Instructions

GEK-86050B

DIRECTIONAL DISTANCE (REACTANCE RELAY)

Types:

GCX51M - N
GCX51P
GCX51R

CONTENTS

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DESCRIPTION

The Type GCX51M and GCX51N relays are low range, 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 characteristic, while the third zone has a directional mho characteristic. The GCX51M and GCX51N relays are identical, except that the GCX51N contains an instantaneous overcurrent fault detector while the GCX51M does not. Three 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, Figure 4.

The Type GCX51P relay is similar to the GCX51N relay, except for the following:

1. The GCX51P relay has two studs, 4 and 14, which are not available on the GCX51N relays.

2. Stud 4 is jumpered internally to stud 1 in the GCX51P, and stud 14 is jumpered internally to stud 13.

3. The GCX51P internal connections diagram is different from that of the GCX51M and GCX51N to show these internal jumpers (see Figure 8).

The Type GCX51R relay is a single phase, three zone distance relay. It is similar to the GCX51M relay, except that the mho unit is factory set for an angle of maximum torque of 75 degrees lag.

APPLICATION

Because of the reactance characteristics of their first and second zones, the GCX51M, N and R relays are particularly well suited for the protection of circuits where arc resistance is a problem. Since the arc resistance in a fault is directly related to the length of the arc, and inversely related 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. The GCX type characteristic is ideally suited for the protection of short transmission lines. However, they may also be applied to longer lines if the range of the relay permits the required reach settings.

The reactance unit in each GCX51 relay provides three basic minimum reach settings which are selected by means of a tap link at the front of the relay (see **RATINGS**). In general, when setting these units for a given reach, use the highest basic reach tap that will accommodate the required first zone reach setting. For example, if a 0.30 ohm setting is required for the first zone of a standard reach relay, the 0.2 ohm basic reach tap should be used rather than the 0.10 ohm tap. The ohm unit tap leads should not be set for less than ten percent.

The third zone mho unit of the GCX51M and GCX51N relays is adjusted at the factory for an angle of maximum torque of 60 degrees. Although this can be adjusted up to 75 degrees, the 60 degrees setting obtains maximum arc resistance accommodation for first zone faults close to the relay location. The mho unit tap leads should not be set for less than 25 percent. The mho unit reach setting may be subject to further limitations, as described in Appendix I.

The third zone mho unit of the GCX51R relay is similar to the mho unit in the GCX51M and GCX51N relays, except that it is adjusted at the factory for an angle of maximum torque of 75 degrees lag at the basic reach taps of the GCX51M and GCX51N relays at 60 degrees lag. The GCX51R can also be adjusted down to 60 degrees lag, if so desired, with a 20 percent reduction in reach.

The GCX51P relays were designed to provide a measure of interchangeability with the GCX17A and GCX17B relays. The areas of interchangeability are noted below:

1. GCX51P relays may be plugged directly into GCX17A or GCX17B cases on an existing switchboard without external wiring changes if, and only if, all three phases are so replaced. Note that the DC control voltage links must be in their proper position in the relays.

2. One GCX51P relay may be used to replace one of three GCX17A or GCX17B relays in an existing installation by plugging it into the existing case after all external connections have been removed from stud 1 of that case.

3. Two GCX51P relays may be used to replace two of three GCX17A or GCX17B relays in an existing installation by plugging it into the existing case after all external connections have been removed from stud 1 of those two cases.

The external connections diagrams for GCX51M and GCX51N relays can be used for the interchanged GCX51P relays. When these connections have been made, GCX17A or GCX17B relays cannot be plugged into GCX51P cases without rewiring the panel .

GCX51P relays can be used to replace GCX17A or GCX17B relays. Three GCX51P relays could be replaced by three GCX17A or GCX17B relays by just plugging the latter devices into the existing cases. Also, it is possible to replace only one or two relays. However, this requires removing all the connections from stud 1 of all the GCX51P relays remaining on the panel for that terminal.

Unless there is a real need to replace GCX51P relays with GCX17A or GCX17B relays, the simpler connections shown should be used.

Table I shows 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, mho and ohm unit coordination, and proper unit contact action to determine the limitation for positive relay operation for any multi-phase fault on the line.

TABLE I

Basic Tap Setting	Minimum Three Phase Fault Current, Secondary Amperes
SHORT REACH RELAY:	
0.1 ohms	16 amperes
0.2 ohms	10 amperes
0.4 ohms	10 amperes

GCX51 relays have no significant transient overreach; therefore, the first zone units may be set for 90 percent of the distance to the nearest remote terminal. The second zone units should be set to reach at least 110 percent 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 accommodating arc resistance at the second zone balance point. The third zone mho units are sometimes used to obtain backup protection for faults on remote line sections, but the mho unit should not be set to reach farther than necessary.

The overcurrent fault detector in the GCX51N and GCX51P relays should always be set to pick up at no lower than 115 percent of maximum load current. Fault detector units are not designed to operate continuously in the picked-up position.

For information on settings, see **CALCULATION OF SETTINGS.** Typical external connections for a three step distance scheme are depicted in Figure 2.

RATINGS

Type GCX51M, GCX51N, GCX51P and GCX51R relays are available for 120 volt, five ampere, 50/60 cycle ratings. The one 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.

Basic minimum reach and adjustment ranges for the ohm and mho units of standard reach and short reach forms of the GCX relay are given in Table II.

TABLE II

RELAY	OHM UNIT BASIC MINIMUM REACH* (Ø-N OHMS)	OHM UNIT RANGE (Ø-N OHMS)	MHO UNIT BASIC MINIMUM REACH (Ø-N OHMS)	MHO UNIT RANGE (Ø-N OHMS)	ANGLE OF MAXIMUM TORQUE
GCX51M,N,P	0.1/0.2/0.4	0.1/4	1	1/4	60°**
GCX51R	0.1/0/2/0.4	0.1/4	1	1/4	75°***

* Adjustment link is set at the 0.2 basic minimum 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 percent of the reach at the 60° angle of maximum torque.

*** The angle of maximum torque of the mho unit can be adjusted down to 60° with resulting decrease in reach to approximately 80 percent of the reach at the 75° angle of maximum torque.

For each relay, three basic minimum reach settings are listed for the ohm unit. Selection of the basic minimum reach is made by a link located at the left on the tap.

The reach settings of the ohm and the mho units can be adjusted in one percent steps by means of autotransformer 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 lead, second zone reach by the No. 2 leads, and the mho unit reach by the E^2 leads.

GCX51N and GCX51P relays include an instantaneous overcurrent unit, identified as OC on the internal connection diagrams, Figures 7 and 8. The short reach form of the GCX51 is furnished with an overcurrent unit having a 4-16 ampere calibration range. The standard reach form is available with overcurrent unit calibration ranges of 4-16, 2-8 or 1-4 amperes.

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 seconds	4.0 seconds
Carry 10 amps for:	4.0 seconds	30.0 seconds
DC Resistance	0.6 ohms	0.13 ohms
60 Cycle Impedance	6.0 ohms	0.53 ohms

Contacts of the GCX51 relays will close and carry 30 amperes DC momentarily. 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 II.

OPERATING PRINCIPLES

MHO UNIT

The mho unit of the GCX51 relays is four pole induction cylinder construction (see Figure 14), with schematic connections as shown in Figure 3. 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 be expressed by the following equation:

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

where:
- E = phase to phase voltage (E_{12})
- I = 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 the equation through by E^2 and transposing, it reduces to the following expression in terms of impedance:

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

$$Y \cos(\phi - \theta) = K$$

The unit will pick up at a constant component of admittance at a fixed angle, depending on the angle of maximum torque.

OHM UNIT

The ohm unit of the GCX51 relay is also a four pole induction cylinder construction (see Figure 13) with schematic connections as shown in Figure 3. 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. It can be expressed by the following equation:

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

where: E = phase to phase voltage (E_{12})
I = delta current (I1 - I2)
Z_T = transfer impedance of transactor (design constant)
= angle between I and (IZ_T - E)
K = design constant

The above equation can be trigonometrically reduced to:

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

where: $\emptyset$ = angle between I and IZ_T
(i.e., 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:

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

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

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

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 shown as impedance characteristics on an R-X diagram (see Figure 4).

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) is obtained when the E^2 restraint taps are on 100 percent. 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.

$$\text{Ohmic reach at line angle} = \frac{(\text{Input Tap})\ Z_{min} \cos (\theta - \emptyset)}{E^2 \text{ Tap Setting } (\%)}$$

where: θ = angle of maximum torque of the unit
ϕ = angle of the line
Z_{min} = basic minimum phase to neutral ohmic reach of the unit
Input Tap = setting in percent (normally is 100, except as explained in "Vernier Adjustment")
E^2 Tap Setting (%) = E^2 or voltage restraint tap setting in percent

For E^2 tap and input tap settings of 100 percent, the phase to neutral ohmic reach will be equal to the basic minimum reach shown in Table II 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's directional characteristic will operate correctly for either forward or reverse faults at voltages down to one percent 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.

The ohmic value at which the mho unit will operate at reduced voltage may be somewhat lower than its calculated value. This "pullback" or reduction in reach is shown in Figure 5 for the 1.0 ohm mho unit used in the short reach relay. The percentage of relay reach for a constant tap setting is expressed as a function of the three phase fault current, $I3\phi$, for various ohmic reach settings. The mho unit will operate for all points to the right of the curves. The static curves of Figure 6 were determined by tests performed without any voltage supplied to the relay before the fault was applied. The dynamic curves were obtained with fully 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 is illustrated for a zero voltage fault by referring to Figure 6. A zero voltage fault must be right at the relay bus; therefore, to protect for this fault, the relay must reach zero percent of its setting. Figure 6 shows that the mho unit will not see a fault at zero percent of the relay setting under static conditions, regardless of the tap setting. Under dynamic conditions, however, when the memory action is effective, Figure 6 shows that a 1.0 ohm mho unit with a 100 percent tap setting, will pick up if $I3\phi$ is greater than 4.5 amperes. This is a marginal condition. The minimum safe fault currents are listed in Table I.

OHM UNIT

The ohm unit impedance characteristic, as represented on the R-X diagram (Figure 4), is a straight line, parallel with the R axis. The unit operates for fault impedances lying below its characteristic, and 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 which lies close to the R axis. Load will be very near unit power factor, in contrast with the reactive kVA, which flows during fault conditions. An impedance near the R axis will lie below the ohm unit characteristic (Figure 4) and therefore, the ohm unit contact will be closed. Since the directional mho unit contact will not be closed for this condition (see Figure 2), this will not cause a problem.

The basic minimum reach of the ohm unit, as listed in Table II, is obtained when the restraint tap leads are on 100 percent. 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:

$$\text{Output Tap Setting} = \frac{[\text{Input tap setting } (\%)]\ [\text{Basic minimum ohms}]}{X}$$

For a numerical example of the determination of the ohm and mho unit settings, refer to the section, **CALCULATION 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 disregarded for relay settings that are within the recommended ranges.

OPERATING TIME

The operating time of the 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 at zero. A series of figures is included in this instruction book showing operating time of the mho unit and overall operating time of the relay for a variety of typical conditions. The operating time of the mho unit is given separately, because this unit is frequently used for carrier stop function in directional comparison carrier schemes.

The time curve figures are listed in Table IV for the mho unit, and in Table V for the relay.

TABLE IV
Time Curves for Mho Unit

Relay	Basic Minimum Reach (Mho Unit)	Volts Prior to Fault	Figure
Short Reach	1.0 ohm 1.0 ohm	120 0	15 16

Time curves are given in each figure for three ratios of fault impedance to relay reach setting. For zero voltage condition, an additional curve (shown by a dotted line) is also given for a four volt resistive fault condition. In all cases, the E^2 and/or the No. 1 taps were in the 100 percent position, and the mho unit angle of maximum torque was set at 60 degrees lag.

TABLE V
Overall Time Curves for Relay

Relay	Basic Minimum Reach (Mho Unit)	Volts Prior to Fault	Figure
Short Reach	1.0 ohm	120	17
	1.0 ohm	0	18
	0.2 ohm	120	19
	0.2 ohm	0	20
	0.4 ohm	120	21
	0.4 ohm	0	22

VERNIER ADJUSTMENT FOR LOW TAP SETTINGS

The input leads are normally set at 100 percent, but with a high secondary line reactance with the No. 1 tap leads 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 0.3 ohms and the basic minimum reach of the ohm unit is 0.2 ohm, with the input on 100 percent the output tap setting would be:

$$100/0.3 \times 0.2 = 66.7\%$$

OHM UNIT TRANSFER AUXILIARY

The ohm unit transfer auxiliary, OX, is a telephone type relay. The coils and contacts of the OX unit are shown in the internal connection diagram, Figure 8. The unit, which is mounted at the top of the relay, 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 RPM or SAM timing relays, as shown by external connections diagram, Figure 2. The normally closed contacts of the transfer auxiliary provide the circuit for instantaneous tripping 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 which supplies a smaller potential 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 five amperes are listed in Table VI.

TABLE VI

AMPS	CYCLES	R	X	PF	W	VA
5	60	0.32	0.12	0.94	8	8.5

This data is for the 1.0 ohm minimum basic reach tap of the standard reach relay. The burden on the 0.5 and 0.25 amp taps of the standard reach relay, 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 equations. All potential burdens are at 120 volts and are for 60 cycle relays:

Ohm Unit:

$$VA = (a + jb) \left[\frac{\text{E2 Tap Setting (\%)}}{\text{Input Tap Setting (\%)}} \right]^2$$

Mho Unit:

$$VA = (c + jd) \left[\frac{\text{E2 Tap Setting (\%)}}{\text{Input Tap Setting (\%)}} \right]^2 + (e + jf)$$

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 percent. The term (e + jf) represents the burden of the mho unit polarizing circuit. The values of these terms are given in Table VII.

TABLE VII
Potential Burdens

Frequency Rating		60 Cycles
Ohm	(a + jb)	12.3 + j0
Mho Restraint	(c + jd)	4.5 - j5.7
Mho Polarizing	(e + jf)	10 + j0

Complete potential burden data is given in Table VIII for the No. 1 and E^2 taps on 100 percent, and the input on 100 percent.

TABLE VIII
Maximum Potential Burden

	Frequency	Volts	Impedance	PF	Watts	VA
Ohm	60	120	1169 + j0	1.0	12.3	12.3
Mho Restraint	60	120	1245 + j1540	0.68	4.6	7.3
Mho Polarizing	60	120	1460 + j0	1.0	10	10
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 three DC voltage taps:

TABLE IX

VOLTS	OHMS
48	800
125	2000
250	4000

CALCULATION OF SETTINGS

Table X is a qualitative illustration of how to set the three zones of the relays when applied in a straight distance scheme. See GEK-7384 for directional comparison applications.

Assume GCX51B relays are used to protect the two terminal, five mile, 69 kV transmission line shown in Figure 9.

Maximum load current = 450 amps
CT Ratio: 600/5
PT Ratio: 69,000/115

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

$$Z_{sec} = 5(0.14 + j0.80)\,\frac{120}{600} = 0.14 = j0.80 \text{ ohms}$$

$$Z_{sec} = 0.813 \,\angle 80^{o}$$

Select the standard reach relay.

Determine the minimum secondary fault current at breaker #1 for a three phase fault at bus B (from a system fault study). Determine the minimum secondary fault current at breaker #2 for a three phase fault at bus A. Both these values should exceed five amperes for the relay selected above when set on the 0.5 ohm base reach tap 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

Assuming that the first zone is set for 90 percent of the distance to the remote terminal, then:

$$X_L = 0.9(0.80) = 0.72 \text{ secondary ohms}$$

For this ohmic reach, use a 0.5 ohm basic reach tap setting; thus,

$$X_{min} = 0.50, \text{ and}$$

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

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

The tap lead from the lower No. 1 position would have to be connected to the 70 percent point, and the tap lead from the upper No. 1 position would have to be connected to the zero percent point to realize this setting.

The second zone must be set to reach beyond the far terminal. Assume that the second zone reaction reach is set for 1.5 secondary ohms. The percent tap setting required to obtain this reach is derived from the same equation that was used for the first zone. Since the same unit is used for second zone, the same base reach tap setting is common to both zones. So, for the second zone:

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

TABLE X

UNIT	SETTINGS ON TWO TERMINAL LINES	SETTINGS ON THREE TERMINAL LINES
01	Set for 90 percent of the total line	Set for 90 percent of the reactance to the nearest remote terminal. Do not include the effects of infeed.
02	Set for at least 110 percent 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 percent 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 backup protection for faults on remote lines	

The tap lead from the lower No. 2 position would have to be connected to the 30 percent point, and the tap lead from the upper No. 2 position would have to be connected to the three percent point to realize this setting.

The tap setting for the third zone mho unit is given in 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 (this is 1.0 ohms for the short reach relay)
- Z_L = impedance reach in secondary phase to neutral ohms
- ϕ = impedance angle of Z_L
- 60^o = angle of maximum torque of the mho unit

Assume that in this case, the third zone is set to reach 2.75 $\angle 80^o$ secondary phase to neutral ohms. The percent tap setting for this reach is:

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

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

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

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

The GCX relays will not operate for any faults that do not produce at least 4.3 amperes.

CONSTRUCTION

The GCX51 relays are assembled in a standard large size, double-end (L2) drawout case, which has 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. A removable connecting plug, which completes the circuit, nests between these stationary blocks. The outer blocks attached to the case have studs for external connections, and the inner blocks have terminals for internal connections.

The relay mechanism is mounted in a steel framework called a cradle, and is a complete unit with all leads terminated at the inner block. The 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. Besides making the electrical connections between the respective blocks of the cradle and case, the connecting plug locks the latch 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 some other source. The relay can be drawn out and replaced by another relay, which has already been laboratory tested.

The relay has three major subassembly 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 (OPX), the combination target with seal-in unit, transactor associated with the ohm unit potential circuit, tapped autotransformer, which determines the reach of the ohm and mho units. The type GCX51N relay includes the instantaneous overcurrent unit. The tap block associated with the autotransformer is mounted along the right side of the relay.

Figure 1 show the relay removed from its drawout case with all major components identified. Symbols used to identify circuit components are the same as those which appear on the internal connection diagram, Figure 7 or 8.

ACCEPTANCE TESTS

Immediately upon receipt of a relay, an inspection and acceptance test should be made to insure that no damage has been sustained during shipment, and that relay calibrations have not been disturbed. If examination or test indicates that adjustment is necessary, refer to the section, **SERVICING.**

VISUAL INSPECTION

Check the nameplate stamping to insure 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 damage, and that all screws are tight.

MECHANICAL INSPECTION

1. The following mechanical adjustments should be checked:

Check Point:	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. The control springs should not be deformed, and spring convolutions should not touch each other.

4. The ohm unit and mho unit contacts must be open when the relay is well-leveled in its upright position. The moving contact of both the ohm and mho unit should rest against its backstop.

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

6. The armature of the telephone type relay (OX) should move freely.

7. The location of the contact brushes on the cradle and case blocks should be checked against the internal connection diagram for the relay.

ELECTRICAL CHECKS

Before making any electrical checks 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 only the potential circuit (studs 17-18) energized at rated voltage, and with the E^2 and No. 1 taps set at 100 percent. The units were allowed to warm up prior to adjustment at the factory, and if checked when cold, they tend to underreach by three or four percent. Of course, accurately calibrated meters are essential.

Check the factory settings and calibrations using the tests described in the following sections. The ohm and mho units were carefully adjusted at the factory, and these settings should not be disturbed unless the tests performed conclusively indicate that the settings are out of adjustment. If readjustment is necessary, refer to **SERVICING** for the recommended procedures.

Mho Unit Checks

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

With the current set at five amperes and the voltage across studs 17-18 at 120 volts, set the phase shifter so that the phase angle meter reads 300 degrees (i.e., current lags the voltage on studs 17-18 by 60 degrees). 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 one ohm mho unit.

Ohmic Reach: With the relay still connected as shown in Figure 10 and the E^2 taps in the 100 percent 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 MINIMUM REACH (Ø-N OHMS)	V17-18 SET AT	PICKUP AMPS	EQUIVALENT TEST REACH (Ø-Ø OHMS)
Short Reach	1	40V	19.4-20.6	2

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

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 percent, and the voltage set at the value shown in Table XI. The pickup should be checked with the current displaced 30 degrees from the maximum torque position in both the lead and lag direction.

Set the phase shifter so that the phase angle meter reads 330 degrees. Note that while the phase angle is being set, the current should be at five amperes and the voltage on studs 17-18 should be increased temporarily to 120 volts. With the 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.

Reset the phase angle at 270 degrees, 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 previously, 330 degrees and 270 degrees, are read 30 degrees away from the angle of maximum torque. An examination of the mho unit impedance characteristic in Figure 4 shows that the ohmic reach of the unit should be the same at both 330 and 270 degrees, and should be 0.866 times the reach at the angle of maximum torque.

Ohm Unit Checks

Control Spring Adjustment: With the relay well-leveled in its upright position, the moving contact should just touch its backstop.

Ohmic Reach and Angle of Maximum Torque: Since the ohm unit is a reactance measuring device, its angle of maximum torque occurs at 90 degrees, current lagging voltage.

To check the ohmic reach, use the connections shown in Figure 10. Set the No. 1 tap leads on 100 percent and the current at ten amperes. Set the phase shifter so that the phase angle meter reads 270 degrees (i.e., current lags voltage by 90 degrees). Now vary the voltage across studs 17-18 until the point is found where the ohm units just close. Table XIV shows the pickup voltage point for the intermediate range settings. A plus or minus three percent variation is permitted.

To check the angle of maximum torque, use the same connections and settings as above, except set the phase shifter so that the phase angle meter reads 315 degrees (i.e., current lags voltage by 45 degrees). 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 in column, "45°." A plus or minus three percent variation is permitted.

The relays are shipped from the factory with the basic minimum reach adjustment taps on the intermediate setting, 0.2 ohms.

TABLE XII
Ohm Unit Check Points

RELAY	BASIC MINIMUM REACH SETTING	NO. 1 TAP	SET CURRENT AT	OPERATING POINTS (V17-18) I LAGS V BY ±3% 90°	45°
Short Reach	0.2 ohms	100%	15A	6V	8.5V

The three basic minimum reach tap settings are adjusted by selecting the proper reach tap link and adjusting the R1 resistor. The reach tap link is located at the left of the ohm unit and the R1 resistor is located above the ohm unit. The basic reach taps are 0.1/0.2/0.4 ohms phase-to-neutral, and each is adjusted separately by a band on the R1 resistor.

Reach Tap Phase-to-Neutral	Adjustment R1
0.1 ohms	Left Band (front view)
0.2 ohms	Middle Band (front view)
0.4 ohms	Right Band (front view)

Other Checks and Tests

In addition to the tests on the ohm and mho units, the following general tests and checks should be made as a part of the acceptance test routine.

Ohm Unit Transfer Relay (OX): The ohm unit transfer relay, identified as OX in Figure 7, 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 percent or less of the nominal tap voltage for each link position.

Target Seal-in Unit: The target seal-in unit has an operating coil tapped at 0.6 or 2.0 amperes. It is shipped from the factory with the tap screw in the 0.6 ampere position. Check the operating point of the seal-in unit by connecting 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 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.

To change the tap setting from 0.6 to 2.0 amperes, proceed as follows: Remove the tap screw from the left hand contact strip and insert it in the 2.0 ampere position of the right hand contact strip. Then, remove the screw from the 0.6 ampere tap and put it in the vacant position in the left hand plate. This procedure will not disturb the contact adjustments.

INSTALLATION PROCEDURE

LOCATION

The relay should be located in an area that is clean and dry, free from dust, excessive heat and vibration. The area should be well lighted to facilitate inspection and testing.

MOUNTING

Mount the relay on a vertical surface. Outline and panel drilling dimensions are shown in Figure 24.

CONNECTIONS

Figure 7 is the internal connections diagram for the GCX51A and GCX51B relays. Figure 2 is the elementary diagram which depicts typical external connections.

As shipped from the factory, internal jumpers are connected between cradle terminals 17-19 and 18-20 (see Figure 7). These jumpers can be removed if a separate polarizing potential is used. Then the restraint voltage would be connected to studs 17-18 and the polarizing voltage to studs 19-20.

VISUAL INSPECTION

Remove the relay from its case to check that there are no broken or cracked component parts. Check that all screws are tightened.

MECHANICAL INSPECTION

Recheck the adjustments in the **ACCEPTANCE** section listed under "MECHANICAL INSPECTION."

ELECTRICAL CHECK TESTS ON INDUCTION UNITS

How settings for the ohm and mho units are made is discussed briefly in the section, **CALCULATION OF SETTINGS**. Typical settings are calculated in the examples. The purpose of the electrical tests in this section is to check the ohm and mho unit pickup at the settings which have been made for a particular line section.

The test circuit depicted in schematic form in Figure 10 will eliminate errors which may result from instrument inaccuracies, and will permit testing the ohm and mho units from a single phase AC test source. In this test circuit, $R_S + jX_S$ is the source impedance; S_R 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 ten percent and one percent steps so that the line impedance, $R_L + jX_L$, may appear to the relay to be nearly the actual line on which te relay is to be used. This is necessary because it is not feasible to provide the portable test reactor, X_L, and the test resistor with enough taps so that the combination will match any line.

For field testing convenience, the fault switch and tapped autotransformer of Figure 11 have been arranged in a portable test box, GE catalog number 102L201, which is particularly adapted for testing directional and distance relays. The box has terminals to readily connect the relay current and potential circuits, as well as line and source impedances. For a complete description of the test box, refer to instruction book GEI-38977, "Portable Test Unit."

Testing the Ohm Unit

To check the ohm unit calibration, portable test box (catalog 102L201), portable test reactor (catalog 6054975), and test resistor (catalog 6158546) should 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 of Figure 11, except that now the XLA test plug connections are included.

Simulating the $R_S + jX_S$ source impedance conditions that would actually be encountered is only necessary if the relay is to be tested for overreach or contact coordination. These tests are not normally considered necessary at 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 being checked. A reactor or suitable value should be used for this purpose, since it will tend to limit harmonics in the fault current.

The relay is being tested for the ohmic reach that it will have when in service; therefore, the value of X_L selected should be the portable test reactor tap that is nearest to above twice the relay phase to neutral ohmic reach.

Explanation of the "twice factor" follows: As normally connected (V_{1-2} potential and $I_1 - I_2$ current) the relay 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 test box autotransformer percent tap which should cause the ohm unit to just close its contacts with the fault switch closed is determined by the equation:

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

For this test, the unit value of R_L is zero, since the ohm unit responds only to a reactance quantity. The load box may be adjusted to give a fault current of approximately 20 amperes, however, or whatever fault current is expected during three phase and/or phase to phase fault conditions.

This is best illustrated by assuming 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 0.2 ohms. Further, assume that the No. 1 taps are set at 70 percent, providing a zone 1 reach of approximately 0.285 ohms, phase to neutral. These values were used in the example in the section, **CALCULATION OF SETTINGS.**

$$2X_{Relay} = 2\ (0.285) = 0.57 \text{ ohms}$$

Therefore, the 1 ohm reactor tap should be used, since it is the nearest tap above twice the unit phase to neutral ohmic reach. Now assume that the calibration curve for the particular test reactor used has been checked, and that the reactance of the 1 ohm tap at the current level to be used in the test is actually 1.1 ohms. The percent tap of the test box autotransformer at which the ohm unit contact will just close can be calculated by:

$$\% \text{ Tap} = \frac{0.57}{1.1} \times (100) = 51.9\%$$

Theoretically, the ohms unit should close its contact with the test box autotransformer taps set at 52 percent and remain open with the taps at 53 percent. A range of from 51 to 54 percent is acceptable.

The phase angle of the ohm unit reactance characteristic can be checked by adding resistance, R_L, in series with the line reactance, X_L, in the test circuit (Figure 12). This resistance should be non-inductive and about three to four times as large as the line reactance. Adjust the source impedance so that the fault current will be approximately the same as in the previous test with reactance only, when the pickup point is checked. 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 can be made in the same manner, except that the transfer relay, OX, must be picked up by applying rated DC voltage between studs 12-13 (be sure the DC voltage selection link position agrees with the voltage to be used). A different test reactor tap setting may also be necessary.

Testing the Mho Unit

The mho unit is tested in a manner similar to the ohm unit. The major difference is the determination of the test box autotransformer percent tap setting for pickup. The 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 normally is 60 degrees with respect to the R axis.

The test reactor reactance may be accurately determined from its calibration curve; however, the relay pickup can be checked with the fault reactor only, taking into account the angular difference between the line reactance, X_L, and the relay angle of maximum reach. As with the ohm unit, the line reactance selected should be the test reactor tap nearest above twice the mho unit reach, taking into account the difference in angle of the test reactor tap impedance and the relay angle of maximum reach. Figure 12 shows twice relay reach at the angle of the test reactor is:

$$2Z_{Relay} = 2 \, , \frac{Z_{min}}{E2\ tap} . \cos(\emptyset-\theta)$$

where: $\emptyset$ = 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:

$$\%\ Tap = \frac{2\ (Z_{Relay})}{Z_L} \times (100)$$

To illustrate, the example in **CALCULATION OF SETTINGS** will again be used. In that example, the E^2 tap setting was calculated to be 85 percent. Since a standard reach relay was used, the basic minimum reach of the mho unit is 85 ohms at the 60 degree angle of maximum torque. Assume an approximate angle $\emptyset$ of the test reactor impedance is 80 degrees in order to determine the test reactor tap setting. Based on this assumption, twice the relay reach at the angle of the test reactor will be:

$$2Z_{Relay} = 2 \, , \frac{1.0 \times 100}{85} . \cos(80 - 60)$$
$$= 2.21 \text{ ohms}$$

Therefore, use the 3 ohm tap of the test reactor. Twice 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 value of 80 degrees. Table XIII shows the angles for reach of the reactor taps.

TABLE XIII

TAP	ANGLE	COS ($\emptyset$-60)
24	88	0.883
12	87	0.891
6	86	0.899
3	85	0.906
2	83	0.921
1	83	0.934
0.5	78	0.951

From Table XIII, the angle of impedance of the 3 ohm tap is 85 degrees; therefore:

$$2Z_{Relay} = 2\left[\frac{1.0 \times 100}{85}\right]\cos(85 - 60)$$
$$= 2.13 \text{ ohms}$$

Refer to the calibration curve of the portable test reactor to determine exact reactance of the 3 ohm tap at the current level being used. For this illustration, assume that reactance is 3.1 ohms. Since the angle of impedance of the 3 ohm tap is 85 degrees, the impedance of this tap is calculated as follows:

$$Z_L = X_L/\cos 5 = \frac{3.1}{.9962} = 3.11 \text{ ohms}$$

Now the test box autotransformer tap setting required to close the mho unit contact with the fault switch closed, can be determined as follows:

$$\% \text{ Tap} = \frac{2.13}{3.11} = 68.4\%$$

If the ohmic pickup of the mho unit checks correctly, then the angle of the characteristic is probably correct. However, the angle may be easily checked by using the calibrated test resistor in combination with various reactor taps. The calibrated test resistor taps are preset so that when used with 12 and 6 ohm taps of the specified test reactor, impedance will be available at 60 degrees and 30 degrees, respectively, to check 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 at the line impedance. The calibrated test resistor is supplied with a data sheet that 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:

$$\% \text{ Tap} = \frac{2\ (1.0)\ \cos\ (60 - a)}{(E^2 \text{ Tap } \%)\ Z_L}\ (100)$$

where: a = angle of test impedance, Z_L

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

E^2 = mho unit restraint tap setting

As in previous tests, the source impedance should be adjusted 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, two factors 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 Figure 13, where at the zero degree position, a two or three degree error in phase angle will cause a considerable apparent error in reach. Second, the effect of the control spring should be considered, since the mho unit can only have a perfectly circular characteristic when control spring torque is negligible. The control spring may be neglected for any normal level of polarizing voltage, but in testing the unit as indicated above, the test box autotransformer tap setting may be reduced to a point where the voltage supplied to the unit is relatively low. The torque level will be reduced, since polarizing voltage, as well as the restraint, will be low. The result is that the control spring torque will no longer be negligible. The control spring causes the reach of the mho unit to be somewhat reduced a low polarizing voltages.

The effect of the above errors can be seen in their true proportions if the reach characteristic, determined by test, is plotted on an R-X impedance diagram (as typified by Figure 4). It is obvious that the apparent errors in reach, resulting from phase angle error at angles well of the maximum reach position, occur in a region where the fault impedance vector does not lie. As for the error introduced by spring torque, 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 a first zone unit.

The mho unit 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 1.0 ohm tap. With the test box switch closed, the mho unit contact should remain closed for a current range of 6-60 amperes with two percent rated voltage applied. Use a voltmeter to read the voltage at studs 17-18 of the relay. The voltage over the 6-60 ampere current range is adjusted with the text box autotransformer tap switches. The mho unit contacts should remain open for the same conditions as described above when the connections are changed to the reverse position.

Other Checks and Tests

In addition to the calibration checks on the ohm and mho units, the following general tests can be made:

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 250 volts). Check that the OX unit is picking up at 80 percent of nominal rated voltage, as determined by the link position, by applying a variable DC voltage between studs 12-13.

2. Check that the target seal-in unit is operating at tap value by using the connections of Figure 12. This can be checked if the zone 1 signal circuit is loaded with the proper bypass resistor to draw a current of approximately tap value and the ohm and mho contacts (and OC unit if present) are closed by hand. The seal-in unit tap screw should be left in the required position (0.6 or 2.0 amps) for the application. To change tap settings, follow the procedure outlined in **ACCEPTANCE TESTS**.

3. The pickup of the overcurrent unit (OC) should be checked for Type GCX51N and GCX51R relays. Adjust the fault current level using the load box (Figure 12). Calibration points of the OC unit are marked on the relay nameplate. Normally, the OC unit is factory set for minimum pickup. However, by changing the position of the knurled armature on the plunger rod, pickup of the OC unit can be set to another value. An approximate adjustment can be obtained by using 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. For the ohm unit, short studs 17 and 18 (remove voltage). Place reach taps in center tap.

Rating	Clutch Action
0.2	Slips above 60 amps

For the mho unit, remove the short and set voltage at 120 volts across studs 17-18 and 19-20.

Rating	Clutch Action
1.0	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 the flats on the bakelite on the cup shaft. Hold this wrench, and using a 5/16 inch open end wrench, loosen or tighten the clutch by turning the nut below the spring windup sprocket. Turn the nut clockwise (top front view) to tighten the clutch setting, and counterclockwise to loosen it.

Overall Tests

Use the test connections and tabulation in Figure 23 for an overall check of current transformer polarities and connections to the complete relay installation. Checking the phase angle meter readings shown in the table for 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 2.

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

Since protective relays play a vital role in the operation of power systems, it is important that a periodic test program be followed. The interval between periodic checks will vary depending upon the installation environment, the type of relay, and the user's experience. The points listed in **INSTALLATION PROCEDURE** should be checked at intervals of one to two years until the test interval best suited to an individual user's requirements is determined.

CONTACT CLEANING

A flexible burnishing tool should be used for cleaning relay contacts. This is a flexible strip of metal with an etched-roughened surface, which in effect resembles a superfine file. The polishing action of this file is so delicate that no scratches are left on the contacts, yet it cleans off any corrosion thoroughly and rapidly. The flexibility of the tool insures 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 the ohm or mho unit calibrations are found to be out of limits during installation or periodic tests, recalibrate as outlined in the following paragraphs. These calibrations should be made in the laboratory. The circuit components listed below, normally considered factory adjustments, are used in recalibrating the units. These parts are located on Figure 1.

R1 - ohm unit reach adjustment

R2 - ohm unit phase angle adjustment

R3 - mho unit reach adjustment

R4 - mho unit phase angle adjustment

NOTE: Before making pickup or phase angle adjustments on mho or ohm units, the unit should be warmed up for approximately 15 minutes, energized with voltage alone. Also, the relay should be mounted in an upright position, so that the units are level.

MHO UNIT

Control Spring Adjustment: Connect the relay as shown in Figure 10, and set the E^2 tap leads at 100 percent. Be sure the relay is in its upright position. With the current set at five amperes and 120 volts across studs 17-18, set the phase shifter so that the phase angle meter reads 300 degrees (i.e., current lags voltage by 60 degrees).

Reduce the voltage to 2 volts and set the current to 4.5 amperes for one ohm mho units. Insert the blade of a thin screw driver 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 close below the 4.5 ampere set point, the adjusting ring should be turned to the right; above the set point, the adjusting rings should be turned to the left. Apply 2 percent of rated voltage to the relay.

Increase the current from 4.5 to 60 amperes - the contact should stay closed. If it does not, adjust the core. Next, remove the potential, short studs 17 and 18 - the contact should remain open from zero to 60 amperes. The core must be in the proper position to pass both tests. Figure 14 shows an exploded view of the core and the associated parts that lock the core in position to the unit sled. A special wrench, 0178A9455, part 1, is used to rotate the core 360 degrees in either direction without holding the locking nut, "F," or retightening after the final core position has been determined.

Ohmic Reach Adjustment: The basic minimum reach of the mho unit can be adjusted by rheostat R3. Increasing R3 by turning the screw driver adjustment counterclockwise increases the reach of the unit.

Connect the relay as shown in Figure 10. Set the E2 taps in the 100 percent position. Set the current to five amperes and the voltage at 120 volts, and set the phase shifter so that the phase angle meter reads 300 degrees (i.e., current lags voltage by 60 degrees). Set the voltage on studs 17-18 at the value shown in Table XI, and adjust R3 so that the mho unit picks up at 20 amperes, plus or minus two percent, for the short reach relay.

Angle of Maximum Torque: The angle of maximum torque of the mho unit is controlled by adjusting rheostat R4. A counterclockwise screw driver adjustment of R4 increases the angle of maximum torque.

Connect the relay as shown in Figure 10 with the E2 taps in the 100 percent position. Set the voltage across studs 17-18 at 40 volts for the short reach relay (see Table XI). Then adjust R4 so that the unit picks up at the same current level (21 to 23 amperes for the short reach relay) at phase angle meter readings of 330 degrees and 270 degrees (see "Mho Unit Checks" in **ACCEPTANCE TESTS**).

NOTE: Adjusting rheostat R3 has a secondary effect on the angle of maximum torque, and adjustment of R4 likewise affects the reach of the unit. Therefore, for very accurate settings, recheck the reach after the angle of maximum torque has been set. Continue readjusting until the reach and angle of maximum torque are both within the limits specified.

OHM UNIT

Control Spring Adjustment: With the relay well-leveled in its upright position, insert the blade of a thin screw driver into one of the slots in the edge of the spring adjusting ring. Set the ring so that the moving contact just touches its backstop. Properly adjusted, if the backstop is backed off, the moving contact will not follow.

NOTE: The control spring adjustments for both the ohms and mho units should be checked with the relay mounted in its final position on the panel.

Reach and Angle of Maximum Torque: Each basic minimum reach of the ohm unit is controlled by an individual slide band on the adjustable resistor, R1. Angle of maximum torque (90 degrees current lagging voltage) may be adjusted by rheostat R2. However, these adjustments are not independent; that is, an adjustment of R2 will have some effect on the reach of the ohm unit, and adjustments of R1 will affect the angle of maximum torque.

To calibrate the ohm unit, place the No. 1 taps in the 100 percent position, and make the connections shown in Figure 10. Follow the steps outlined below.

Step 1: Set current at five amperes and voltage at 120 volts. Adjust the phase shifter so that the phase angle meter reads 270 degrees (i.e., current lags voltage by 90 degrees). Then set the current for the value listed in the "90°" column. For example, for 0.2 ohm basic minimum reach, current would be set at 15 amperes and voltage at 6 volts. Adjust R1 rheostat until the ohm unit contacts just close. Now raise the voltage and lower it again slowly until the ohm unit contacts just close. The voltage at the operating point should be within plus or minus one percent of the voltage listed in Table XIV, "90°" column. Readjust R1 until the operating voltage is within the plus or minus one percent limit.

Note that 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.

Step 2: Reset the phase shifter so that the phase angle meter reads 315 degrees (current lags voltage by 45 degrees), and with the same current as in Step 1, set the voltage at the value listed in the column, "45°." Then adjust R2 until the contacts just close. The voltage at this operating point should be within plus or minus one percent of the value in Table XIV, "45°" column. Modify the R2 setting until the operating voltage is within this plus or minus one percent limit.

Step 3: Recheck Step 1. Ohm unit contacts should close within plus or minus two percent of the voltage listed in the column "90°." 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

Sufficient quantities of renewal parts should be kept in stock for 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 the name of the part wanted, quantity required, and complete nameplate data, including the serial number, of the relay.

TABLE XIV

RELAY	BASIC MINIMUM REACH SETTING	NO. 1 TAP	SET CURRENT AT	OPERATING POINTS (V17-18) I LAGS V BY:	
				90°	45°
Short Reach	0.1 ohm	100%	20	4V	5.7V
	0.2	100%	15	6V	8.5V
	0.4	100%	15	12V	17.0V

The three basic minimum reach tap settings are adjusted by selecting the proper reach tap link and adjusting the R1 resistor. The reach tap link is located at the left of the ohm unit and the R1 resistor is located above the ohm unit. The basic reach taps are 0.1/0.2/0.4 ohms phase-to-neutral, and each is adjusted separately by a band on the R1 resistor.

Reach Tap Phase-to-Neutral	Adjustment R1
0.1 ohms	Left Band (front view)
0.2 ohms	Middle Band (front view)
0.4 ohms	Right Band (front view)

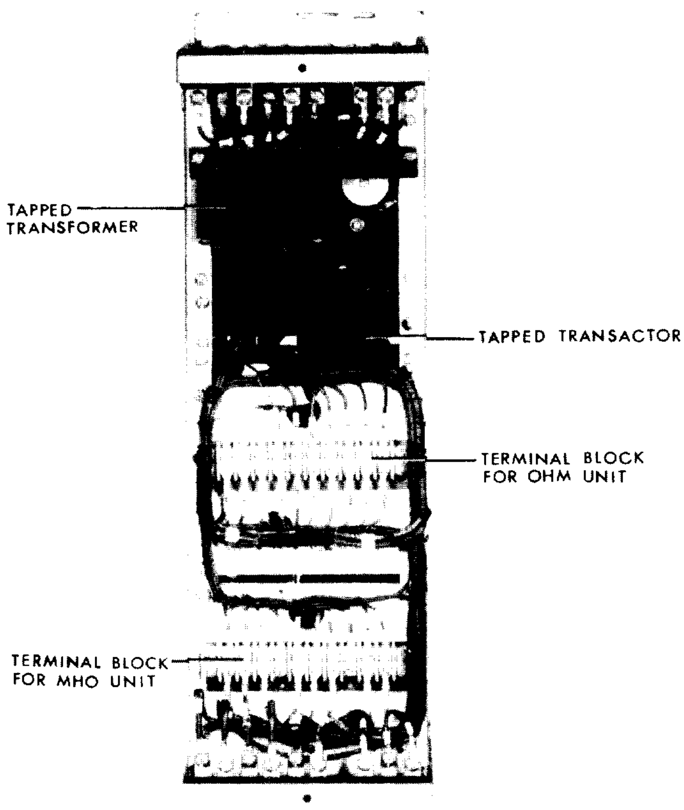


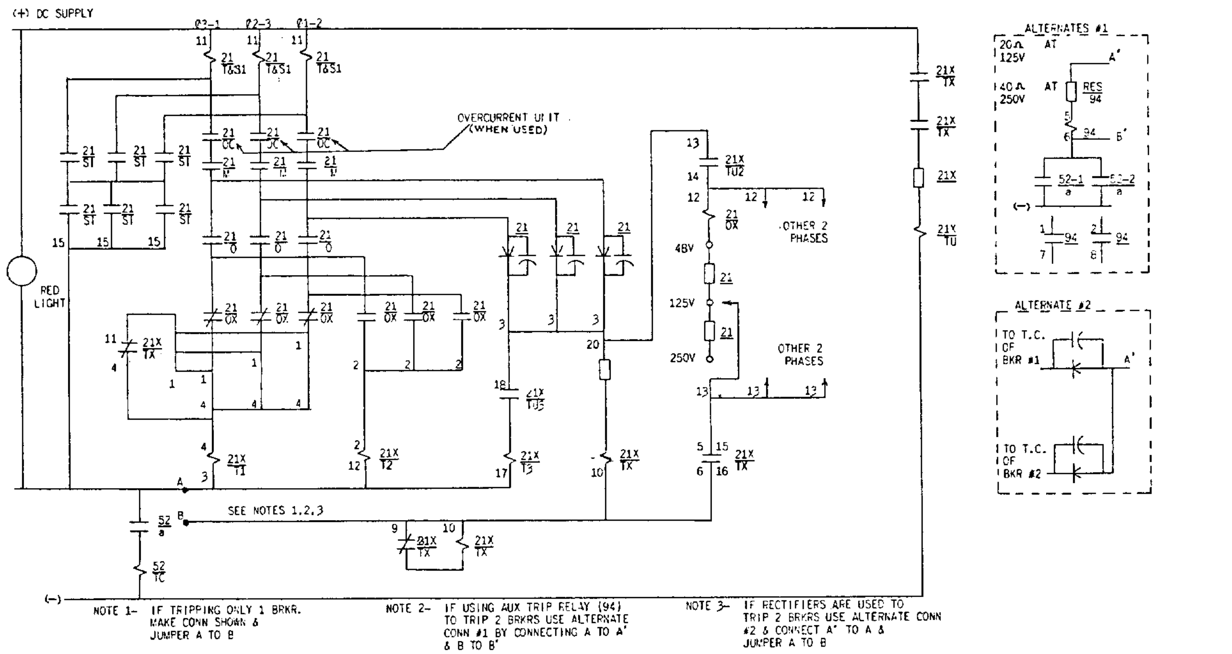
Figure 1 (8034917) Type GCX51M, N, P or R Relay Removed from Case (Rear View)

LEGEND			
DEVICE NO.	DEVICE TYPE	INCL ELEM.	DESCRIPTION
21	GCX51A,B,M,N&R		REACTANCE TYPE STEP DISTANCE RELAY
		TR	TRANSACTOR
		M	MHO UNIT
		C	REACTANCE UNIT
		OX	ZONE TRANSFER AUXILIARY FOR O
		T&S	TARGET AND SEAL-IN
21X	RPM11D & 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	HGA14AM OR AL		AUXILIARY TRIPPING RELAY

* OR SAM14B, 14K

TABULATION OF DEVICES		
DEVICE TYPE	INT. CONNS.	OUTLINE
GCX51A,B,M,N,R	0165A7706	K-6209276
RPM11D&H, OR SAM14B,14K	0176A7092	K-6209272
HGA14AM (BACK CONNS)	K-6400533	K-6400533
HGA14AL (FRONT CONNS)	377A139	377A139
TRIP RECTIFIER (102L2186-2) 125V		104A8584
TRIP RECTIFIER (102L2186-4) 250V		104A8584

Figure 2 (7381B93-6) Three Step Distance Protection for a Transmission Line Using Three Type GCX51M, N or R Phase Distance Relays and One Type SAM14B or SAM14K Timing Relay



LEGEND			
DEVICE NO.	DEVICE TYPE	INCL ELEM.	DESCRIPTION
21	GCX51E,F&P		REACTANCE TYPE STEP DISTANCE RELAY
		TR	TRANSACTOR
		M	MHO UNIT
		O	REACTANCE UNIT
		OX	ZONE TRANSFER AUXILIARY FOR O
		T & SI	TARGET AND SEAL-IN
21X	RPM11D & 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	HGA14AM OR AL		AUXILIARY TRIPPING RELAY

* OR SAM14B,14K

TABULATION OF DEVICES		
DEVICE TYPE	INT. CONNS.	OUTLINE
GCX51E&F&P	0195A4925	K-6209176
RPM11D&H - SAM14B,14K	0178A7092	K-6209272
HGA14AM (BACK CONNS)	K-6400533	K-6400533
HGA14AL (FRONT CONNS)	377A139	377A139
TRIP RECTIFIER (102L2186-2) 125V		104A8584
TRIP RECTIFIER (102L2186-4) 250V		104A8584

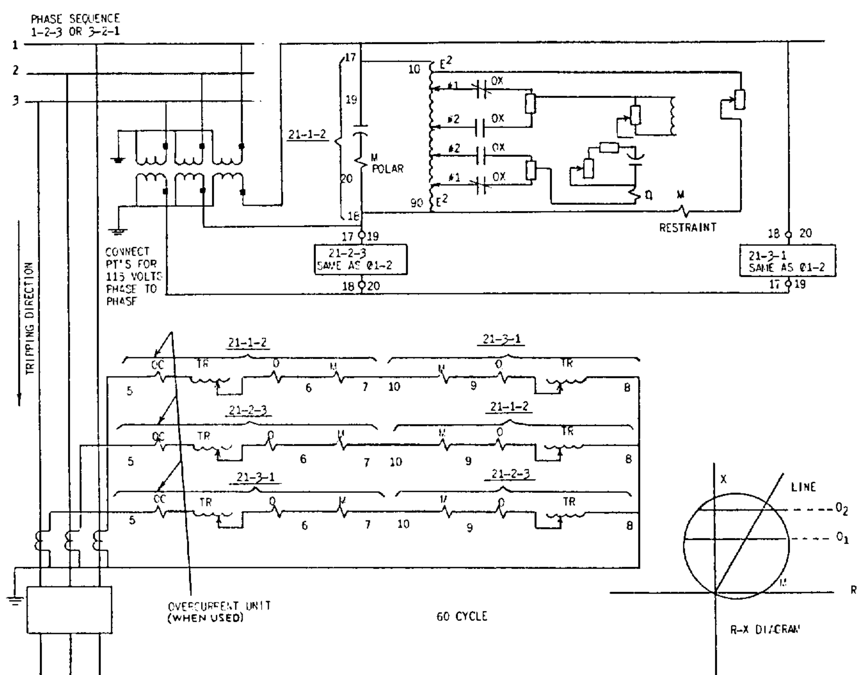


Figure 3 (0116B9355-1) Three Step Distance Protection for a Transmission Line Using Three Type GCX51P Phase Distance Relays and One Type SAM14B or SAM14K Timing Relays. Special Connections for Interchangeability with the GCX17A and GCX17B Relays

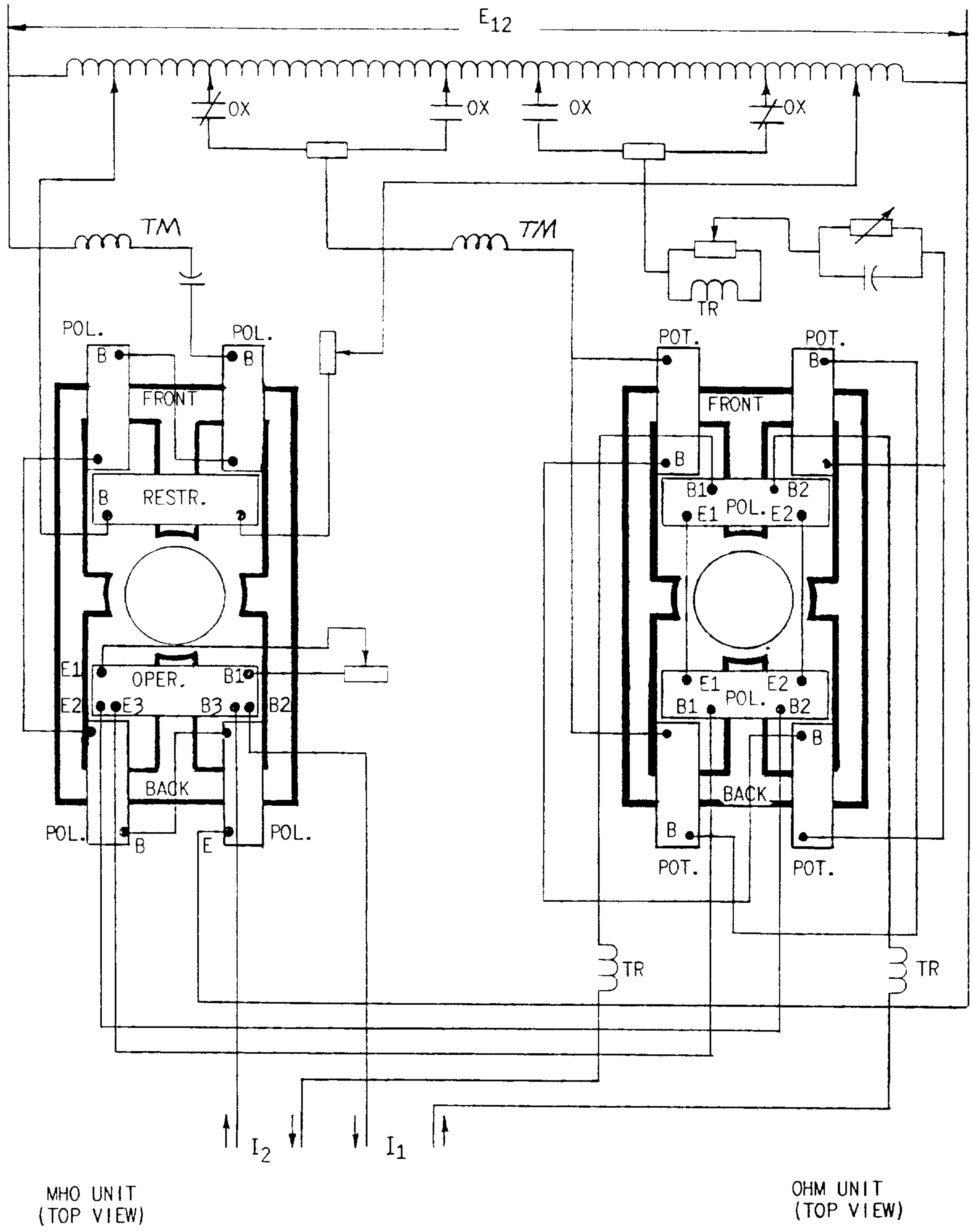


Figure 4 (0116B6856-1) Schematic Diagrams of the Mho and Ohm Units of the GCX51 Relays

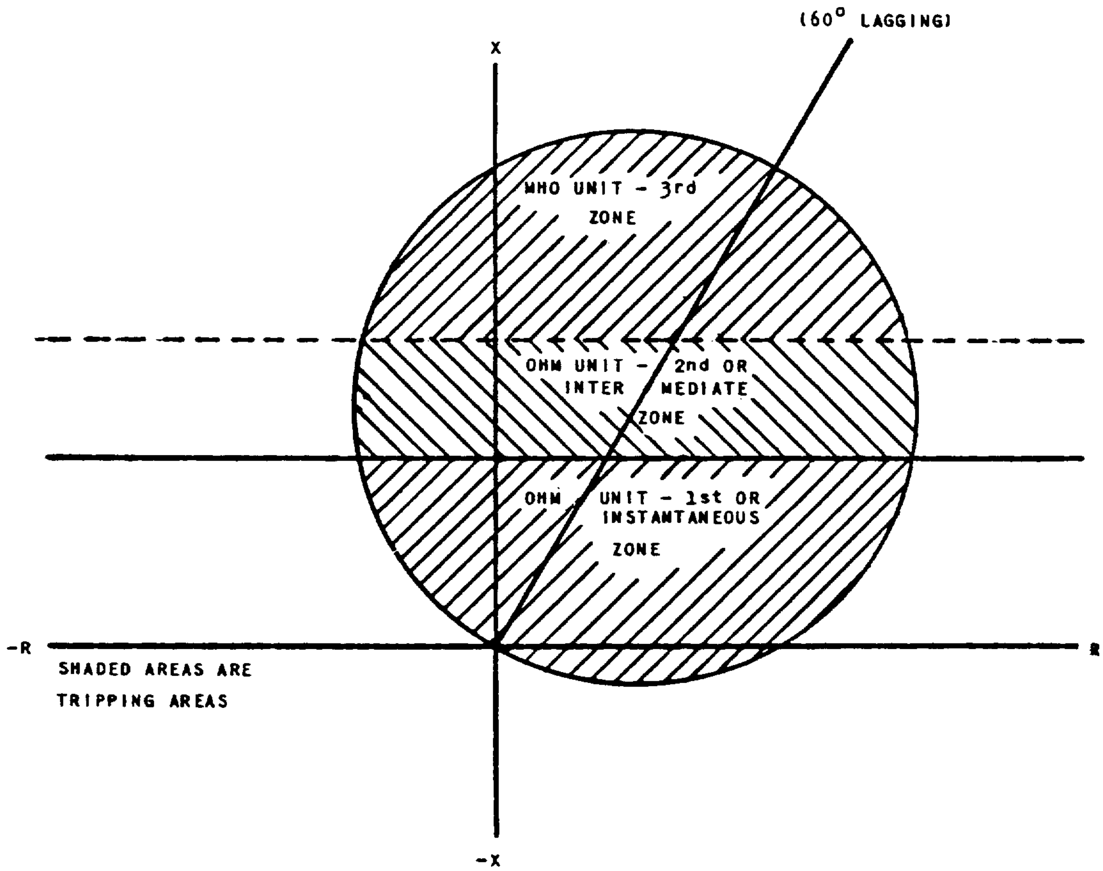


Figure 5 (6305889-4) Characteristics of the Ohm and Mho Units on an Impedance Diagram for the GCX51 Relay

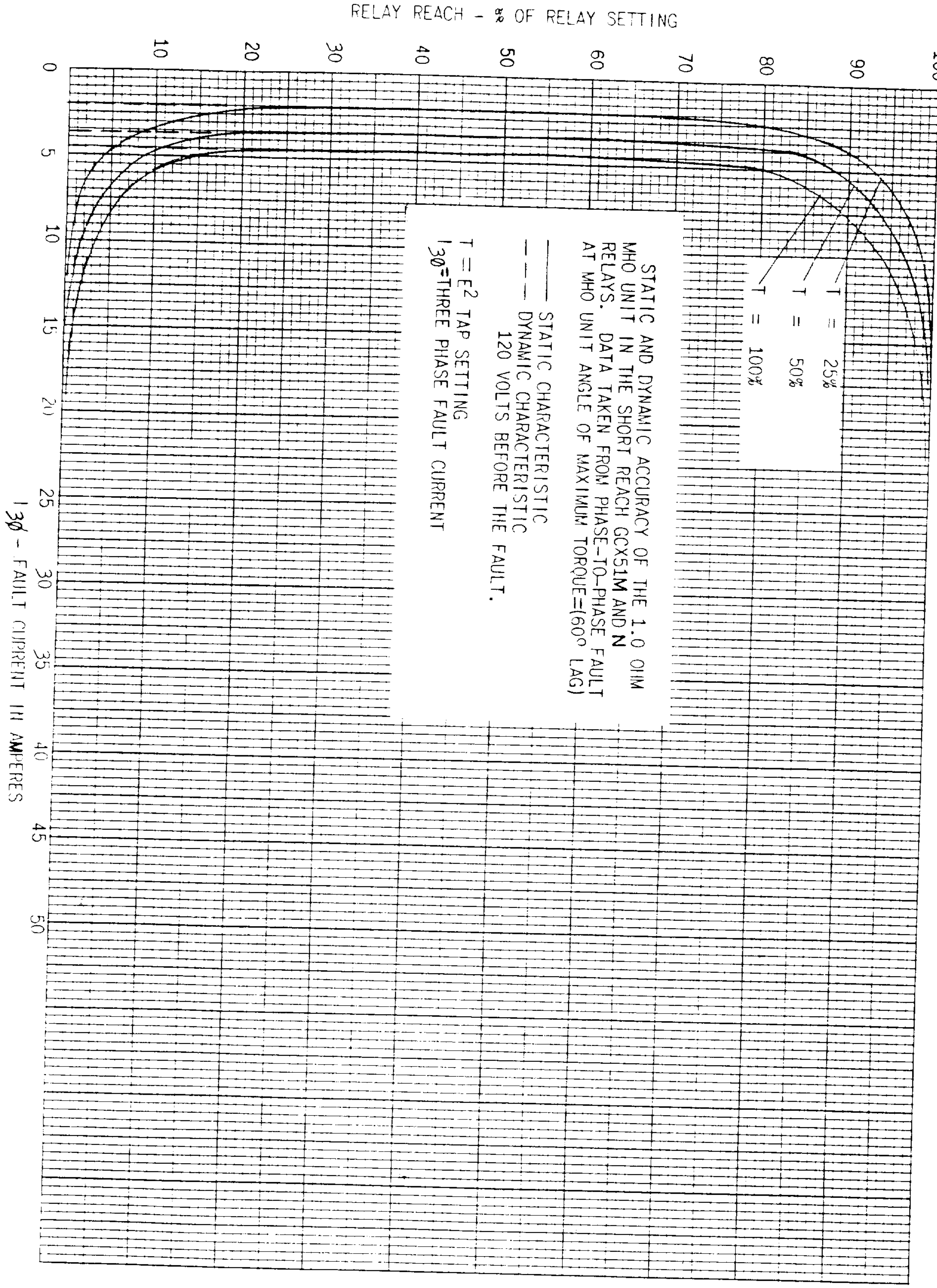


Figure 6 (0285A9173-0) Static and Dynamic Reach Data for the 1.0 Ohm Mho Unit used in the Short Reach GCX51M, N, P and R Relay

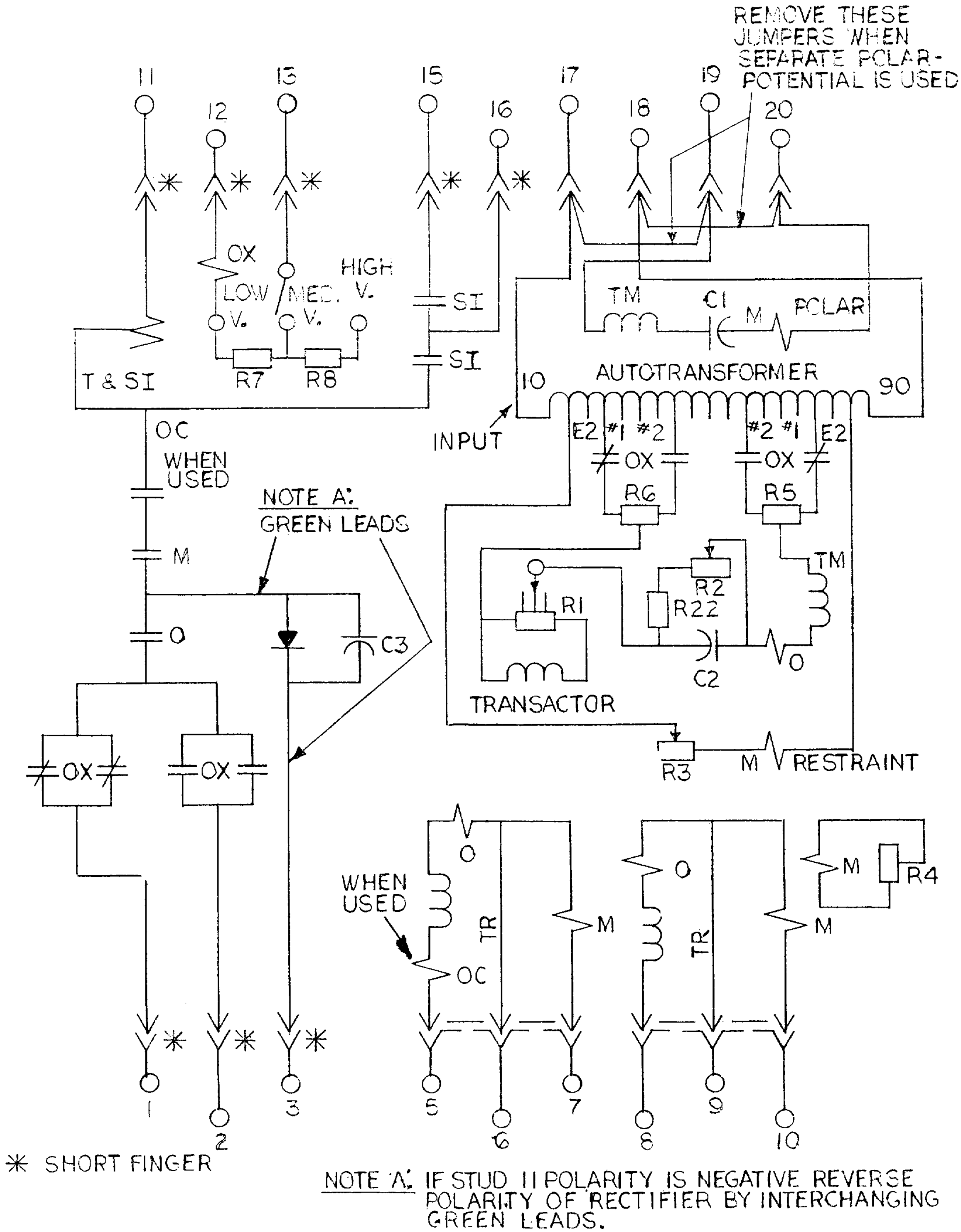


Figure 7 (0285A6632-1) Internal Connections Diagram (Front View) of the Type GCX51M, N and R Relays

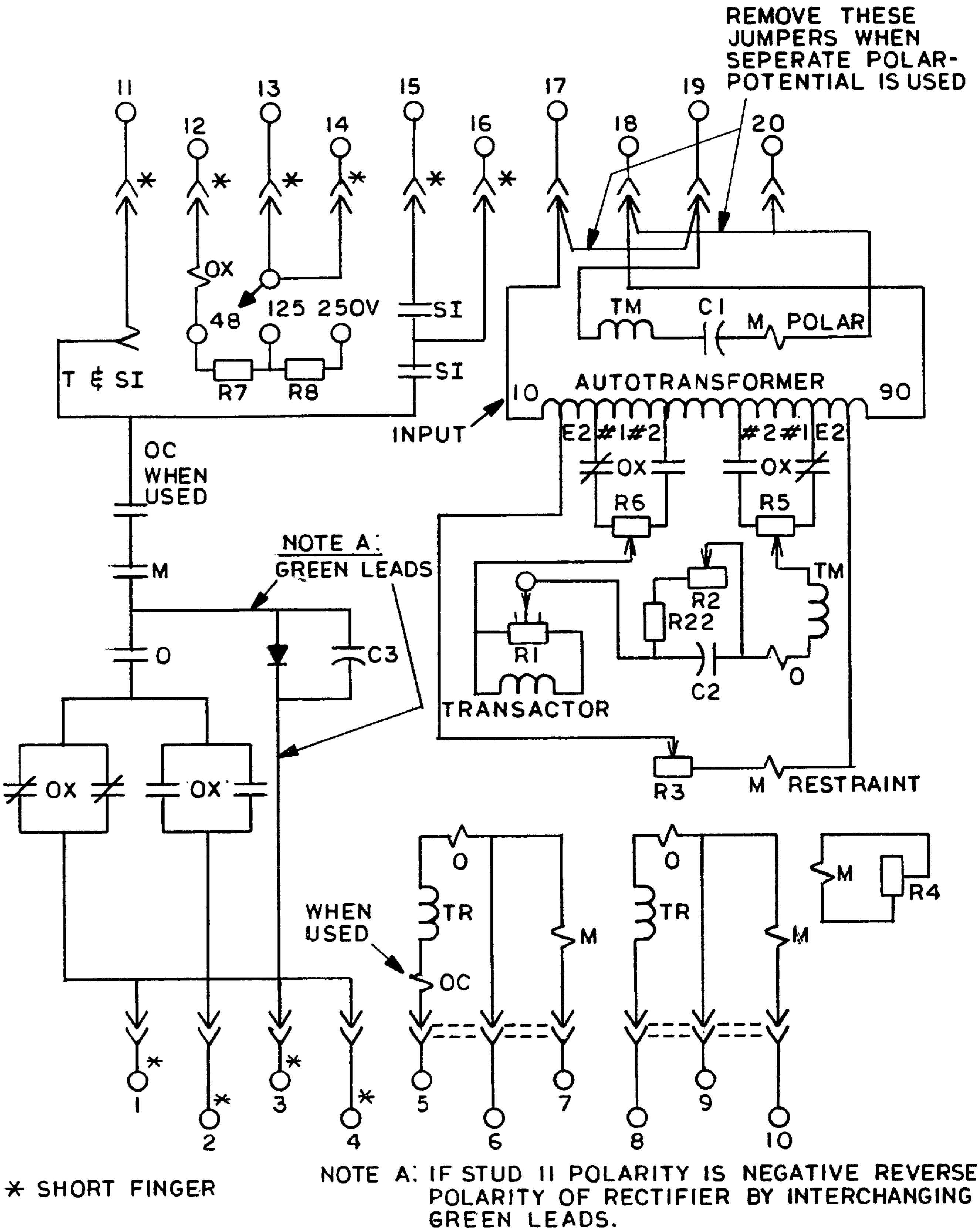


Figure 8 (0285A6714-3) Internal Connections Diagram (Front View) of the Type GCX51P Relay

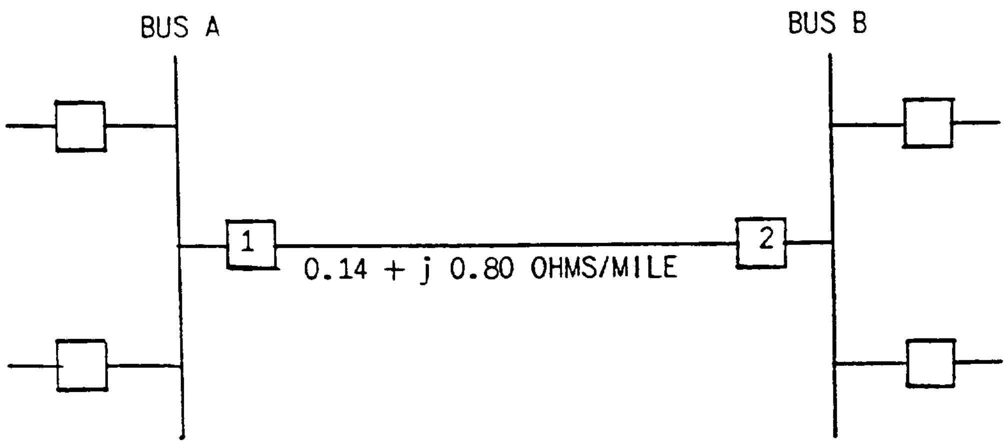


Figure 9 (0178A7169-1) Schematic Diagram of a Typical Two Terminal Line

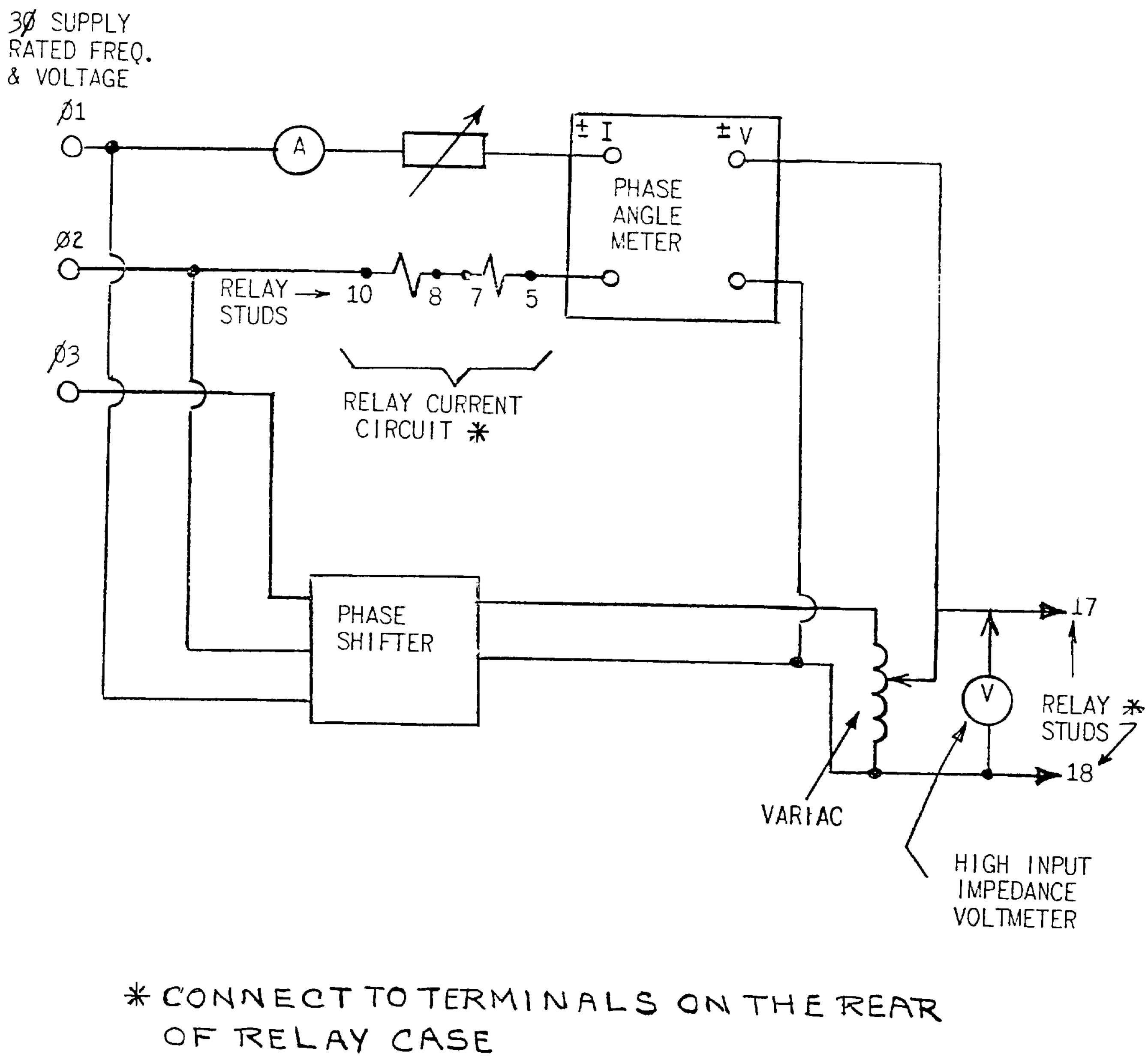


Figure 10 (0165A6069-2) Test Circuit for the GCX51M, N, P and R Relays Using a Phase Shifter

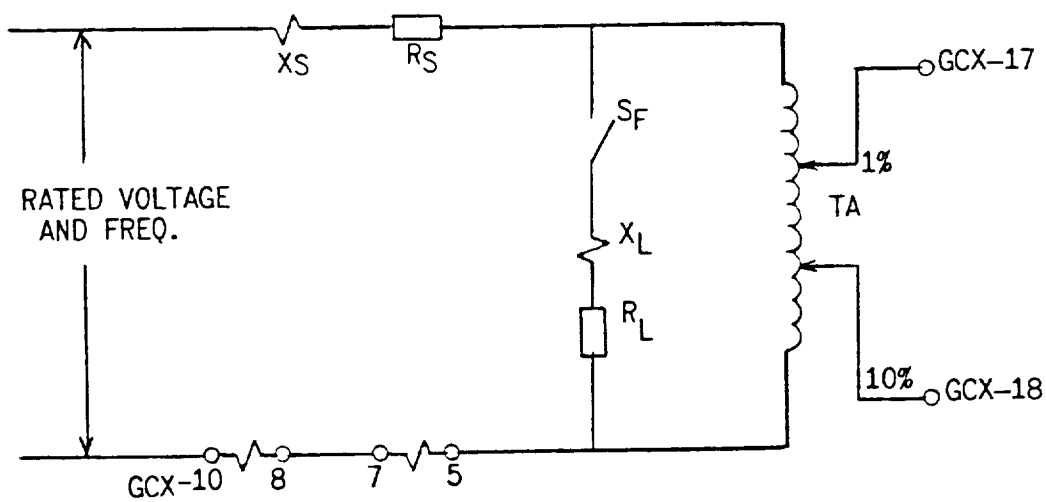


Figure 11 (0362A624-2) Schematic Diagram of the GCX51 Test Circuit

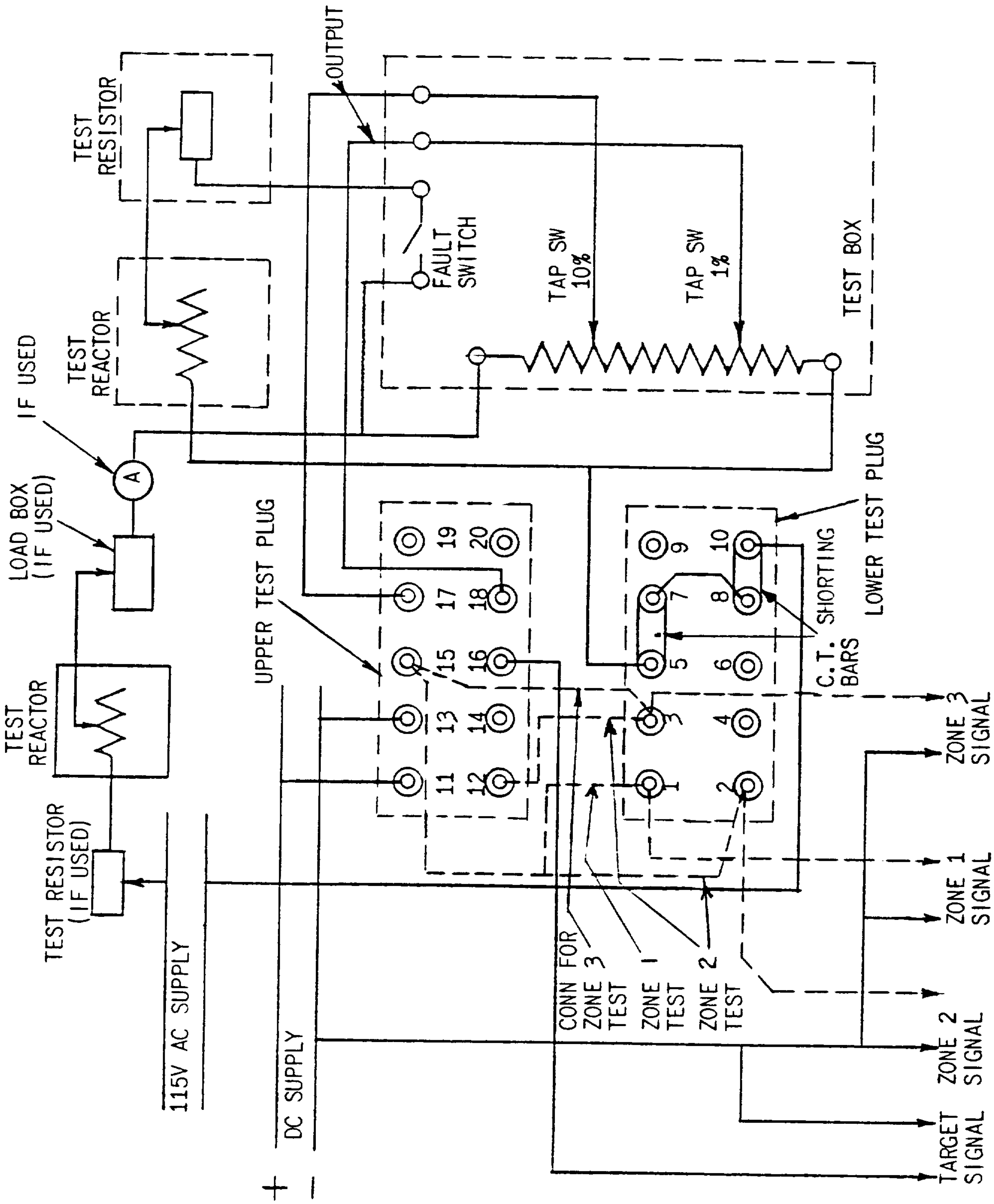


Figure 12 (0178A7162-1) Connections for Field Testing the GCX51M, N, P and R Relays Showing the XLA12A Test Plug

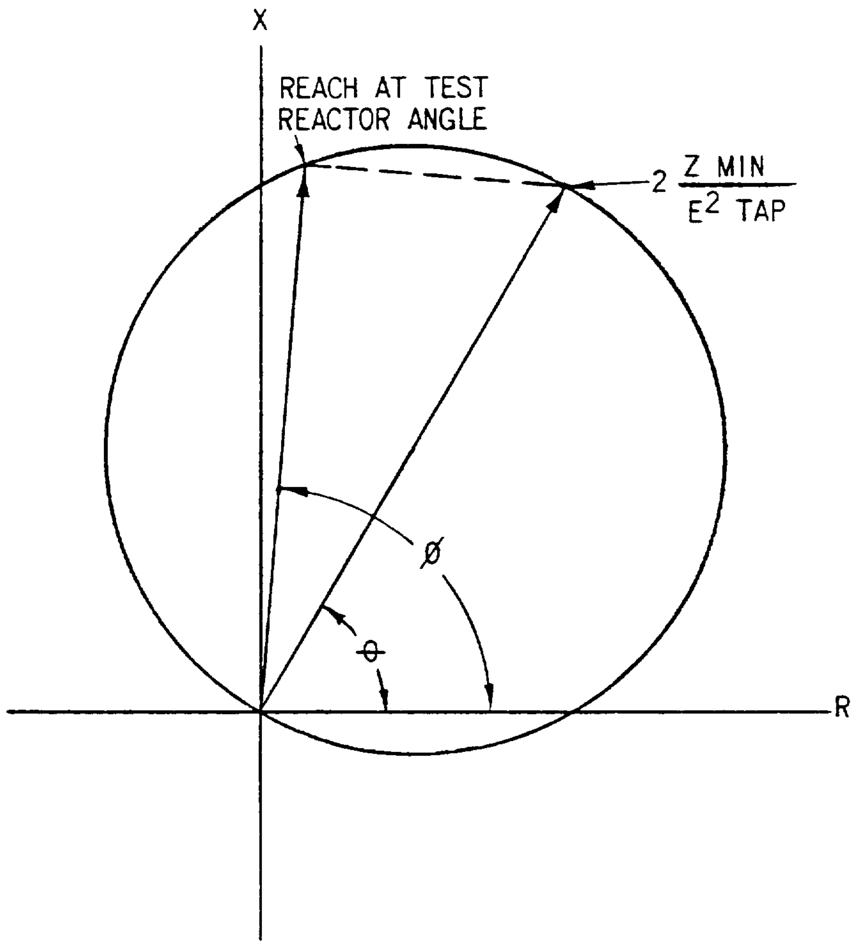


Figure 13 (0362A625-5) Reach of the Mho Unit at the Angle of the Test Reactor

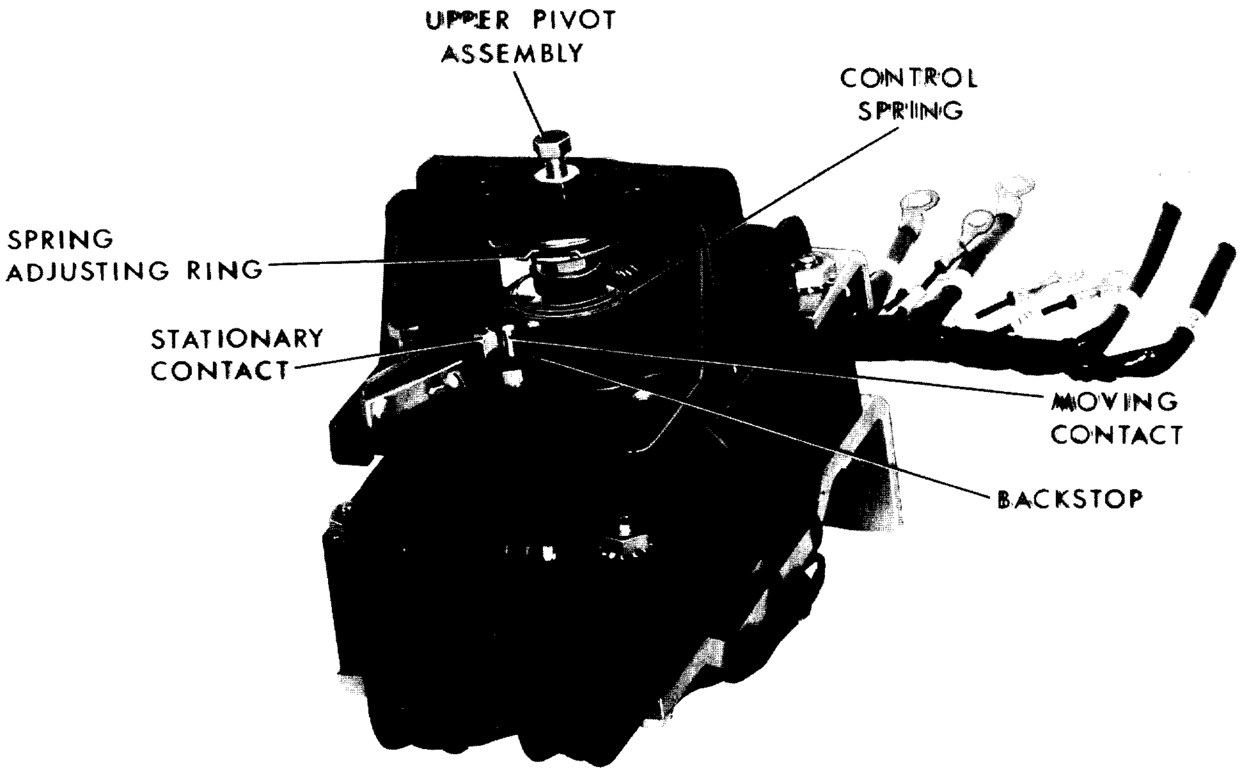


Figure 14 (8034958-1) Four Pole Induction Cylinder of the GCX51 Relay Mho and Ohm Unit

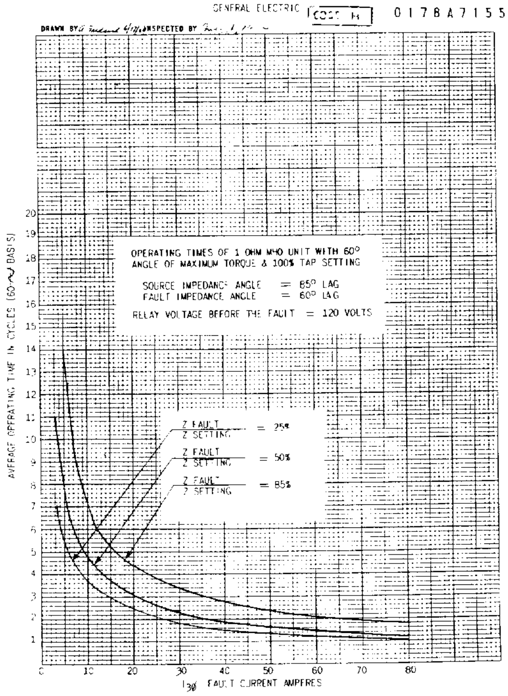


Figure 15 (0178A7155-0) Operating Time Curves for the 1.0 Ohm Mho Unit in the Short Reach Relay When the Voltage Before the Fault is 120 Volts

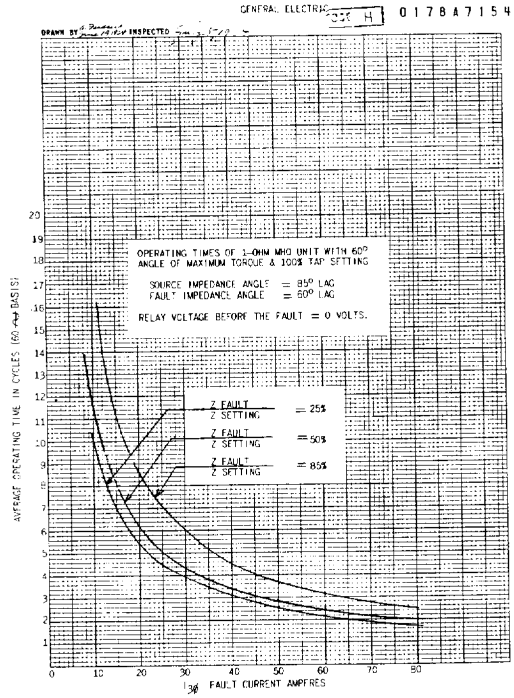


Figure 16 (0178A7154-0) Operating Time Curves for the 1.0 Ohm Mho Unit in the Short Reach When the Relay Voltage Before the Fault is Zero Volts

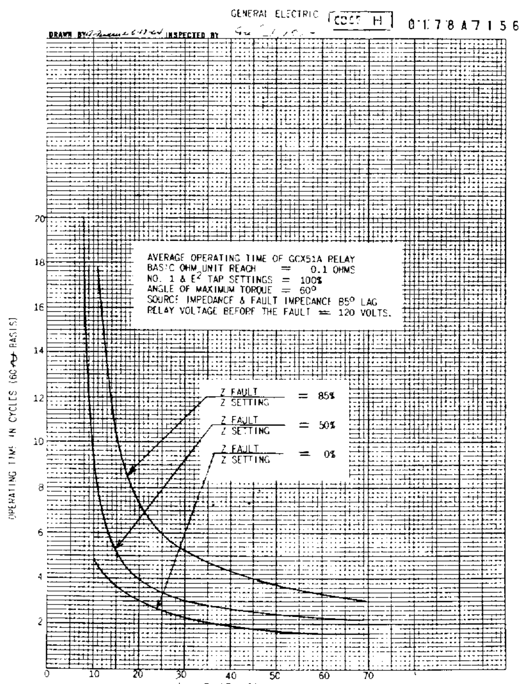


Figure 17 (0178A7156-0) Operating Time Curves for the 0.1 Ohm Short Reach GCX51 Relay. Voltage Before the Fault is 120 Volts

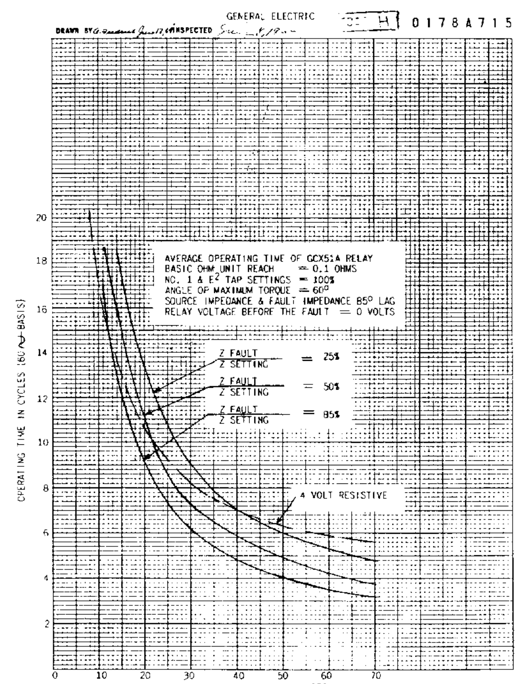


Figure 18 (0178A7159-0) Operating Time Curves for the 0.1 Ohm Short Reach GCX51 Relay. Voltage Before the Before the Fault is Zero Volts

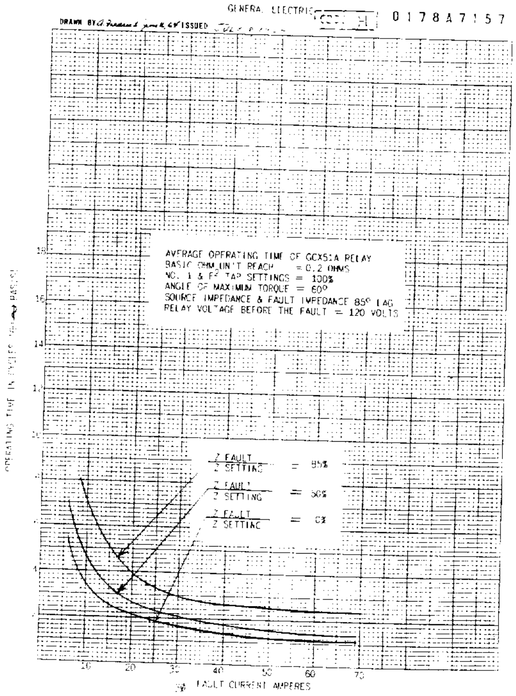


Figure 19 (0178A7157-0) Operating Time Curves for the 0.2 Ohm Short Reach GCX51 Relay. Voltage Before the Fault is 120 Volts

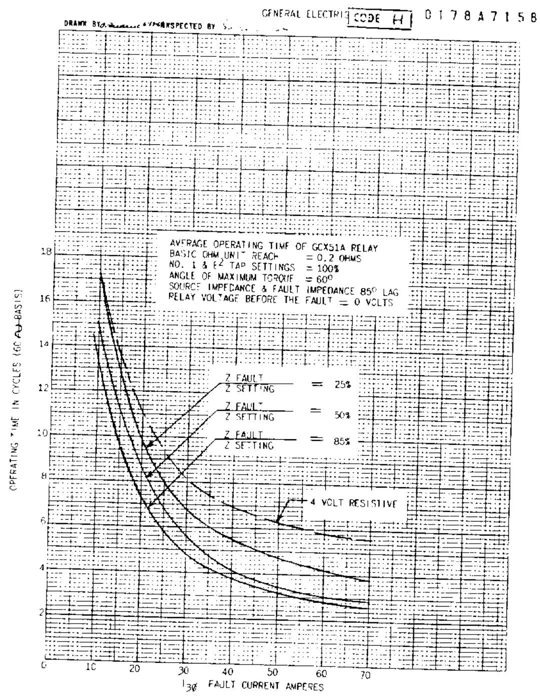


Figure 20 (0178A7158-0) Operating Time Curves for the 0.2 Ohm Short Reach GCX51 Relay. Voltage Before the Before the Fault is Zero Volts

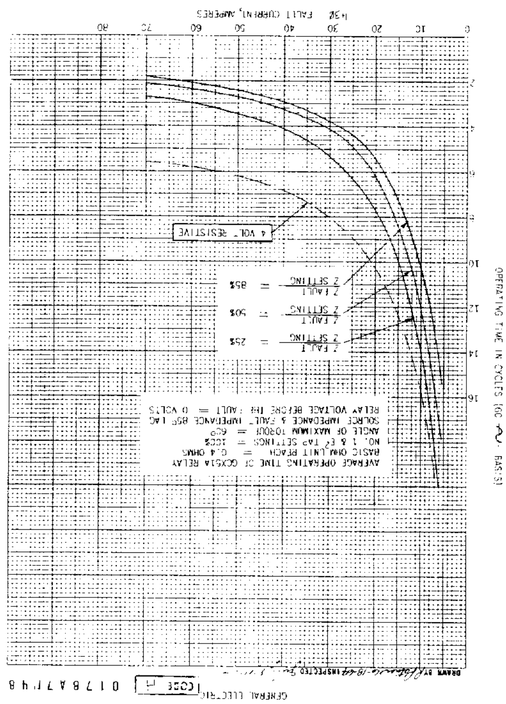


Figure 21 (0178A7149-0) Operating Time Curves for the 0.4 Ohm Short Reach GCX51 Relay. Voltage Before the Fault is 120 Volts

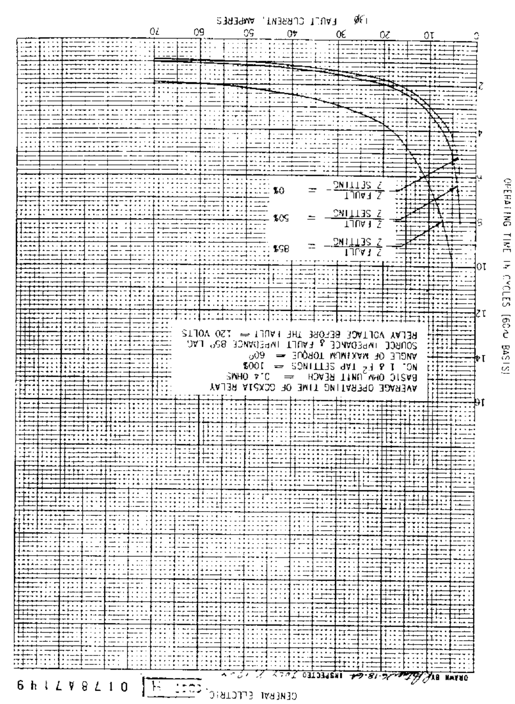
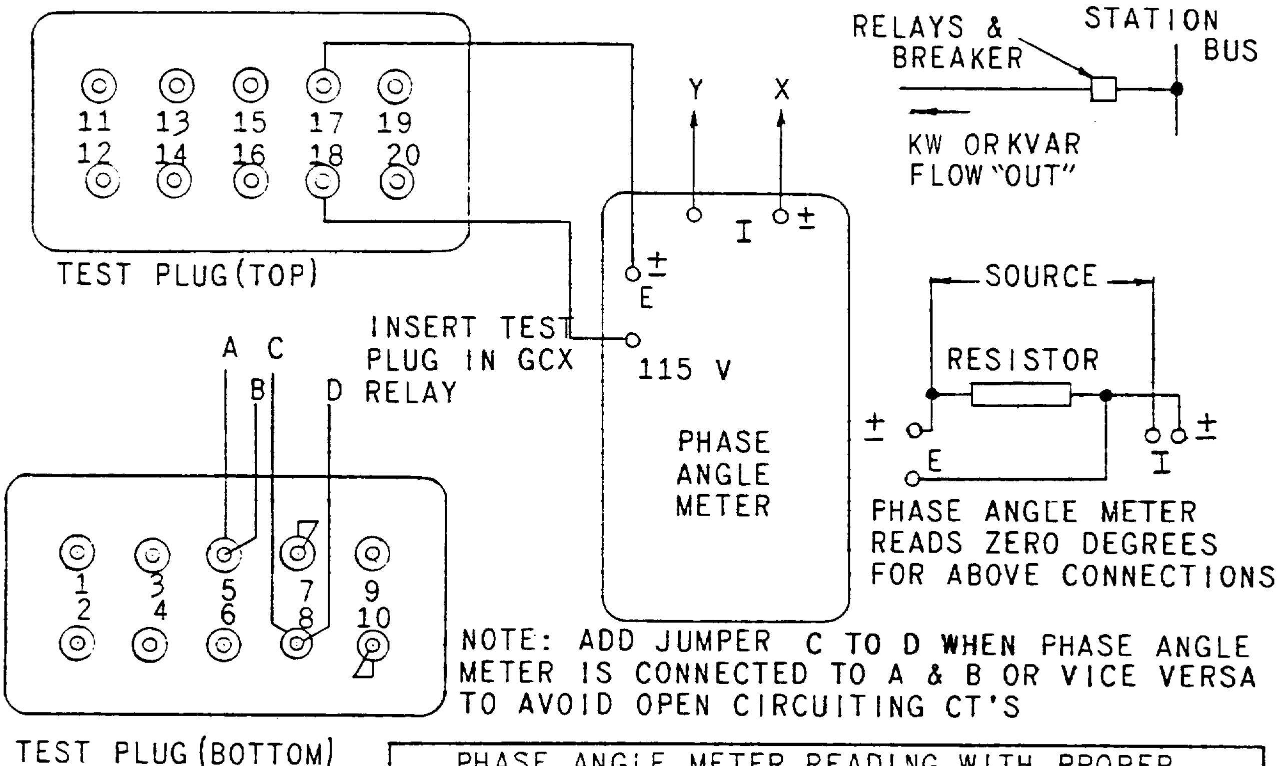


Figure 22 (0178A7148-0) Operating Time Curves for the 0.4 Ohm Short Reach GCX51 Relay. Voltage Before the Before the Fault is Zero Volts



	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 23 (0377A196-1) Test Connections for the Overall Test of the GCX51 Relays

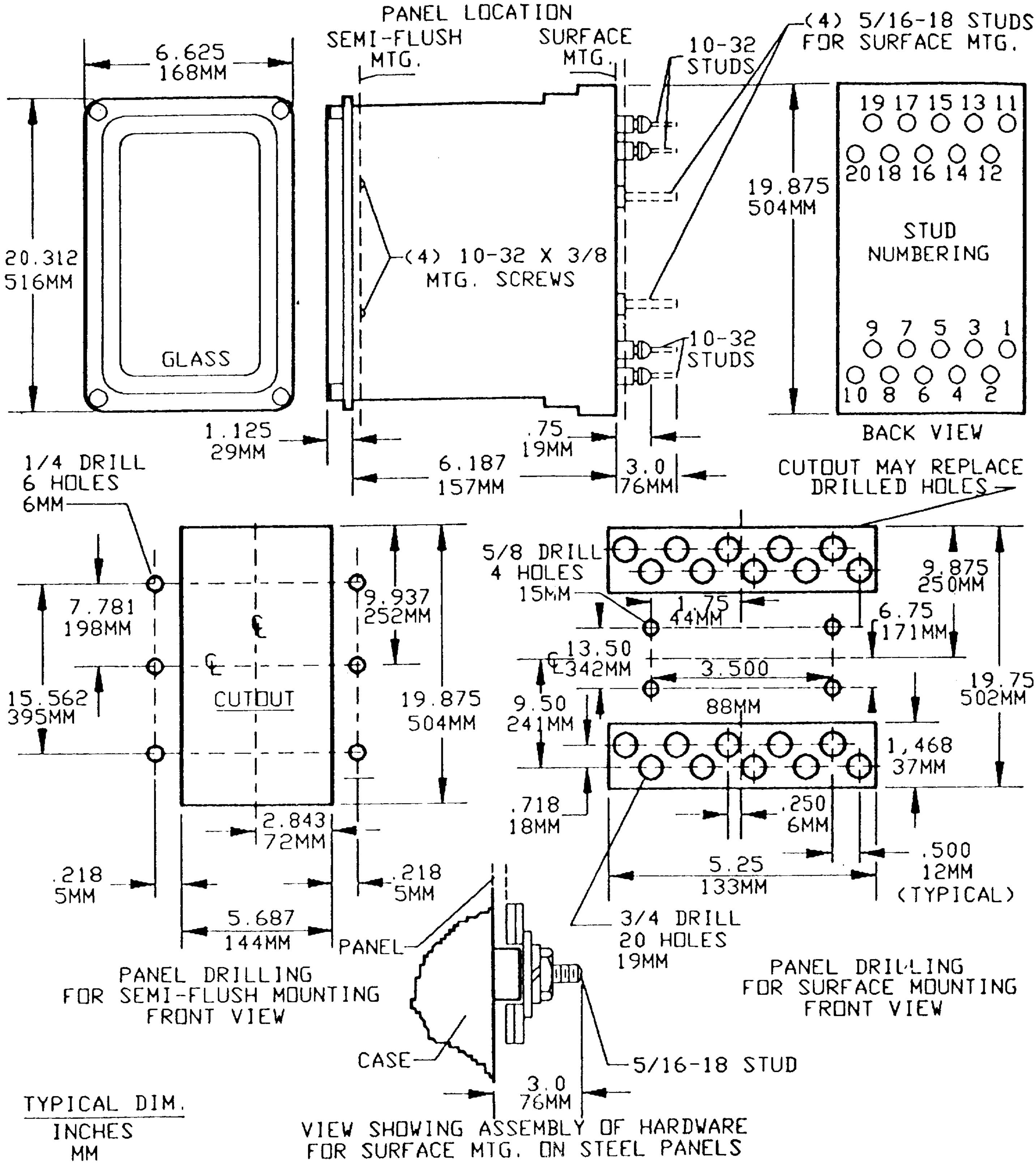


*Figure 24 (6209276 [4]) Outline and Panel Drilling for GCX51 Relays

* Indicates revision

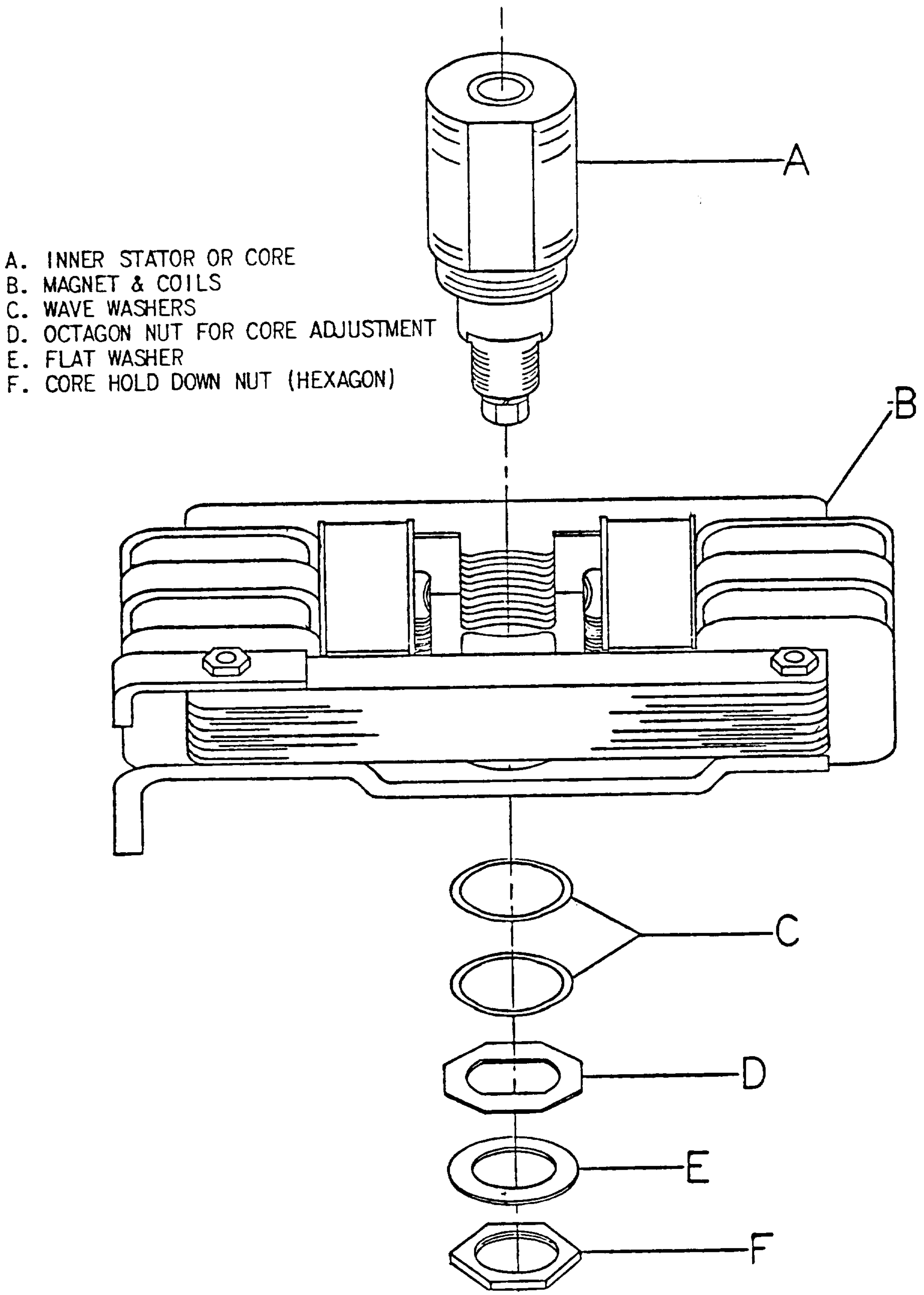


Figure 25 (0208A3583-0) Magnet and Coil Assembly - Four Pole Induction Cylinder Construction of the GCX51 Relay

APPENDIX I

When GCX51 phase relay applications are used, one relay provides 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 operate for three phase faults within the set reach.

The further limitation on the mho unit reach, mentioned in **APPLICATION AND CALCULATION OF SETTINGS**, 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.

Refer to the R-X diagram, Figure I-1. OL represents the protected circuit with 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, the reach setting of the mho unit must be limited. 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 (/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 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'3Ø supplied through the relay terminal in secondary amperes with the remote breaker open. Then,

$$X_S = \frac{67}{I'3\phi}$$

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.

The curves of Figure I-2 and I-3 have been computed to simplify the investigation. The family of curves for various line angles in Figure I-2 provides the means of determining the permissible M 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 provides 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 example:

Assume a transmission line having secondary impedance of 0.813 ohms at an angle of 80 degrees. For a 90 percent 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 degree 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 Z_{MO}/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 five, 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 M unit setting is 0.83 (6.7) or 5.57 ohms.

Since the curves in Figures I-2 and I-3 do not include margin, at least ten percent margin should be taken. Therefore, the maximum reach setting of the M unit for this example should be 5.57 - 0.56 = 5.01 ohms.

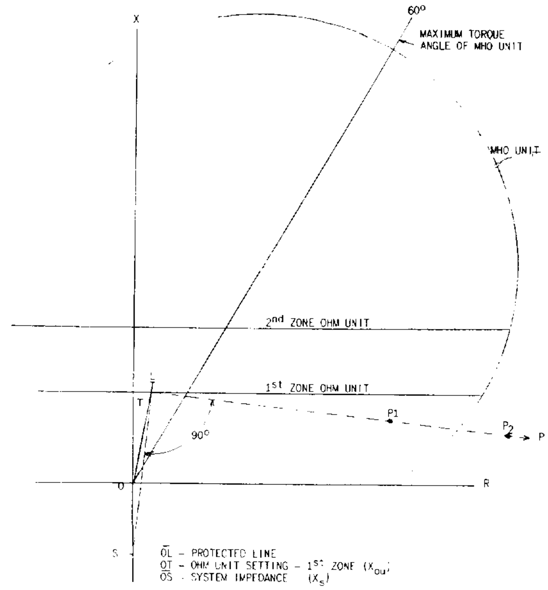


Figure I-1 (0178A8101-0) R-X Diagram Illustrating Response of GCX51 Relay to Phase to Phase Fault on Adjacent Phase Pair

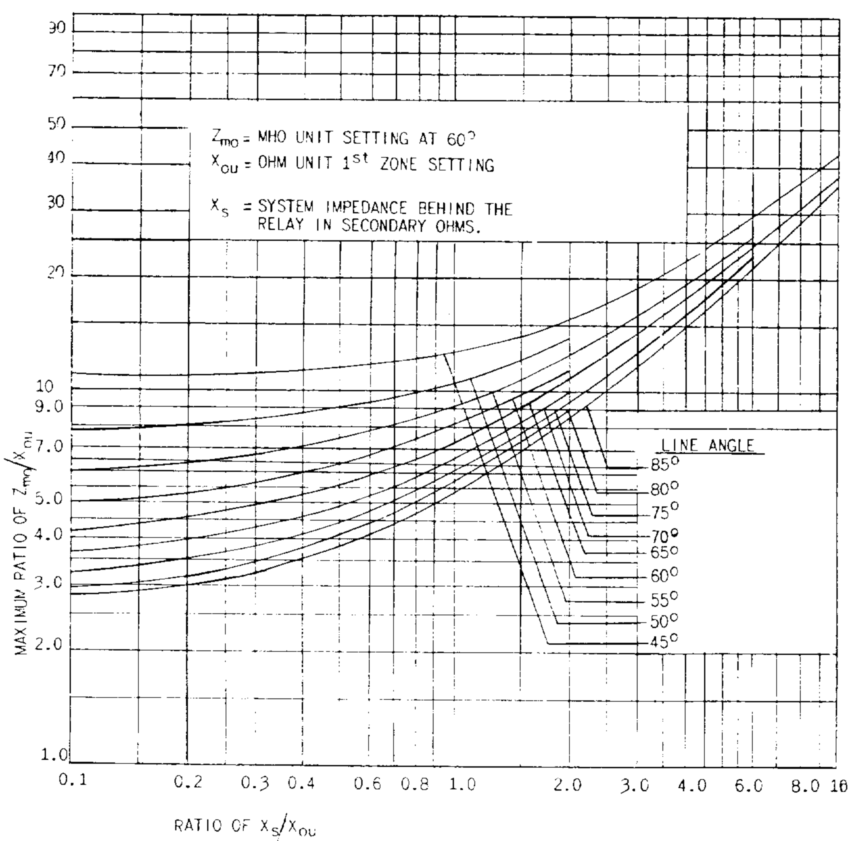


Figure I-2 (0178A8100-0) Curves for Determining Maximum Safe Setting of the Mho Unit in the GCX51 Relay

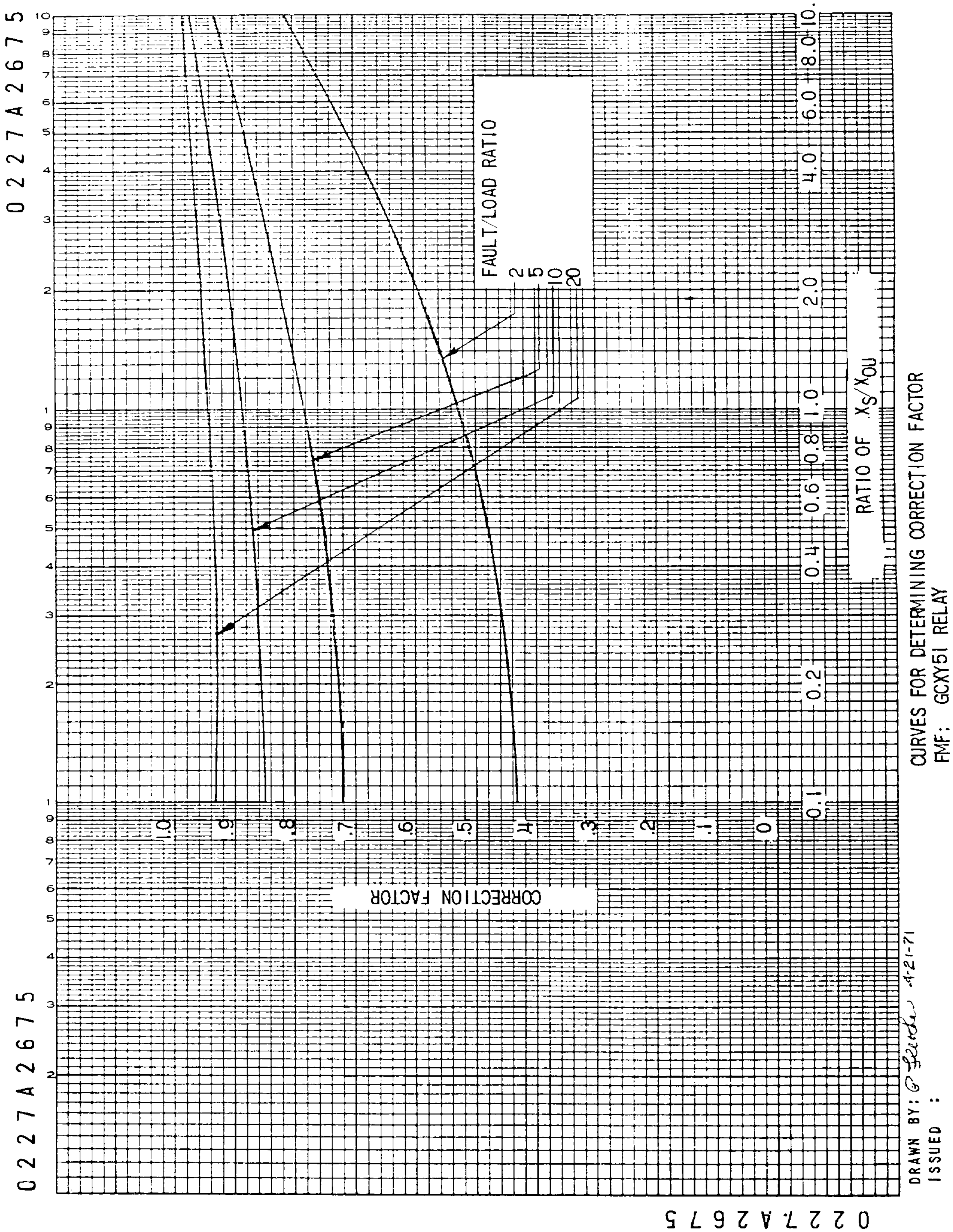


Figure I-3 (0227A2675-0) Curves for Determining the Correction Factor of the GCX51 Relay

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