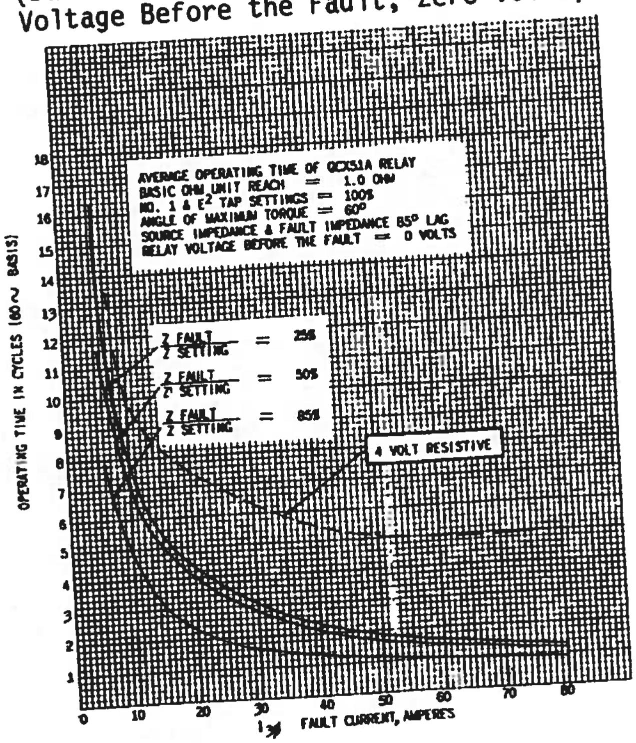
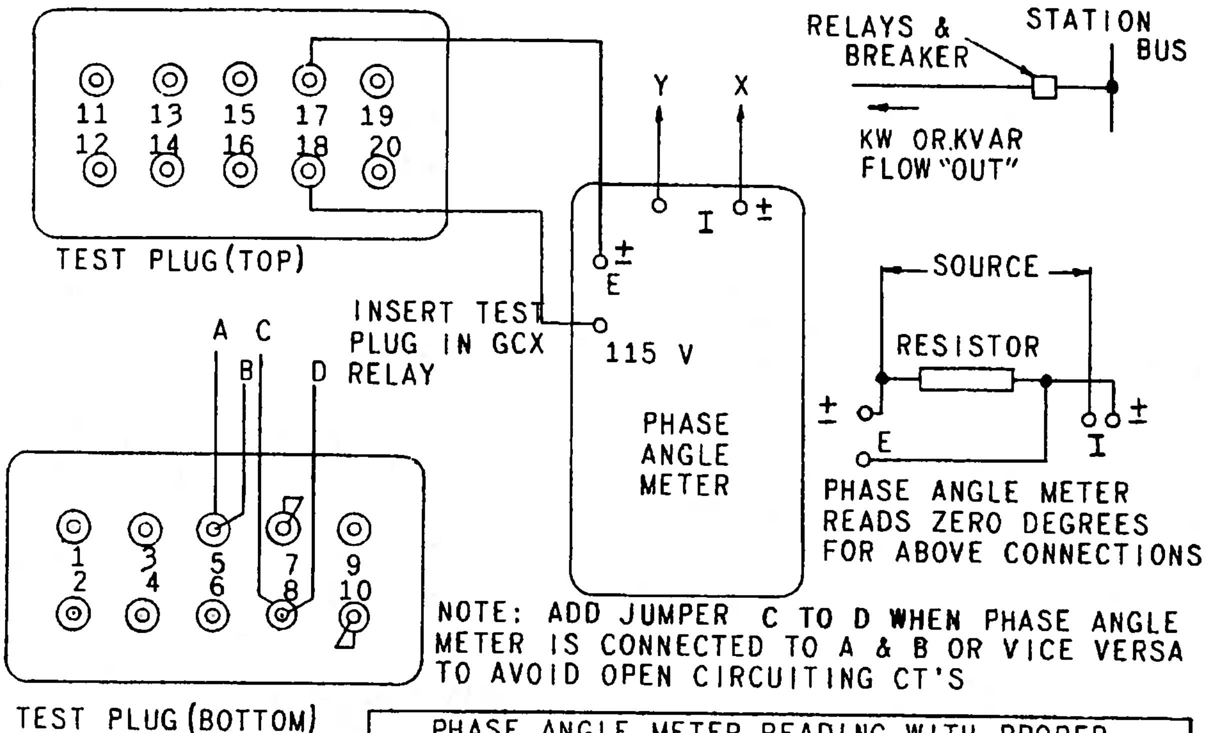


Figure 30 (0178A7153) Operating-Time Curves for Standard-Reach GCX51 Relay (Basic OHM-Unit Reach 1.0 Ohm, Voltage Before the Fault, Zero Volts)



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

		PHASE ANGLE 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.

Figure 31 (377A196-1) Test Connections for Overall Test of the GCX51 Relays

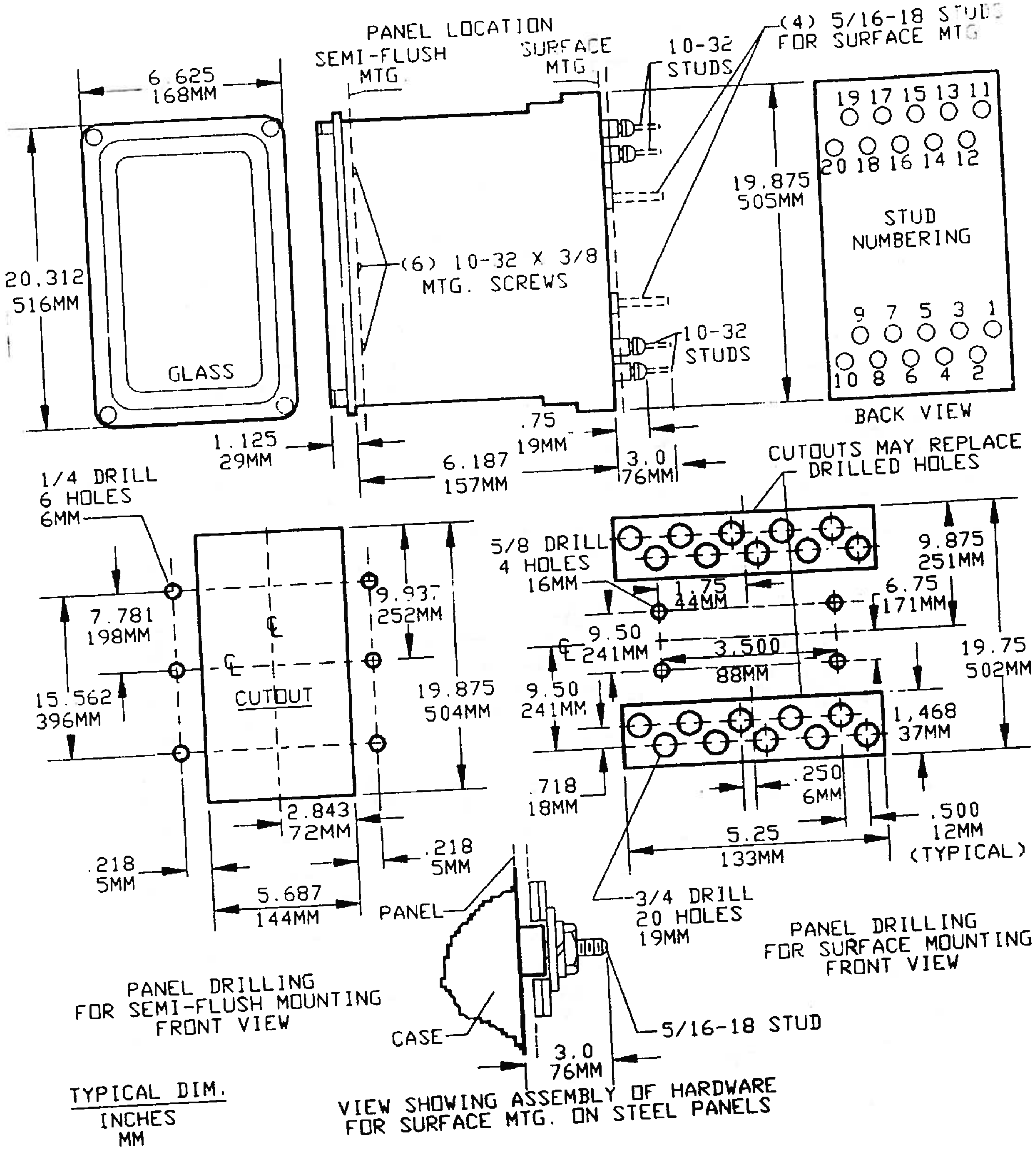


Figure 32 (6209276 [5]) Outline and Panel Drilling for GCX51A and GCX51B Relays

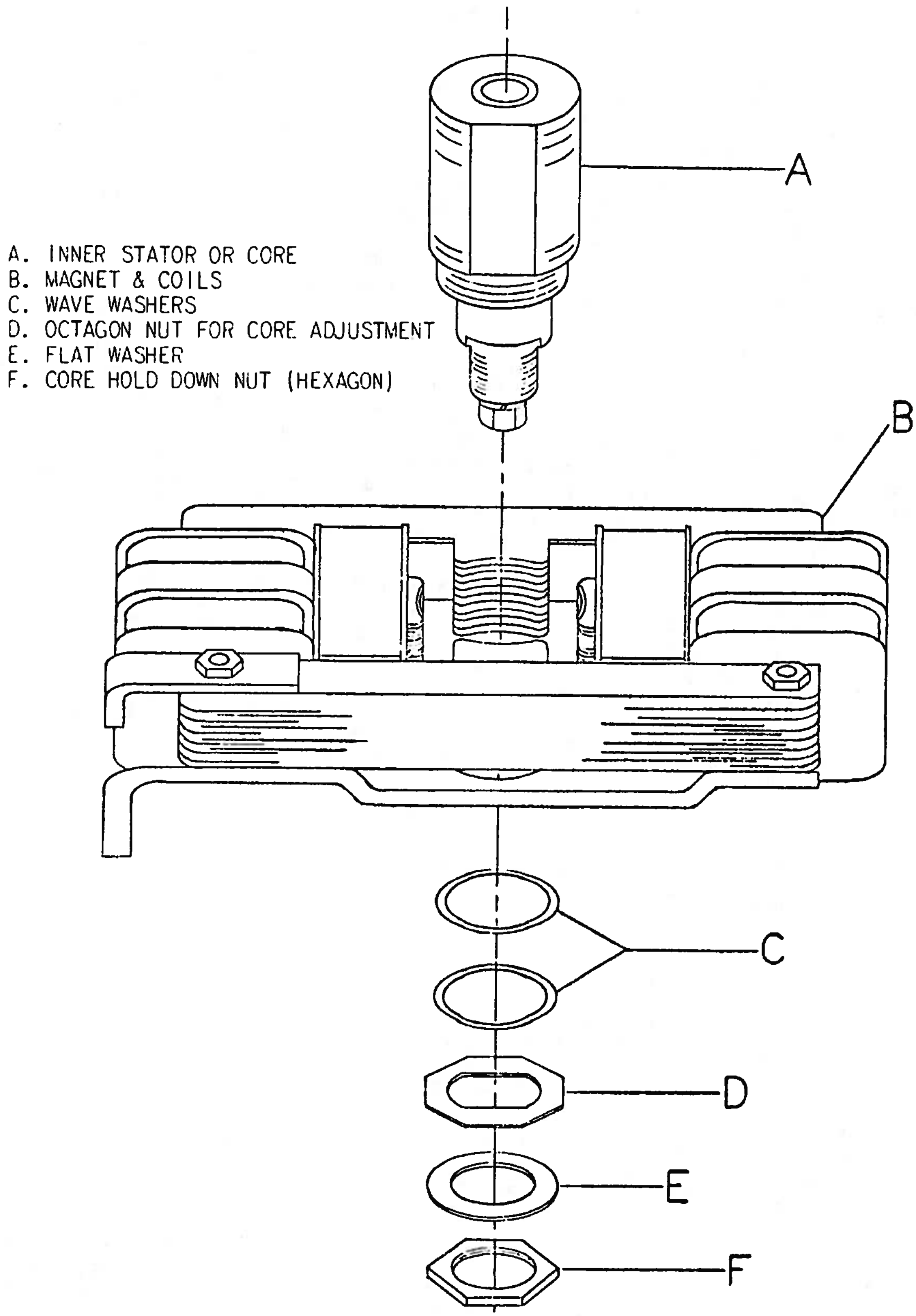


Figure 33 (0208A3583) Magnet and Coil Assembly

APPENDIX I

In the application of GCX51 phase relays, one relay is used to provide phase fault protection for each pair of phases. Thus one relay is used for phases a-b, a second relay for phases b-c, and a third relay for phases c-a, or a total of three relays, all of which will operate for three-phase faults within the set reach.

The further limitation on the MHO unit reach, mentioned in the **APPLICATION** and **CALCULATION OF SETTINGS** sections, is experienced on phase-to-phase faults and involves one of the two relays associated with the unfaulted phases rather than the relay protecting the faulted phases. For example, if we assume a phase b-c fault, it is the phase a-b relay which may tend to overreach.

Referring to the R-X diagram of Figure I-1, OL represents the protected circuit with the relays located at O, and OT represents the reach of the first-zone OHM unit setting. For a phase b-c fault at the first-zone setting (T), the phase b-c relay will properly see an impedance OT. However, the phase a-b relay will see an impedance originating at O and terminating somewhere along the line TP, depending on system conditions. If this impedance happens to be OP_1, it will fall within the first zone characteristic of the phase a-b relay. This is, in effect, overreaching. If the impedance happens to be OP_2, it will fall outside the MHO characteristic of the a-b relay and there will be no tripping of that relay.

In order to prevent the relay associated with the unfaulted phase from overreaching as described above, it is necessary to limit the reach setting of the MHO unit. In order to do this, it is necessary to know where along the TP line the impedance seen by the unfaulted phase relay terminates. Referring to Figure I-1 and with everything plotted in terms of secondary ohms, the secondary impedance TP is equal to ($\sqrt{3}$) (ST), where ST is the vector sum of the system impedance behind the relay (OS) plus the impedance OT, all in secondary ohms. The system impedance is plotted as a pure reactance in order to obtain conservative results.

The system impedance behind the relay in secondary ohms (X_S) may be obtained as follows: Assume a three-phase fault at the relay terminals of the protected line and determine the maximum fault current $I'_{3\phi}$ supplied through the relay terminal in secondary amperes with the remote breaker open.

$$\text{Then,} \quad XS = \frac{67}{I'_{3\phi}}$$

Once TP is plotted on the R-X diagram, a MHO circle may be drawn so that the impedance, OP, seen by the unfaulted phase relays falls outside the circle.

In order to simplify the investigation, the curves of Figure I-2 and I-3 have been computed. The family of curves for various line angles in Figure I-2 provides the means of determining the permissible Mho unit setting (Z_{MO}) as a multiple of the zone 1 reactance unit setting (X_{OU}) in terms of the ratio of X_S/X_{OU}, where X_S is the system impedance behind the relay location.

The curves in Figure I-2 are on the basis of no load flow in the protected line. Load flow into the protected line at the relay location tends to aggravate the situation represented by the plot in Figure I-2. In other words, with load present the permissible ratio of Z_{MO}/X_{OU} will be less than the curves in Figure I-2 indicate.

The family of curves in Figure I-3 provide the information to determine how much less the safe ratio of Z_{MO}/X_{OU} can be. Curves are provided for several ratios of fault current I_F to load current I_L. The two sets of curves in Figures I- 2 and I-3 may be used as described in the following worked example.

Assume a transmission line having a secondary impedance of 0.813 ohms at an angle of 80°. For a 90% reach, the first-zone OHM unit (X_{OU}) would be approximately 0.72 ohms. Assume further that X_S as determined from a study is 1.5 secondary ohms.

Thus: $X_S/X_{OU} = 1.5/0.72 = 2.1$

Refer to Figure I-2 and select the curve for the 80° line angle. Find the point on this curve corresponding to $X_S/X_{OU} = 2.1$. This yields a value of about 9.3 for X_S/X_{OU}, and since $X_{OU} = 0.72$, the maximum setting of $Z_{MO} = 9.3\ (0.72) = 6.7$ ohms. This is on the basis of no load current and must be further corrected as determined by the ratio of fault current to load current as shown in Figure I-3. If the ratio of the fault current to maximum load current is 5, find the point on the curve for this ratio corresponding to $X_S/X_{OU} = 2.1$. This yields a value of 0.83, and the maximum permissible Mho unit setting is thus 0.83 (6.7) or 5.57 ohms.

Since the curves in Figures I-2 and I-3 do not include margin, it is suggested that at least 10% margin be taken. Therefore, the maximum reach setting of the Mho unit for this example should be 5.57 - 0.56 = 5.01 ohms.

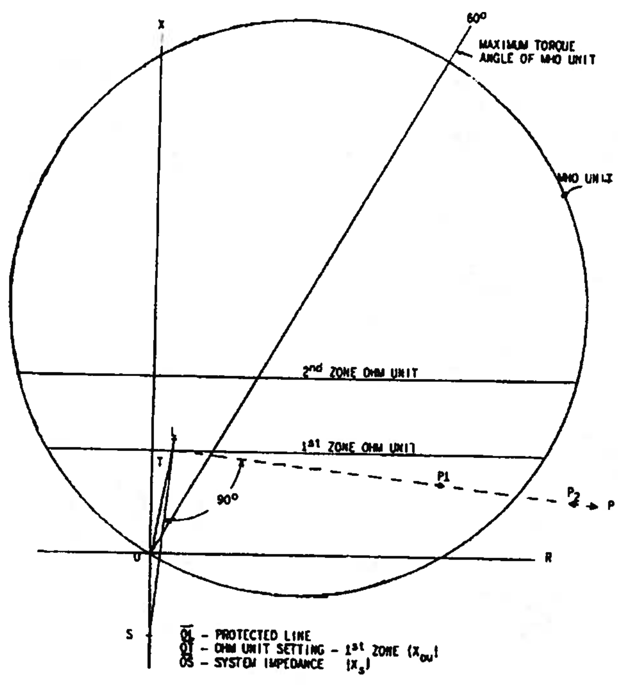


Figure I-1. (0178A8101-0) R-X Diagram Illustrating Response of GCX51 Relay to Phase-to-Phase Fault on Adjacent Phase Pair

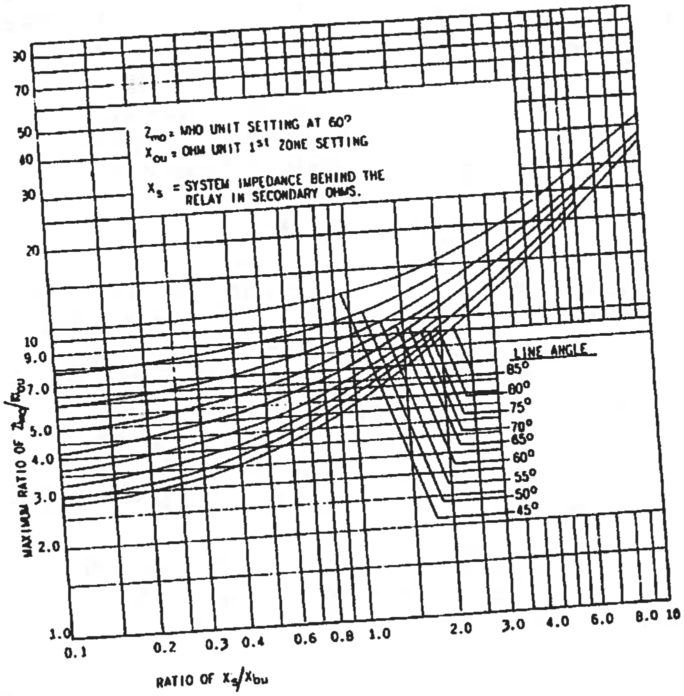


Figure I-2. (0178A8100-0) Curves for Determining Maximum Safe Setting of MHO Unit in GCX51 Relay

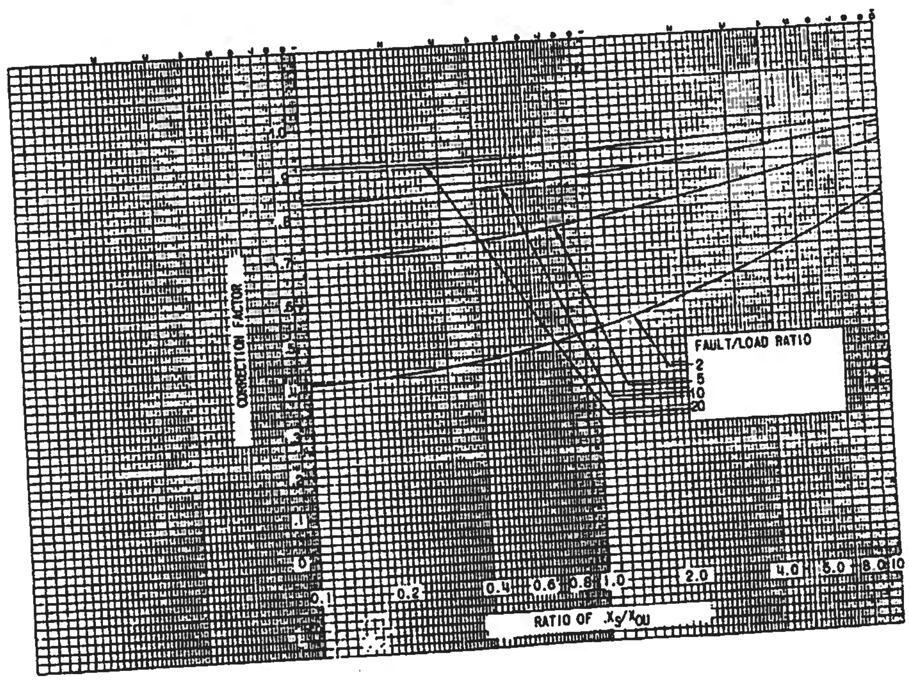


Figure I-3. (0227A2675-0) Curves for Determining the Correction Factor of the GCX51 Relay

GE Power Management

215 Anderson Avenue
Markham, Ontario
Canada L6E 1B3
Tel: (905) 294-6222
Fax: (905) 201-2098
www.ge.com/indsys/pm