INSTRUCTIONS

GEK- 27904A

REACTANCE DISTANCE RELAY

TYPE GCXY51A

GENERAL ELECTRIC

CONTENTS

FIG.1

Photo

Not Available At This Time

FIG. 2

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REACTANCE DISTANCE RELAY

TYPE GCXY51A

The Type GCXY51A relay is a single-phase, four-zone step distance relay for phase fault protection of transmission or sub-transmission lines. Two zones of distance measurement are provided by a unit having a reactance (or ohm) characteristic, in cooperation with a transfer auxiliary unit OX. A third zone is provided by a unit having a directional MHO characteristic, and a fourth zone is provided by a unit with an offset (optional) MHO characteristic.

APPLICATION

GENERAL

The Type GCXY51A relay can be applied in conjunction with a timer (either type RPM or SAM) in a variety of step distance schemes for the protection of transmission lines against all multi-phase faults. The relays are also applicable for multi-phase fault protection in directional comparison or line transferred tripping schemes.

The GCXY51A relay, because of the reactance characteristic available for first and second zone, is well suited for the protection of lines where arc resistance may present 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 length of the protected line gets shorter. It is for this reason that the reactance characteristic of the GCXY51A relay is well suited for the protection of relatively short transmission lines. The relay has a further advantage where the short, protected line section is followed by a relatively long adjacent line and backup of the entire adjacent line is desired. This feature is described in more detail in a following paragraph and in Appendix I.

TYPICAL APPLICATIONS

The elementary diagram in Figure 3 illustrates a typical application of the GCXY51A relay in a step distance scheme with directional comparison carrier. This scheme has been selected because it illustrates maximum utilization of all functions in the relay. Three GCXY51A relays plus a suitable timer, such as the RPM11D or SAM14B, are required at each terminal of the protected line. In addition ground relays, the necessary carrier auxiliary relays, and of course the carrier equipment would be required. The user is referred to Instructions GEK-7384 for complete information on the application of this and other relays in directional comparison carrier schemes. In the scheme shown in Figure 3, first zone is provided by the reactance unit O under the supervision of the directional mho unit M. The second zone, also with a reactance characteristic, is provided by the auxiliary unit OX which is picked up by the timer and which extends the reach of the reactance unit, as will be apparent from the a-c connections of Figure 3. Zone 3 is provided by the mho unit M via a contact of the timer. The M units would also provide the carrier stop function via carrier auxiliary units not shown on this diagram. Initiation of carrier is by means of the normally closed contacts of OM, which would be connected to operate for faults in the reverse direction, with offset. A "reverse third zone" function is also provided by means of the normally open OM contacts via the zone 3 contacts of the timer.

There are several possible variations of the scheme shown in Figure 3. For example, the relay is commonly used in straight step-distance applications without carrier. The arrangement of Figure 3A might be used, providing three forward zones and one offset reverse zone. On the OM unit could be connected to lock in the forward direction, either with or without offset. Probably a worse typical application would omit the OM function, thus providing two reactance and one mho zone in the forward direction.

In another variation the connections can be arranged to provide a reactance first zone with mho characteristics for zones 2 and 3. To accomplish this the connections to the OX unit could be omitted, the M contacts would be connected to trip through the zone 2 contact of the timer as well as supervising the zone 1 reactance unit, and the OM contacts would trip through the zone 3 timer contact. Offset would usually be omitted so that zone 3 would be directional mho.

Where a short line section is followed by a relatively long adjacent line out of the remote station, it may be advantageous to arrange the circuit so that the first and second zones have reactance characteristics with the mho unit M connected to supervise the unit but not connected to trip. Third zone backup would be provided by the OM units without offset. With this arrangement limitations on the permissible reach of the supervising M units will not interfere with the backup function. One such limitation is that the restraint taps of the supervising M units must not be set for less than 25 percent is proper coordination with the reactance unit contacts is to be realized. Another limitation in the reach setting of the M units results from the possibility that during a phase to phase fault it is possible for the mho and zone 1 reactance combination on an adjacent unfaulted phase pair to overreach. This overreach phenomenon is described in detail, and limitations on the M unit reach are defined, in Appendix I.

It will be noted in the section on RATINGS that the reactance units and directional mho units M each provide three basic minimum reach settings readily selected by means of tap links on 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 which will accommodate the required reach setting. For example if a 0.6 ohm zone 1 setting is required on the reactance unit, 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 restraint tap be set for less than 10 percent. And similarly if a 2.5 ohm reach is required for the MHO unit (M), the 2 ohm basic reach tap should be used rather than the 1.0 ohm tap. The MHO unit (M) restraint tap should not be set for less than 25 percent, and may be subject to further limitations as described in Appendix I.

The directional MHO unit M has been set at the factory to have an angle of maximum torque of 60 degrees. Although this can be adjusted up to 75 degrees, it is recommended that the 60 degree setting be retained in order to obtain maximum accommodation of arc resistance for first zone faults close to the relay location.

Table I shows the minimum current required in the relay for a three phase fault at the remote end of the protected line to insure positive operation of the relay for any multi-phase fault on the protected line. These are the current levels which insure reliable operation of the overall scheme and do not necessarily indicate the minimum current which would operate the individual units. The minimum three phase fault current requirements for the directional mho units (M) can be obtained from the "bullet-shaped" curves in Figure 18. The M units will operate if the point representing the impedance to the fault (in percent of reach setting) and the three-phase fault current plots to the right of the curve representing the particular restraint tap setting. However, the best overall operation will be realized if the current in the relay for a three phase fault at the remote bus exceeds the values in Table I.

TABLE I

BASIC TAP SETTING	MIN. 3-PHASE FAULT CURRENT (SEC. AMPS)
0.25	6 Amperes
0.5	5 " "
1.0	4 " "

The MHO unit identified as OM has a fixed basic minimum reach (typically 3 ohms) and a fixed angle of maximum torque of 75 degrees. It is not recommended that its restraint tap be set for less than 10 percent. A tap is provided so that the unit can be set for either zero offset for a 0.5 ohm offset. When this circuit is used for carrier start in a directional comparison scheme, where it is essential that it pick up and remain picked up on a zero voltage fault on the bus directly behind the relay location, the 0.5 ohm offset must be used, and the minimum 3-phase fault current supplied over the line to this fault must be at least 2 amperes (secondary). The unit must of course be connected to look away from the protected line.

When the relay is being used in a step distance application, the OM unit may be used with or without offset, and looking either into the protected line section or away from it, as desired for the particular situation. The "bullet-shaped" curves in Figures 19 and 20 show the dynamic and/or steady state three phase fault current requirements for the OM unit, either with or without offset.

Since they have no significant transient overreach, the first zone reactance units of the GCXY51 relays may be set for 90 percent of the distance to the nearest remote terminal. The second-zone reactance step when used should typically be set to reach at least 110 percent of the distance to be farthest remote terminal including effects of infeed if present. The supervising mho units (M) must be set to reach sufficiently farther than the zone 2 reactance step to accomodate arc resistance at the zone 2 balance point. The setting of the M units must be within the limitations defined in Appendix I. These limitations are most apt to be restricting if the M unit is used to provide backup protection for faults on a remote line. Its restraint tap must not be set for less than 25 percent regardless of limitations determined from Appendix I.

The setting of the OM unit depends on the mode of application. If the unit is used to start carrier in a directional comparison blocking scheme, it must outreach the carrier stop and tripping unit at the remote end of the line with margin. This, of course, is necessary to insure that blocking carrier will be transmitted for any external fault in back of the relay location which can result in operating of the M unit at the remote terminal. If the unit is used in a step distance scheme, looking into the protected line it should if possible be set to provide zone 3 backup protection for the line (or lines) out of the remote station. This may not always be practical when the effects of infeed at the remote bus are considered. The limitations on OM forward reach are the 10 percent minimum restraint tap previously noted and the obvious limitation that it must not operate on maximum expected load flow.

RATINGS

The Type GCXY51A relay covered by these instructions are available for 120 volts, 5 amperes, 60 Hz rating. The one-second current rating is 225 amperes. The D.C. 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 relay are given in Table II.

TABLE II

UNIT	(ØN OHMS) BASIC MIN. REACH	(ØN OHMS) RANGE	ANGLE OF MAX. TORQUE	(ØN OHMS) OFFSET
OM	3	3 - 30	60° - 75°*	0/0.5
M	1/2/3	1 - 12	60°* - 75°	------
OHM	0.25/0.5/1.0	0.25 - 10	90°	------

* Indicates the standard factory adjustment of the M and OM mho units. (Zone 3 + Zone 4)

The angle of maximum torque of the M unit can be adjusted up to 75° but its reach will increase to approximately 120 percent of its reach at the 60° setting.

The angle of maximum torque of the OM unit can be adjusted to 60° but its reach will decrease to approximately 80 percent of its reach at the 75° setting.

CONTACTS

The contacts of the GCXY51A relay when closed will momentarily carry 30 amperes D.C. However, the circuit breaker trip circuit must be opened by an auxiliary switch contact or some other suitable means since the relay contacts have no interrupting rating.

TARGET AND SEAL-IN

The burdens and ratings of the target seal-in unit is shown in Table III.

TABLE III

TARGET SEAL-IN UNIT			
	0.6 Amp Tap	2.0 Amp Tap	0.2 Amp Tap
Minimum operating	0.6 amps	2.0 amps	0.2 amps
Carry Continuously	1.5 amps	3.5 amps	0.4 amps
Carry 30 amps for	0.5 sec.	4 secs.	--------
Carry 10 amps for	4 secs.	30 secs.	0.1 sec.
DC Resistance	0.6 ohms	0.13 ohms	7 ohms
60 Cycle Impedance	6 ohms	0.53 ohms	52 ohms

OX TELEPHONE RELAY

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

TABLE IV

VOLTS	OHMS
48	800
125	2000
250	4000

OPERATING PRINCIPLES

OHM UNIT

The ohm unit of the GCXY51A relay is of the four pole inductor cylinder construction as shown in figure 5 and the schematic connections as shown in figure 6. The front and back poles are energized with delta currents, and 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 poles and the polarizing flux in the front and rear poles and at the balance point can be expressed by the following equation:

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

where: E = phase to phase voltage (E_{12})

I = delta current ($I_1 - I_2$)

Z_T = transfer impedance of transactor (design constant)

δ = 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.

MHO UNITS

The mho units of the GCXY51 are also of the four pole induction cylinder construction in which torque is produced by the interaction between the polarizing flux and the fluxes proportional to the restraining or operating quantities.

M UNIT

The schematic connections of the M unit are shown in Fig. 6. The two side poles, energized by phase-to-phase voltage, produce the polarizing flux. The flux in the front pole, which is energized by a percentage of the sane phase-to-phase voltage, interacts with the polarizing flux to produce restraint torque. The flux in the rear pole, which is energized by the two line currents associated with the same phase-to-phase voltage, interacts with the polarizing flux to produce operating torque.

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

$$\text{Torque} = 0 = EI \cos(\phi - \theta) - KE^2 \qquad (2)$$

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.

To prove that equation (2) defines a mho characteristic divide both sides by E^2 and transpose. The equation reduces to:

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

or:

$$Y \cos(\phi - \theta) = K \qquad (3)$$

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.

OM UNIT

The schematic connections of the OM unit are similar to those for the M unit in Fig. 6 except that a transactor TR-3 has been added with primary windings energized by the two line currents. The transactor secondary voltage can, if desired, be introduced in series with the voltage which energizes the side poles, resulting in a polarizing quantity proportional to $E + IZ_{T3}$, where Z_{T3} is the transfer impedance of transactor TR-3.

The inclusion of IZ_{T3} term in the polarizing quantity has the effect of enlarging the mho characteristic of the OM unit to include a portion of the system behind the relay location while retaining the forward reach of the unit.

CHARACTERISTICS

IMPEDANCE CHARACTERISTICS

The ohm unit, zone 1 and zone 2 and the mho units M (Zone 3) and OM (Zone 4) have impedance characteristics as represented on the R + X diagram of figure 7.

OHM UNIT

The OHM unit impedance characteristic when represented on the R-X diagram (Fig. 7) 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 which lies close to the R axis since load will be very near unity 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 (see Fig. 7) 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.

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 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:

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

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 GCXY51 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 GCXY51 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 the relay reach, and whether relay voltage prior to the fault is at rated 120 volts or is zero. 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.

TABLE V

OPERATING TIME CURVES FOR OHM UNIT

Relay	Basic Min. Reach (OHM Unit)	Volts Prior to Fault	Figure
Stand. Reach	0.25	120	8
	0.25	0	9
	0.5	120	10
	0.5	0	11
	1.0	120	12
	1.0	0	13

VERNIER ADJUSTMENT FOR LOW TAP SETTINGS

The input leads are normally set at 100 percent 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 percent the output tap setting would be 100/1.2 or 83.3 percent, which can be set within 0.4 percent.

However, if the desired first zone reach were 9.5 ohms, the output setting would be 100/9.5 or 10.55 percent. The nearest output tap would be 11 percent which is 4 percent off the desired value. To correct this, the input leads can be shifted to 95 percent, in which case the output setting would be 95/9.5 or 10 percent 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 in the internal connection diagram of Fig. 17. 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 Fig. 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 if the OHM unit and enables it to operate for faults in the second zone of transmission-line protection.

M UNIT

IMPEDANCE CHARACTERISTIC

The impedance characteristic of the M unit is shown in Fig. 14 for the 1 ohm basic minimum reach setting at a maximum torque angle of 60 degrees. This circle can be expanded by means of the M taps on the autotransformer tap block providing a range of up to 4/1, or by changing the basic minimum reach of the unit by means of the links on the rear of the M subassembly providing a total range of up to 12/1. The circle will always pass through the origin and have a diameter along the 60 degree impedance line equal to the ohmic reach of the unit as expressed by the following:

$$\text{Ohmic Reach} = \frac{(\text{Input Tap})\ Z_{min}}{\text{M Tap Setting } (\%)} \qquad (5)$$

where:

Z_{min} = basic min. phase to neutral ohmic reach of the unit.

Input Tap = input tap setting in percent (normally 100%)

The angle of maximum torque of the M unit can be adjusted up to 75° with resulting increase in reach to approximately 120 percent of its reach at 60° for the same tap setting. This is shown by the dotted characteristic in Fig. 14.

M OPERATING TIME

The operating time of the mho unit is determined by a number of factors such as the basic minimum reach setting of the unit, fault current magnitude, ratio of fault impedance to relay reach, and magnitude of relay voltage prior to the fault. The curves in Fig. 15 are for the condition of rated volts prior to the fault. Time curves are given for four ratios of fault impedance to relay reach setting. In all cases, the mho taps were in the 100 percent position and the angle of maximum torque was set at 60° lag.

UNDERREACH

At reduced voltage the ohmic value at which the mho unit will operate may be somewhat lower than the calculated value. This "pullback" or reduction in reach is shown in Figure 18 for the 1, 2, and 3 ohm basic minimum reach settings. The unit reach in percent of setting is plotted against the three-phase fault current for three ohmic reach tap settings. Note that the fault current scale changes with the basic minimum reach setting. The mho unit will operate for all points to the right of the curve. The steady-state curves of Fig. 18 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.

MEMORY ACTION

The dynamic curves of Fig. 18 illustrate the effect of memory action in the mho unit which maintains the polarizing flux for a few cycles following 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 Fig. 18. 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 of its setting. Fig. 18 shows that the mho unit, under static conditions, will not see a fault at zero percent of the relay setting regardless of the tap setting. However, under dynamic conditions when the memory action is effective, Fig. 18 shows that the mho unit with a 3 ohm basic minimum reach and 100% tap setting will operate if $I_{3\phi}$ is greater than 1.5 amperes.

The memory action will close the contact for only a short period of time and therefore, memory action cannot be relied on if the tripping is delayed. When the relay is used, as a second zone relay and tripping is delayed by the zone 2 setting of the type RPM relay, the static characteristic should be used. For this application to operate for nearby faults and there will be sufficient voltage to give tripping without depending on memory action.

TRANSIENT OVERREACH

Since the M unit is used to trip the circuit breaker through the contacts of a timing relay, or as the directional unit in a carrier current relaying scheme, it is not necessary to control the transient overreach since the M_2 unit will have correct directional action during transient conditions.

OM UNIT

IMPEDANCE CHARACTERISTIC

The OM unit is similar to the M unit except that a transactor has been included with primary windings which can be connected in series with each current operating coil, and a secondary winding connected in series with the polarizing circuit. The primary windings are connected to a terminal block so that the windings can be either inserted into or removed from the current operating circuit be means of links.

When the transactor primary windings are out of the circuit the OM impedance characteristic will be similar to the M characteristic except that the factory-set maximum torque angle is 75 degrees. This characteristic is represented by the solid circle in Fig. 16 which shows the 3-ohm basic minimum reach.

When the transactor primary is in the circuit, the transactor secondary output is added in series with the relay terminal voltage and the vector sum applied to the polarizing circuit. The effect of this is to enlarge the OM characteristic to include the origin of the R-X diagram while retaining the forward reach at its initial value, OA in Fig. 16. The resulting characteristic will be offset by approximately 0.5 ohms as shown by the dotted circle in the figure.

The forward ohmic reach of the unit along the 75 degree impedance line, OA in Fig. 16 can be increased by means of the OM taps on the autotransformer tap block, which provide a range of 10/1:

$$\text{Ohmic Reach} = \frac{(\text{Input Tap})\ Z_{min}}{\text{OM Tap Setting }(\%)} \qquad (6)$$

where:

Z_{min} = basic minimum phase to neutral ohmic reach of the unit (3 ohms unless otherwise stamped on the nameplate).

Input Tap = input tap setting in percent (normally 100%)

It is important to note that the ohmic reach as determined from equation (6) is always the distance along the 75 degree maximum torque line from the origin to the intercept with the circle, OA in Fig. 16 whether the circle passes through the origin or is offset. Changing the ohmic reach over the recommended 10/1 range will have little affect on the 0.5 ohm offset.

OM OPERATING TIME

The operating time curves for the OM unit are shown in Figs. 21 and 22. All curves in these figures are for the condition of rated volts prior to the fault with 100% restraint tap setting.

The curves in Fig. 21 show the average operating time of the unit, that is time to close the normally open contact with the unit connected for zero offset. These curves also apply for faults in the forward direction if the unit is connected for 0.5 ohm offset.

The curves in Fig. 22 show opening times of the normally closed contact, with the unit connected for 0.5 ohm offset, for faults in the direction of the reach setting (forward) and for faults in the direction of the offset (reverse). It will be noted that for equivalent conditions, that is for the same operating current and the same ratio of fault impedance to reach setting (or offset), the OM unit is faster for faults in the forward direction. This results from the strong initial "memory action" inherent in the unit which tends to sustain the polarizing flux for a few cycles following inception of the fault. For faults in the forward direction this produces a higher operating torque and hence faster operation.

UNDERREACH

At reduced voltage the ohmic value at which the OM unit will operate may be somewhat lower than the calculated value. This "pullback" or reduction in reach is shown in Figs. 19 and 20. The unit reach in percent of setting is plotted against the three-phase fault current for three ohmic reach tap settings. Note that the fault current scale changes with the basic minimum reach setting. The OM unit will operate for all points to the right of the curve. The steady-state curves of Figs. 19 and 20 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.

4. MEMORY ACTION

The dynamic curves of Figs. 19 and 20 illustrate the effect of memory action in the OM unit which maintains the polarizing flux for a few cycles following the inception of the fault. This memory action is particularly effective at low voltage levels where it enables the OM unit to operate for low fault currents. This can be most forcefully illustrated for a zero voltage fault by referring to Figs. 19 and 20. 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 of its setting. Figs. 19 amd 20 show that the mho unit, under static conditions, will not see a fault at zero percent of the relay setting regardless of the tap setting. However, under dynamic conditions when the memory action is effective, Fig. 19 shows that the mho unit with a 3 ohm basic miminum reach and 100% tap setting will operate if $I_{3\phi}$ is greater than 2 amperes.

The memory action will close the contact for only a short period of time and therefore, memory action cannot be relied on if the tripping is delayed. When the relay is used to trip the breaker through the contacts of a timing relay the static characteristic should be used. For this application the relay is not required to operate for nearby faults and there will be sufficient voltage to give tripping without depending on memory action.

5. TRANSIENT OVERREACH

Under transient conditions the OM unit has a tendency to close its contact momentarily for a fault impedance greater than its impedance setting. This tendency is called transient overreach and is a function of the degree of assymetry in the fault current wave, and the circuit angle (The angle of system from the point of the fault to the source of generation). For normal applications, transient overreach is of no significance since the OM unit does not perform a precise measuring function.

BURDENS

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

CURRENT CIRCUITS TABLE V

AMPS	HZ	R	X	P.F.	W.	V.A.
5	60	.34	.196	0.866	8.5	9.9

The potential burden will vary with the tap settings used for the ohm and mho units restraint circuits and can be calculated from the following formula. All potential burdens are at 120 volts and at 60 Hz.

A. OHM UNIT

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

B. M UNIT

$$VA = (e + Jf)\left[\frac{\text{No. 3 tap setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2 + (G + JH)$$

C. OM UNIT

$$VA = (K + JM)\left[\frac{\text{No. 4 tap setting (\%)}}{\text{Input Tap Setting (\%)}}\right]^2 + (N + JP)$$

The terms (a + Jb) (c + Jd) etc. represent the burdens of the ohm, M and OM potential circuits expressed in watts and vars with their restraint taps set on 100 percent. The values of these terms for 60 Hz relays are given in table VII.

TABLE VII

CIRCUIT	TERM WATTS & VARS	(WATTS ± J VARS)
OM Restraint	K + JM	4.6 + J 6.5
OM Polarizing	N + JP	9.1 - J 1.0
M Restraint	e + JF	5.2 + J 6.2
M Polarizing	G + JH	9.7 - J 1.5
Ohm Potential	A + Jb	15.0 + J 0

The data in table VI applies when the ohm, M and the OM unit tap leads are in the 100 percent restraint. The restraint burdens and the total burdens will decrease when the tap leads are set at less than 100 percent.

TABLE VI

CIRCUIT	R	JX	P.F.	WATTS	VA
OM Restraint	1025	+J1460	0.57	4.6	8.0
OM Polarizing	1540	-J162	0.99	9.1	9.2
M Restraint	1150	+J1370	0.64	5.2	8.1
M Polarizing	1440	-J217	0.99	9.7	9.8
Ohm Restraint	975	+J0	1.0	15.0	15.0
Total Relay	289	+J123	0.92	42.3	45.8

CALCULATION OF SETTINGS

The qualitative requirements which must be met by the settings of the four zones of protection in the GCXY51A relay have been described in the section on APPLICATION, and further details on directional comparison applications are given in GEK-7384.

Assume that it is desired to use GCXY51A relays to protect the two terminal, 5 mile, 69KV transmission line shown in figure 4.

CT Ratio = 600/5 = 120/1
PT Ratio = 69,000/115 = 600/1

$$Zsec = Zpri \left[\frac{\text{CT Ratio}}{\text{PT Ratio}}\right]$$

$$Zsec = 5(0.14 + j\ 0.8)\ \frac{120}{600}$$

$$= 0.14 + j\ 0.80$$

$$= 0.813\ \underline{/80^{0}}\ \text{ohms}$$

Use the 0.5 ohm basic minimum reach tap setting on the reactance unit. From the system fault study data determine the minimum secondary fault current at breaker #1 for a three-phase fault at bus B. And then determine the minimum secondary fault current at breaker #2 for a three-phase fault at bus A. As shown in Table I in APPLICATION, both these fault current values must exceed 5 amperes for the 0.5 ohm basic tap.

The restraint 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} = minimum ohms of reactance unit
X_L = desired reactance reach in secondary phase-to-neutral ohms

If it is assumed that the first zone will be set for 90 percent of the distance to the remote terminal, then:

$$X_L = 0.9\ (0.8) = 0.72 \text{ ohms}$$

$$X_{min} = 0.5 \text{ ohms}$$

Thus: $T = \frac{0.5}{0.72} \times 100 = 69.4$ percent

Since the result is not an integral number use the next higher #1 tap which will be 70 percent.

Assume that the second reactance step is to be used for zone 2. It must be set to reach beyond the remote terminal and as noted in APPLICATION is typically set to reach 110 percent of the protected line including affects of infeed at the remote bus. Assume that after due consideration it is found that zone 2 should be set for a reactance reach of 1.5 ohms.

The percent tap setting required to obtain this reach is determined from the same equation used for the first zone and since the same unit is used for both first and second reactance zones, the 0.5 ohm basic reach tap is common to both zones. Thus for the second zone.

$$T = \frac{0.5}{1.5} \times 100 = 33 \text{ percent}$$

This setting is made by means of the #2 tap leads.

The setting of the directional mho unit M will depend to a great extent its mode of application as discussed in the section on APPLICATION. Assume that it has been determined that the M unit should be set for a reach of 2.5 ohms at the line angle of 80 degrees and that the angle of maximum torque of the unit is 60 degrees. The percent restraint tap setting for such a reach is:

$$T = {}^{Zmin}/Z_L \times 100 \text{ Cos } (60^o - \emptyset)$$

where: T = Tap setting in percent

Zmin = Minimum reach of the M unit as selected by tap.

Z_L = Desired reach in secondary phase-to-neutral ohms at the line angle.

$\emptyset$ = Impedance angle of Z_L.

60^o = Angle of maximum torque of M.

For the desired reach of 2.5 ohms the 2.0 ohm basic tap would be used. Thus:

$$T = \frac{2.0}{2.5} \times 100 \text{ Cos } (60^o - 80^o)$$

$$T = 75.2 \text{ percent}$$

This setting of 75 percent would be made by means of the #3 tap leads. Note that the restraint tap of M must not be set for less than 25 percent. Also refer to Appendix I for possible further instructions on the reach setting of M.

The OM unit may be set to lock in either the forward or the reverse direction and it may be set with either zero ot 0.5 ohm offset. If it is to be set with zero offset, regardless of the direction in which it looks the required tap setting is given by the following equation:

$$T = \frac{Zmin}{Z_L} \times 100 \text{ Cos } (75^o - \emptyset)$$

where: T = #4 tap setting in percent

Zmin = Minimum reach of the OM unit (typically 3 ohms non-adjustable).

Z_L = Desired reach in secondary phase-to-neutral ohms at the line angle.

$\emptyset$ = Angle of impedance Z_L

75^o = Angle of maximum of OM.

Assume that it is desired to set this unit for a reach of 4.5 ohms phase-to-neutral at an angle of 80 degrees. The tap setting would be:

$$T = \frac{3}{4.5} \times 100 \cos (75^o - 80^o)$$

$$T = 66.7 \text{ percent.}$$

A restraint tap setting of 67 percent would be used and would be obtained by means of the #4 taps.

Consider now a case where the 0.5 ohm offset is desired, and that the same 4.5 ohms reach at 80 degrees is required. The addition of the 0.5 ohm offset will not change the forward reach of the unit at its angle of maximum torque, but it will effect the reach at other angles. Therefore it is suggested that a graphical approach be used in determining the restraint tap setting. Figure 29 illustrates how this is done.

First draw the R-X diagram and a line EC at an angle of 75 degrees passing through the origin. This is the maximum torque line of the OM unit. Now draw the impedance angle line OD at 80 degrees. On line OD, scale off a distance OP equal to 4.5 ohms. On line EC, scale off a distance OA equal to the 0.5 ohm offset of this unit. Now draw a circle with its center on line OC and passing through both points P and A. The desired tap setting for the OM unit may now be determined from the scaled off diameter OB of the circle.

$$T = \frac{300}{OB}$$

Where:

T = tap setting in percent

OB = secondary phase to neutral ohms

In the example the angle of maximum torque (75°) and the line angle (80°) are so nearly equal that the restraint tap of 67 percent determined in the preceding paragraphs for zero offset will apply here also. However, for cases where there is a significant difference between the line angle and angle of maximum torque of the relay, the graphical method will result in a different tap setting.

CONSTRUCTION

The type GCXY51 relays are assembled in a deep large size, double-ended (L2D) 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 connection plug which completes the circuits. The outer blocks attached to the case have the studs for the external connections and the inner blocks have the terminals for the internal connections.

Every circuit in the drawout case has an auxiliary brush, as shown in Fig. 23 to provide adequate overlap when the connecting plug is withdrawn or inserted. Some circuits are equipped with shorting bars (see internal connections in Fig. 17) and on those circuits, it is especially important that the auxiliary brush make contact as indicated in Fig. 23 with adequate pressure to prevent the opening of important interlocking circuits.

The relay mechanism is mounted in a steel framework called the cradle and is a complete unit with all leads 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. The target reset mechanism is a part of the cover assembly.

The relay case is suitable for either semi-flush or surface mounting on all panels up to 2 inches thick and appropriate hardware is available. However, panel thickness must be indicated on the relay order to insure that proper hardware will be included.

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

Figs. 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 which appear on the internal connection diagram in Fig. 17.

AUTOTRANSFORMER

The GCXY51A relay uses a single (restraint) reach transformer mounted on the right side, front view of the relay. The taps on the lower part of the transformer can be adjusted in 10% steps while the upper portion can be adjusted in 1% steps. The unit zone leads are identified on the barrier strip between the units and the transformer block along with the percent taps.

In order to test the transformer electrically, put 100 volts at rated frequency to studs 17 and 18 and read with a high impedance voltmeter from 0 at the center of the transformer block to each tap. They should read tap value + - 1 percent.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to insure 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 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 physical damage, and that all screws are tight.

MECHANICAL INSPECTION

It is recommended that the mechanical adjustments in Table VIII be checked.

There should not be any noticable friction in the rotating structure of the units.

Check that the control springs are not deformed and the spring convolutions do not touch each other.

With the relay leveled in the upright position, the contacts of all 3 units must be open. The moving contacts should rest against the backstops.

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.

Check the location of the contact brushes on the cradle and case blocks against the internal connection diagram. (Figure 17)

INSTALLATION PROCEDURE

LOCATION

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

MOUNTING

The relay should be mounted on a vertical surface. The case outline and panel drilling dimensions are shown in figure 24.

CONNECTIONS

The internal connections diagram for the GCXY51A relay is shown in figure 17. An elementary diagram of typical external connections is shown in figure 3 of this instruction book.

SERVICING
PHASE SHIFTER AND PHASE ANGLE METER

MECHANICAL ADJUSTMENTS

VIII

CHECK POINTS	OHM UNIT	M UNIT	OM UNIT
Shaft End Play	5 - 8 mils	10 - 15 mils	10 - 15 mils
Contact Gap	35 - 45 mils	18 - 22 mils	40 - 60 mils
Contact Wipe	3 - 6 mils	3 - 5 mils	3 - 5 mils

The shaft end play is adjusted by the upper pivot stud and locking nut. (Figure 5)

The contact gap is adjusted on the ohm and the M unit by the bakelite backstop. The OM unit is adjusted by shifting one or both of the stationary contacts.

The contact wipes are adjusted by the screw that is located near the center of the stationary contact.

ELECTRICAL TESTS

Connect the relay per the connections diagram shown in figure 25. Put lead A to stud 17, lead B to stud 18, lead C to stud 3 and lead D to stud 10. Jumper studs 4-5, 6-7 and 8-9.

The relay must be level and tested in its own case or equivalent test case. It should be preheated at rated volts with the restraint taps in 100% for at least 15 minutes. The relay will tend to under-reach by 3 or 4 percent when tested cold. Check figures 1 and 2 for the location of the adjustment components mentioned in the following text.

OHM UNIT CALIBRATION
Clutch Checks:

With zero voltage - short studs 17 and 18 at the relay studs.

Set the reach taps in the positions shown in table IX shown below. Apply current to the current circuits to check the clutch action.

The clutch is adjusted by a wrench that holds the bakelite piece above the damping ring and with another wrench either loosen or tighten the nut directly below the adjusting ring on the cup shaft.

TABLE IX

UNIT	RATING	TAP SETTING	CLUTCH SLIPS BETWEEN
Ohm	0.25/.5/1.0	0.5 ohm	34 to 44 amperes
M	1/2/3	3 ohm	35 to 55 amperes
OM	3	-	35 to 55 amperes

CONTROL SPRING ADJUSTMENT

With 120 volts, 5 amperes, set the phase angle meter at 90° lag or 270° lead. Remove the voltage at studs 17 and 18. Short studs 17 and 18 at the relay terminals and adjust the control spring to close the ohm unit contact at 0.5 to 0.8 amperes.

REACH AND ANGLE OF MAXIMUM TORQUE ADJUSTMENTS

The basic minimum reach of the ohm unit is controlled by rheostat R11, and its reach with arc resistance can be adjusted by means of R21. These adjustments are not independent of each other but will have an effect on each other.

To calibrate the ohm unit put the taps in 100% position and use the same connections as shown in figure 25. Set the reach tap in 0.5 ohm position.

1. Set the current at 5 amperes, voltage at 120 volts and adjust the phase shifter so the phase angle meter reads 90° lag or 270° lead depending on the properties of the test equipment used.

2. Set the current for the value shown in Table X for 90° lag. Reduce the voltage to the values shown under operating point. The ohm unit should close its contact at that voltage. R11 is used for the adjustment of this setting.

3. Adjust the phase angle meter to read 45° lag (315° lead) and check the voltage pick up of the ohm unit for this phase angle. R21 is used for this adjustment. Keep the current constant for both of these adjustments.

4. Cross adjust paragraphs 2 and 3 until both adjustments are in calibration without any further adjustments of R11 and R21.

5. Place the reach taps in the 0.25 ohm tap and check according to the current and voltage conditions in Table X to check this reach tap. The adjustment for this tap is an adjustment of the core. See figure 26 for the schematic breakdown of the core and its associated parts. The position of the core is adjusted with a special wrench (Cat. No. 0178A9455PT1) without having to loosen any parts of the core locking mechanism. Therefore, adjust the core to get the unit tap in calibration as in table X. If the core was adjusted, cross adjust paragraphs 2, 3, 4 and 5 until the unit is in test limits without any further adjustments of R11, R21 or the core.

6. Put the tap in the 1 ohm position and check its reach according to table X. There isn't any adjustment for this tap but its accuracy is a resultant of the accuracy performed in the adjustments of the other two taps.

7. Recheck the clutch adjustments and spring windup previously described.

TABLE X

BASIC MINIMUM REACH SETTINGS	NO. 1 TAP SETTING	SET CURRENT AT	OPERATING VOLTAGE I LAGS V BY	
			90^0	45^0
0.25 ohm	100%	15 amps	7.5 volts	10.6 volts
0.5 ohm	100%	10 amps	10 volts	14.1 volts
1.0 ohm	100%	10 amps	20 volts	28.3 volts

The voltage pickups can be acceptable if they are within + - 3% of the value shown in Table X.

M UNIT (MIDDLE) CALIBRATION

With the same connections as in figure 25, calibrate the M unit per the following procedure. Check figure 2 for the link reach setting.

A. DIRECTIONAL TEST:

Set the moving contact (by means of the control spring adjustor), so that it floats between the stationary contact and the stop.

Set I = 5 amperes and V_{17-18} = 120 volts

Adjust the phase shifter so that the phase angle meter reads 60^0 (I lagging V by 60^0) or 300^0 lead (I leading E).

Set V_{17-18} = 0 volts, (Short 17-18). Increase I from 0 to 60 amperes and adjust the core so that the unit contacts develop slight opening torque. Check figure 26 for core construction. Use the special wrench Cat. No. 0178A9455 for this adjustment.

Now set V_{17-18} = 1.5 volts and adjust the control spring to get pickup at 2.13 - 2.36 amperes. Hold V_{17-18} = 1.5 volts and increase the current from 2.36 to 60 amperes the unit contacts should remain closed for the entire current range.

B. ANGLE OF MAXIMUM TORQUE - 2 OHM TAP

1. Apply 60 volts and 20 amperes to the relay and make sure that angle of maximum torque can be adjusted to 75 degrees lag or more by means of R22 (set R12 at maximum.)

2. With the same current and voltage adjust R22 to give a maximum torque angle of 60 degrees (300^0 on phase angle meter).

$$\text{Angle of maximum torque} = \frac{\angle\text{min torque} + \angle\ \text{min. torque}}{2}$$

C. PICK UP - 2 OHM TAP

1. Apply 60 volts and 15 amps at an angle of 300 degrees on the phase angle meter and adjust R12 until the contacts just close.

2. Repeat steps B2 and C1 until no further adjustment is required and the current at pick-up is 14.7 to 15.3 amperes.

D. REPEAT TEST A (DIRECTIONAL TEST)

If unit fails to meet the specified limits readjust the CORE AND CONTROL SPRING.

E. REPEAT TEST B (CALIBRATION)

If readjustment of core or control spring was required in (C) above the unit must be recalibrated.

F. CHECK PICKUP AT 1.0 AND 3.0 OHM TAPS

Make settings shown on table below and check the pickup current.

SET A & B LINKS TO POSITION A	B	SET Ø / -METER TO READ LAG	SET V_{17-18}	PICKUP CURRENT AMPERES
1	0	60^{o}	40	19.4 - 20.6
1	2	60^{o}	60	9.7 - 10.3

G. CLUTCH CHECK

M voltage taps open. (No. tap leads on auto transformer)

M current taps A and B set to positions 1 and 2 respectively.

V_{17-18} = 120 volts

Clutch should slip between 35-55 amperes. (Current lagging voltage by 60^{o}).

Place M2 taps on 100%. Open current circuit. Check that clutch does not slip with 120 volts applied to the relay.

OM UNIT CALIBRATION

Use same connections as for M unit.

A. DIRECTIONAL TEST

Set the moving contact, (by means of the control spring adjustor), so that it floats between the stationary contacts.

Set 5 amperes and V_{17-18} = 120 volts

Adjust the phase shifter so that the phase angle meter reads 75^{0} (I lagging V by 75^{0} or 285^{0} lead (I leading E).

Set V_{17-18} = 0 volts (Short 17-18).
Increase I from 0 to 60 amperes and adjust the core so that the unit contacts develop slight opening torque.

Now set V_{17-18} = 4 volts and adjust the control spring to get pickup at 1.33 - 1.47 amperes.

Hold V_{17-18} = 4 volts and increase the current from 1.47 to 60 amperes, the unit contacts should remain closed for the entire current range.

B. ANGLE OF MAXIMUM TORQUE

1. Apply 90 volts and 20 amperes to the relay and make sure that angle of maximum torque can be adjusted to 60 degrees or less by means of R23 (Set R13 at maximum).

2. With same current and voltage adjust R23 to give a maximum torque angle of 75^o (I lag E) or 285^o (I lead E).

C. PICK-UP

1. Apply 90 volts and 15 amperes at an angle of 75^o lag on the phase angle meter and adjust R13 until the contacts just close.

2. Repeat steps B2 and C1 until no further adjustment is required and the current at pick-up is 14.7 - 15.3 amperes.

D. REPEAT TEST A (DIRECTIONAL TEST)

If unit fails to meet the specified limits readjust the CORE & CONTROL SPRING.

E. REPEAT TEST B (CALIBRATION)

If readjustment of core or control spring was required in (c) above the unit must be recalibrated.

F. CHECK OFFSET (Figure 2 for offset link)

1. Set offset links to position IN, de-energize potential circuit and short studs 17-18. Increase the current slowly in OM operating circuit until the left hand contact just closes. This should occur between 1.5-1.9 amperes.

2. Set phase angle meter to read 255^o lag. Set V_{17-18} = 20 volts. Increase the current slowly until the unit left hand contacts just close. The unit contacts should close at 17-23 amperes.

G. CLUTCH CHECK

OM voltage taps open (No. 4 leads on the autotransformer)

Offset - OUT

V_{17-18} - 120 volts.

Clutch should slip between 35-55 amperes. (Current lagging voltage by 75^o.)

Place OM Restraint Taps on 100%. Open current circuit. Check that clutch does not slip with 120 volts applied to the relay.

H. HIPOT

The relay should be hipotential tested at 1850 volts from all studs to ground and between all circuit combinations to insure that any component in the relay is not grounded to the case or shorted to each other.

X AND R TEST PROCEDURE

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 pickup at the settings which have been made for a particular line section.

To eliminate the errors which may result from instrument inaccuracies and to permit testing the OHM and MHO units from a single-phase A-C test source, the test circuit shown in schematic form in Fig. 27 is recommended. In this figure 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 percent and 1 percent 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.

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 Fig. 28. These connections of the test box and other equipment are similar to the schematic connections shown in Fig. 27 except that the Type XLA test plug connections are now included.

Use of the source impedance $R_S + jX_S$, simulating the conditions which 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 the phase to phase voltage through the impedance of each of the involved phases. In the test circuit, the line impedance, Z_L, is in effect the sum of the impedance of each of the phase conductors and must be so arranged in order to be equivalent to the actual fault condition. Since the impedance of each phase must be used to make up the line impedance in the test circuit, its value will be twice that of the phase-to-neutral relay reach.

The per cent tap of the test box autotransformer, which should cause the OHM unit to just close its contacts with the fault switch closed, is given by:

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

For this test the value of R_L may be made zero since the OHM unit responds only to a reactance quantity. The load box, however, may be adjusted to give a fault current of approximately 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 percent 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 per cent tap of the test box autotransformer at which the OHM unit contact will just close can be calculated as follows:

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

The OHM unit should therefore theoretically close its contact with the test box autotransformer taps set at 68 percent and remain open with the taps at 69 percent. A range of 67 to 70 percent 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 Fig. 28. This resistance R_L should be non-indictive 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.

The adjustments if necessary are as follows:

X_L only - Adjust R-11
$X_L + R_L$ - Adjust R-21

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 19 and 20 (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, depending on the zone 2 test restraint lead tap setting.

TESTING THE MHO UNIT

The MHO unit is tested in a manner very similar to the OHM unit above, the major difference being in the manner in which the test box autotransformer per cent tap setting for pickup is determined. This difference results from the fact that unlike the OHM unit, the impedance 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, for the M unit and 75° for the OM unit.

Since the reactance of the test reactor may be very accurately determined from its calibration curve, it is desirable to check relay pickup with the fault reactor alone, due account being taken of the angular difference between the line reactance, X_L, and relay angle of maximum reach. As in the case of the OHM unit, the line reactance, X_L, selected should be the test reactor tap nearest above twice the MHO unit reach with account being taken of the difference in angle of the test reactor tap impedance and the relay angle of maximum reach. Therefore, twice the relay reach at the angle of the test reactor impedance is shown by the following formula:

$$2Z_{Relay} = 2\left[\frac{Z_{min}}{E^2\ Tap}\right] \cos\ (\emptyset-\theta)$$

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:

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

As an illustration of the above 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 88 percent, 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 $\emptyset$ of the test reactor impedance is 80°. Based on this assumption, twice the relay reach at the angle of the test reactor will be:

$$2Z_{Relay} = 2\left[\frac{2.5 \times 100}{86}\right]\ \cos\ (80-60)$$
$$= 5.6 \text{ ohms}$$

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 degrees. Table XI shows the angles for reach of the reactor taps.

TABLE XI

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	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 degrees. Therefore:

$$2Z_{Relay} = 2 \left[\frac{2.5 \times 100}{86} \right] \cos (86-60)$$

$$= 5.22 \text{ ohms}$$

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 degrees, the impedance of this tap may be calculated as follows:

$$Z_L = \frac{X_L}{\cos 4^o} = \frac{6.2}{.9976}$$

$$= 6.23 \text{ ohms}$$

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 degrees and 30 degrees respectively will be available for checking the MHO-unit reach at the 60 degree and 30 degree positions. The MHO unit ohmic reach at the zero degree position may be checked by using the calibrated test resistor alone 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:

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

where:

θ = 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 which affect the accuracy of the results. First, when checking the MHO unit at angles of more than 30 degrees off the maximum reach position, the error becomes relatively large with phase angle error. This is apparent from Fig. 13 where it is seen, for example, at the zero-degree position that a two or three degree error in phase angle will cause a considerable apparent error in reach. Secondly, the effect of the control spring should be considered since the MHO unit can only have a perfectly circular characteristic when the control spring torque is negligible. For any normal level of polarizing voltage, the control spring may be neglected but in testing the unit as indicated above it may be necessary to reduce the test-box autotransformer tap setting to a point where the voltage supplied to the unit may be relatively low. This reduces the torque level since the polarizing as well as the restraint will be low with the result being that the control spring torque will no longer be negligible. The result of the control spring at low polarizing voltages is to cause the reach of the MHO unit to be somewhat reduced.

In order to see the 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

Fig. 7. It is obvious that the apparent errors in reach, resulting from phase angle error at angles well off the minimum 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. 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 or fourth 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 test-box circuit as shown in Fig. 28. 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 percent 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.

OTHER CHECKS AND TESTS

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

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 will pick at 80 percent of nominal rated voltage, as determined by the link position, by applying a variable DC voltage between studs 19 and 20.

Check that the target seal-in unit is operating at tap value. This can be checked by means of the connections in Fig. 17 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 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.

ELECTRICAL TESTS

DRAWOUT RELAYS GENERAL

Since all drawout relays in service operate in their case, it is recommended that they be tested in their case or an equivalent steel case. In this way any magnetic effects of the enclosure will be accurately duplicated during testing. A relay may be tested without removing it from the panel by using a 12XLA13A test plug. This plug makes connections only with the relay and does not disturb any shorting bars in the case. Of course, the 12XLA12A test plug may also be used. Although this test plug allows greater testing flexibility, it also requires C.T. shorting jumpers and the exercise of greater care since connections are made to both the relay and the external circuitry.

POWER REQUIREMENTS GENERAL

All alternating current operated devices are affected by frequency. Since non-sinusoidal waveforms can be analyzed as a fundamental frequency plus harmonics of the fundamental frequency, it follows that alternating current devices (relays) will be affected by the applied waveform.

Therefore, in order to properly test alternating current relays it is essential to use a sine wave of current and/or voltage. The purity of the sine wave (i.e. its freedom from harmonics) cannot be expressed as a finite number for any particular relay, however, any relay using tuned circuits, R-L or RC networks, or saturating electromagnets (such as time overcurrent relays) would be essentially affected by non-sinusoidal wave forms.

Similarly, relays requiring dc control power should be tested using dc and not full wave rectified power. Unless the rectified supply is well filtered, many relays will not operate properly due to the dips in the rectified power. Zener diodes, for example, can turn off during these dips. As a general rule the dc source should not contain more than 5% ripple.

RECEIVING, HANDLING AND STORAGE

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

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

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

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 relay contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface resembling in effect a superfine file. The polishing action is so delicate that no scratches are left, yet it will clean off any corrosion throughly and rapidly. Its flexibility 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.

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 of the part wanted, and the complete model number of the relay for which the part is required.

APPENDIX

In the application of GCXY51A 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 problem of "overreaching" 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 cause the trouble.

Referring to the R-X diagram of Fig. 30, 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 TP_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 TP_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 Fig. 30 and with everything plotted in terms of secondary ohms, the secondary impedance TP is equal to $(\sqrt{3})(\overline{ST})$, where $\overline{ST}$ is the vector sum of the system impedance behind therelay $(\overline{OS})$ plus the impedance $(\overline{OT})$ 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 closed.

Then, $X_S = \frac{67}{I'_{3\emptyset}}$

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

In order to simplify the investigation the curves of Figure 31 and 32 have been computed. The family of curves for various line angles in Fig. 31 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 31 are on the basis of no load flow in the protected line. Load flow into the protected line at the relay location tends to agravate the situation represented by the plot in Figure 31. In other words with load present the permissible ratio of Z_{MO}/X_{OU} will be less than the curves in Figure 31 indicate. The family of curves in Figure 32 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 31 and 32 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 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 31 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 32. 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 M unit setting is thus 0.83(6.7) or 5.57 ohms.

Since the curves in Figures 31 and 32 do not include margin, it is suggested that at least 10 percent margin be taken. Therefore the maximum reach setting of the M unit for this example would be 5.57 - 0.56 = 5.01 ohms.

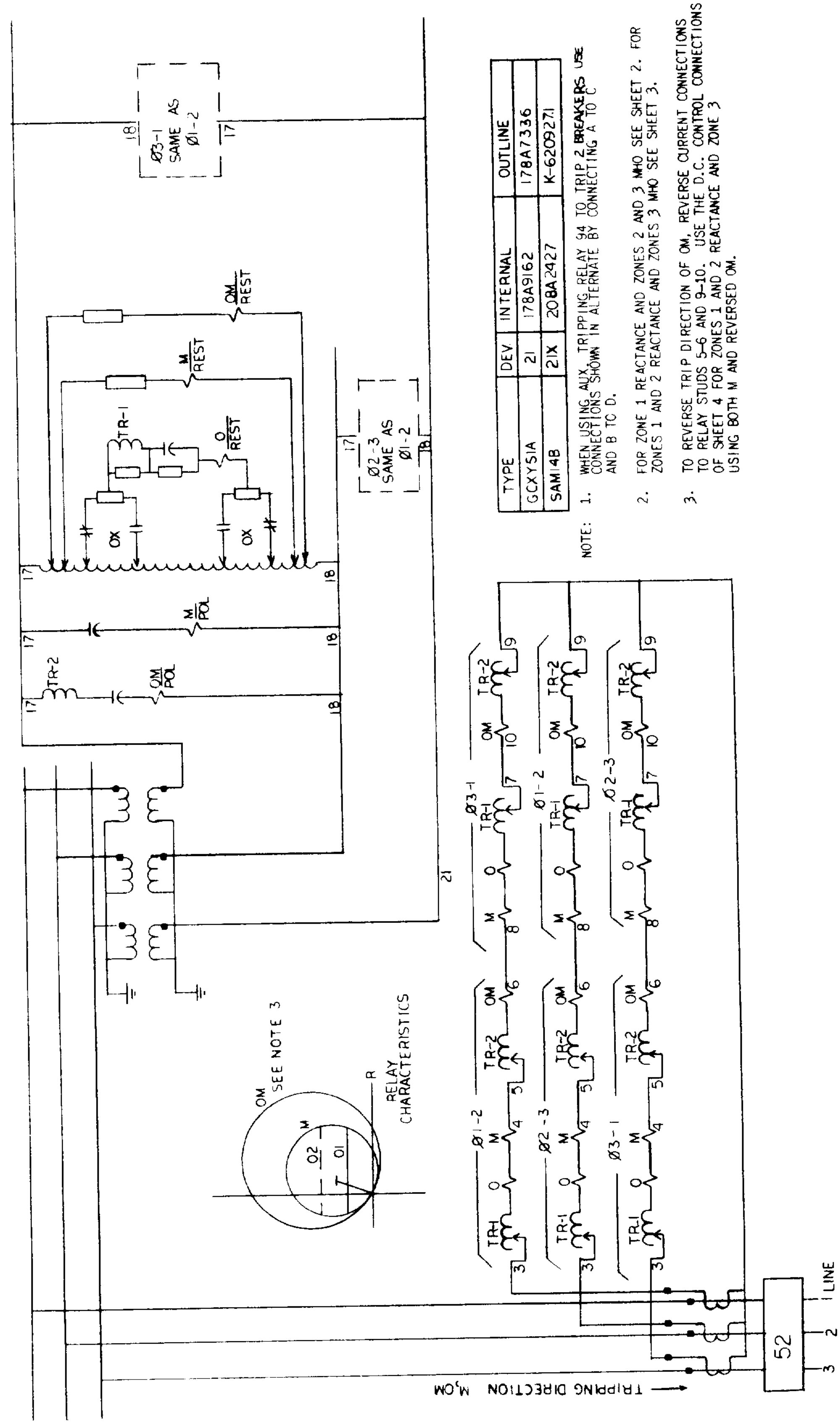


FIG. 3 (0165B2333-0) Sh. 1 Elementary Diagram For Step Distance Protection For Transmission Lines

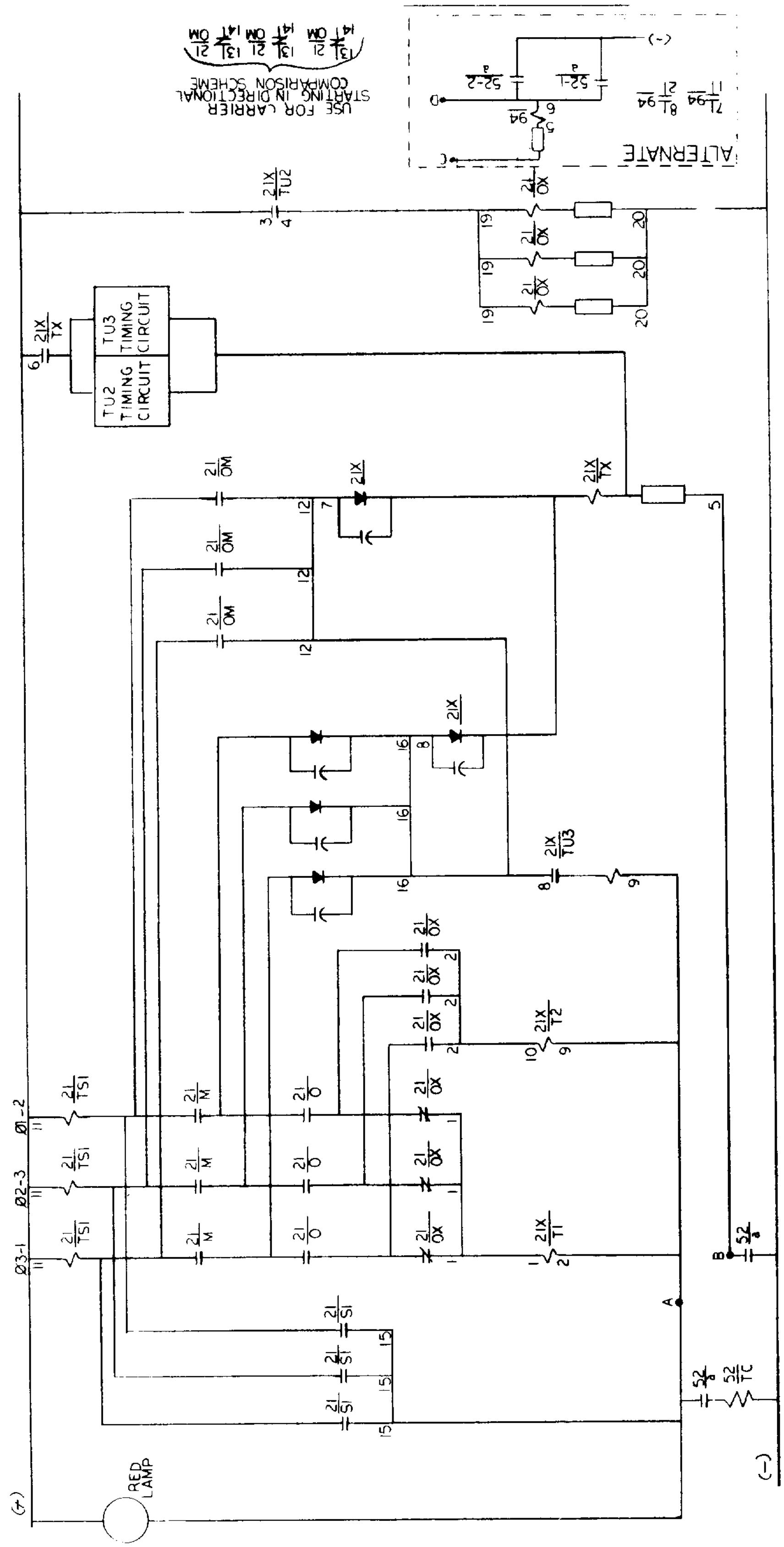


FIG. 3A (0165B2333-0) Sh. 4 Elementary Diagram For Step Distance Protection For Transmission Lines

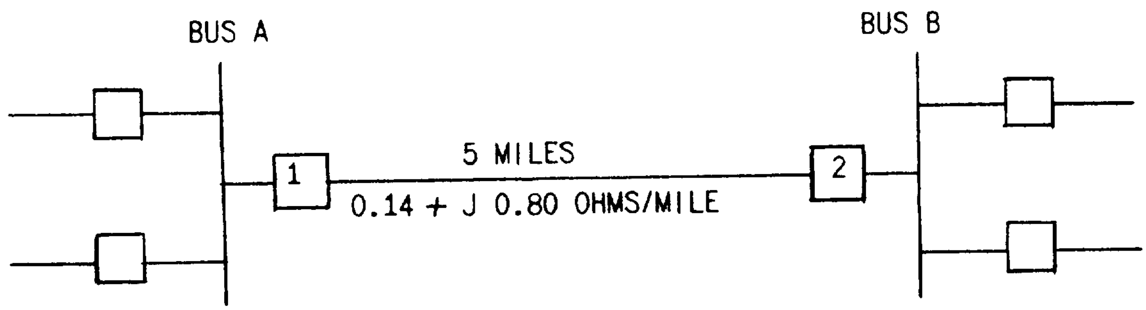


FIG. 4 (0165A7715-0) Typical Transmission Line Diagram

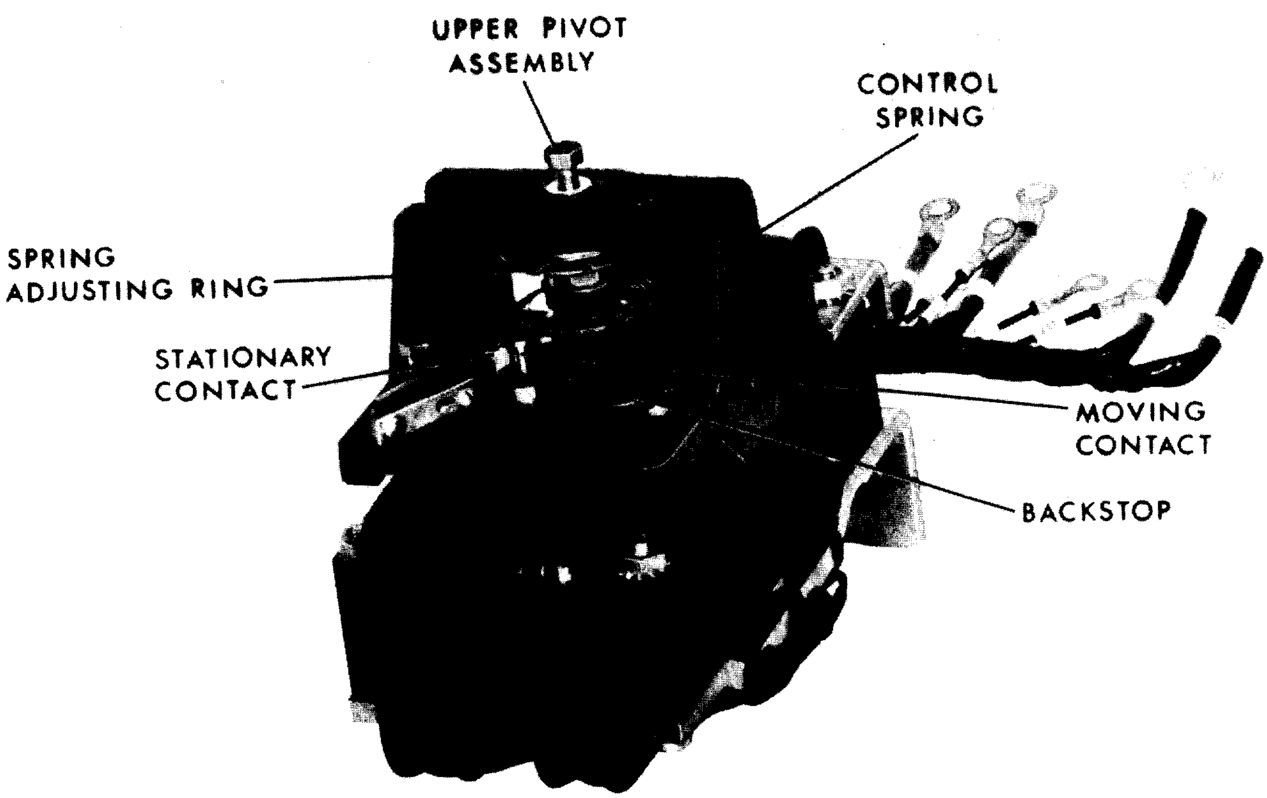


FIG. 5 (8034958) 4 Pole Induction Cylinder Unit - Mho And Ohm

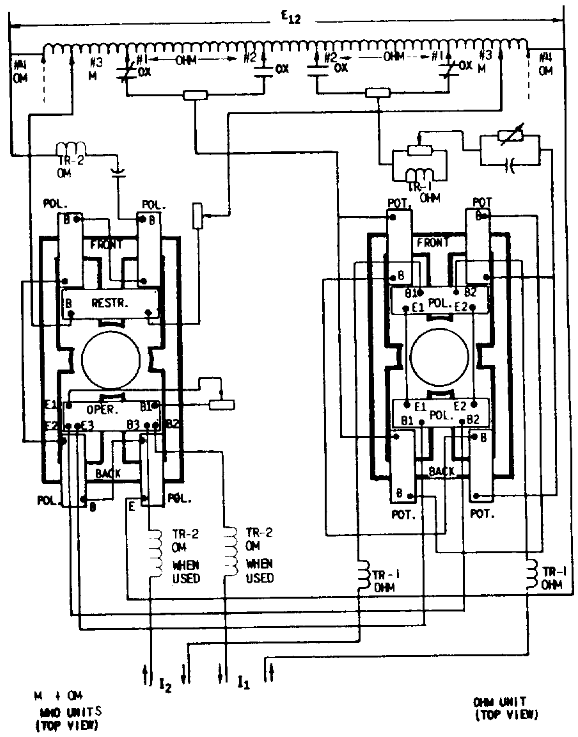


FIG. 6 (0183B2315-0) Schematic Diagram Of The Mho And Ohm Units Used In GCXY51A Relays

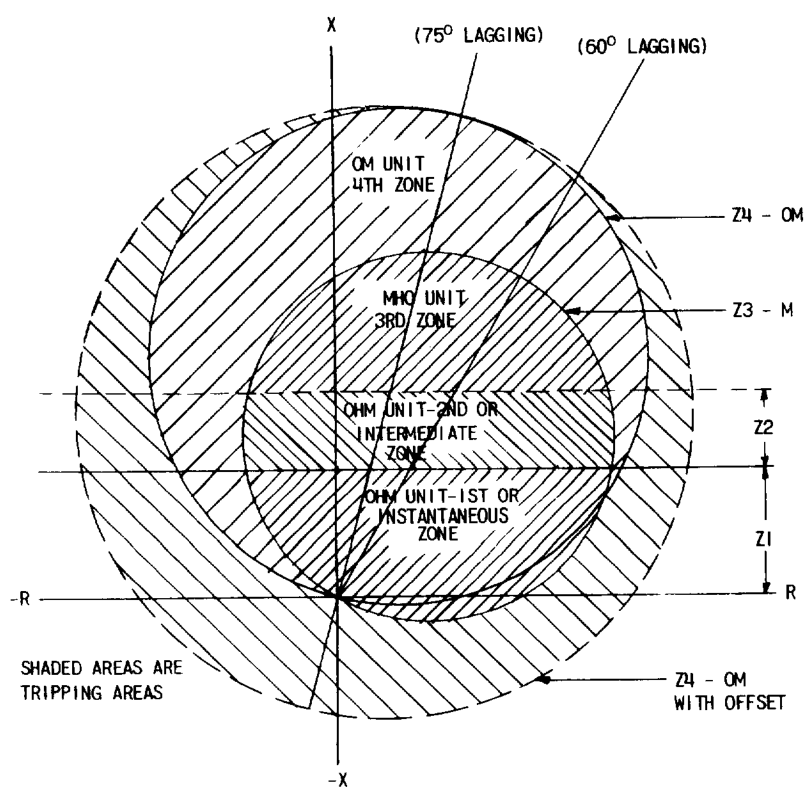


FIG. 7 (0227A7167-0) Characteristics Of The Mho And Ohm Units On An Impedance Diagram

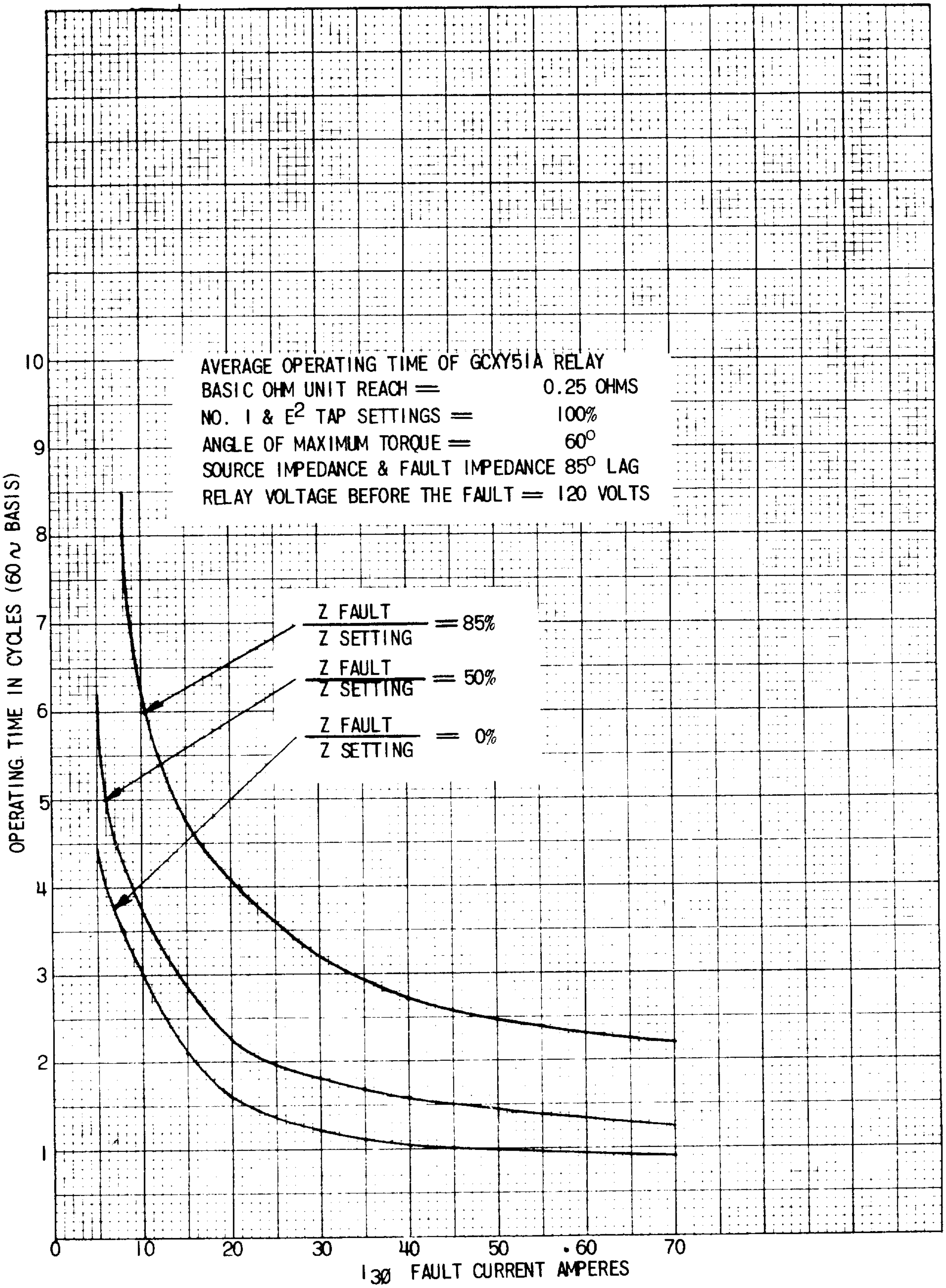


FIG. 8 (0227A7143-0) Operating Time Curves For The 0.25 Ohm-Ohm Unit Of The GCXY51A Relay

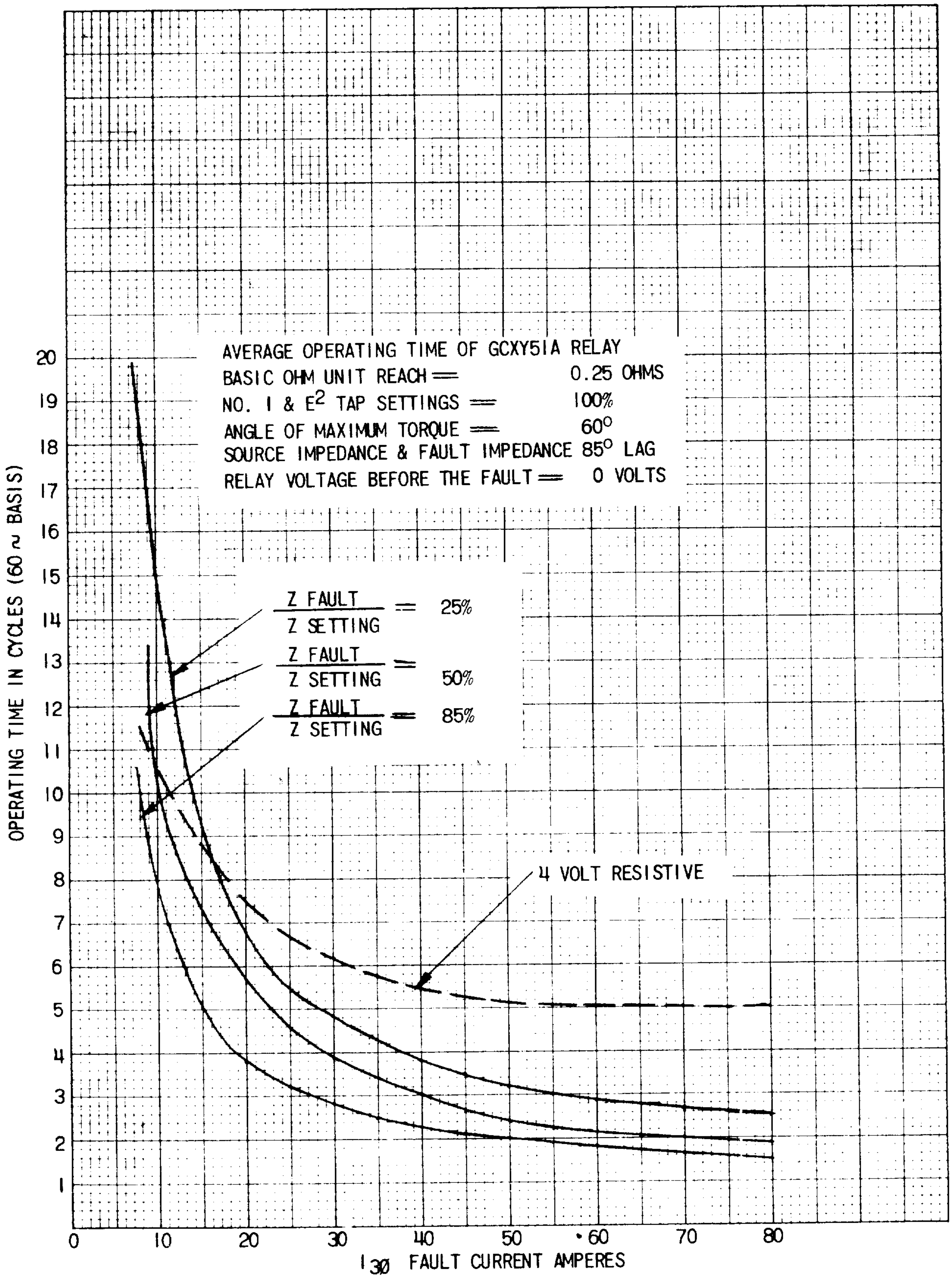


FIG. 9 (0227A7144-0) Operating Time Curves For The 0.25 Ohm-Ohm Unit Of The GCXY51A Relay

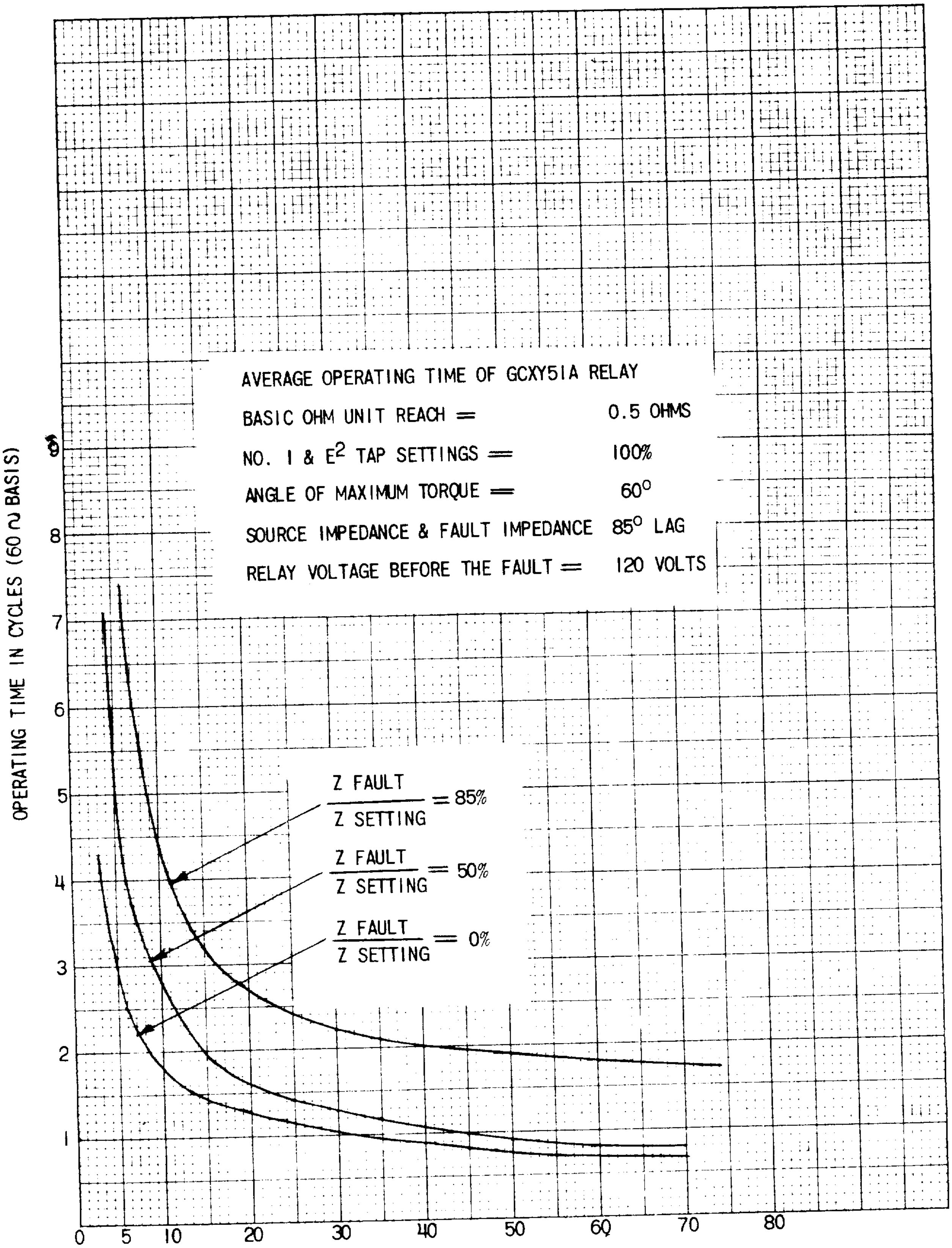


FIG. 10 (0227A7141-0) Operating Time Curves For The 0.5 Ohm-Ohm Unit Of The GCXY51A Relay

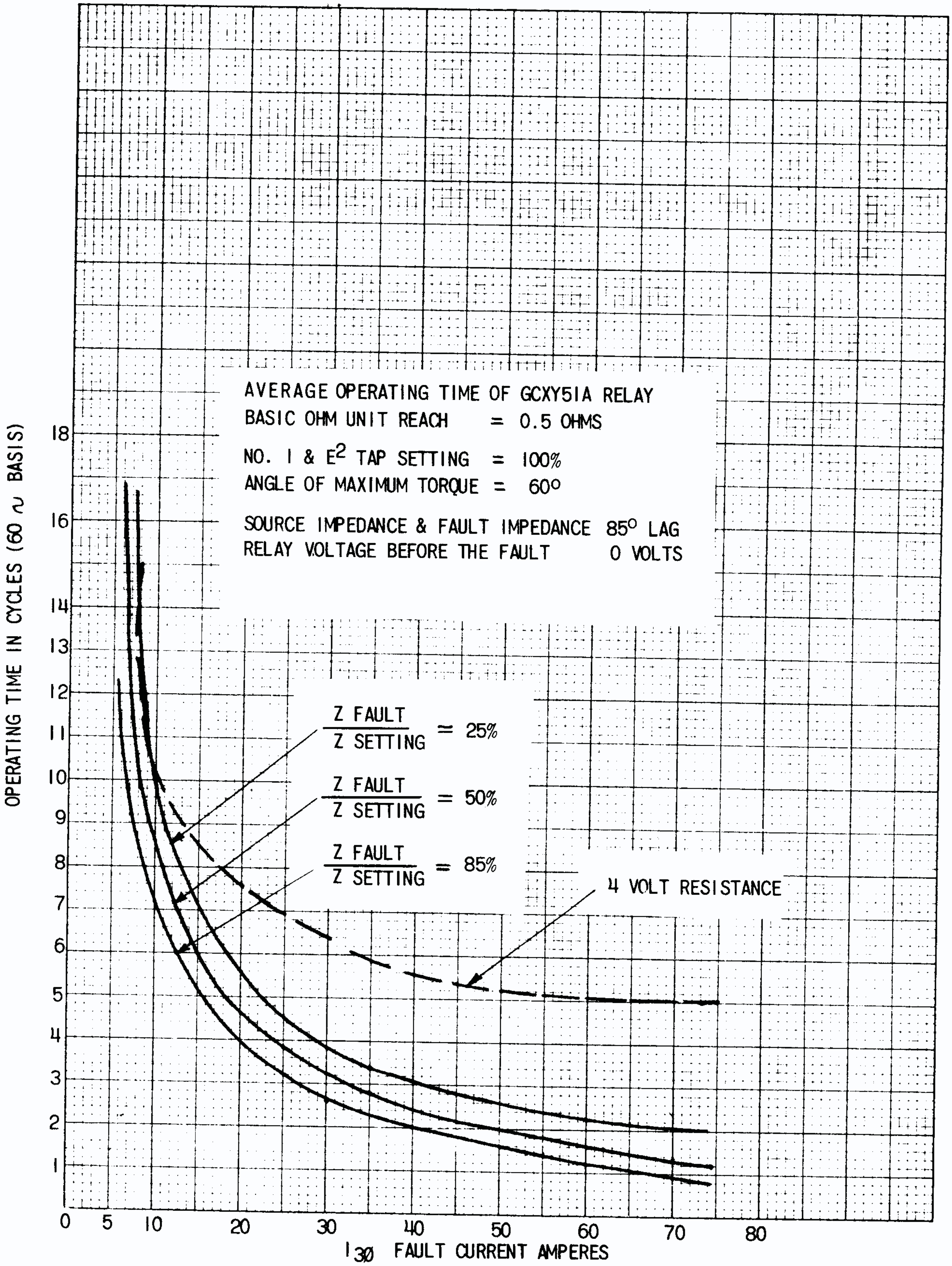


FIG. 11 (0227A7142-0) Operating Time Curves For The 0.5 Ohm-Ohm Unit Of The GCXY51A Relay

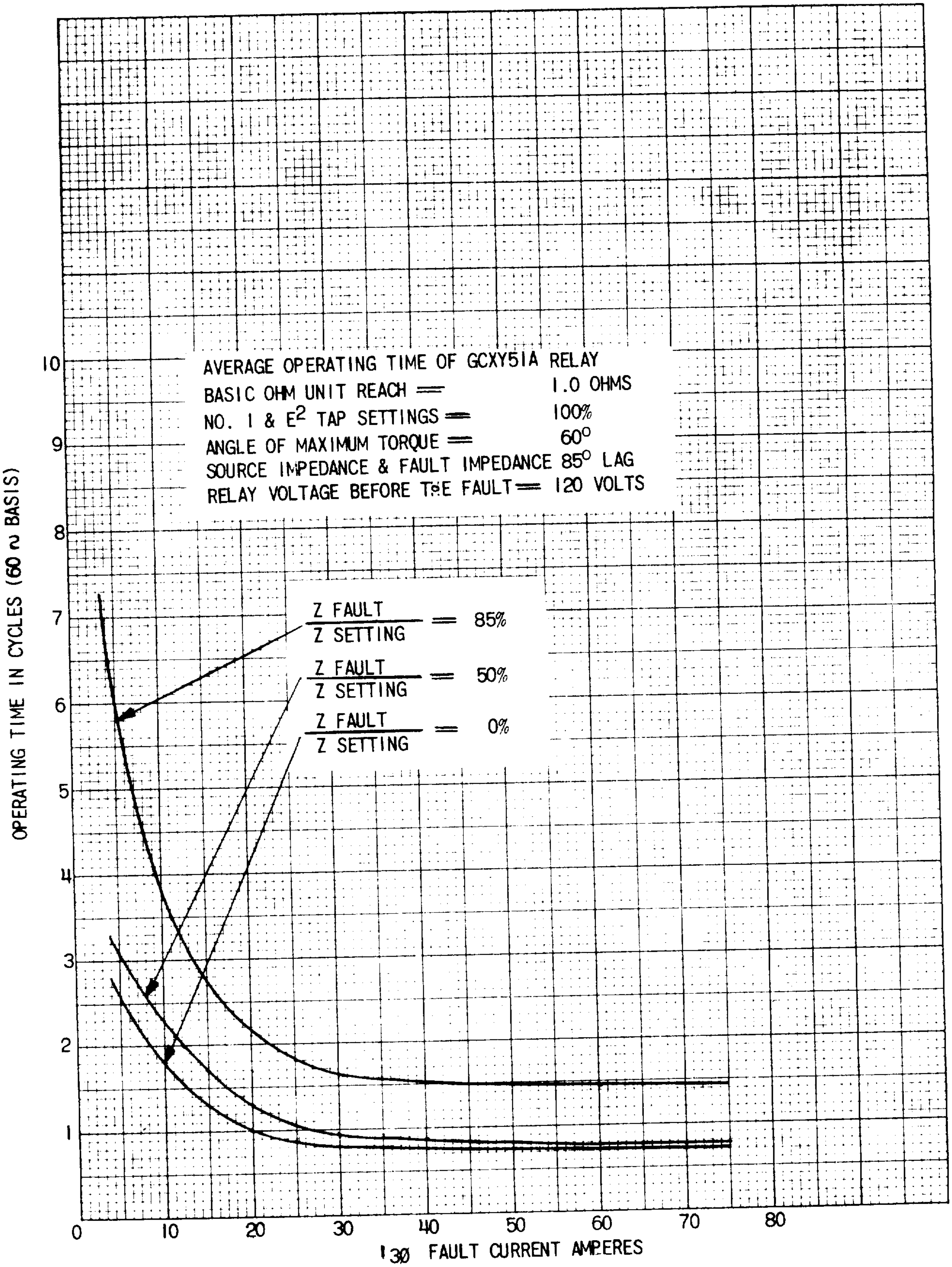


FIG. 12 (0227A7145-0) Operating Time Curves For The 1.0 Ohm-Ohm Unit Of The GCXY51A Relay

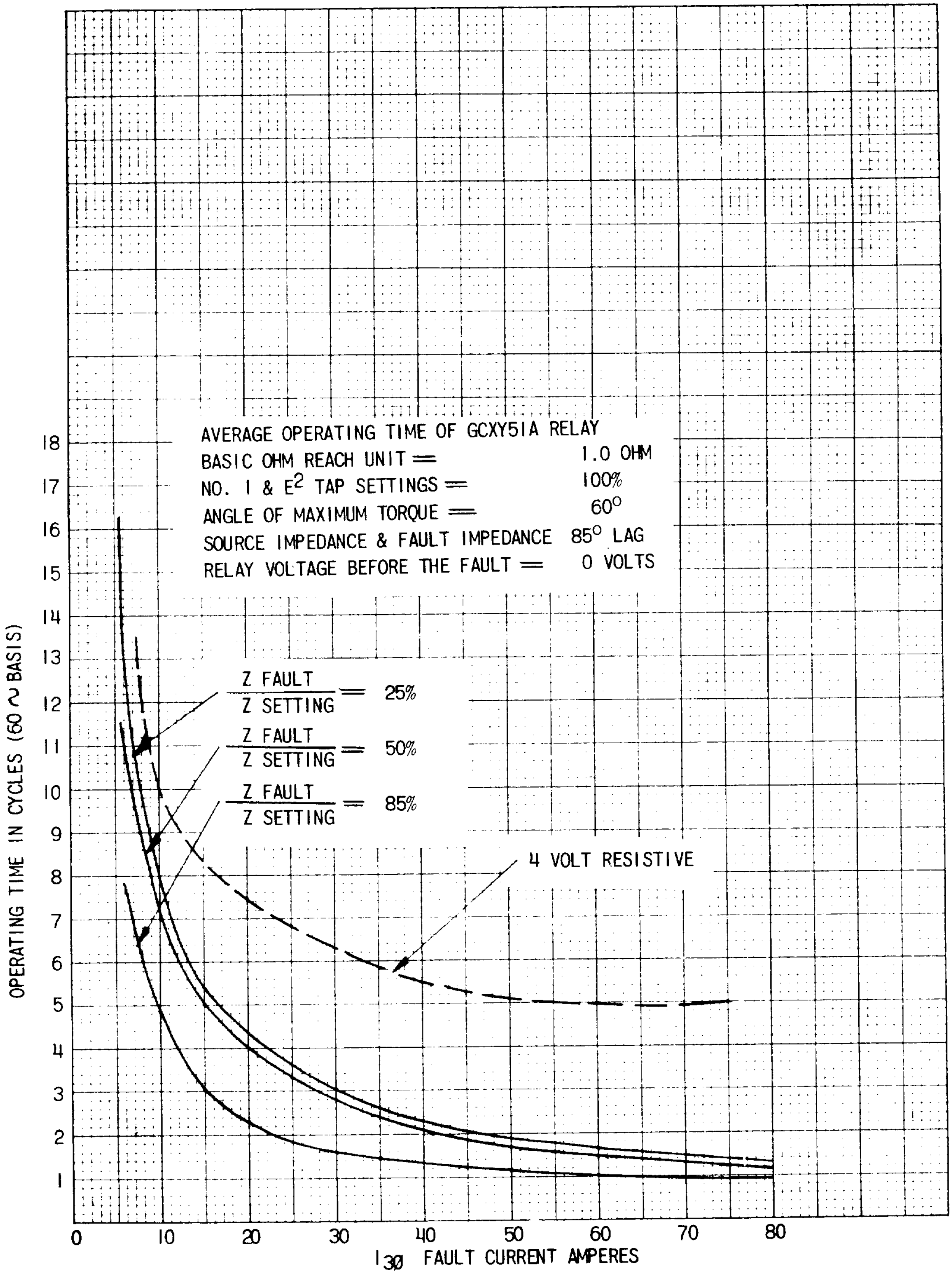


FIG. 13 (0227A7146-0) Operating Time Curve For The 1.0 Ohm-Ohm Unit Of The GCXY51A Relay

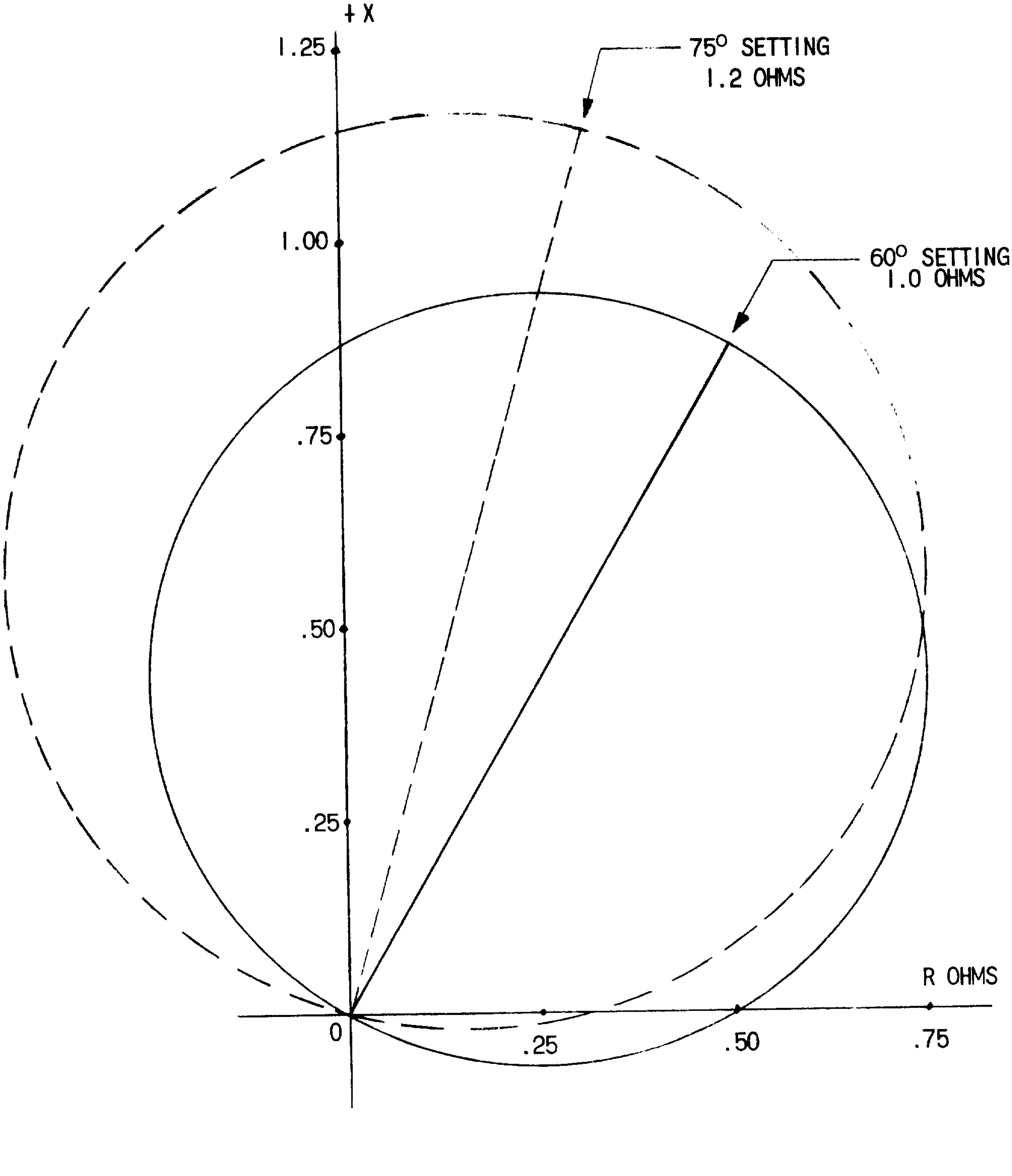


FIG. 14 (0227A7160-0) Minimum Steady-State Operating Characteristics Of The M Unit

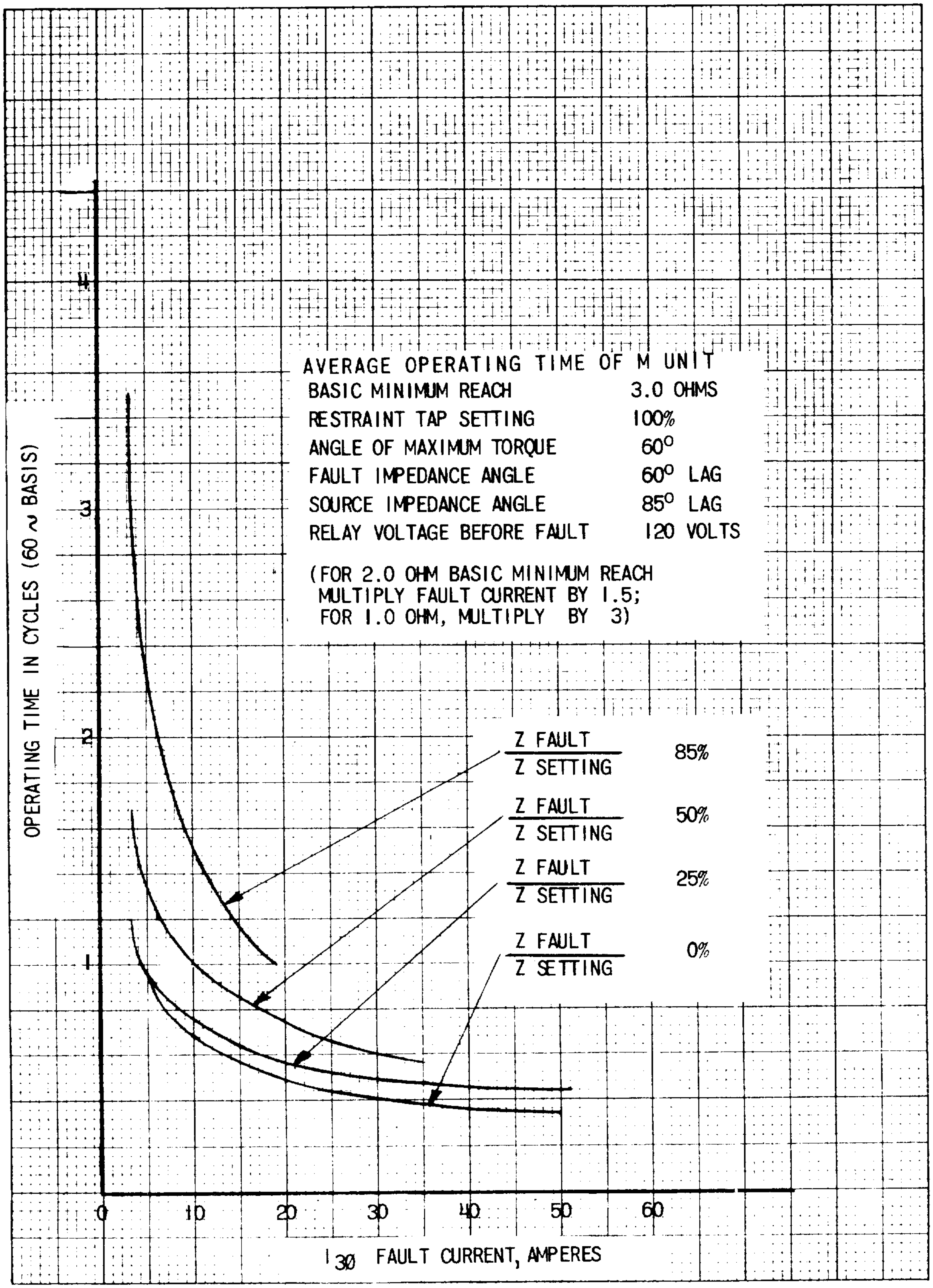


FIG. 15 (0227A7148-0) Operating Time Curves For The M Unit Of The GCXY51A Relay

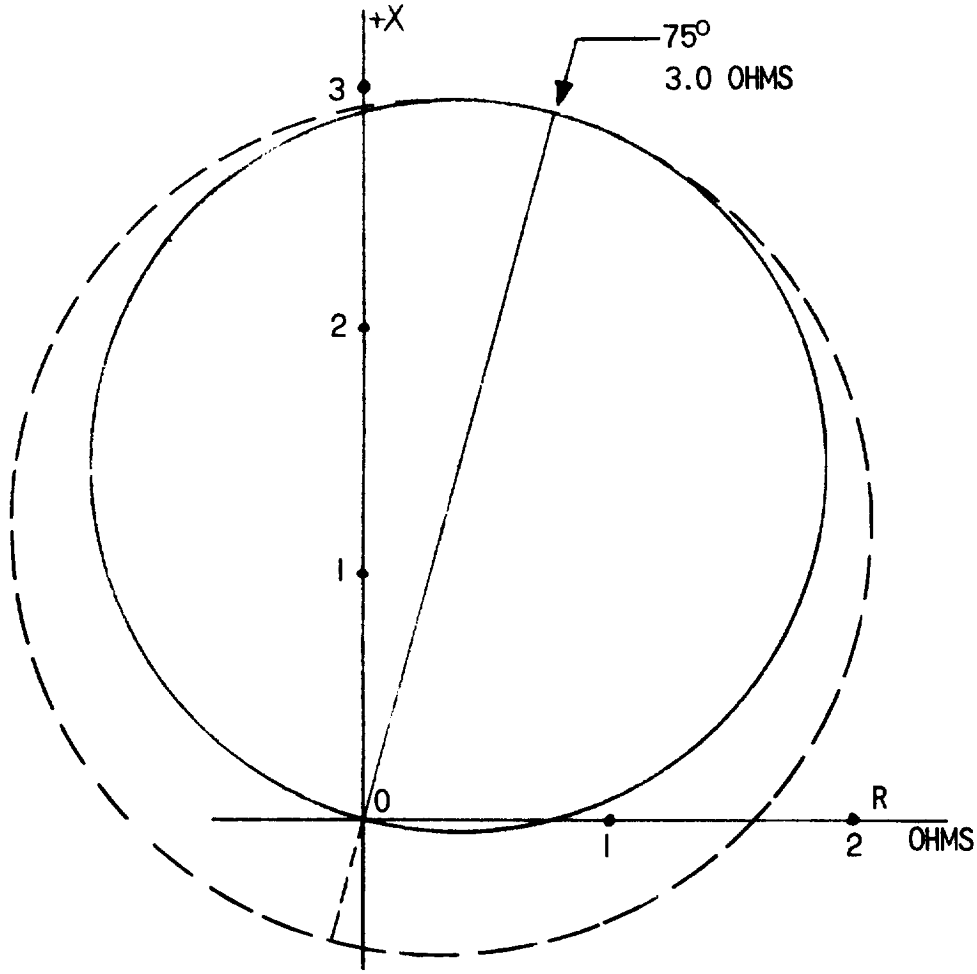
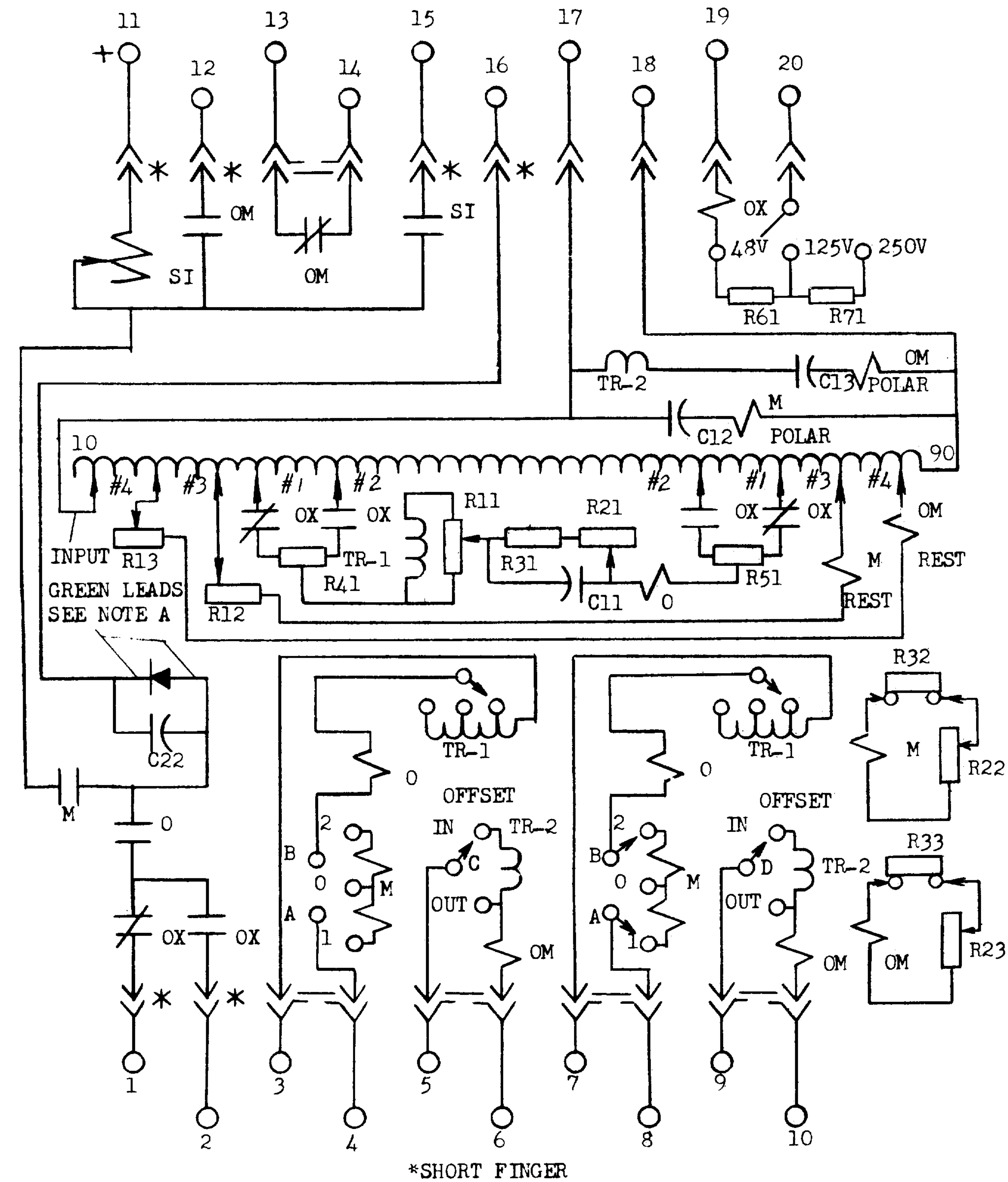


FIG. 16 (0227A7158-0) Minimum Steady-State Operating Characteristics Of The OM Unit



OM=TOP UNIT
M=MIDDLE UNIT
O=BOTTOM UNIT

NOTE A: IF STUD 11 POLARITY IS NEGATIVE REVERSE POLARITY OF RECTIFIER BY INTERCHANGING GREEN LEADS

FIG. 17 (0178A9162-1) Internal Connections Diagram For The GCXY51A Relay (Front View)

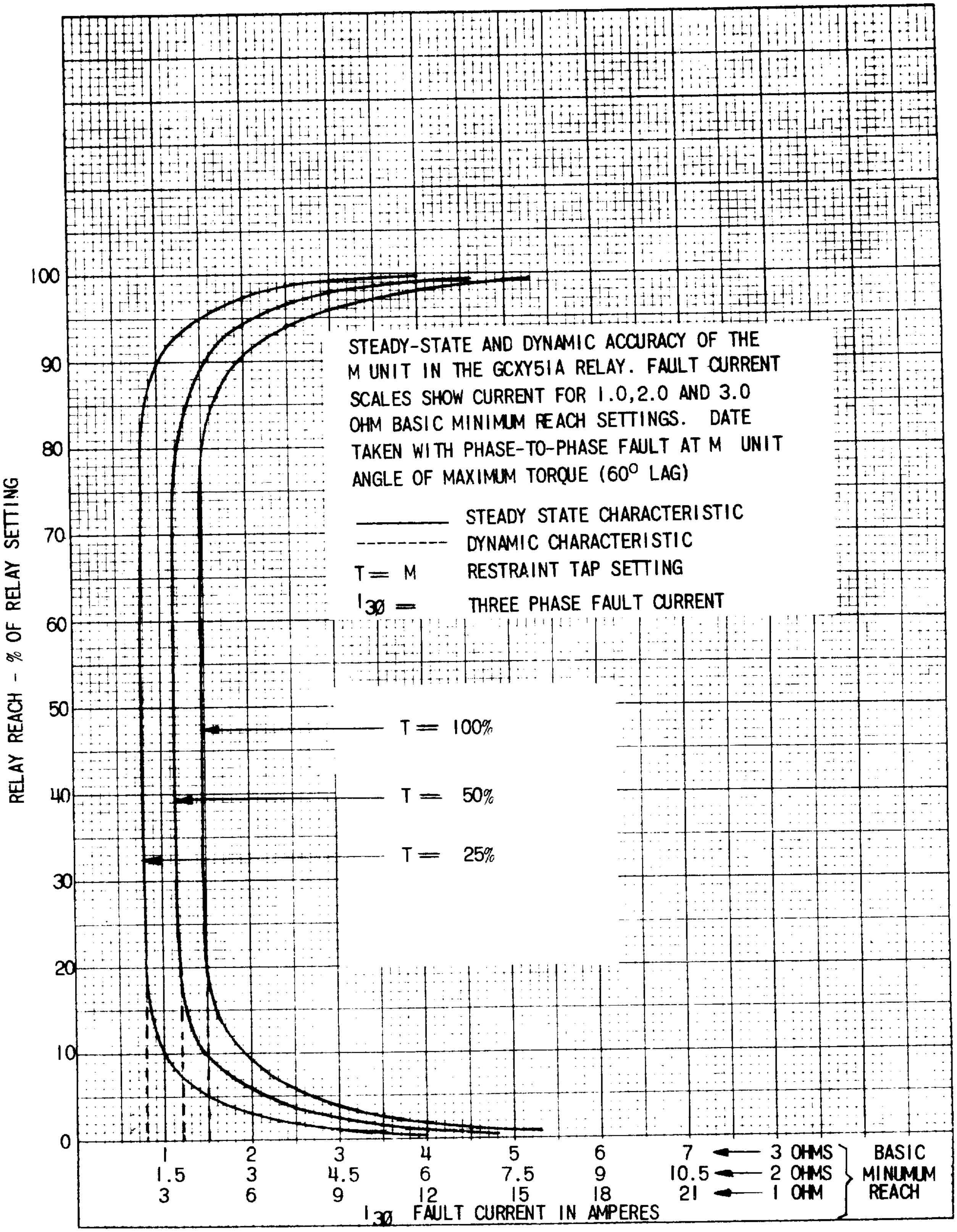


FIG. 18 (0227A7147-0) Steady-State And Dynamic Reach Curves For The M Unit Of The GCXY51A Relay

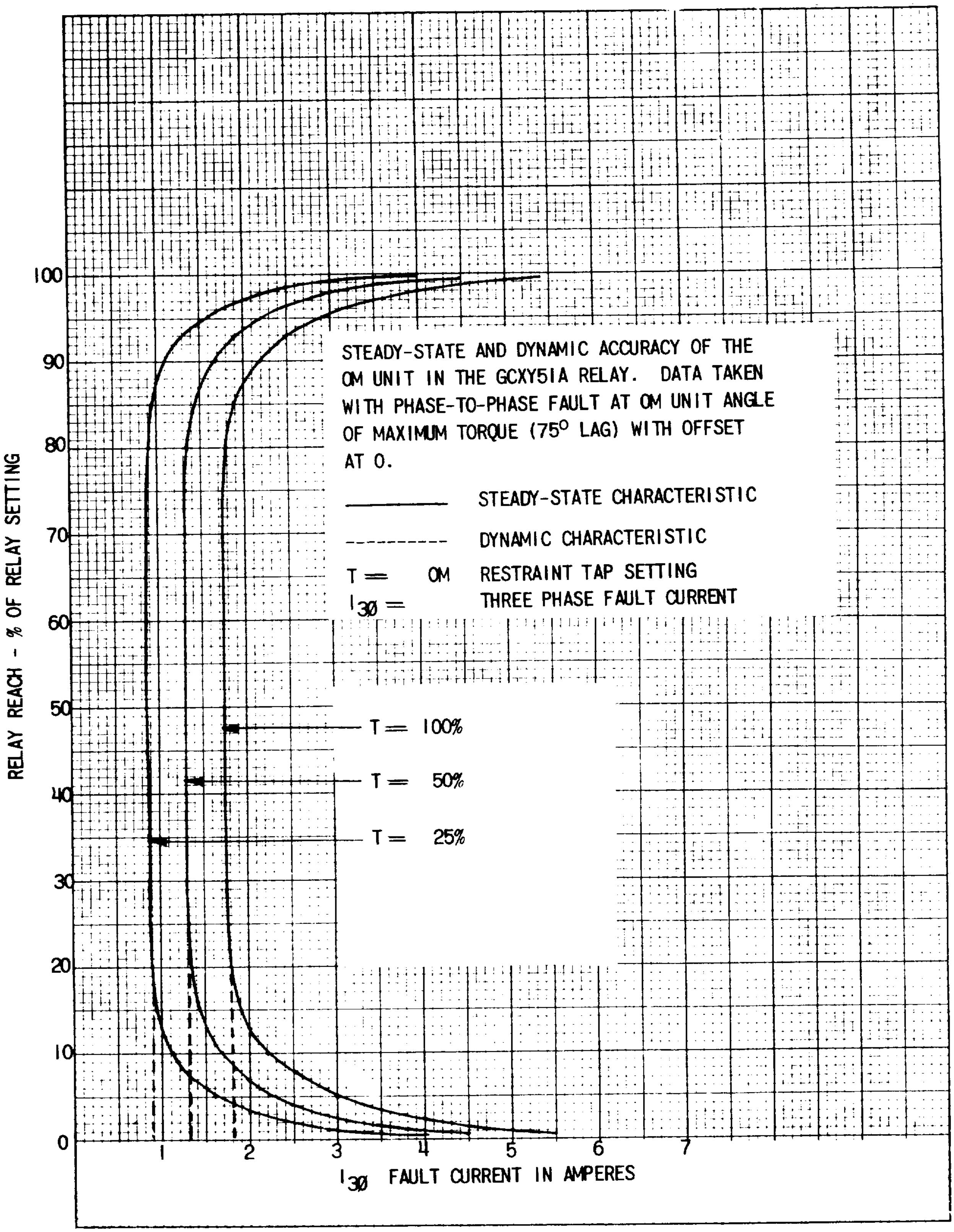


FIG. 19 (0227A7149-0) Steady-State And Dynamic Reach Curves For The OM Unit With Offset At Zero

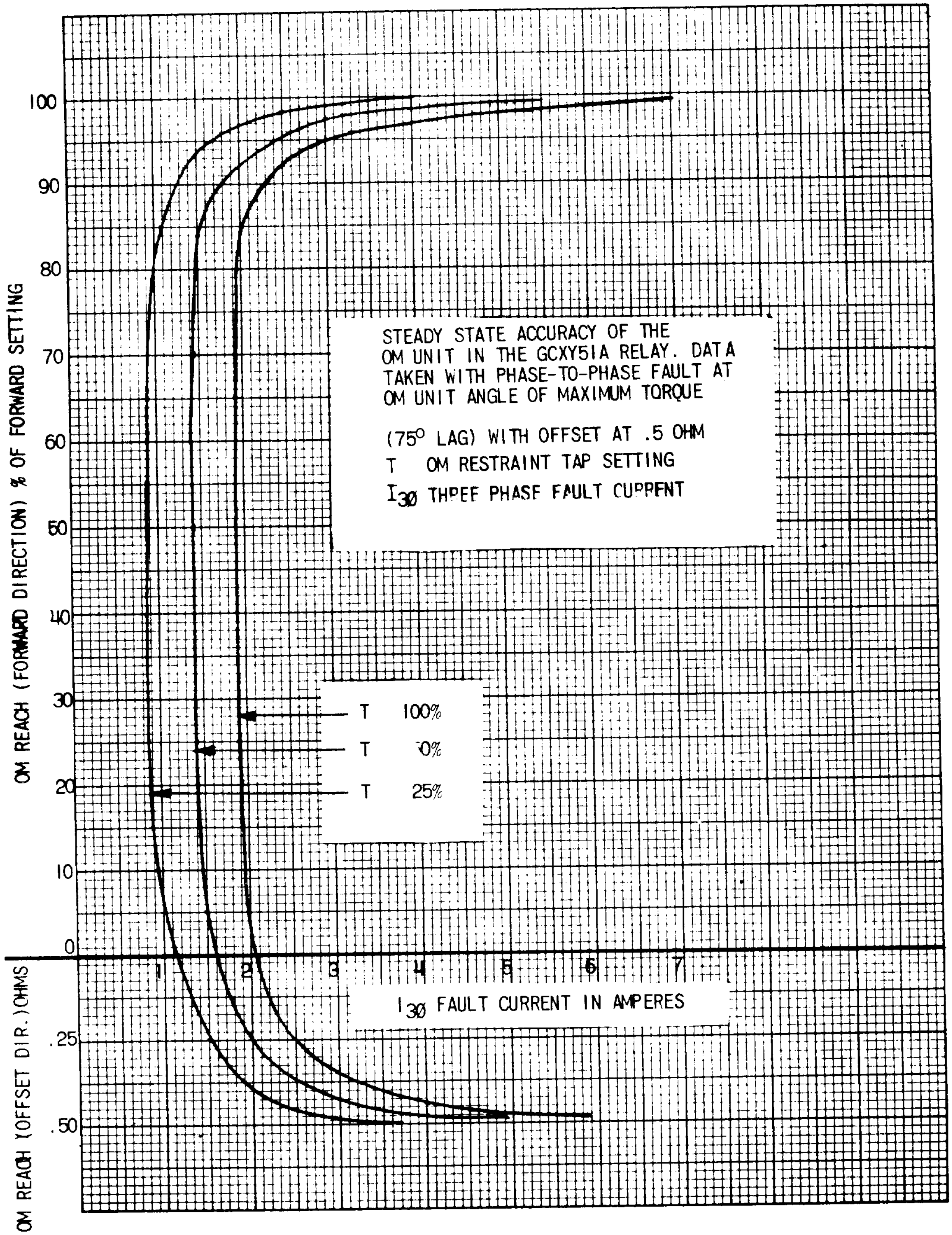
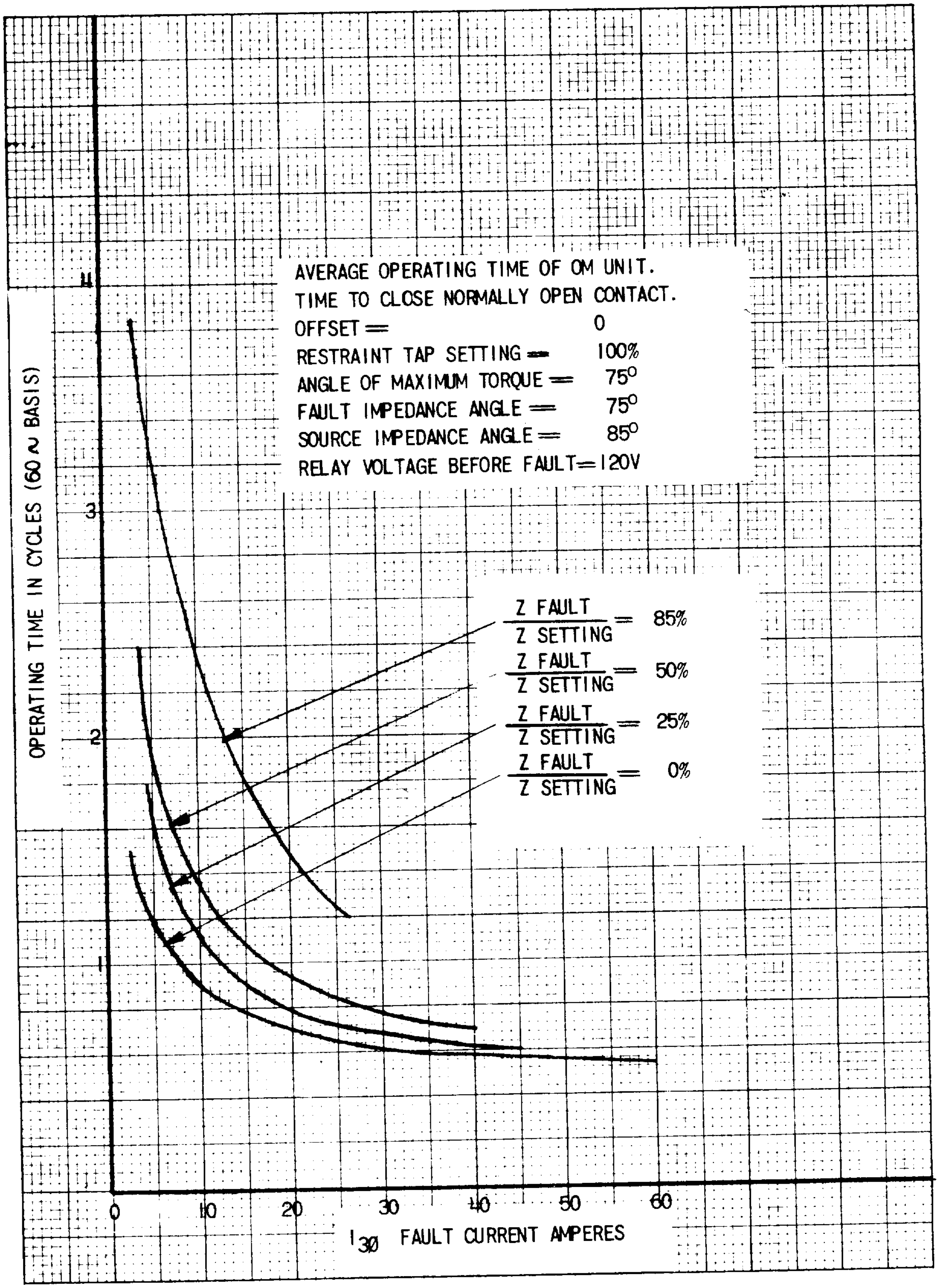


FIG. 20 (0227A7150-0) Steady-State Reach Curves For The OM Unit With Offset At 0.5 Ohms



G. 21 (0227A7151-0) Operating Time Curves For The OM Unit With Zero Offset Showing The Time To Close The Normally Open Contact

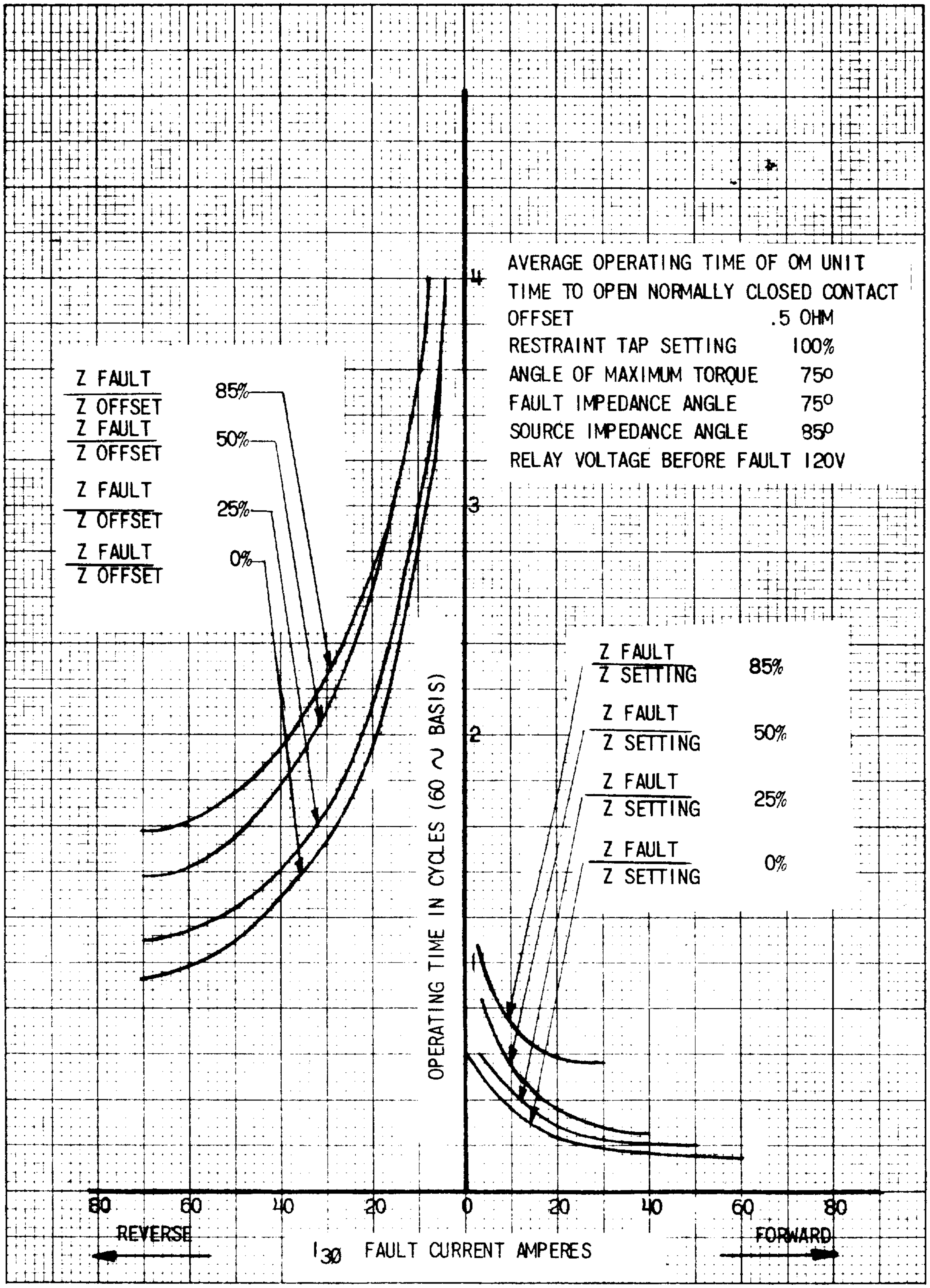


FIG. 22 (0227A7152-0) Operating Time Curves For The OM Unit With 0.5 Ohm Offset Showing The Time To Open The Normally Closed Contact

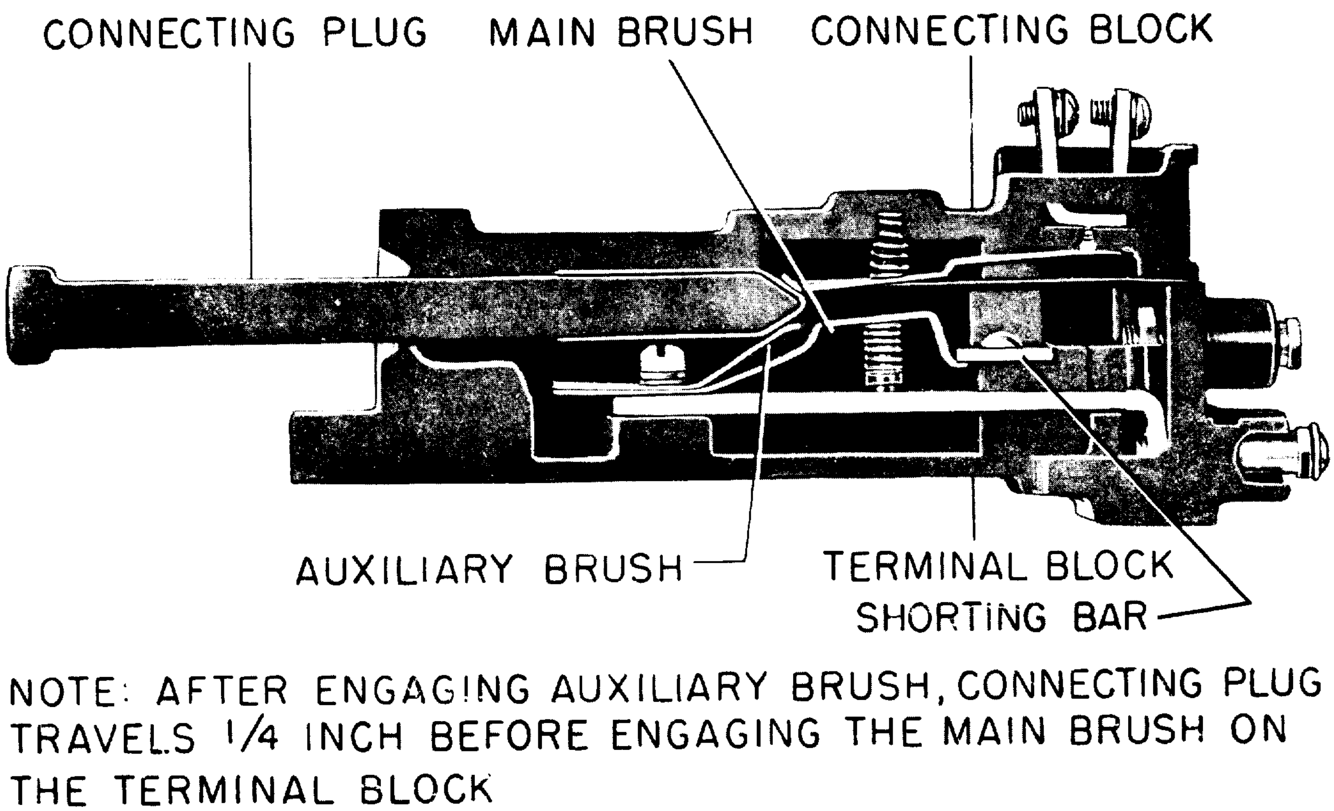


FIG. 23 (8025039) Cross Section Of Drawout Case And Cradle Block

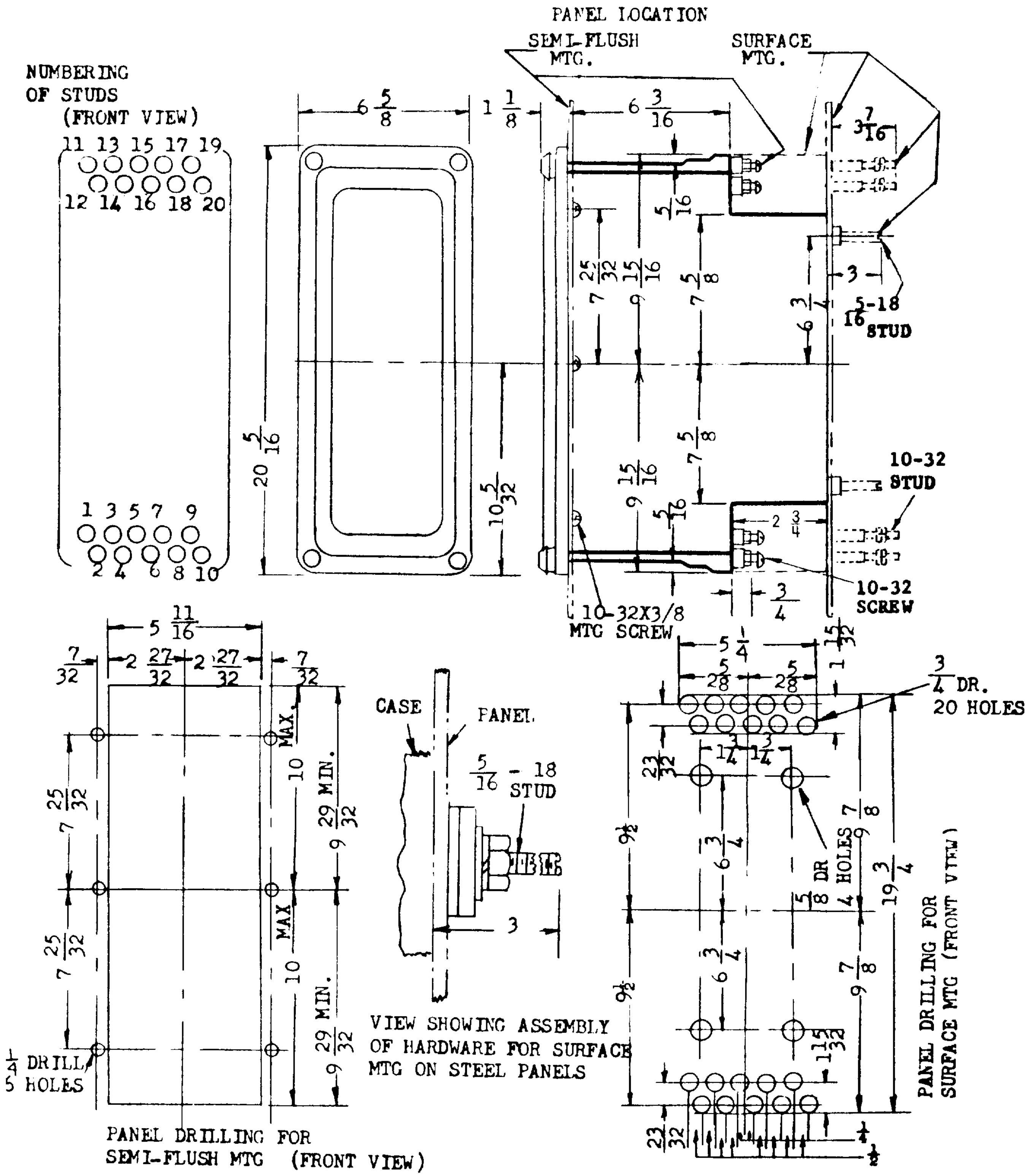


FIG. 24 (0178A7336-2) Outline And Panel Drilling Dimensions For The GCXY51A Relay

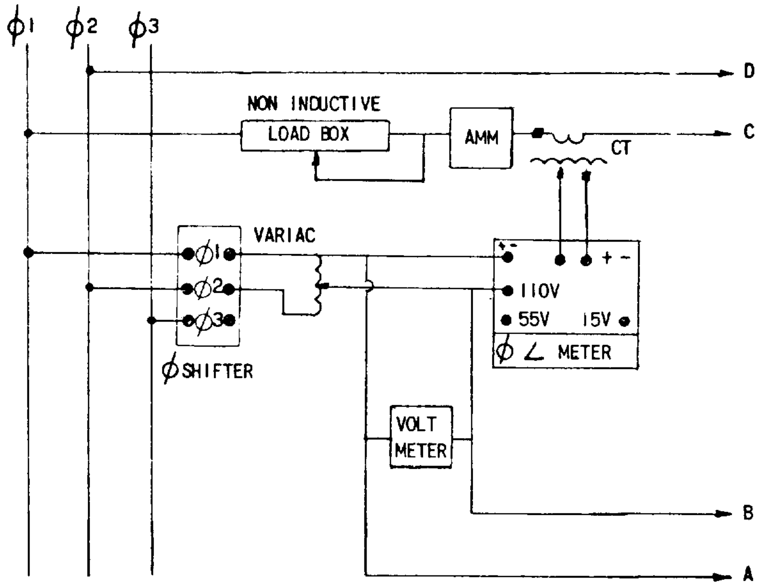


FIG. 25 (0227A8407-0) Connections Diagram For The Electrical Tests On The GCXY51A Relay

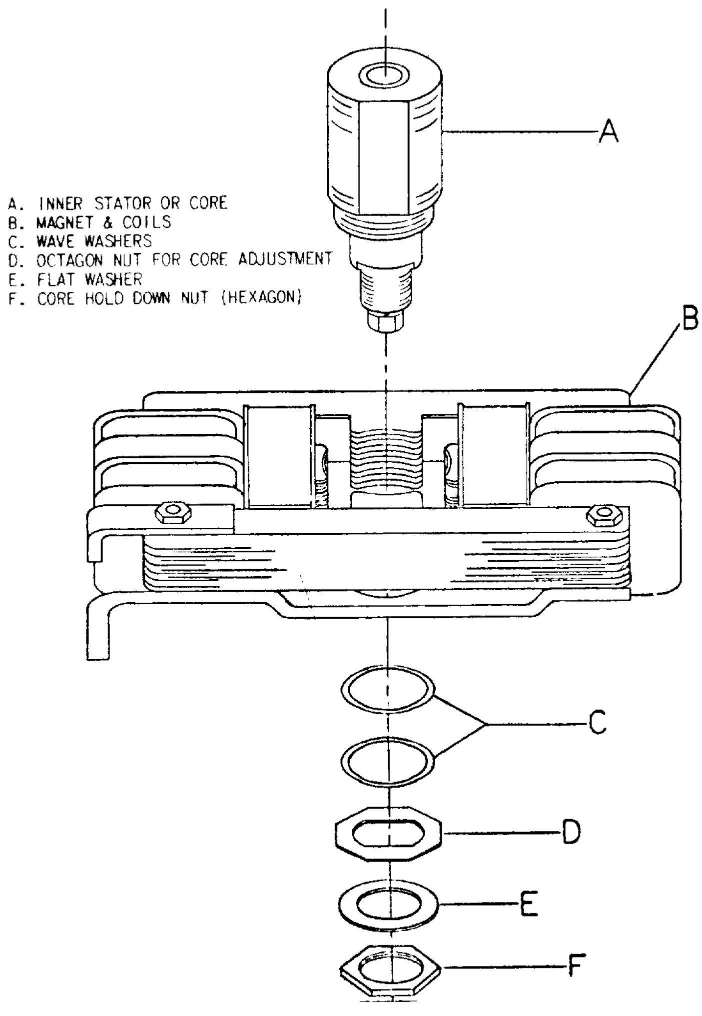


FIG. 26 (0208A3583-0) Core Adjustment Parts

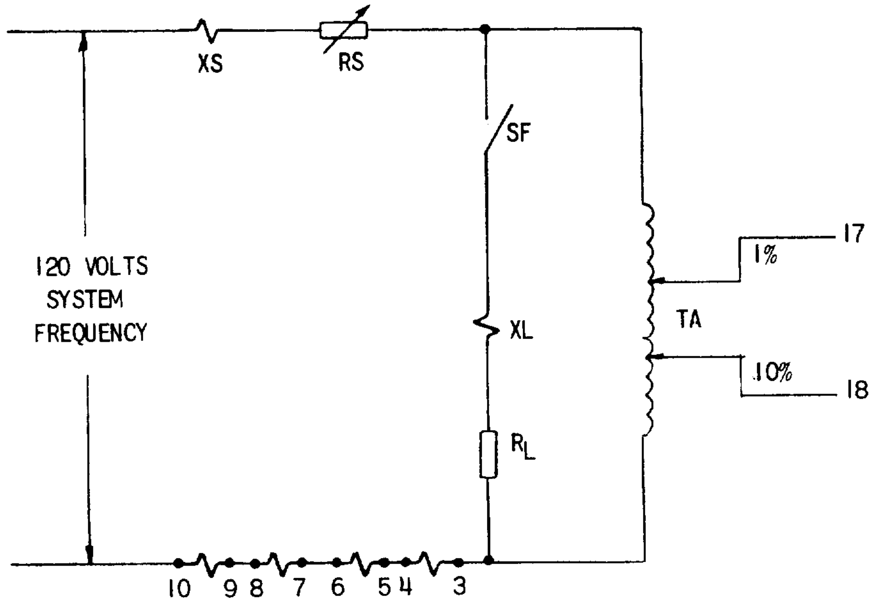


FIG. 27 (0227A8413-0) R & X Test Schematic

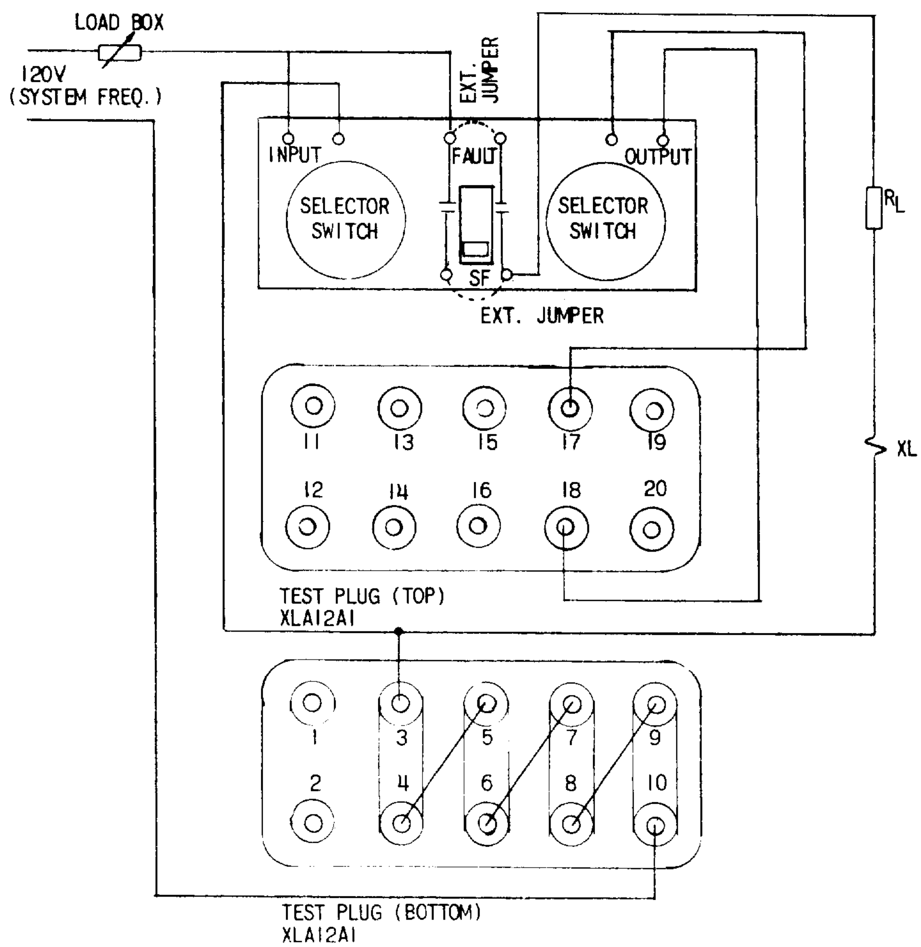


FIG. 28 (0227A8410-0) Test Connections Diagram For The GCXY51A Relay Using Test Reactor, Resistor, Test Box And XLA Plugs

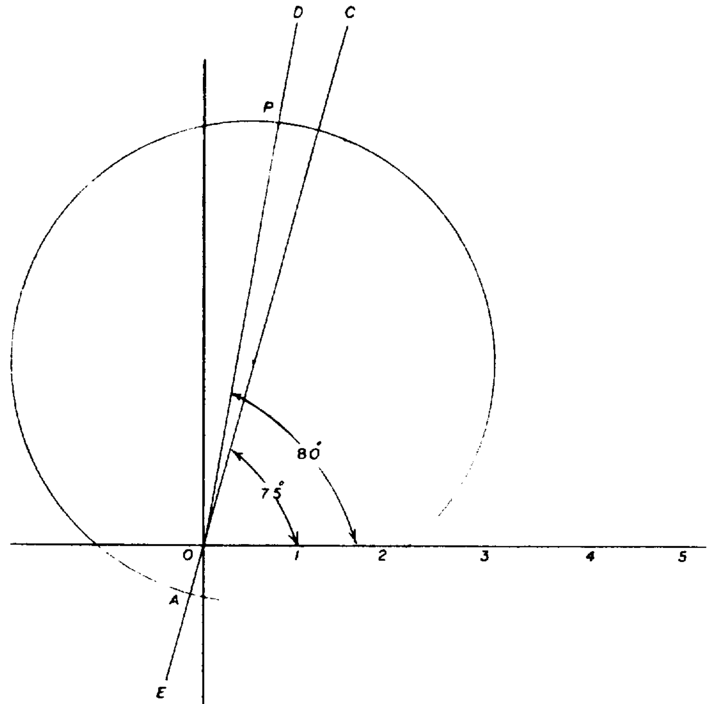


FIG. 29 (0227A8504-0) Graphical Determination Of Restraint Tap Setting Of The OM Unit When Offset Is Included

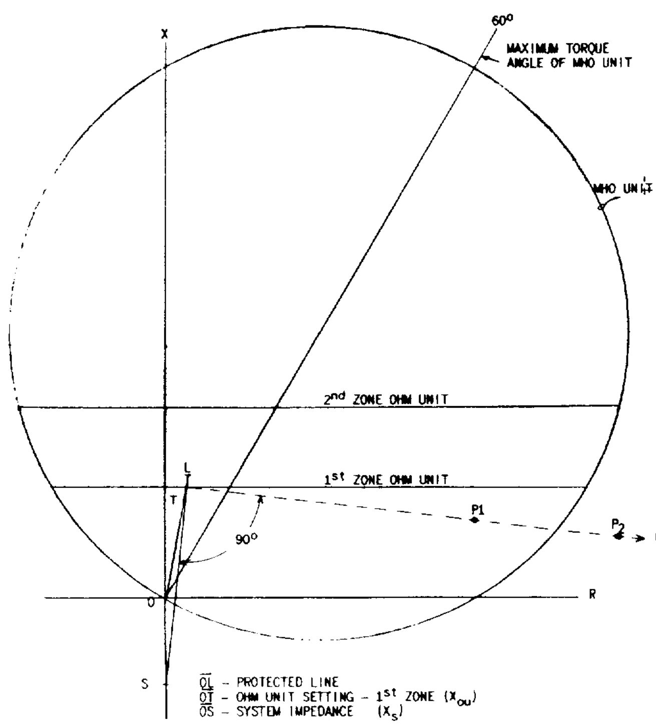


FIG. 30 (0178A8101-0) R-X Diagram Illustrating Response Of GCXY51A Relay To Phase-To-Phase Fault On An Adjacent Phase Pair

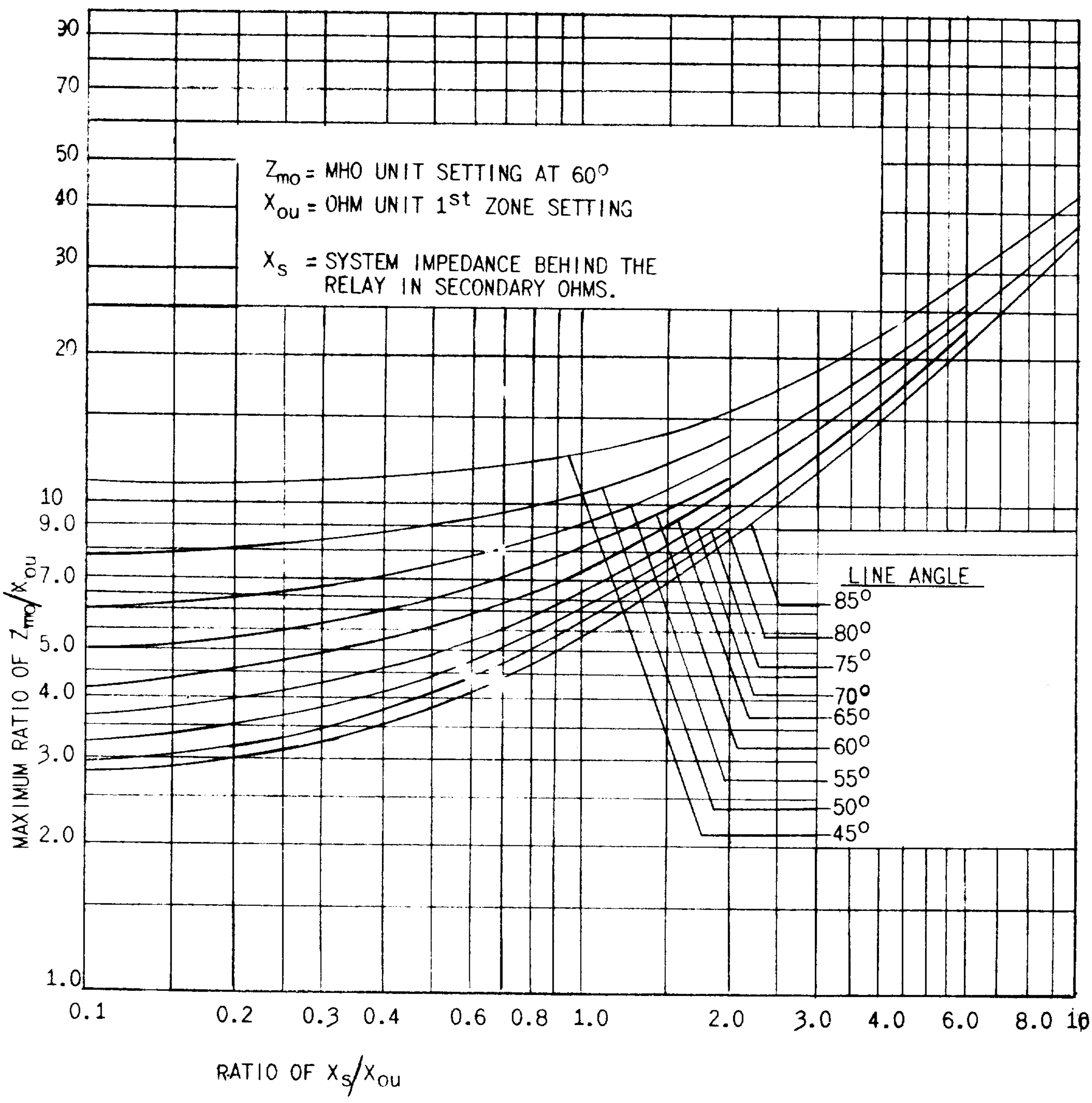


FIG. 31 (0178A8100-0) Curves For Determining Maximum Safe Setting Of Mho Unit In The GCXY51A Relay

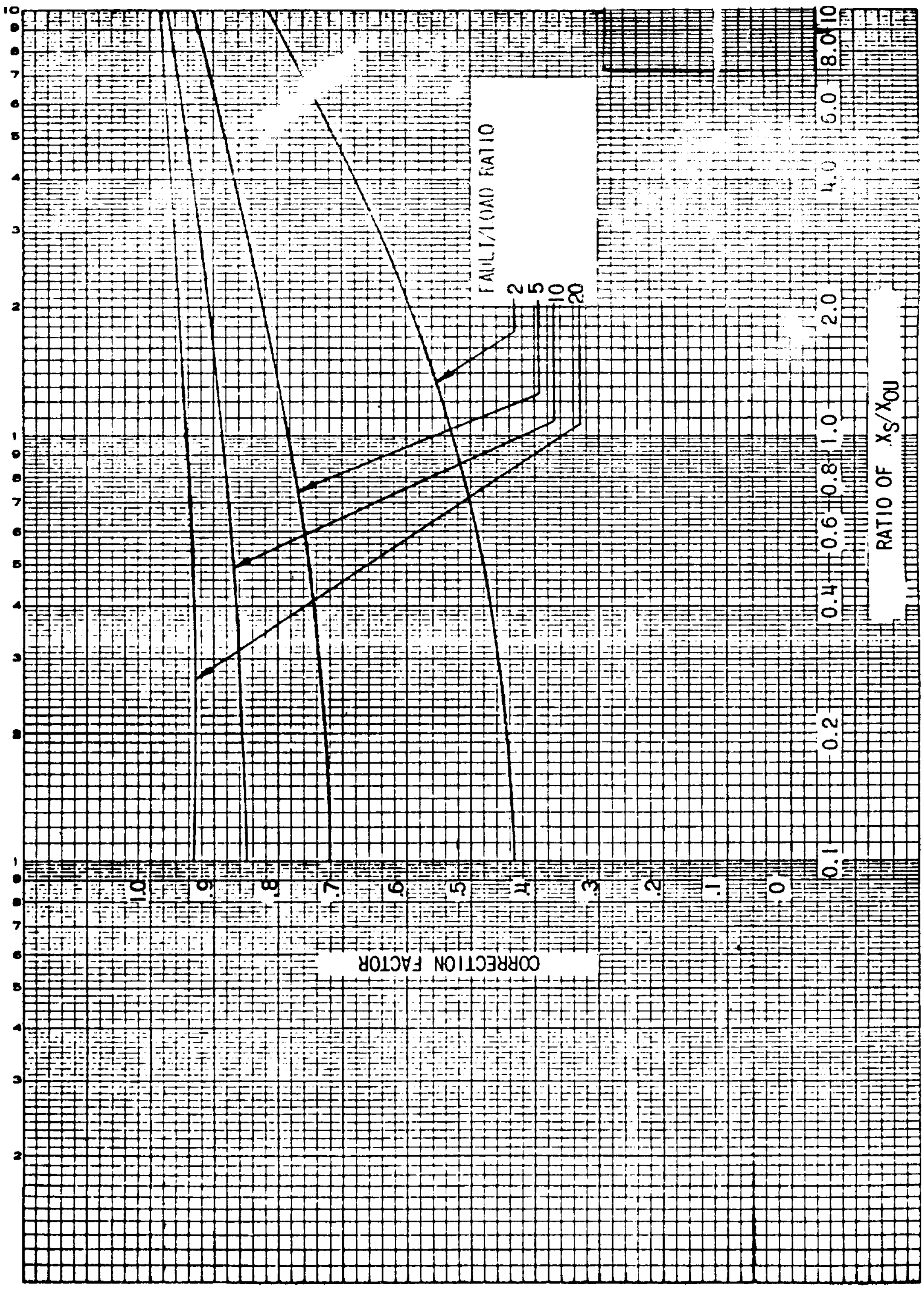


FIG. 32 (0227A2675-0) Curves For Determining The Correction Factor Of The GCXY51A Relay

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