INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HXS GROUND REACTANCE RELAYING SYSTEM

CAUTION Before putting protective relays into service, remove all blocking which may have been inserted for the purpose of securing the parts during shipment. Make sure that all moving parts operate freely. Inspect the contacts to see that they are clean and close properly, and operate the relay to check the settings and electrical connections.

APPLICATION

The Type HXS ground reactance relaying system is of the high speed three zone directional distance type. It is designed to protect a transmission line upon the occurrence of a single line to ground fault within the protected zones. Zone one, usually set for 70 to 80 percent of the first line section, will initiate breaker operation without intentional time delay. Zones two and three can be delayed to coordinate with other relays on the adjacent line sections. For faults involving more than one phase, this equipment will not initiate breaker operation. The usual phase relays are required for these faults.

The distance elements are of the balanced beam reactance type and utilize zero sequence quantities to determine the zero sequence reactance of the line from the relay to the balance point. These quantities are obtained from the fault current and voltage at the relay by the use of sequence networks. Only one distance relay is needed to provide complete three phase protection since use is made of a phase selector relay operated by these same sequence quantities, to connect only the line to ground voltage of the faulted phase to the distance element.

Three phase star-connected current and potential transformers are needed at the relay location as well as 125 or 250 volts d-c station battery service.

CONSTRUCTION

One terminal of relaying consists of the following equipment:

one type HXS relay
one type HPS relay
one auxiliary unit
one set of 5/15 auxiliary current transformers
one negative sequence filter

TYPE HXS RELAY

The type HXS relay contains three reactance beam elements, one for each zone, auxiliary switches, operation indicators, one single loop type directional element and a synchronous timer. These are shown schematically in Figs. 1 and 2.

Reactance Elements

The reactance elements are of the balanced beam high speed type. The reactance characteristic is obtained by balancing the torques resulting from the vector sum of current and voltage on the contact or operating end against the voltage restraint on the opposing end of the beam. The current ampere turns on the operating end must be shifted 90 electrical degrees from the voltage ampere turns. This is accomplished by the use of an air gap transformer in the zero sequence current circuit.

The voltage drop induced in the secondary of the zero sequence transformer is proportional to $3KI_0$ and will lead the primary current $3I_0$ by 90°. This voltage causes a current to flow

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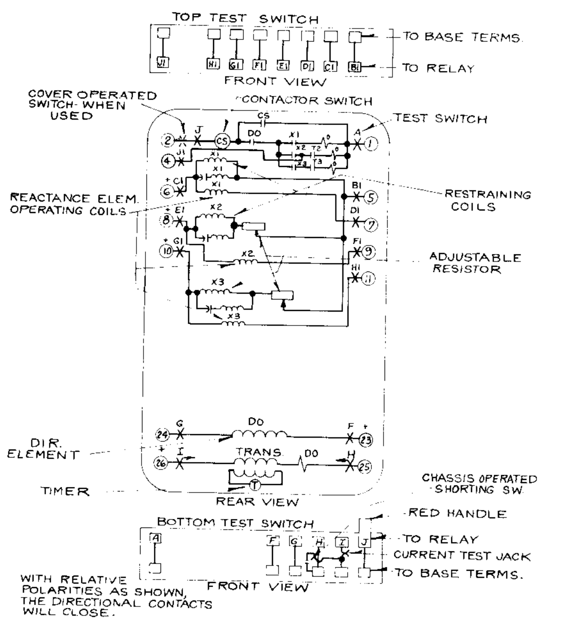

Fig. 1—Internal Schematic Of Type HXS Relay In The Type FT Case. Omit Test Switches For Relays In The Standard Case.

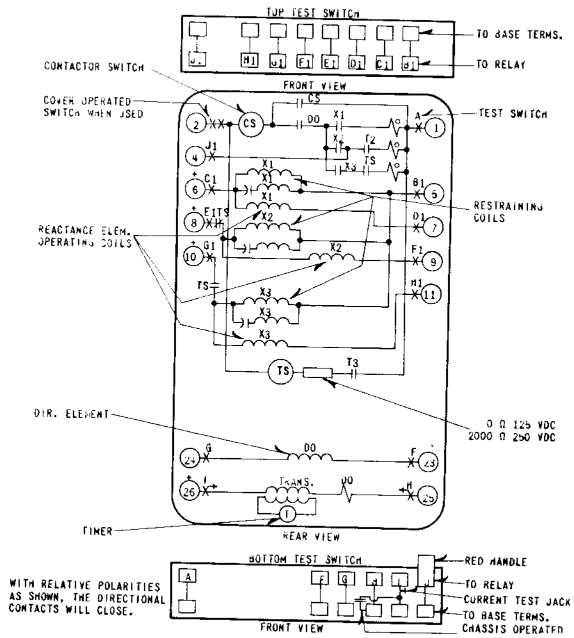

Fig. 2.—Internal Schematic of the Type HXS Relay with the TS Transfer Switch. Omit Test Switches for Relays in the Standard Case.

in the operating coil of the relay, which is proportional to the zero sequence current in the primary of the transformer. The vector sum of this current and the current caused by the voltage drop (I_0Z_0), applied to the element will give a resultant which will impart a reactance characteristic to the beam at the balance point.

There are no taps or adjustments on the reactance elements. Tap settings, which are made on the auxiliary unit, are in terms of secondary zero sequence reactance ohms and will be described fully under Adjustments.

A rectangular silver contact is flexibly fastened on the forward end of the beam. As the beam trips, the contact bridges two silver stationary hemispherical contacts mounted on the free end of the two short leaf springs. A small set screw determines the position of each leaf spring and provides means for adjusting the contact gap.

Synchronous Timer

The timer is a small sub-synchronous motor which operates from the neutral current through a saturating transformer, and drives a moving contact arm through a gear train. The contact on the moving arm is a cylindrical silver sleeve, loosely fitted on the moving arm. In making contact, this sleeve rolls across two vertically projecting stationary butt contacts to bridge the gap between them. The loose fit of the sleeve permits a positive alignment in bridging these contacts. Two sets of stationary contacts are mounted on Micarta insulating blocks which are adjustable around a semi-circular calibrated guide. The maximum time setting of the timer is three seconds.

The synchronous motor has a pinion on its rotor which is in mesh with the gear train only when the motor is energized. The rotor pinion falls out of mesh instantly when the motor is de-energized, allowing a spring to reset the moving arm.

Directional Element

The voltage coil of the directional element serves as the primary winding of a small transformer. The secondary winding consists of a one turn movable coil, or loop, pivoted along its center line. This loop carries a current which is proportional to and substantially in phase with the voltage applied to the primary winding. The pivoted loop has a portion of its length lying in a magnetic field established by the current coils of the directional element. The interaction of the current in the loop with the flux established by the current coils produces torque which rotates the loop in one of two directions, depending upon the phase angle relationship between the applied current and the applied voltage.

A Micarta arm extends from the movable loop from which projects a short leaf spring. A small cylindrical contact filled with powdered tungsten is rigidly attached to the outer end of the spring. The movement of the tungsten powder creates sufficient friction to absorb practically all of the energy of impact and thus the tendency of the contact to bounce is reduced to a minimum.

The stationary contact screw fastens to a rigid projecting arm. Contact follow is secured by permitting the loop to travel for a short distance after the contacts close, thus deflecting the leaf spring. This is done by an adjustable stop screw. Another stop screw limits the travel of the loop in the opening direction. These stop screws act directly on the loop and are accessible from the sides of the directional element. This directional element has nearly true wattmeter characteristics.

Auxiliary Contact Switch

The d-c contactor switch in the relay is a small solenoid type switch. A cylindrical plunger with a silver disc mounted on its lower end moves in the core of the solenoid. As the plunger travels, upward, the disc bridges three silver stationary contacts. The coil is in series with the main contacts of the relay and with the trip coil of the breaker. When the relay contacts close, the coil becomes energized and closes the switch

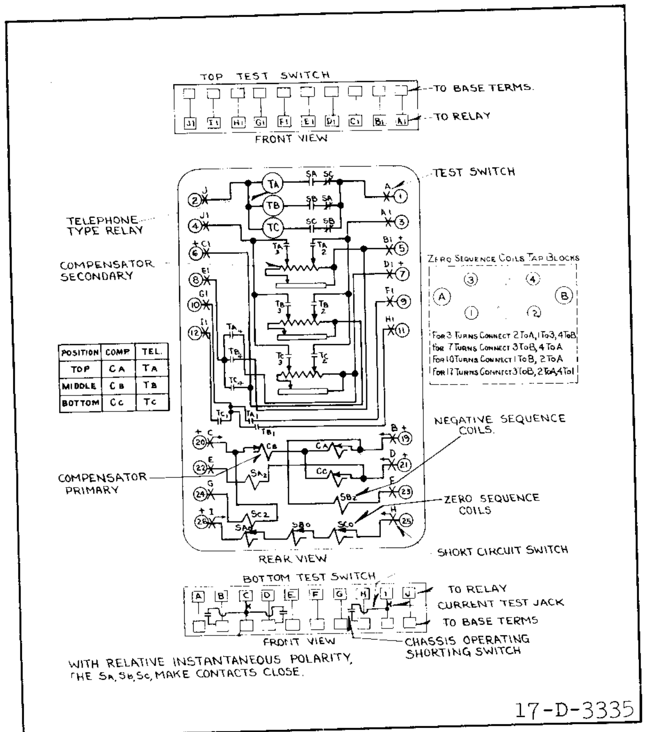

Fig. 3—Internal Schematic Of Type HPS Relay In The Type FT Case. Omit Test Switches For Relays In The Standard Case.

contacts. This shunts the main relay contacts, thereby relieving them of the duty of carrying tripping current. These contacts remain closed until the trip circuit is opened by the auxiliary switch on the breaker.

Operation Indicator

The operation indicator is a small solenoid coil connected in the trip circuit. When the coil is energized, a spring-restrained armature releases a white target which falls by gravity to indicate completion of the trip circuit. The indicator is reset from outside of the case by a push rod in the cover or cover stud.

Telephone Relay

A small transfer switch, as shown in the internal schematic Fig. 2, has been added to the HXS relay to separate the second and third zone compensation. The curve Fig. 13 of reach vs. ratio of the second and third zone does not apply to relays with the transfer switch.

TYPE HPS RELAY

The type HPS Relay is used on systems which

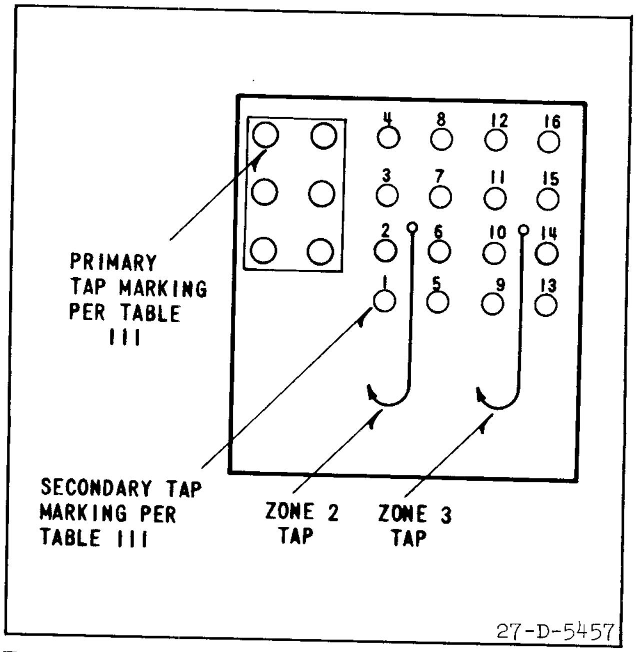

Fig. 4.—Second and Third Zone Line Drop Compensator Tap Identification (In Type HPS Relay).

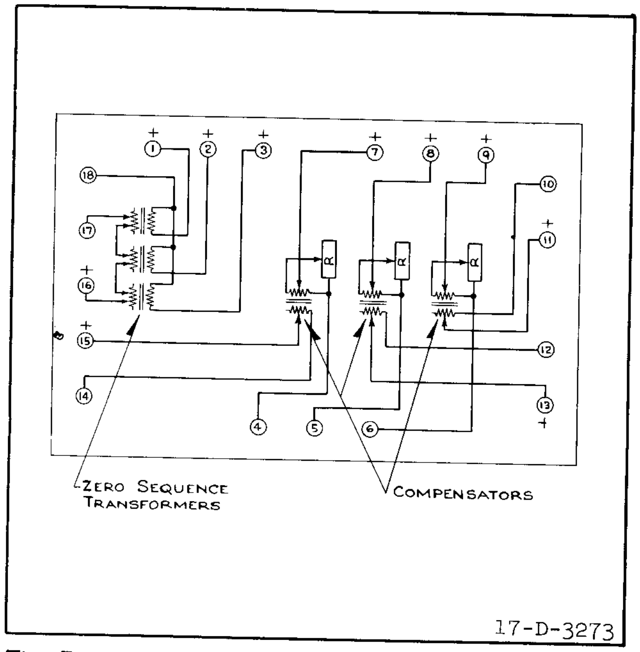

Fig. 5.—Internal Schematic of the Type HXS Auxiliary Unit.

have solidly grounded neutrals. The relay contains three phase selectors, three second and third zone compensators and three auxiliary telephone type relays. These are shown schematically in Fig. 3.

Selector Elements

The three selector elements are constructed in the same manner as the directional element of the type HXS Relay, except that a current coil replaces the potential coil. The coil ends are brought out to a tap plate.

Compensators For Second And Third Zone Positive And Negative Sequence Line Drop

Each compensator consists of a tapped transformer and an adjusting resistor. The transformer has relatively few turns of heavy wire on the primary and many turns of fine wire on the secondary wound on punchings having an air gap. A resistor is shunted across the secondary winding to provide the angular adjustment. The primary and secondary taps for range adjustment are brought out to a plate as shown in Fig. 4.

TYPE HXS AUXILIARY UNIT

The unit consists of three zero sequence air gap transformers and three zone one positive and negative sequence line drop compensators. An internal schematic of this unit is shown in Fig. 5.

The zero sequence air gap transformers are similar to the compensating transformers except that all taps are brought out from the primary winding to a tap plate. These taps are for the adjustment of the reach of each zone in terms of secondary zero sequence reactance of the line.

The zone one positive and negative sequence line drop compensators are similar to the zones two and three positive and negative sequence line drop compensators in the type HPS Relay, except that the phase angle adjustments are made by means of taps. The 90° tap is but an approximation.

Negative Sequence Current Filter

The filter contains three mutual reactors with three windings each and three resistors as shown schematically in Fig. 6. The output of the filter will be proportional to the negative sequence components of the unbalanced input. There are no taps or adjustments on the filter unit.

OPERATION

Phase Selection With Type HPS Relay

The function of the type HPS relay is to

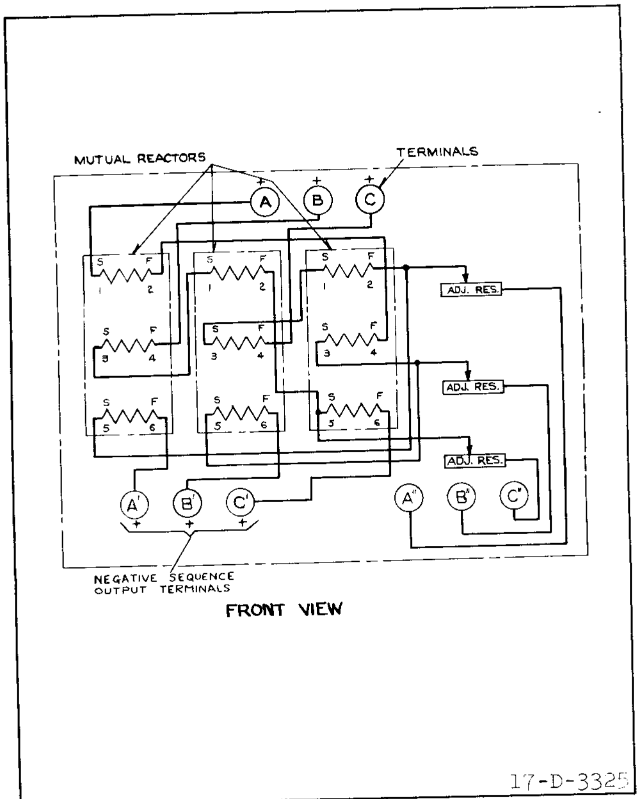

Fig. 6—Internal Schematic Of Negative Sequence Filter.

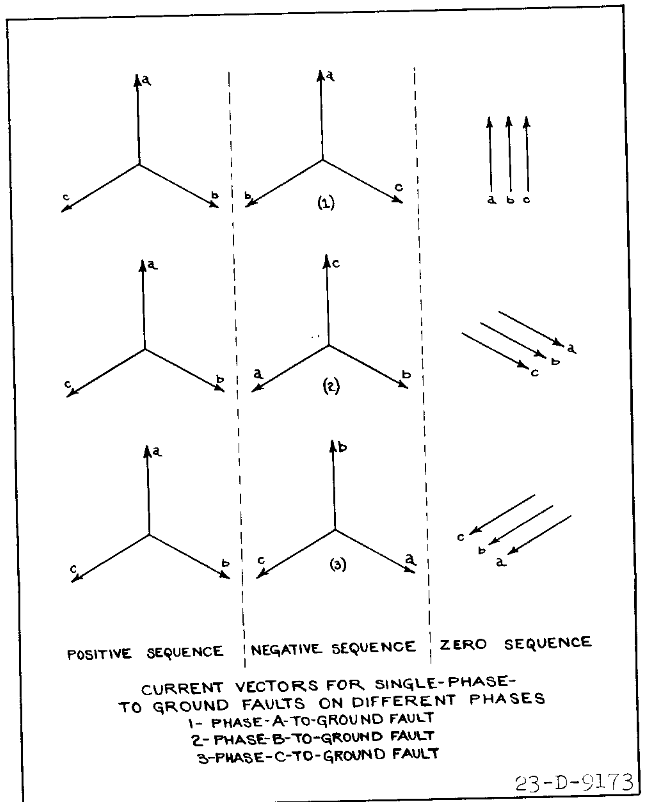

Fig. 7—Phase Relations Of Sequence Currents On Single-Phase-To-Ground Faults.

select the phase which is faulted and to connect the proper phase wire of the secondary of the star connected potential transformer to the reactance elements and the potential coil of the directional elements in the type HXS relay.

The relationship between the positive, negative and zero sequence components of current is shown in Fig. 7. For single phase to ground faults the zero sequence component of current is equal to and in phase with the negative sequence component of current of the phase which is faulted. Thus, a selector element using zero sequence polarizing current and phase A negative sequence current in its other winding will have torque in one direction for a ground fault on phase A and in the opposite direction for a ground fault on phases B and C.

For this application three single loop type directional elements are used. Each is polarized by zero sequence current. A three phase negative sequence current filter is used to provide three phase negative sequence currents. Phase A negative sequence current is supplied to one selector element coil and phase B and C currents to the other two. For a fault on phase A, the element receiving zero sequence current and the phase A component of negative sequence current will have torque in the contact closing direction. The elements receiving the phase B and phase C components of negative sequence current will have torque in the opening direction. Similarly on phase B or C-to-ground fault one element will have closing torque and the other two opening torque.

The a-c connections for one terminal of protection is shown schematically in Fig. 8. The d-c connections are shown in Fig. 9. (These schematics are shown with the transfer switch TS. This telephone relay and its contacts would merely be omitted for relays wired per Fig. 1 and the T3 timer contact would replace the TS contact in series with the third zone indicator.) The phase selector elements have both front and back contacts and these are sc arranged that when the elements operate as ex-

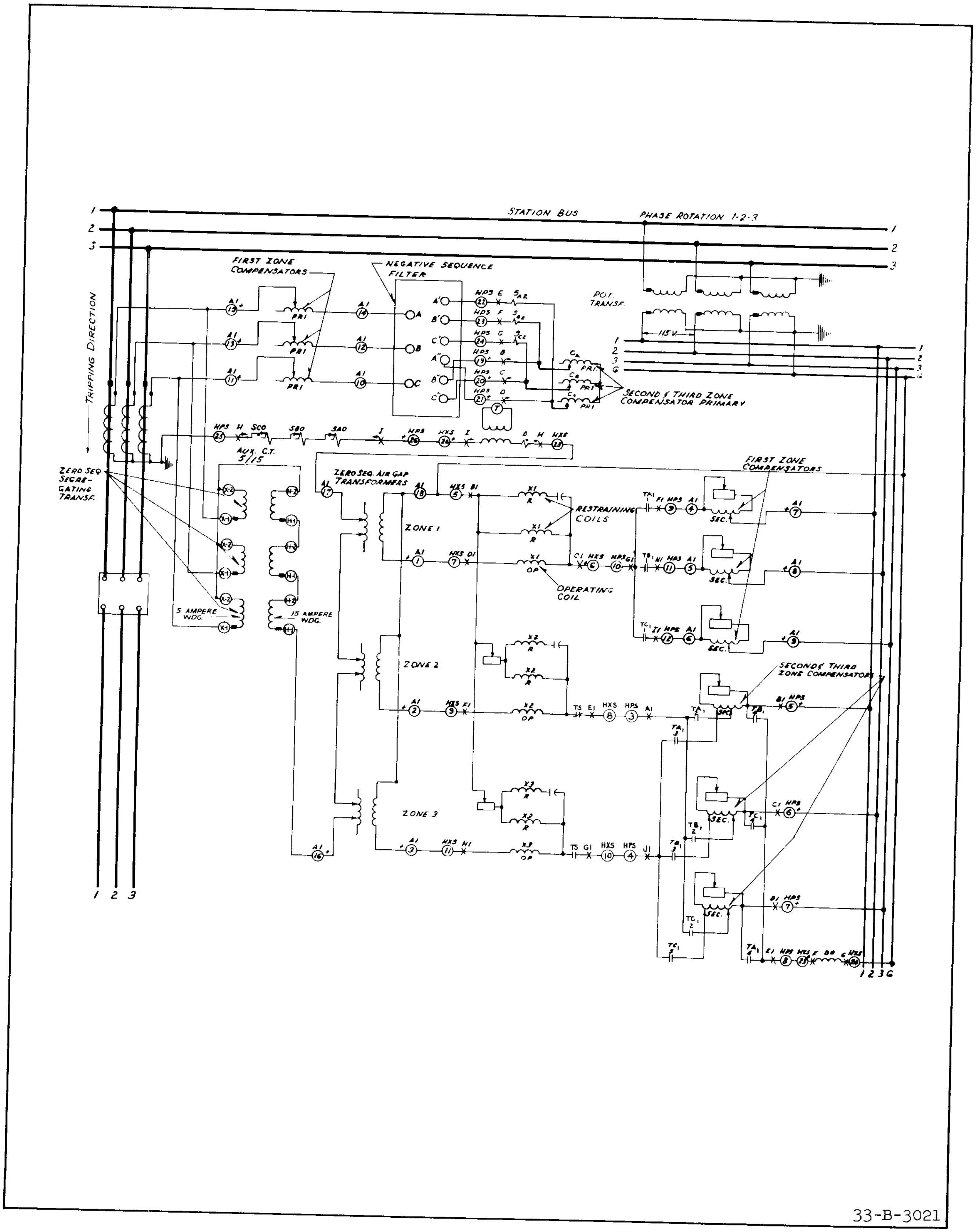

Fig. 8—AC External Schematic Of Type HXS Ground Reactance Relaying Scheme With Type HPS Relay.

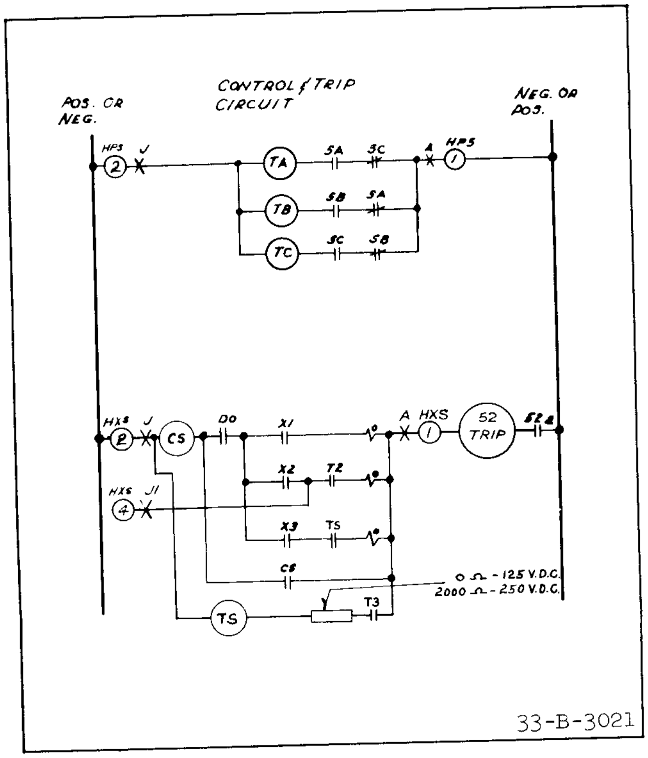

Fig. 9—DC Connections For Type HXS Ground Reactance Relaying Scheme. Using Type HPS Phase Selector.

plained above, the front contacts of the selector element on the faulted phase and the back contacts of one selector element on one of the unfaulted phases form a closed circuit through one telephone type relay coil. This will cause the telephone type relay to pick-up and close its four make contacts simultaneously. The telephone type relay T_A will pick-up on a phase-A-to-ground fault and T_B or T_C will pick-up on a phase B or phase-C-to-ground fault respectively.

In addition to connecting the compensated line to ground voltage of the faulted phase to the reactance elements each telephone relay has one extra make contact which connects the potential coil of the directional element to the proper uncompensated line-to-ground voltage. The line-to-ground voltage selected depends on the phase which is faulted. For a phase-A-to-ground fault the directional element will be connected to phase-C-to-ground

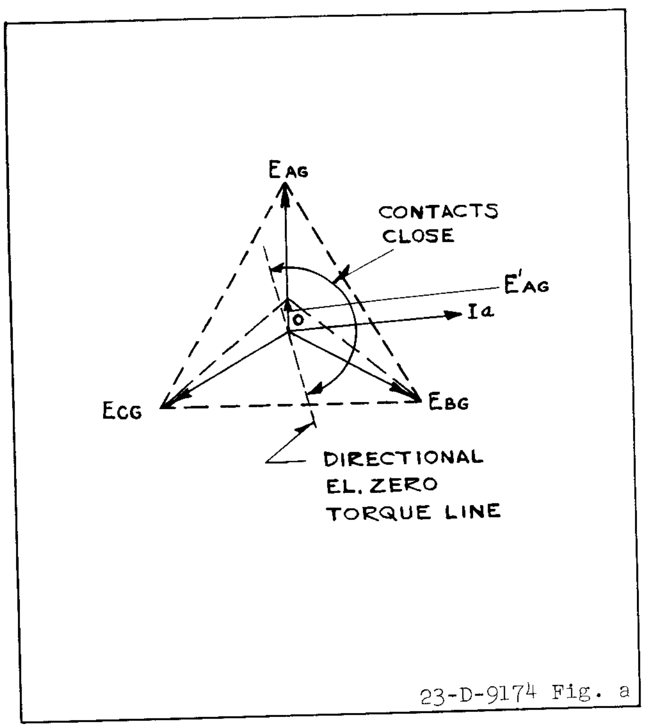

Fig. 10—Vector Diagram Showing Operation Of Directional Element On Single-Phase-To-Ground Fault On Phase A.

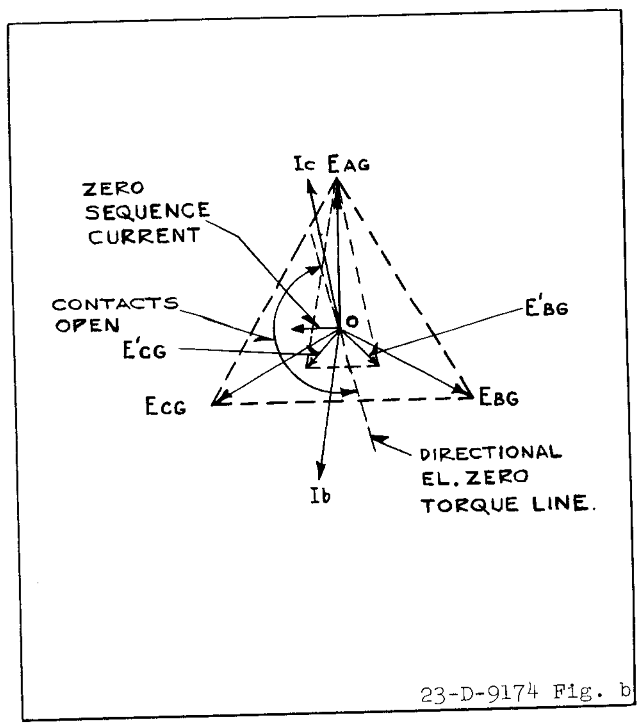

Fig. 11.—Vector Diagram Showing Operation of Directional Element on B-C-to-Ground Fault.

voltage. For a phase B-to-ground fault it will be connected to phase A-to-ground voltage, and for phase C-to-ground fault, it will be connected to phase B-to-ground voltage. Fig. 10 shows the vector diagram for the directional element for a phase-to-ground fault. The directional element current coil is so connected as to receive $-3I_o$ current, and therefore will operate to close contacts and be in the region of maximum torque for all single-phase-to-ground faults.

The type HXS relay scheme, however, does not provide tripping for two-phase-to-ground faults. For a fault such as phases B and C to ground, the zero sequence component of current will be in phase with the negative sequence component of current on the unfaulted phase. This will cause the phase A selector to operate and telephone relay T_A to pick-up. A set of contacts on this relay connects the unfaulted phase A to neutral voltage to the reactance element causing the reactance element to close contacts. The relay is prevented from tripping the breaker, however, due to the fact that telephone relay T_A also connects phase C to neutral voltage to the directional element through another set of contacts. Since the directional element current coil is connected to receive $-3I_o$, it may be seen from Fig. 11 that the directional element will have torque in the opening direction and prevent the breaker from tripping.

Distance Measurement With The Type HXS Relay And Auxiliary Unit For Single-Line-To-Ground Faults.

Since the line to ground voltage at the relay is composed of positive, negative and zero sequence line drops, it is necessary to compensate for the positive and negative sequence line drops. For a phase-A-to-ground fault assuming the fault current from both terminals to be in phase:

$$E_{ag} = (I_1 + I_2)\, MZ_1 + I_o\, MZ_o + 3I_oR_g \qquad (1)$$

where E_{ag} = phase-A-to-ground voltage, and $Z_2 = Z_1$.

I_1 = positive sequence line current
I_2 = negative sequence line current
I_o = zero sequence line current
Z_1 = positive sequence impedance of line
Z_o = zero sequence impedance of line
M = fractional distance of line at which fault occurs.
R_g = fault resistance

The relay will respond to the following impedance:

$$\frac{E_{ag}}{I_o} = \frac{(I_1 + I_2)\, MZ_1 + MI_oZ_o + 3I_oR_g}{I_o} \qquad (2)$$

or:

$$Z_{relay} = \frac{E_{ag}}{I_o} = \frac{(I_1 + I_2)}{I_o} MZ_1 + MZ_o + 3R_g \qquad (3)$$

In equation (3) the first term on the right hand side of the equation is a variable depending upon the distribution of $I_1 + I_2$ and I_o which may change with system connections external to the protected section. The voltage E_{ag} which is applied to the relay, however, may have this term subtracted out, for a fault at the balance point, through the use of the line drop compensator. The voltage which the compensator supplies is $-N(I_1 + I_2)\, Z_1$, where:

N = fractional distance of line section which the relay is set to protect.

$$E_{ag} = I_oMZ_o + (I_1 + I_2)(M-N)Z_1 + 3I_oR_g \qquad (4)$$

$$Z\ relay = MZ_o + 3R_g + \frac{(I_1 + I_2)(M-N)Z_1}{I_o} \qquad (5)$$

at the balance point M = N; therefore,

$$Z\ relay = MZ_o + 3R_g \qquad (6)$$

The relay therefore will receive a constant indication for a fault at the balance point regardless of system connections. The calibration of the element is such that it will respond to the 90° component of this impedance, i.e., reactance, within the limits shown in Fig. 17 and is relatively independent of changes in R_g. Therefore:

$$X_{relay} = MX_o$$

where: X_o = zero sequence reactance of the line.

With relays per Fig. 3, the telephone switch TS is used to separate zone 2 and zone 3 compensation by switching zone 3 into the scheme after the T3 timer contacts close. Thus the current from zone 3 is not flowing in the compensator or the second zone coils when zone 2 only is connected. The TS relay removes zone 2 from the scheme, closes a set of contacts in the zone 3 trip circuit, and connects zone 3 into the scheme. This connection is electrically similar to the phase selector connection of zone 1 and 2. Thus if the fault is in zone 3, the subsequent operation of X3 will initiate tripping. The CS switch would immediately seal around the D_O, X_3, and TS contacts. The TS switch will drop out as soon as the timer begins to reset.

SETTINGS

AUXILIARY UNIT

There are three settings to be made on the auxiliary box. They are (a) the settings for the zero sequence reactance of the line for that portion of the line to be protected, (b) the zone one positive and negative sequence line drop compensation, and (c) the phase angle of positive sequence impedance for zone one of the relay.

(a) Zero Sequence Settings for Zone 1, 2 and 3

Table I gives the nominal tap values for P_o and S_o for the three zones of protection in terms of zero sequence reactance ohms. Tap setting is determined by using the following formula:

$$P_o + S_o = \frac{R_c K_2 X_o}{R_v}$$

where P_o = tap setting on primary of zero sequence transformer in terms of zero sequence reactance.

S_o = fine tap setting on primary of zero sequence transformer in terms of zero sequence reactance.

X_o = zero sequence reactance of line
R_c = current transformer ratio
R_v = voltage transformer ratio
K_2 = portion of line protected

Recommended values:

For the First Element - 75% of protected section.

For the Second Element - Approx. 50% into the adjacent section.

For the Third Element - Approx. 25% into the third line section.

(b) Positive and Negative Sequence Line Drop Compensator Settings for Zone 1

Tables II and III give the nominal tap settings for the compensators for the three zones. Fig. 12 gives the value of constant K_1.

The line drop compensator setting is made in accordance with the formula:

$$P_c S_c = \frac{Z_1 R_C K_1 K_2}{R_v}$$

where:

P_c = setting of compensator primary in ohms
S_c = setting of compensator secondary in ohms
Z_1 = positive sequence impedance of line in ohms
R_c = current transformer ratio
R_v = voltage transformer ratio
K_2 = portion of line to be protected. In general this should be the same as K_2 used in zero setting.
K_1 = a constant determined by positive sequence angle of the line. See Fig. 12.

(c) Zone One Phase Angle Settings

The compensator has a phase angle setting, ϕ_c. This is chosen by selecting a tap whose value is close to the positive sequence impedance angle of the line. The possible settings of the first zone compensator are listed in Table II.

The formula settings will be sufficiently accurate for most installations. Where it is

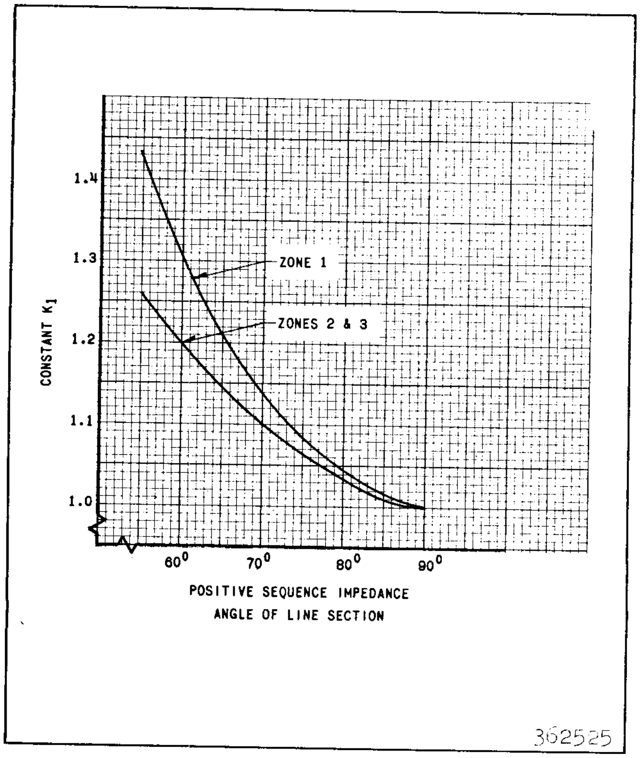

Fig. 12—Curve For Determining Value Of Formula Constant K1.

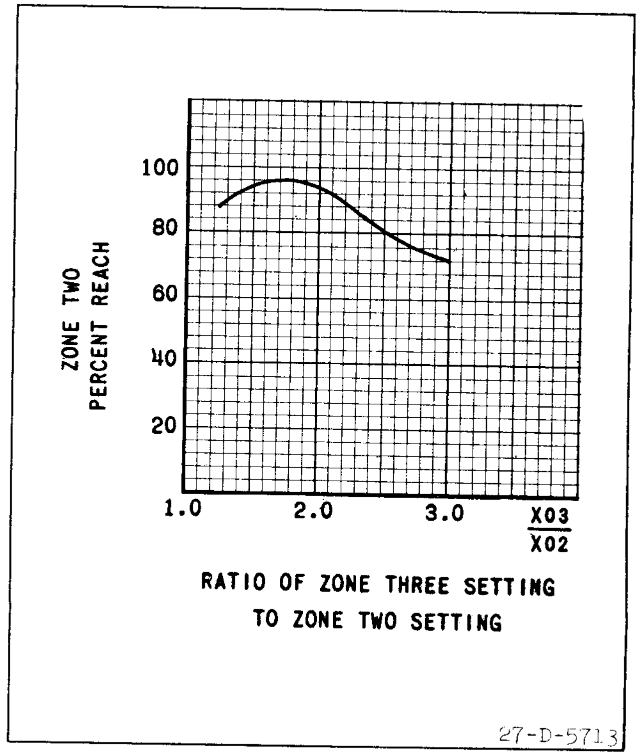

Fig. 13—Curve of Reach vs Ratio of 2nd And 3rd Zone Setting.

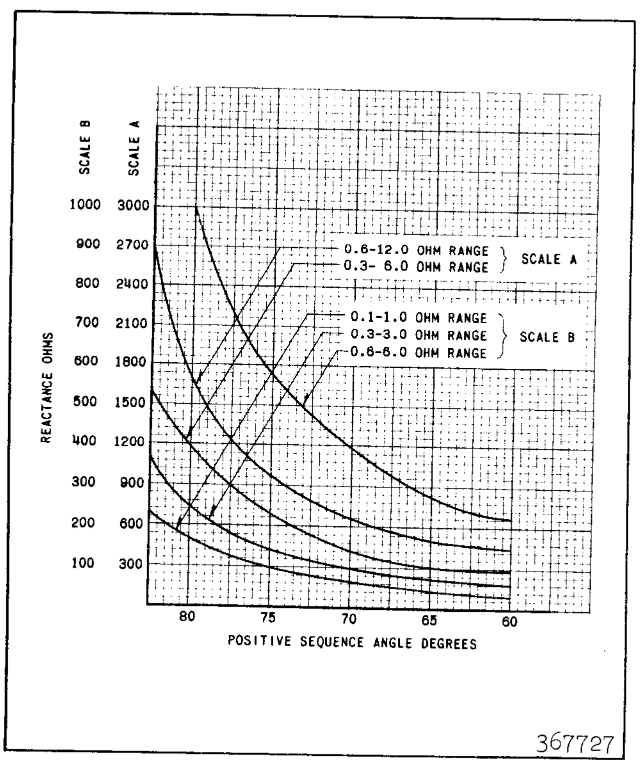

Fig. 14—Line Drop Compensators Resistances vs. Phase Angle Setting.

desired to set the balance point more accurately the tap values may be checked by applying to the relay the voltage, current and phase angle conditions which will be impressed on it for a fault at the desired balance point. A slight change in the tap value from the calculated value may be required on either the zero sequence ohms tap or the compensator tap for the relay to just trip for the fault at the simulated balance point.

NEGATIVE SEQUENCE FILTER

This unit is adjusted and calibrated at the factory and requires no setting.

TYPE HXS RELAY

There are no settings to be made on this relay. The reactance element is calibrated at the factory and should require no further adjustment. If, however, it is desired to check or recalibrate this element, the procedure to be followed is given under "Reactance Element Calibration". The settings for adjustment of the reach of this element are located on the auxiliary Unit.

TYPE HXS RELAYING SYSTEM

TYPE HPS RELAY

There are three settings to make on the HPS relay. They are: (a) sensitivity of the selector elements, (b) second and third zone Line Drop Compensators, (c) Positive sequence impedance angle.

(a) Phase Selector Elements

The minimum pick up of the element can be adjusted by means of taps on the polarizing winding. A tap plate located on each selector element is provided to select the number of polarizing winding turns on each selector element. The ten turn tap is recommended for all applications and this combination should be selected. The minimum pick up for this tap is 1.3 amperes. Other available taps are listed in Table IV.

The negative sequence coils of HPS selector elements are connected to terminals A' A" B' B" and C' C". With this connection zero sequence must be eliminated from the filter input. This is done by the action of the zero sequence segregating network on the input to the filter.

(b) Second and Third Zone Line Drop Compensators

The settings for positive sequence impedance are made exactly as for the first zone compensators except that having selected the primary tap P_c when setting the second zone compensation, the third zone reach is achieved by moving the zone three secondary tap so that the product of P_C S_C3 will equal the value desired for the third zone. Sufficient range of secondary tap adjustment is provided for this. Table III gives values of secondary taps and Fig. 12 gives the constant K_1 for the formula.

The tap values of P_c in terms of the secondary positive sequence impedance ohms are marked on the tap plate located on the left hand side of the line drop compensator tap block. The secondary adjustment, consisting of 16 taps is located on the right side of the block. There are two secondary leads. One is for the second zone adjustment S_c2 and the other is for the third zone adjustment S_c3. These leads can be moved independently of each other. The lead farthest to the right is S_c3. Fig. 4 shows the positions of these taps.

(c) Positive Sequence Impedance Angle

The adjustment of the angle of the line drop compensators for zones two and three to match the angle of the positive sequence impedance of the line, is accomplished by setting an adjustable resistor. There is one resistor for each compensator. The three resistors are located at the bottom of the relay case. From left to right (front view) they are phase A, phase B, and phase C. The values of resistance for a given angle are checked at the factory and a setting should be selected so that the compensator angle is equal to the line angle. The curve in Fig. 14 shows the resistance at which to set the sliders to obtain the desired angle.

There are no adjustments on the telephone relays. If it is desired to check them electrically for positive pick-up, 125 volts d-c should be applied across terminals 1 and 2 to the HPS relay and the proper selector contacts operated mechanically or electrically to pick-up each relay. Front contacts of S_A and back contacts of S_C must be closed to pickup T_A. These relays are not continuously energized in service. When testing at 125 volts d-c these relays should not be energized for any appreciable length of time since their continuous rating is 60 V. d-c.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount each relay vertically by means of the two mounting studs for the standard case and the type FT projection case, or by means of the four mounting holes on the flange for the semi-flush type FT case. Either of the studs or the mounting screws may be utilized for grounding the relay. The electrical connections may be made direct to the terminals by means of screws for steel panel mounting or to terminal studs furnished with the relay for ebony/asbestos or slate panel mounting. The terminal studs may be easily removed or inserted by locking two nuts on the studs and then turning the proper nut with a wrench.

CONNECTIONS

Fig. 8 shows schematically the connections for one line terminal and the interconnections of relays and auxiliary units.

ADJUSTMENTS AND MAINTENANCE

Type HXS Relay

The proper adjustment to insure correct operation of this relay has been made at the factory and should not be disturbed after receipt. It it is desired to check the adjustments at regular maintenance periods, the instructions below should be followed.

All contacts should be periodically cleaned with a fine file. S#1002110 file is recommended for this purpose. The use of abrasive material for cleaning contacts is not recommended because of the danger of embedding small particles in the face of the soft silver. and thus impairing the contact.

Type HXS Relay Directional Element

Check the free movement of the directional element loop. The loop should assume approximately a vertical position with contacts open when the element is completely de-energized.

The movement of the loop is limited in the contact opening direction by a stop screw which strikes the lower part of the loop. This screw is located on the left-hand side of the element to the rear of the current coil. The back stop screw should be screwed forward until it just touches the loop when it is in its natural de-energized position. Set the contacts for a separation of .020 inches. Set the front loop stop screw so that it touches the loop at the same time the contacts close. Then back off this screw 1/4 of a turn to give the contacts the right amount of follow.

Energize the loop with normal potential and adjust the bearing screws so there is about .010 inch end play. See that the loop does not bind or strike against the iron or coil when pressed against either end jewel.

Apply 5 amperes suddenly at 2.5 volts in phase to the directional element and make sure that a good contact is made. It may be necessary to adjust the stationary contact slightly in order to obtain a good steady contact. Reverse the polarity and apply 70 volts and 5 amperes. This polarity reversal will cause the contacts to open. Make sure that the contacts will not bounce closed when the voltage is suddenly interrupted.

Too much follow on the directional contacts should be avoided in order to allow the directional element to reset fast enough by gravity to properly coordinate with the high speed reactance elements.

When the directional element is energized on voltage alone, there may be a small torque which may hold contacts either open or closed. This torque is small and shows up only at high voltages with the entire absence of current. At voltages high enough to make this torque discernible, it will be found that only a fraction of an ampere in the current coils will produce wattmeter torque to insure positive action. This is mentioned because the slight torque shown on voltage alone has no significance in actual service and has no practical effect on the directional element operation.

Contactor Switch (Seal-In-Switch)

Adjust the stationary core of the switch for clearance between the stationary core and the moving core of .025 inch when the switch is picked up. This can be done by disconnecting the switch, turning it up-side-down and turning the core screw until the contact just separates. Back off the core screw approximately one turn and lock in place. This prevents the moving core from striking and sticking to the stationary core because of residual magnetism. Adjust the contact clearance for 3/32 inch by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 1.0 ampere direct current. Test for sticking after 30 amperes direct current is passed through the coil. The resistance of the coil is approximately 0.8 ohms.

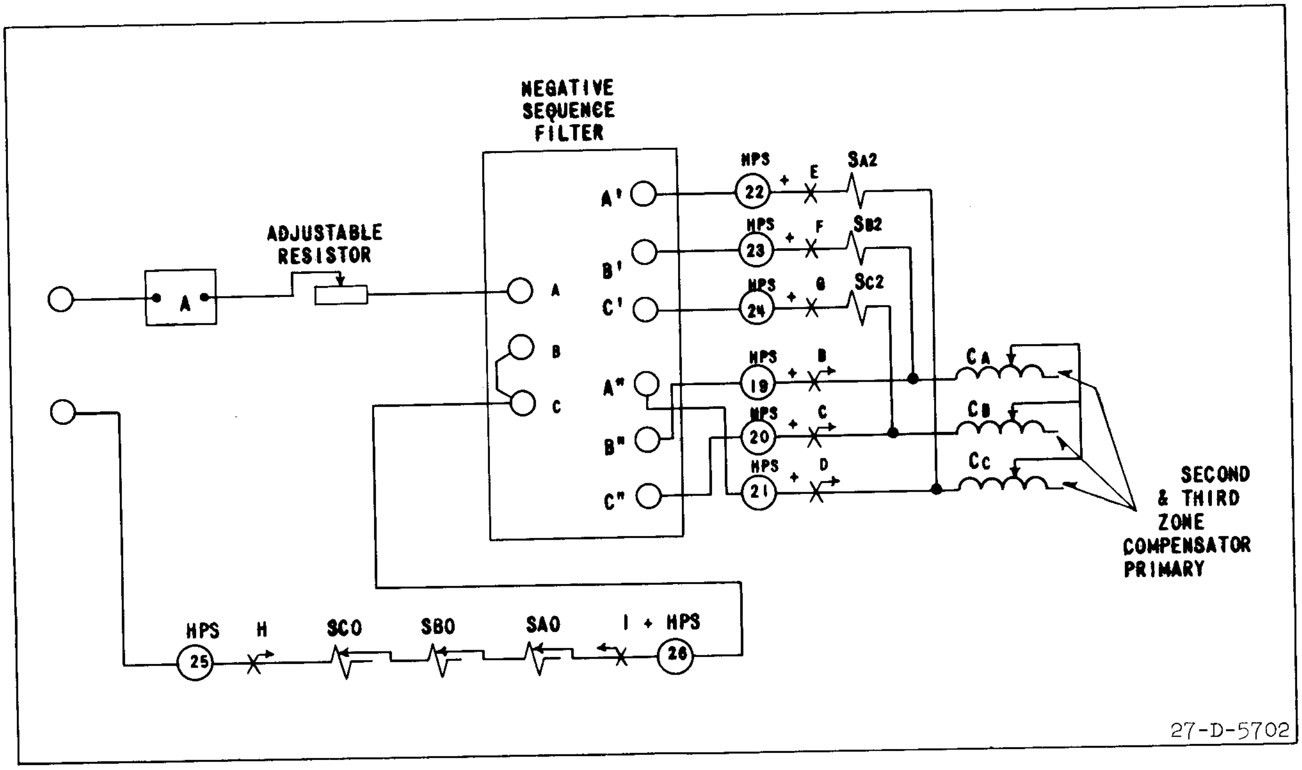

Fig. 15 – Test For Calibration Of Phase Selector Elements.

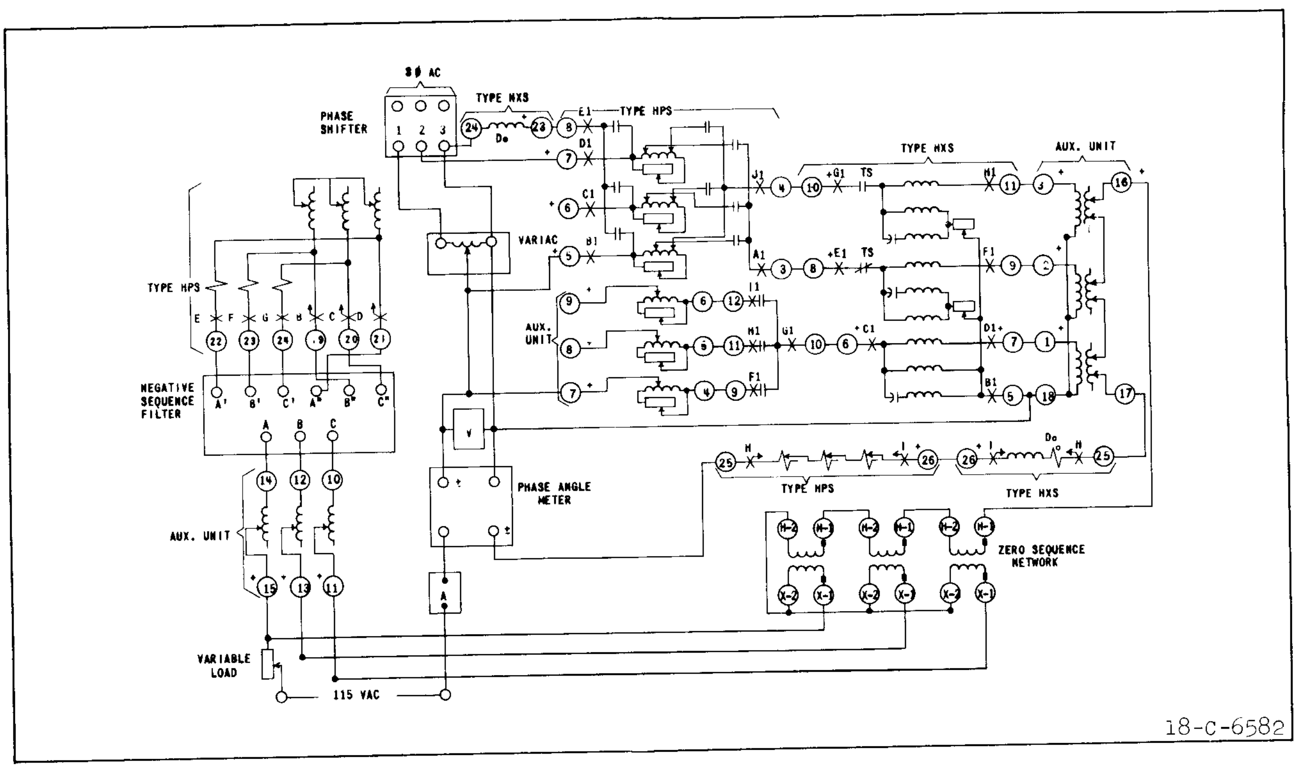

Fig. 16 – Test Connections For Calibration Check of a Reactance Element.

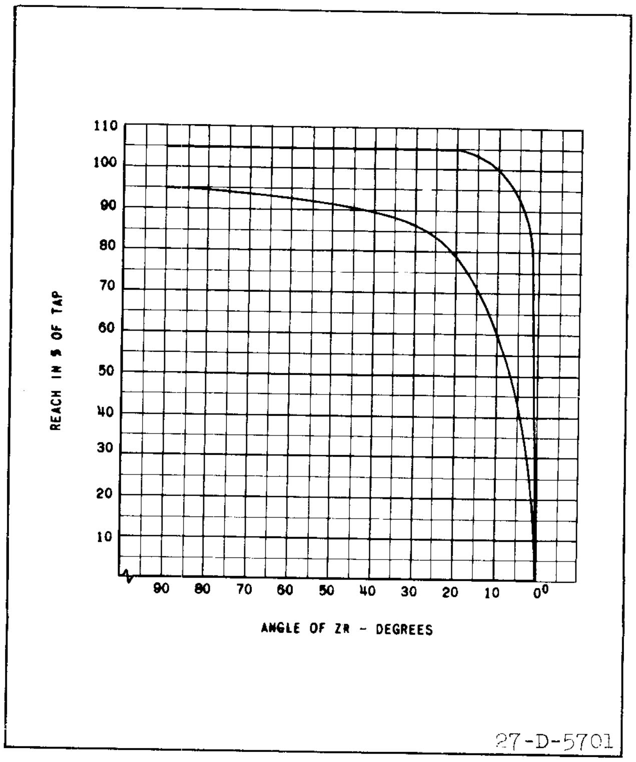

Fig. 17—Typical Reactance Characteristics.

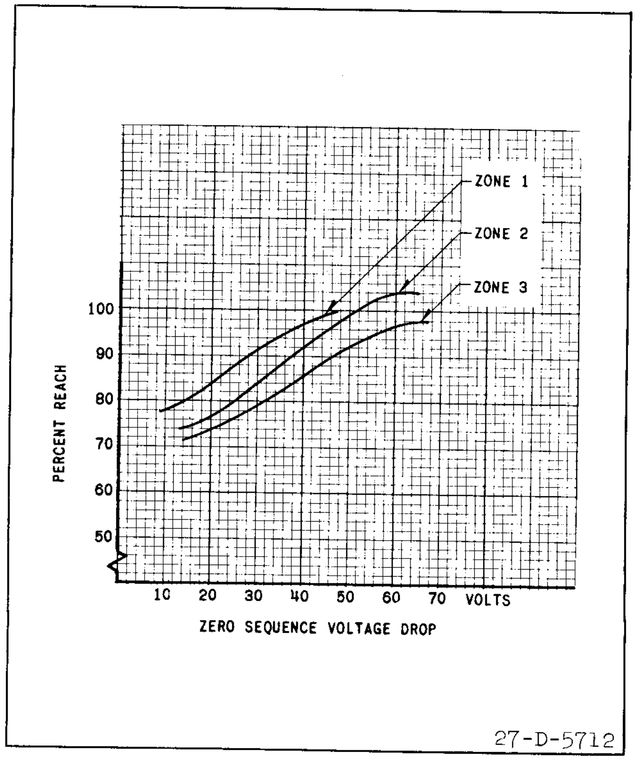

Fig. 18—Voltage Characteristic of Type HXS Relay.

Operation Indicator

Adjust the indicator to operate at 1.0 ampere direct current gradually applied. Test for sticking after 30 amperes direct current is passed through the coil.

Synchronous Timer

Pass 2.5 amperes through the timer transformer primary. Check the timer motor with a neon lamp or with a cycle counter to see if it runs at synchronous speed. See that the moving contact properly bridges both sets of stationary contacts and resets from any position.

Trip Circuit

The contactor switch operates on a minimum of 1.0 amperes but the trip circuit should draw at least 4 to 5 amperes in order to reduce time of operation of the switch to a minimum and provide positive operation.

Telephone Relay

There is no adjustment on the telephone relay. If it is desired to check the electrical pick-up, d-c voltage should be applied across terminals 1 and 2 of the HXS relay. Care should be taken not to close the D and K contacts unless the test circuit also contains a current limiting load for the CS switch. This relay is not continuously energized in service When testing at 125 volt d-c the relay should not be energized for any appreciable length of time since the continuous rating is 60 v.d.c.

Beam Type Reactance Element

The magnetic gap settings are made at the factory to set the reactance curve within the limits shown in Fig. 17. These settings are quite critical and should not be disturbed in the field. If it is necessary to check this characteristic the following procedure is recommended.

1. Make set-up similar to Fig. 16.
2. Set taps on auxiliary unit and type HPS relay as follows:

	P_o	S_o	P_c	S_c	ϕ_c
Zone 1	D_1	H_1	#		78°
Zone 2	D_2	H_2			78°
Zone 3	D_3	H_3			78°

#Set $P_c + S_c$ for one third of $P_o + S_o$. The values will depend upon the zero sequence range of the relay being tested (see table I).

Electrical Test:

1. Set voltage source to 70 volts. Close selector element contacts to pick-up auxiliary switch on phase being tested with zero current in the zero sequence circuit. This will apply full line to neutral voltage to the reactance elements. The beams should not trip under repeated tests. This test determines that the relay will not overreach on a very remote fault.

2. Set voltage to 30 volts and the phase angle of line-to-ground voltage and fault current to ϕ_c, the angle of the line. Adjust the resistor in the current circuit to give a value of current slightly less than the trip current. Close the switch several times at this value of current then increase the current and repeat. In this manner determine the value of current at which the beam will trip for every switch operation. Change the phase angle to 30° and 20° and repeat this procedure. A sample calculation follows showing the percent reactance measured.

Sample Calculations:

The following calculation of the reach of the reactance element from test data is shown for zone one of the relay.

#Zero sequence range = 3.0-12.0

Compensator .6-6.0

Settings	#$P_o + S_o$	$P_c \times S_c$	ϕ_c	K
	$D_1 + H_1$	$B_1 \times H_1$	ϕ_2	-
	6.0 + 0.0	1.78x1.24	72°	1.12

Test results:	E_{ag}	I_a	θ
	30.0	8.8a	72°

where: E_{ag} = line to ground voltage on phase A

I_a = fault current in phase A

θ = angle of E_{ag} and I_a

Calculation:

I_a = 8.8 amps.

$I_o = \frac{I_a}{3}$ = 2.94 amps.

$(I_1 + I_2) = 2I_o$ = 5.88 amp.

$$E_{Z1c} = \frac{(I_1 + I_2)\, Z1c}{K} = \frac{5.88 \times 1.78 \times 1.24 \angle 72°}{1.12}$$

$= 11.5 \angle 72°$ volts

$E_{ag} = 30.0 \angle 72°$ volts

$E_{Z1c} = 11.5 \angle 72°$ volts

$E_R = E_{ag} - E_{Z1C} = 18.5 \angle 72°$ volts

$$Z_R = \frac{E_R}{I_c} = \frac{18.5 \angle 72°}{2.94} = 6.3 \angle 72° \text{ ohms}$$

$Z_R = 1.94 + j6.0$

% Reach = 100%

3. Repeat this procedure for zones two and three using 45 volts line to ground and again calculate the reach of the relay. Compare the above results to the curve of Fig. 17.

If the actual operating conditions of the relay are known for faults at the balance point it is of course advisable to test the relays with these conditions impressed.

TYPE HPS RELAY

Adjustment of Selector Elements

With the relay in the vertical position, check the loop to see that it is free from friction, properly centered in the gap and free to swing.

Adjust the bearing screws so that there is about .010" end play on the loop. See that the loop does not bind or strike the iron or coil when pressed against either end jewel.

The adjustments consist of a left and right hand loop stop screw to limit the travel of the loop and a right and left hand spring tension screw adjuster.

Set the left and right hand loop stop screws so that the loop will have maximum travel but will not touch the magnet frame.

Left Hand Contact

With the loop in the normal de-energized position adjust the left contact tension spring screw so that the stationary contacts just touches the movable bridge. Since the bridge is free to turn it is important that both stationary contacts be aligned.

Right Hand Contacts

With loop in the vertical position adjust the right contact tension spring screw for .015 inch gap. Apply the minimum pick-up current as given under Phase Selector Element Settings and align the stationary contacts with the bridging contact so that the auxiliary switch picks-up at this current.

Electrical Check

With equipment connected as shown in Fig. 16 which is a simulated phase A to ground fault and the selector taps set to 10 turns, the phase A selector should close contacts to the right, phase B and C elements should have torque to the left. The telephone relay T_A, should pick-up within the values listed in section on Phase Selector Element Settings.

If it is required to test the type HPS relay and the Negative Sequence Filter separately, a partial circuit may be used. Connect the filter and relay as in Fig. 15. Introduce the current into terminal A of the filter for a simulated phase-A – to-ground fault as shown, and check element operation as above for a phase-B – to-ground fault. Connect current source to terminal B of the filter and connect terminals A and C together. Similarly for a phase-C-to-ground fault connect current source to terminal C of the filter and connect terminals A and B together.

STANDARD RELAY RANGES

The ranges are available in the following combinations:

ZONE	ZERO SEQUENCE REACTANCE 1	2	3	POSITIVE SEQUENCE COMPENSATOR ZONE 1
Range 1	0.5-2.0	1.5-6.0	3-12	0.1-1.0
Range 2	1.5-6.0	3-12	6-24	0.3-3.0
Range 3	3-12	6-24	10-40	0.6-6.0

The second and third zone positive sequence compensator is available with 0.3-6.0 ohms or 0.6-12 ohms. (See Table III)

TABLE I

Zero Sequence Reactance

	Nominal Range 5-2.0	1.5-6.0	3-12	6-24	10-40
P_O Tap Marking					
A	0	0	0	0	0
B	.5	1.0	3.0	6.0	10
C	.75	2.0	4.50	9.5	16
D	1.0	3.0	6.0	13.0	22
E	1.25	4.0	7.50	16.5	28
F	1.50	5.0	9.0	20.0	34
G	1.75	6.0	10.50	23.5	40
S_O Tap Marking					
H	0	0	0	0	0
I	.1	.25	.5	.75	1.0
J	.2	.50	1.0	1.50	2.0
K	.3	.75	1.5	2.25	3.0
L	.4	1.0	2.0	3.0	4.0
M	.5	1.25	2.5	3.75	5.0

Values above are secondary ohms.

TABLE II

First Zone Positive and Negative Sequence Line Drop Compensators (In Auxiliary Unit)

	Nominal Range .1-1.0	.3-3.0	.6-6.0
P_C Tap Marking			
F	.10	.30	.60

G	.17	.52	1.03
H	.30	.89	1.78
I	.51	1.53	3.05
J	.87	2.63	5.25
S_c Tap Marking			
A	1.12	1.12	1.12
B	1.24	1.24	1.24
C	1.36	1.36	1.36
D	1.48	1.48	1.48
E	1.60	1.60	1.60

Values above are in secondary ohms.
The following phase angle taps are available:

66° - 72° - 78° - 84° - 90°

TABLE III

Second and Third Zone Positive Sequence Line Drop Compensators (In Type HPS Relay)

Primary Taps 0.3 - 6.0 P_c	Primary Taps 0.6 - 12 P_c	Tap Positions	+ Secondary Taps 0.3 - 6.0 S_c2	+ Secondary Taps 0.6 - 12 S_c2
.30	.57	1	1.0	1.0
.54	1.02	2	1.10	1.10
.97	1.94	3	1.20	1.20
1.75	3.54	4	1.30	1.30
3.25	6.30	5	1.40	1.40
		6	1.50	1.50
		7	1.60	1.60
		8	1.70	1.70
			S_c3	S_c3
		9	1.80	1.80
		10	1.91	1.91
		11	2.02	2.02
		12	2.13	2.13
		13	2.24	2.24
		14	2.35	2.35
		15	2.46	2.46
		16	2.57	2.57

P_c Values above are in secondary ohms
+ Refer to Fig. 3.

TABLE IV

Polarizing Winding Turns	¢Minimum $3I_o$ Pick-up Amperes	Maximum $3I_o$ Amperes	Connection of Links
17	1.0	100	3 to B, 2 to A, 4 to 1
10	1.3	100	1 to B, 2 to A
7	1.55	100	3 to B, 4 to A
3	2.37	100	2 to A, 1 to 3, 4 to B

¢The approximate minimum pick-up current for single phase to ground fault.

ENERGY REQUIREMENTS

Types HXS Relay	Range Zero Sequence	Amps I	Min. Tap	Burden in V.A. Max Tap	Angle
	.5 - 2.0	5.0	.1	.65	53°
	1.5 - 6.0	5.0	.16	5.75	60°
	3.0 -12.0	5.0	1.44	22.0	70°
	6.0 -24.0	5.0	1.44	23.0	70°
	10.0 -40.0	5.0	1.44	24.0	70°

Zone 1 Positive Sequence Compensator Range	I	Min.	Max.	Angle
.1 - 1.0	5.0	.05	3.25	65°
.3 - 3.0	5.0	.1	4.0	65°
.6 - 6.0	5.0	.16	21.0	65°

Type HPS Relay	Zone 2 & 3 Positive Seq. Compensator Range	I	Min.	Max.	Angle
	.3 - 6.0	5.0	.1	10.0	68°
	.6 -12.0	5.0	.1	12.0	68°
	1.0 -20.0	5.0	.1	12.0	68°

	I	VA
Zero Sequence Segregating Transformers	5.0	9.0

Type HXS Relay	Potential Burden	Volts	VA	PF Angle
HXS Relay	Reactance elements including compensators	67	19.0	20° lag
HXS Relay	Directional element	67	1.25	20° lag

Current Circuits

	Amps	VA	PF Angle
Directional element	5.0	2.22	20° lag
Timer Motor (Based on 3.3 transformer)	5.0	5.6	67° lag

Type HPS Relay	I	VA	PF Angle
Phase Selector Coils SA_2, SB_2, SC_2	5.0	1.75	72° lag
Phase Selector Coils SA_0, SB_0, SC_0	5.0	2.75	2° lag
17 turns			
3 turns	5.0	1.22°	16° lag

Telephone Relays	Ohms	Pick-Up	Rated Volts	Continuous Control Volts
TA	1300	30V, d-c	66V. d-c	125 V. d-c
TB	1300	30V, d-c	66V. d-c	125 V. d-c
TC	1300	30V, d-c	66V. d-c	125 V. d-c

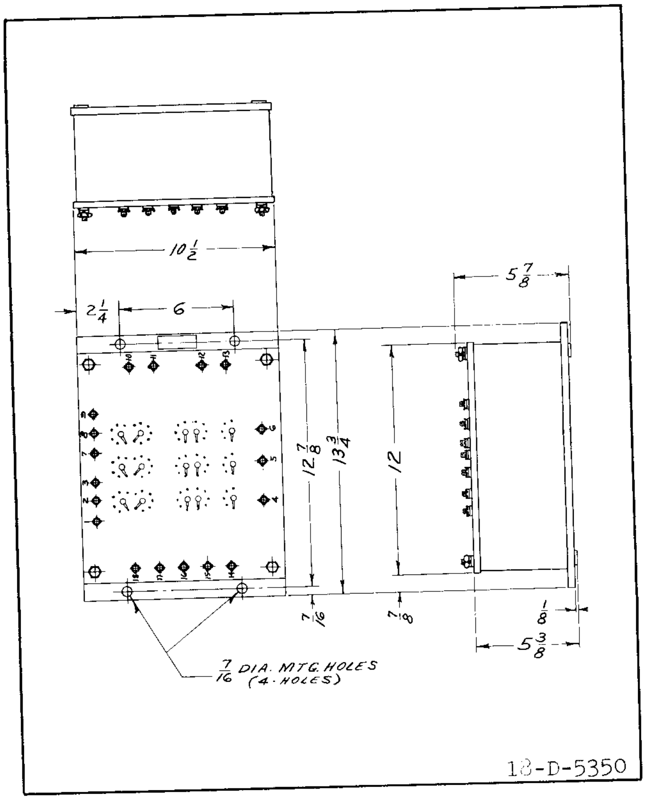

Fig. 19—Outline And Drilling Of The Auxiliary Unit.

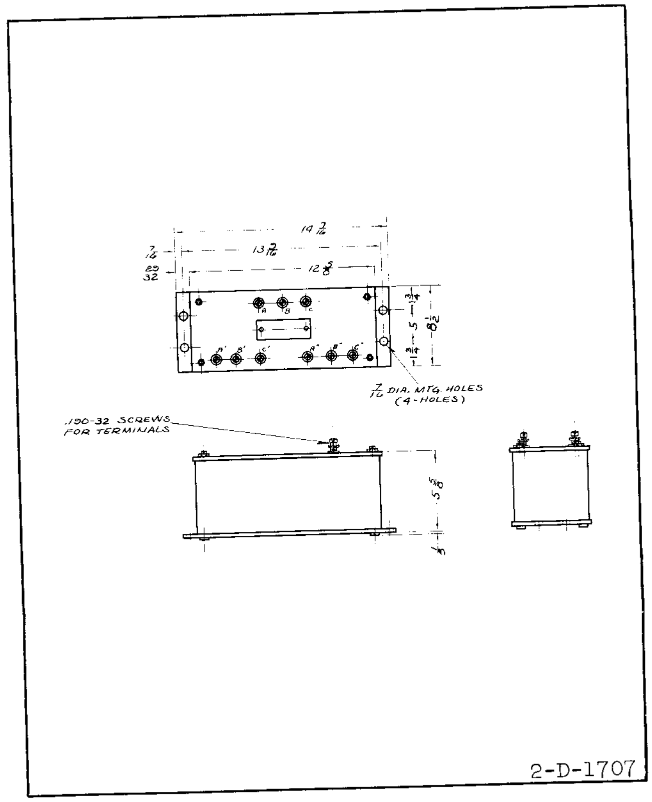

Fig. 20—Outline And Drilling Plan Of The Negative Sequence Filter.

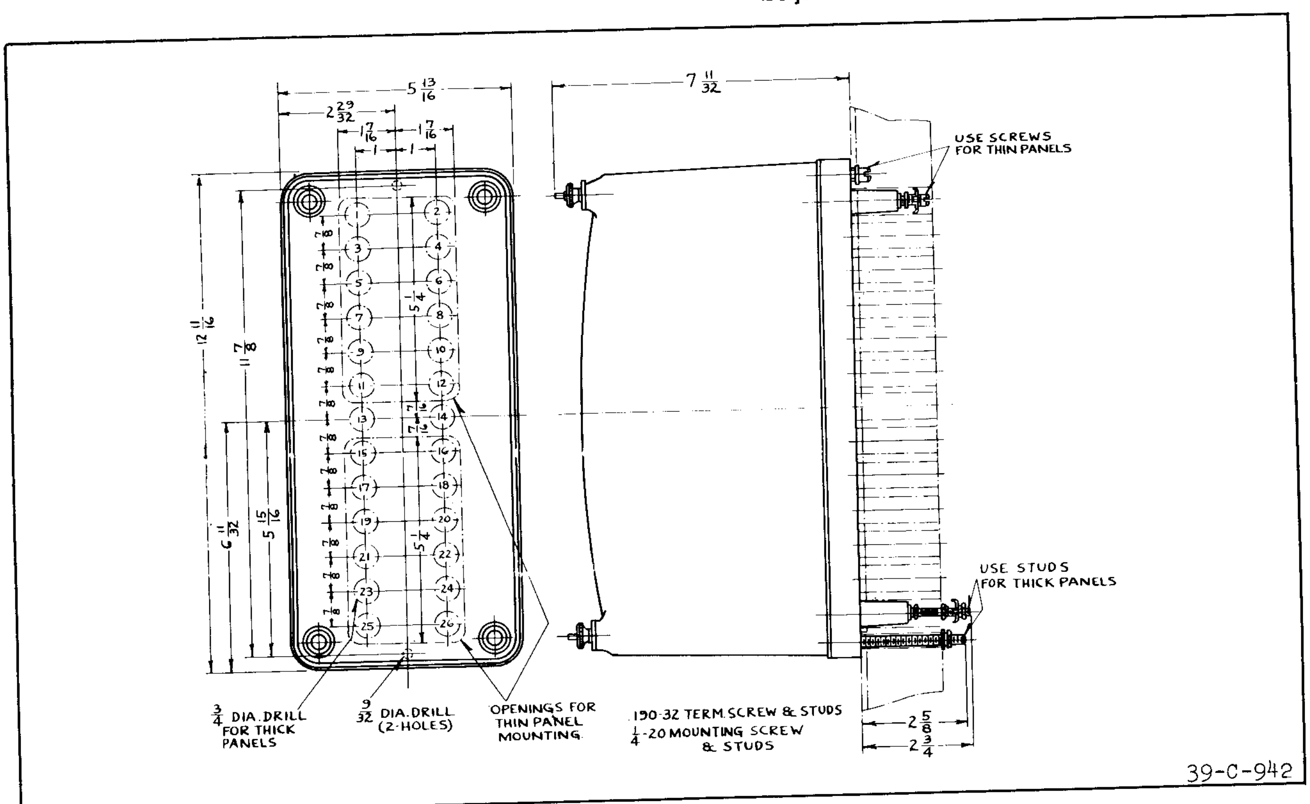

Fig. 21—Outline And Drilling Plan Of The Type HXS Relay And Type HPS Relay For The Standard Projection Case. For Reference Only.

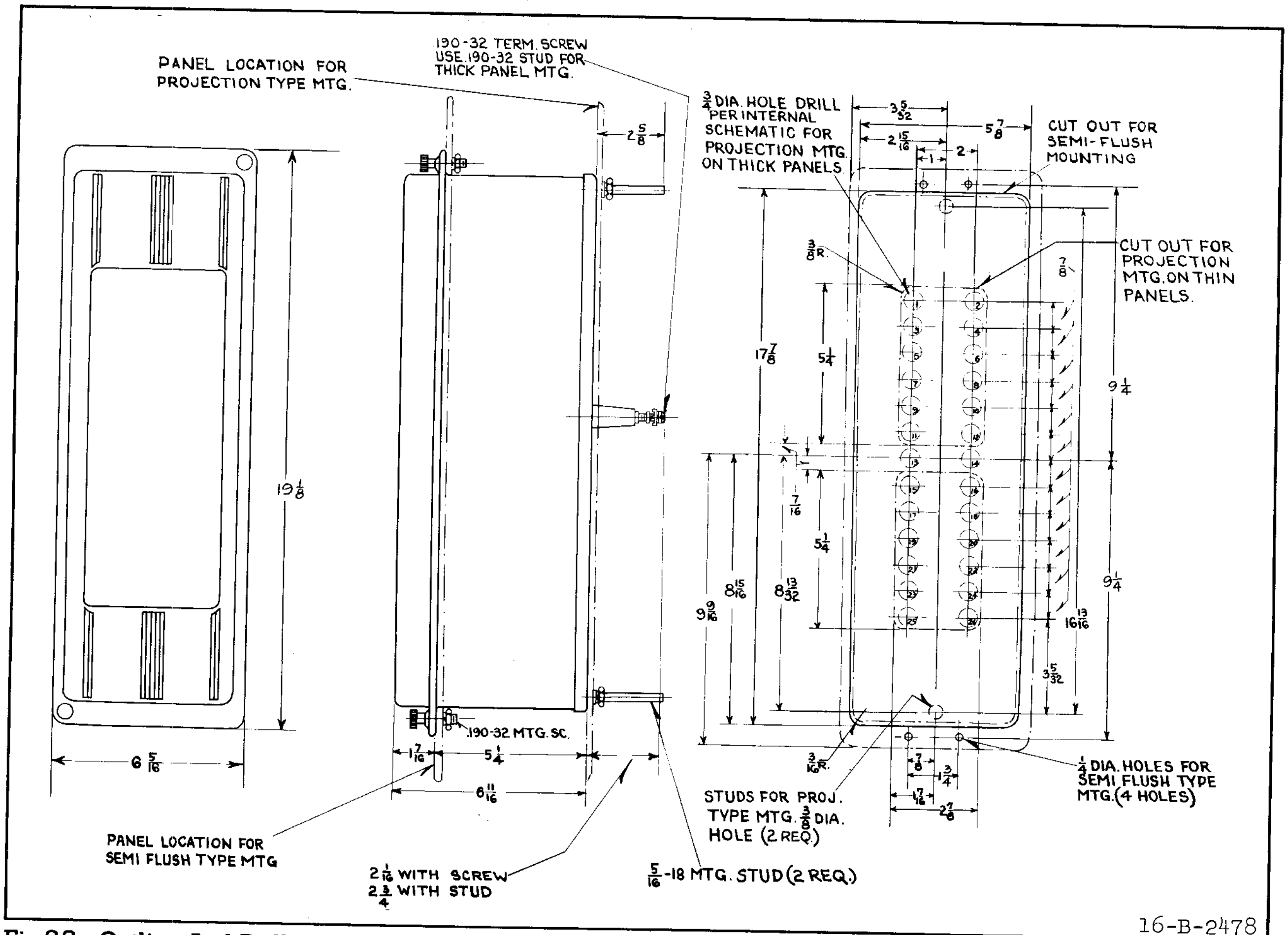

Fig.22—Outline And Drilling Plan For The Type HXS Relay And Type HPS Relay For The Projection Or Semi-Flush Type FT Case. For Reference Only.

INSTALLATION • OPERATION • MAINTENANCE
INSTRUCTIONS

TYPE HXS GROUND REACTANCE RELAYING SYSTEM

CAUTION Before putting protective relays into service, remove all blocking which may have been inserted for the purpose of securing the parts during shipment. Make sure that all moving parts operate freely. Inspect the contacts to see that they are clean and close properly, and operate the relay to check the settings and electrical connections.

APPLICATION

The Type HXS ground reactance relaying system is of the high-speed three-zone directional distance type. It is designed to protect a transmission line upon the occurrence of a single line-to-ground fault within the protected zones. Zone one, usually set for approximately 75 percent of the first line section, will initiate breaker operation without intentional time delay. Zones two and three can be delayed to coordinate with other relays on the adjacent line sections. For faults involving more than one phase, this equipment will not initiate breaker operation. The usual phase relays are required for these faults.

The distance elements are of the balanced beam reactance type and utilize zero sequence quantities to determine the zero sequence reactance of the line from the relay to the balance point. These quantities are obtained from the fault current and voltage at the relay by the use of sequence networks and line drop compensation. Only one distance relay is needed to provide complete three-phase protection, since use is made of a phase-selector relay operated by negative and zero sequence quantities, to connect only the line-to-ground voltage of the faulted phase to the distance element.

Three-phase star-connected current and potential transformers are needed at the relay location as well as station battery service.

CONSTRUCTION

One terminal of relaying consists of the following equipment:

one type HXS relay
one type HPS relay
one auxiliary unit
one set of 5/15 auxiliary current transformers
one negative sequence filter

TYPE HXS RELAY

The type HXS relay contains three reactance beam elements, one for each zone, auxiliary switches, operation indicators, one single loop type directional element and a synchronous timer. These are shown schematically in Fig. 1.

Reactance Elements

The reactance elements are of the balanced beam high speed type. The reactance characteristic is obtained by balancing the torques resulting from the vector sum of current and voltage on the contact or operating end against the voltage restraint on the back end of the beam. The current ampere turns on the operating end must be shifted 90 electrical degrees from the voltage ampere turns. This is accomplished by the use of an air gap transformer in the zero-sequence current circuit.

The voltage drop induced in the secondary of the zero sequence transformer is proportional to $3I_0$ and will lead the primary current $3I_0$ by 90°. This voltage causes a current to flow

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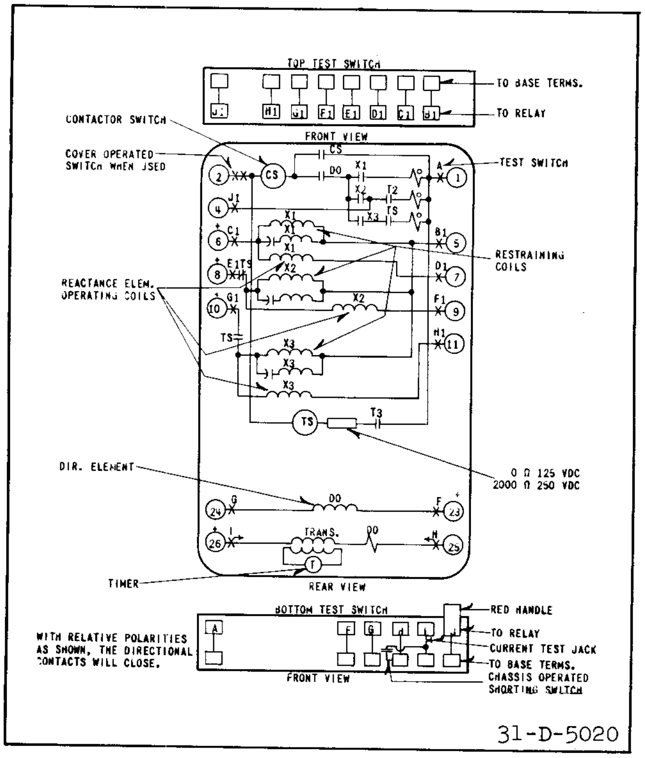

Fig. 1— Internal Schematic of the Type HXS Relay with the TS Transfer Switch In The Type FT Case. Omit Test Switches For Relays In The Standard Case.

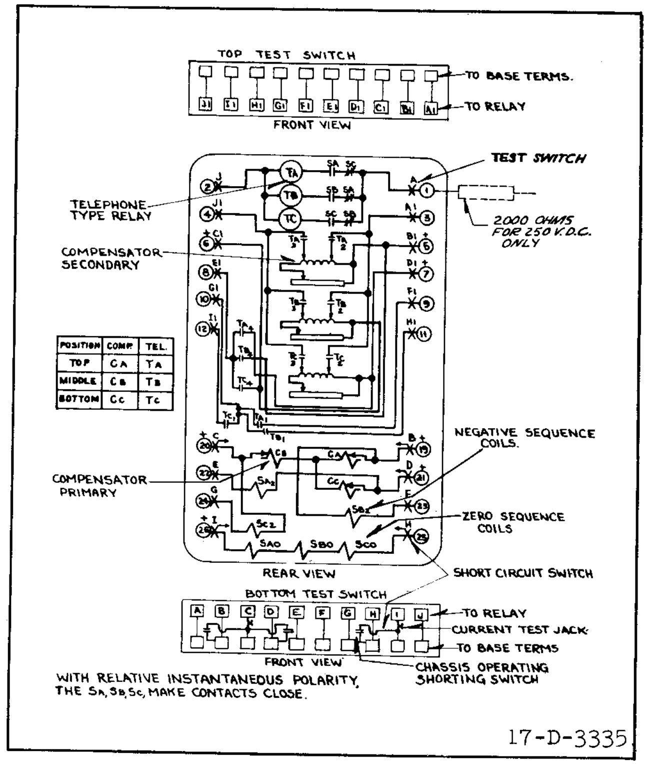

Fig. 2—Internal Schematic Of Type HPS Relay In The Type FT Case. Omit Test Switches For Relays In The Standard Case.

in the operating coil of the relay, which is proportional to the zero-sequence current in the primary of the transformer. The vector sum of this current and a current proportional to the voltage drop (I_0Z_0), applied to the element will give a resultant which will impart a reactance characteristic to the beam at the balance point.

A rectangular silver contact is flexibly fastened on the forward end of the beam. As the beam trips, the contact bridges two silver stationary hemispherical contacts mounted on the free end of the two short leaf springs. A small set screw determines the position of each leaf spring and provides means for adjusting the contact gap.

Synchronous Timer

The timer is a small sub-synchronous motor which operates from the neutral current through a saturating transformer, and drives a moving contact arm through a gear train.

The timer is provided with two stationary contacts which can be adjusted to give time delays up to three seconds. One contact is connected into the trip circuit of the second zone and the other contact is connected into the TS relay coil circuit. Tripping cannot be accomplished for either zone until the appropriate timer contact is closed. Zone 2 and Zone 3 tripping will thus be delayed for a period of time which depends upon the setting of the two timer contacts. The stationary contacts are mounted on separate Micarta insulating blocks which are adjustable around a semi-circular calibrated scale. The contact on the moving arm is a cylindrical silver sleeve which is loosely fitted on the moving arm. The loose fit of the sleeve permits positive alignment in bridging the stationary contacts. An adjustable stop keeps the second set of contacts (T3) closed until the timer is de-energized.

The synchronous motor has a pinion on its rotor which is in mesh with the gear train only when the motor is energized. The rotor pinion falls out of mesh instantly when the motor is de-energized, allowing a spring to reset the moving arm.

Directional Element

The voltage coil of the directional element serves as the primary winding of a small transformer. The secondary winding consists of a one turn movable coil, or loop, pivoted along its center line. This loop carries a current which is proportional to and substantially in phase with the voltage applied to the primary winding. The pivoted loop has a portion of its length lying in a magnetic field established by the current coils of the directional element. The interaction of the current in the loop with the flux established by the current coils produces torque which rotates the loop in one of two directions, depending upon the phase angle relationship between the applied current and the applied voltage.

A Micarta arm extends from the movable loop from which projects a short leaf spring. A small cylindrical contact filled with powdered tungsten is attached to the outer end of the spring. The movement of the tungsten powder creates sufficient friction to absorb practically all of the energy of impact and thus the tendency of the contact to bounce is reduced to a minimum.

The stationary contact screw fastens to a rigid projecting arm. Contact follow is secured by permitting the loop to travel for a short distance after the contacts close, thus deflecting the leaf spring. This is done by an adjustable stop screw. Another stop screw limits the travel of the loop in the opening direction. These stop screws act directly on the loop and are accessible from the sides of the directional element. This directional element has nearly true wattmeter characteristics.

Auxiliary Contact Switch

The d-c contactor switch in the relay is a small solenoid type switch. A cylindrical plunger with a silver disc mounted on its lower end moves in the core of the solenoid. As the plunger travels upward, the disc bridges three silver stationary contacts. The coil is in series with the main contacts of the relay and with the trip coil of the breaker. When the relay contacts close, the coil becomes energized and closes the switch contacts. This shunts the main relay contacts, thereby relieving them of the duty of carrying tripping current. These contacts remain closed until the trip circuit is opened by the auxiliary switch on the breaker.

Operation Indicator

The operation indicator is a small solenoid coil connected in the trip circuit. When the coil is energized, a spring-restrained armature releases a white target which falls by gravity to indicate completion of the trip circuit. The indicator is reset from outside of the case by a push rod in the cover or cover stud.

Telephone Relay

A small transfer switch (TS), as shown in the internal schematic Fig. 1, is included in the HXS relay to separate the second and third zone compensation.

TYPE HPS RELAY

The type HPS relay is used on systems which have solidly grounded neutrals. The relay contains three phase selectors, three second and third zone compensators and three auxiliary telephone type relays. These are shown schematically in Fig. 2.

Selector Elements

The three selector elements are constructed in the same manner as the directional element of the type HXS relay, except that a current coil replaces the potential coil.

Compensators For Second And Third Zone Positive And Negative Sequence Line Drop

Each compensator consists of a tapped transformer and an adjusting resistor. The transformer has relatively few turns of heavy wire on the primary and many turns of fine wire on the secondary wound on punchings having an air gap. A resistor is shunted across the second-

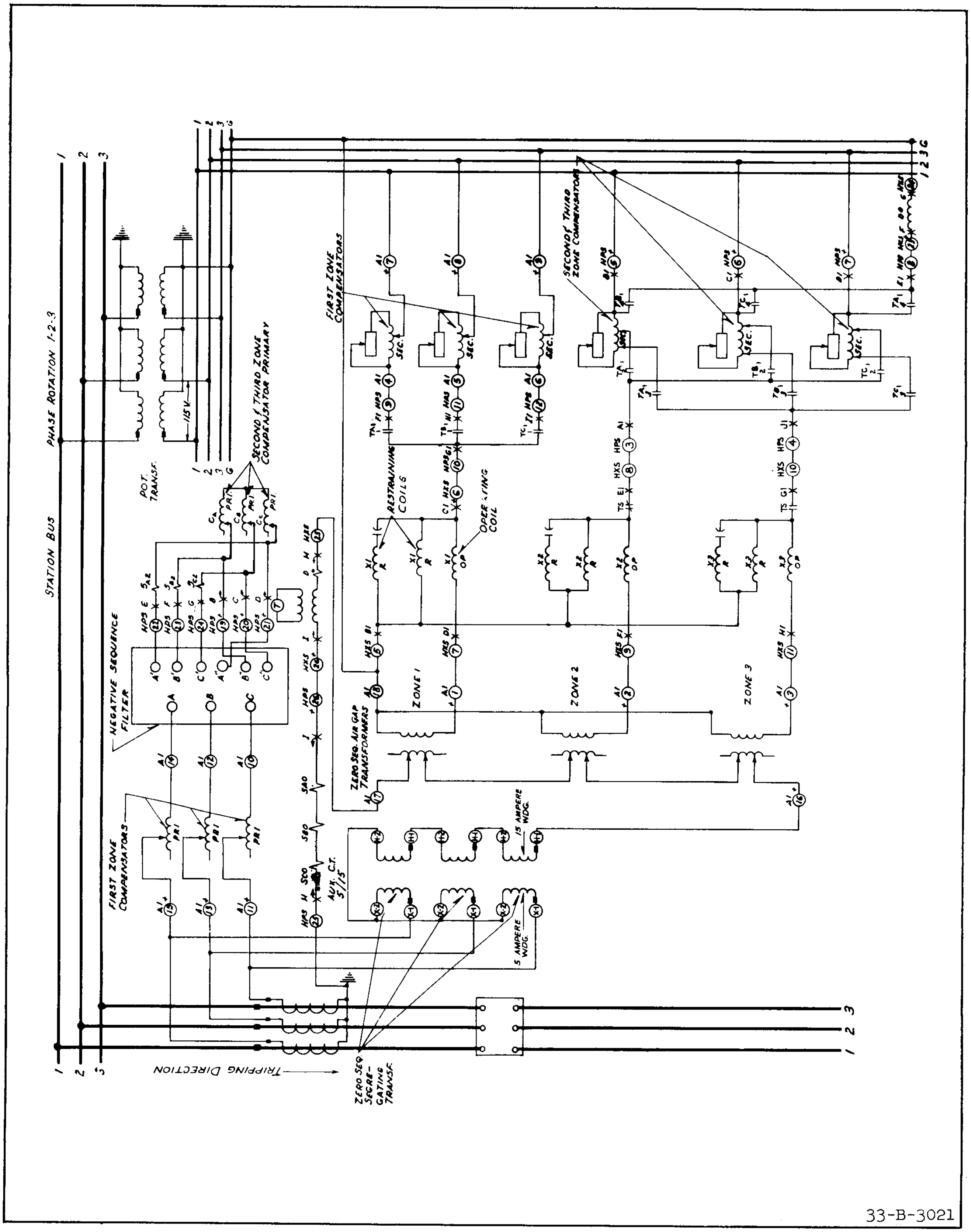

Fig. 7– AC External Schematic Of Type HXS Ground Reactance Relaying Scheme With Type HPS Relay.

line to ground voltage of the faulted phase to the reactance elements, each telephone relay has one extra make contact which connects the potential coil of the directional element to the proper uncompensated line to ground voltage. The line-to-ground voltage selected depends on the phase which is faulted. For a phase-A-to-ground fault the directional element will be connected to phase-C-to-ground voltage. For a phase B-to-ground fault it will be connected to phase A-to-ground voltage, and for phase C-to-ground fault, it will be connected to phase B-to-ground voltage. Fig. 9 shows the vector diagram for the directional element for a phase-to-ground fault. The directional element current coil is so connected as to receive $-3I_0$ current, and therefore will operate to close contacts and be in the region of maximum torque for all single-phase-to-ground faults.

The type HXS relay scheme, however, does not provide tripping for two-phase- to- ground

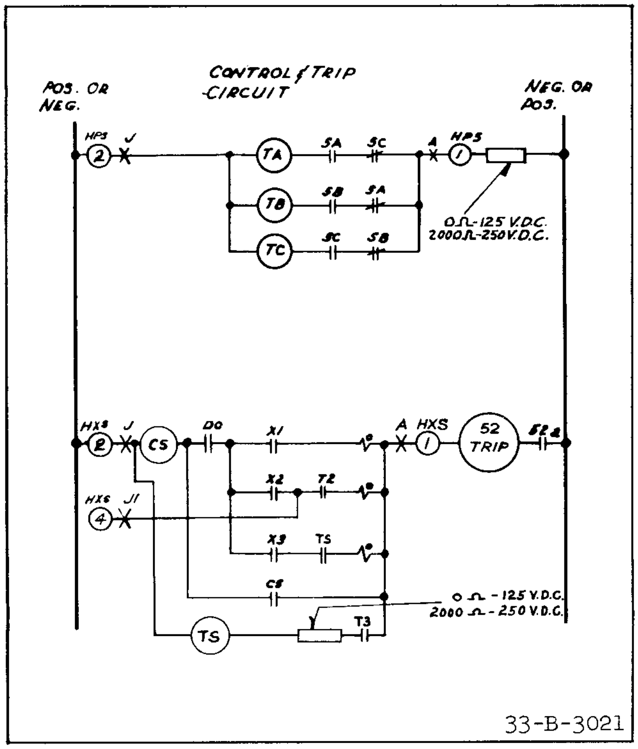

Fig. 8—DC Connections For Type HXS Ground Reactance Relaying Scheme. Using Type HPS Phase Selector.

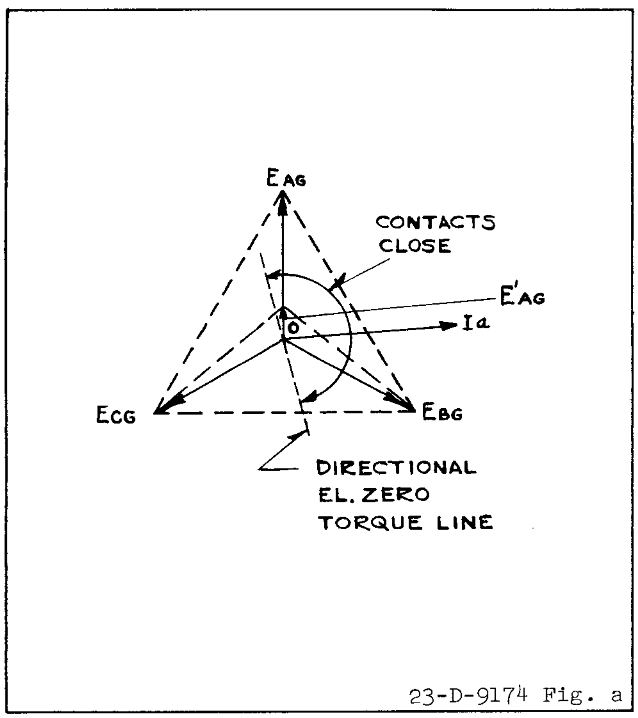

Fig. 9—Vector Diagram Showing Operation Of Directional Element On Single-Phase-To-Ground Fault On Phase A.

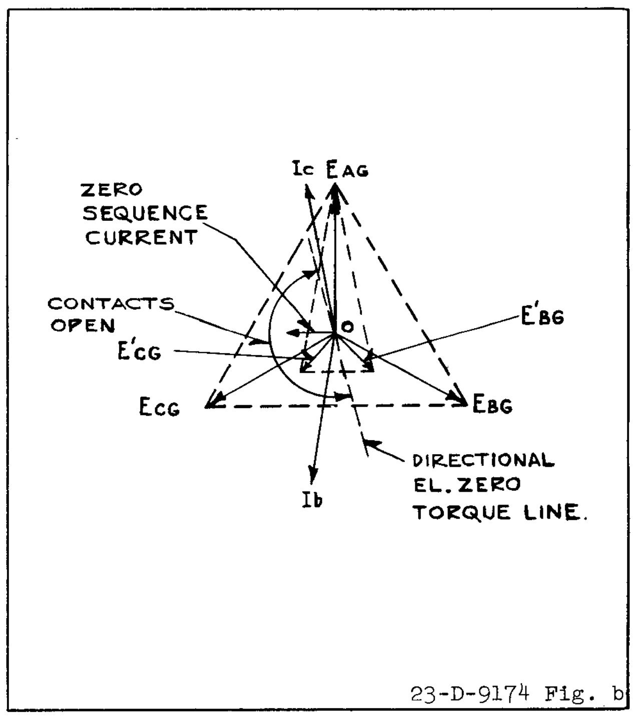

Fig. 10—Vector Diagram Showing Operation of Directional Element on B-C-to-Ground Fault.

faults. For a fault such as phases B and C to ground, the zero sequence component of current will be in phase with the negative sequence component of current on the unfaulted phase. This will cause the phase A selector to operate and telephone relay T_A to pick up. A set of contacts on this relay connects the unfaulted phase A to neutral voltage to the reactance element causing the reactance element to close contacts. The relay is prevented from tripping the breaker, however, due to the fact that telephone relay T_A also connects phase C to neutral voltage to the directional element through another set of contacts. Since the directional element current coil is connected to receive $-3I_o$, it may be seen from Fig. 10 that the directional element will have torque in the opening direction and prevent the breaker from tripping.

Distance Measurement With The Type HXS Relay And Auxiliary Unit For Single-Line-To-Ground Faults.

Since the line to ground voltage at the relay is composed of positive, negative and zero sequence line drops, it is necessary to compensate for the positive and negative sequence line drops. For a phase-A-to-ground fault assuming the fault current from both terminals to be in phase:

$$E_{ag} = (I_1 + I_2)\ MZ_1 + I_o\ MZ_o + 3I_oR_g \qquad (1)$$

where E_{ag} = phase- A- to- ground voltage, and $Z_2 = Z_1$.

I_1 = positive sequence line current
I_2 = negative sequence line current
I_o = zero sequence line current
Z_1 = positive sequence impedance of line
Z_o = zero sequence impedance of line
M = fractional distance of line at which fault occurs.
R_g = fault resistance

The relay will respond to the following impedance:

$$\frac{E_{ag}}{I_o} = \frac{(I_1 + I_2)\ MZ_1 + MI_oZ_o + 3I_oR_g}{I_o} \qquad (2)$$

or:

$$Z_{relay} = \frac{E_{ag}}{I_o} = \frac{(I_1 + I_2)\ MZ_1}{I_o} + MZ_o + 3R_g \qquad (3)$$

In equation (3) the first term on the right hand side of the equation is a variable depending upon the distribution of $I_1 + I_2$ and I_o which may change with system connections external to the protected section. The voltage E_{ag} which is applied to the relay, however, may have this term subtracted out, for a fault at the balance point, through the use of the line drop compensator. The voltage which the compensator supplies is $-N(I_1 + I_2)\ Z_1$, where:

N = fractional distance of line section which the relay is set to protect.

$$E_{ag} = I_oMZ_o + (I_1 + I_2)\ (M-N)Z_1 + 3I_oR_g \qquad (4)$$

$$Z\ relay = MZ_o + 3R_g + \frac{(I_1 + I_2)\ (M-N)Z_1}{I_o} \qquad (5)$$

at the balance point M = N; therefore,

$$Z\ relay = MZ_o + 3R_g \qquad (6)$$

The relay therefore will receive a constant indication for a fault at the balance point regardless of system connections. The calibration of the element is such that it will respond to the 90° component of this impedance, i.e., reactance, within the limits shown in Fig. 15 and is relatively independent of changes in R_g. Therefore:

$$X_{relay} = MX_o$$

where: X_o = zero sequence reactance of the line.

With relays per Fig. 1, the telephone switch TS is used to separate zone 2 and zone 3 compensation by switching zone 3 into the scheme after the T3 timer contacts close. Thus the current from zone 3 is not flowing in the compensator or the second zone coils when zone 2 only is connected. The TS relay removes zone

2 from the scheme, closes a set of contacts in the zone 3 trip circuit, and connects zone 3 into the scheme. This connection is electrically similar to the phase selector connection of zone 1 and 2. Thus if the fault is in zone 3, the subsequent operation of X3 will initiate tripping. The CS switch would immediately seal around the D_O, X_3, and TS contacts. The TS switch will be de-energized as soon as the trip circuit is completed.

SETTINGS

AUXILIARY UNIT

There are three settings to be made on the auxiliary box. They are (a) the settings for the zero sequence reactance of the line for that portion of the line to be protected, (b) the zone one positive and negative sequence line drop compensation, and (c) the phase angle of positive sequence impedance for zone one of the relay.

(a) Zero Sequence Settings for Zone 1, 2 and 3

Table I gives the nominal tap values for P_o and S_o for the three zones of protection in terms of zero sequence reactance ohms. Tap setting is determined by using the following formula:

$$P_o + S_o = \frac{R_c K_2 X_o}{R_v}$$

where P_o = tap setting on primary of zero sequence transformer in terms of zero sequence reactance.

S_o = fine tap setting on primary of zero sequence transformer in terms of zero sequence reactance.
X_o = zero sequence reactance of line
R_c = current transformer ratio
R_v = voltage transformer ratio
K_2 = portion of line protected

Recommended values:

For the First Element - 75% of protected section.

For the Second Element - Approx. 50% into the adjacent section.

For the Third Element - Approx. 25% into the third line section.

(b) Positive and Negative Sequence Line Drop Compensator Settings for Zone 1

Tables II and III give the nominal tap settings for the compensators for the three zones. Fig. 11 gives the value of constant K_1.

The line drop compensator setting is made in accordance with the formula:

$$P_c S_c = \frac{Z_1 R_C K_1 K_2}{R_v}$$

where:

P_c = setting of compensator primary in ohms
S_c = setting of compensator secondary in ohms
Z_1 = positive sequence impedance of line in ohms
R_c = current transformer ratio
R_v = voltage transformer ratio
K_2 = portion of line to be protected. In general this should be the same as K_2 used in zero sequence setting.
K_1 = a constant determined by positive sequence angle of the line. See Fig. 11.

(c) Zone One Phase Angle Settings

The compensator has a phase angle setting, ϕ_c. This is chosen by selecting a tap whose value is close to the positive sequence impedance angle of the line. The possible settings of the first zone compensator are listed in Table II. For reference, the compensator loading resistance values are shown in Fig.12, Scale B.

The formula settings will be sufficiently accurate for most installations. Where it is desired to set the balance point more accurately, the tap values may be checked by applying to the relay the voltage, current and phase angle conditions which will be impressed on it for a fault at the desired balance point. A slight change in the tap value from the calculated value may be required on either the zero sequence ohms tap or the compensator tap for the relay to just trip for the fault at the simulated balance point.

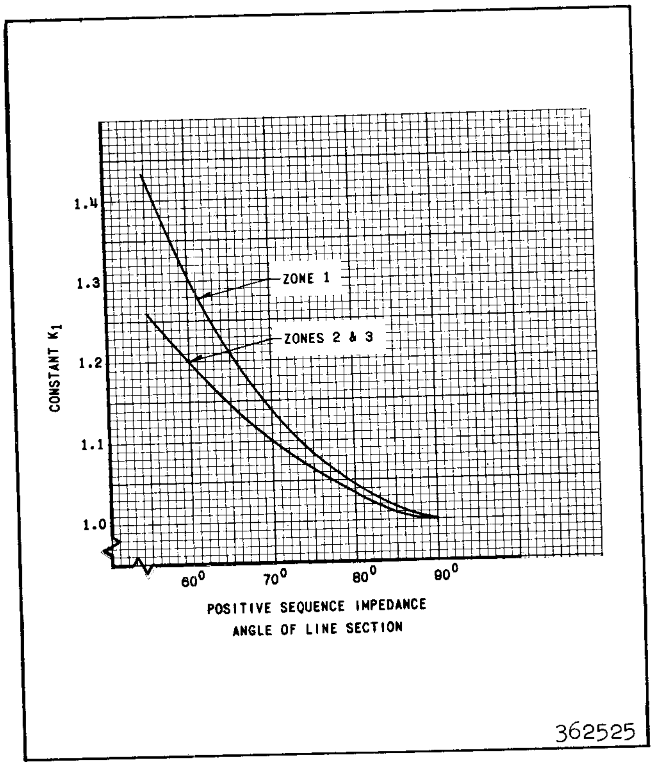

Fig. 11.- Curve For Determining Value Of Formula Constant K1.

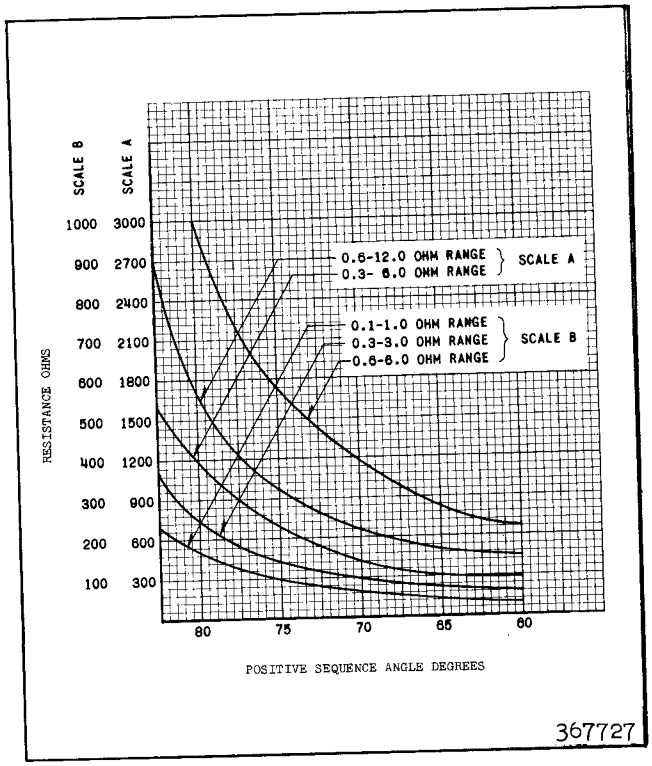

Fig. 12- Line Drop Compensators Resistances VS. Phase Angle Setting.

NEGATIVE SEQUENCE FILTER

This unit is adjusted and calibrated at the factory and requires no setting

TYPE HXS RELAY

There are no reactance settings to be made on this relay. The reactance element is calibrated at the factory and should require no further adjustment. If, however, it is desired to check or recalibrate this element, the procedure to be followed is given under "Adjustment and Maintenance". The settings for adjustment of the reach of this element are located on the auxiliary Unit. Set the T2 and T3 timer contacts to the desired settings. Adjust the T3 contact stop as explained under Adjustment and Maintenance.

TYPE HPS RELAY

There are two settings to make on the HPS relay. They are: (a) second and third zone Line Drop Compensators, (b) Positive sequence impedance angle.

(a) Second and Third Zone Line Drop Compensators

The settings for positive sequence impedance are made exactly as for the first zone compensators except that having selected the primary tap P_c when setting the second zone compensation, the third zone reach is achieved by moving the zone three secondary tap so that the product of $P_C S_{C3}$ will equal the value decided for the third zone. Sufficient range of secondary tap adjustment is provided for this. Table III gives values of secondary taps and Fig. 11 gives the constant K_1 for the formula.

The tap values of P_c in terms of the secondary positive sequence impedance ohms are marked on the tap plate located on the left hand side of the line drop compensator tap block. The secondary adjustment, consisting of 16 taps is located on the right side of the block. There are two secondary leads. One is for the second zone adjustment S_c2 and the other is for the third zone adjustment S_c3. These leads can be moved independently of each other. The lead farthest to the right is S_c3. Fig. 3 shows the positions of these taps.

(b) Positive Sequence Impedance Angle

The adjustment of the angle of the line drop compensators for zones two and three to match the angle of the positive sequence impedance of the line, is accomplished by setting an adjustable resistor. There is one resistor for each compensator. The three resistors are located at the bottom of the relay case. From left to right (front view) they are phase A, phase B, and phase C. The values of resistance for a 78° angle are checked at the factory and a setting should be selected so that the compensator angle is equal to the line angle. The curve in Fig. 12 (Scale A) shows the resistance at which to set the sliders to obtain the desired angle.

There are no adjustments on the telephone relays. If it is desired to check them electrically for positive pick-up, 125 volts d-c should be applied across terminals 1 and 2 to the HPS relay and the proper selector contacts operated mechanically or electrically to pick up each relay. Front contacts of S_A and back contacts of S_C must be closed to pick up T_A. These relays are not continuously energized in service. When testing at 125 volts d-c these relays should not be energized for any appreciable length of time since their continuous rating is 60 V. d-c.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount each relay vertically by means of the two mounting studs for the standard case and the type FT projection case, or by means of the four mounting holes on the flange for the semi-flush type FT case. Either of the studs or the mounting screws may be utilized for grounding the relay. The electrical connections may be made direct to the terminals by means of screws for steel panel mounting or to terminal studs furnished with the relay for ebony-asbestos or slate panel mounting. The terminal studs may be easily removed or inserted by locking two nuts on the studs and then turning the proper nut with a wrench.

CONNECTIONS

Fig. 7 shows schematically the connections for one line terminal and the interconnections of relays and auxiliary units.

ADJUSTMENTS AND MAINTENANCE

The proper adjustment to insure correct operation of this relay has been made at the factory and should not be disturbed after receipt. If it is desired to check the adjustments at regular maintenance periods, the instructions below should be followed.

All contacts should be cleaned periodically. A contact burnisher S#182A836H01 is recommended for this purpose. The use of abrasive material for cleaning contacts is not recommended, because of the danger of embedding small particles in the face of the soft silver and thus impairing the contact.

CAUTION: The relay voltage should be of good wave form. The combination of a phase shifter and autotransformer may give an output voltage of poor wave form if the magnetizing current of the autotransformer is high in proportion to the impedance of the phase shifter used. In case of doubt, check the output voltage wave form with an oscilloscope.

Type HXS Relay Directional Element

Check the free movement of the directional element loop. The loop should assume approximately a vertical position with contacts open when the element is completely de-energized.

The movement of the loop is limited in the contact opening direction by a stop screw which strikes the lower part of the loop. This screw is located on the left-hand side of the element to the rear of the current coil. The back stop screw should be screwed forward until it just touches the loop when it is in its natural de-energized position. Set the contacts for a separation of .020 inches. Set the front loop stop screw so that it touches the loop at the same time the contacts close. Then back off this screw 1/4 of a turn to give the contacts the right amount of follow.

Energize the loop with normal potential and adjust the bearing screws so there is about .010 inch end play. See that the loop does not bind or strike against the iron or coil when pressed against either end jewel.

Apply 5 amperes and 2.5 volts in phase suddenly to the directional element and make sure that a good contact is made. It may be necessary to adjust the stationary contact slightly in order to obtain a good steady contact. Reverse the polarity and apply 70 volts and 5 amperes. This polarity reversal will cause the contacts to open. Make sure that the contacts will not bounce closed when the voltage is suddenly interrupted.

Too much follow on the directional contacts should be avoided in order to allow the directional element to reset fast enough by gravity to properly coordinate with the high speed reactance elements.

When the directional element is energized on voltage alone, there may be a small torque which may hold contacts either open or closed. This torque is small and shows up only at high voltages with the entire absence of current. At voltages high enough to make this torque discernible, it will be found that only a fraction of an ampere in the current coils will produce wattmeter torque to insure positive action. The slight torque shown on voltage alone has no significance in actual service and has no practical effect on the directional element operation.

Contactor Switch (Seal-In-Switch)

Adjust the stationary core of the switch for clearance between the stationary core and the moving core of .025 inch when the switch is picked up. This can be done by disconnecting the switch, turning it up-side-down and turning the core screw until the contact just separates. Back off the core screw approximately one turn and lock in place. This prevents the moving core from striking and sticking to the stationary core because of residual magnetism. Adjust the contact clearance for 3/32 inch by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 1.0 ampere direct current. Test for sticking after 30 amperes direct current is passed through the coil. The resistance of the coil is approximately 0.8 ohms.

Operation Indicator

Adjust the indicator to operate at 1.0 ampere direct current gradually applied. Test for sticking after 30 amperes direct current is passed through the coil.

Synchronous Timer

Pass 2.5 amperes through the timer transformer primary. Check the timer motor with a neon lamp or with a cycle counter to see if it runs at synchronous speed. See that the moving contact properly bridges both sets of stationary contacts and resets from any position.

Set the adjustable stop by first loosening the nut around the lower bearing of the moving contact arm shaft. Then rotate the bracket to a position which will allow the contact arm to touch the bracket when the T3 contact is positively made. Tighten the locking nut in this position.

Trip Circuit

The contactor switch operates on a minimum of 1.0 amperes but the trip circuit should draw at least 4 to 5 amperes in order to reduce time of operation of the switch to a minimum and provide positive operation.

Telephone Relay

There is no adjustment on the telephone relay. If it is desired to check the electrical pick-up, d-c voltage should be applied across terminals 1 and 2 of the HXS relay. Care should be taken not to close the D_o and X_1 contacts unless the test circuit also contains a current limiting load for the CS switch. This relay is not continuously energized in service When testing at 125 volt d-c the relay should not be energized for any appreciable length of

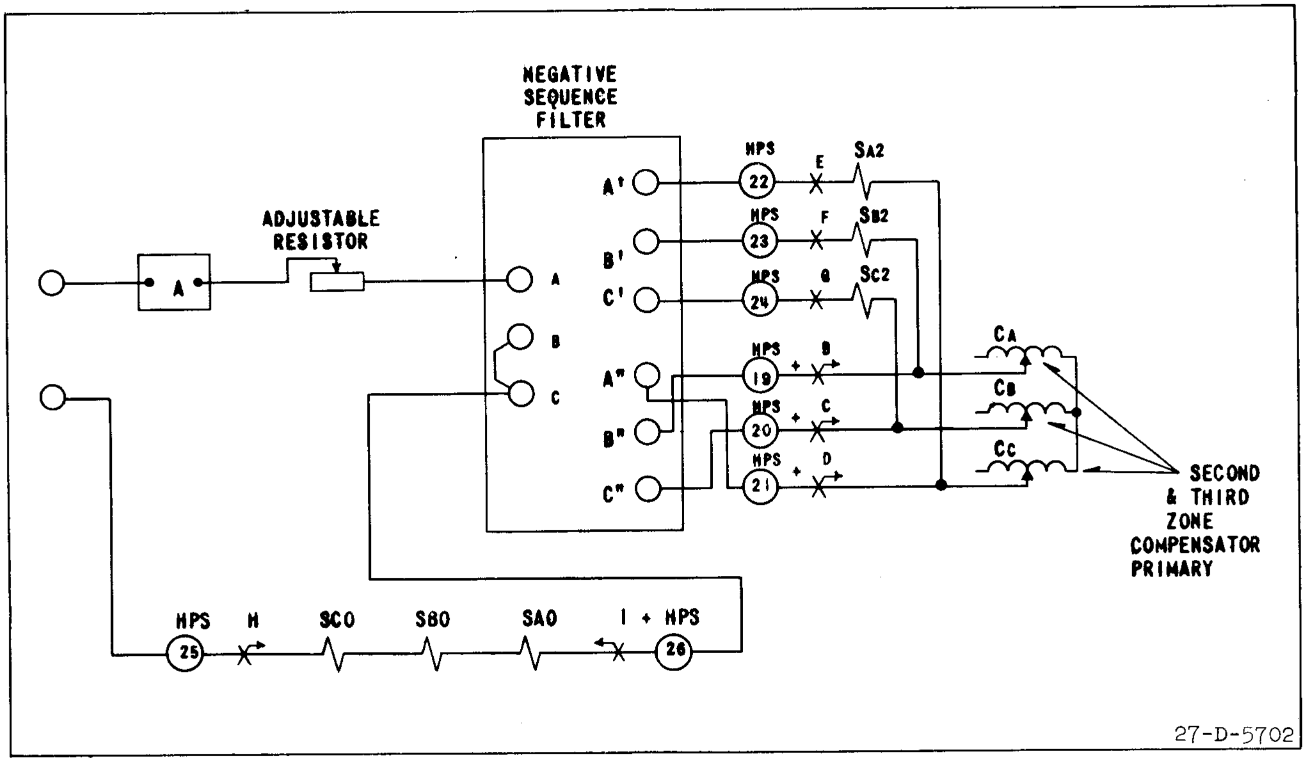

Fig. 13—Test For Calibration Of Phase Selector Elements.

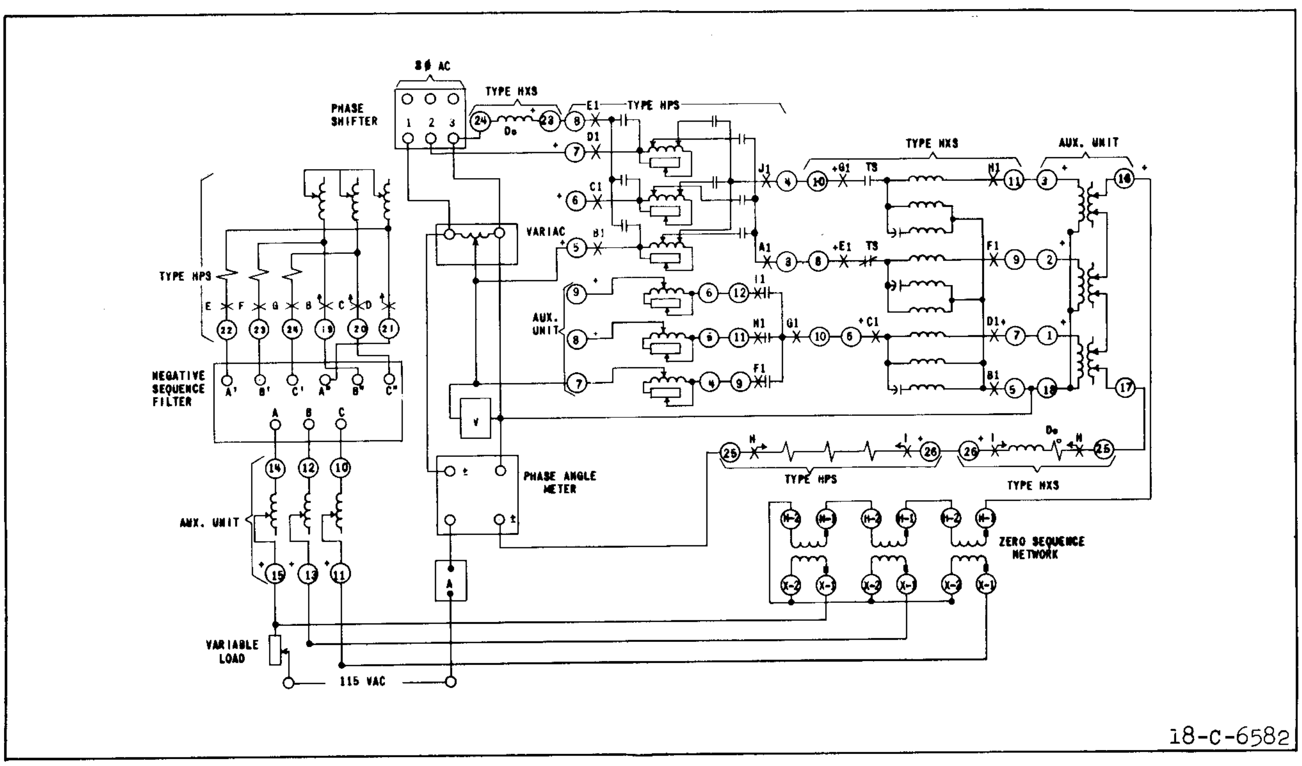

Fig. 14—Test Connections For Calibration Check Of HXS Relaying System

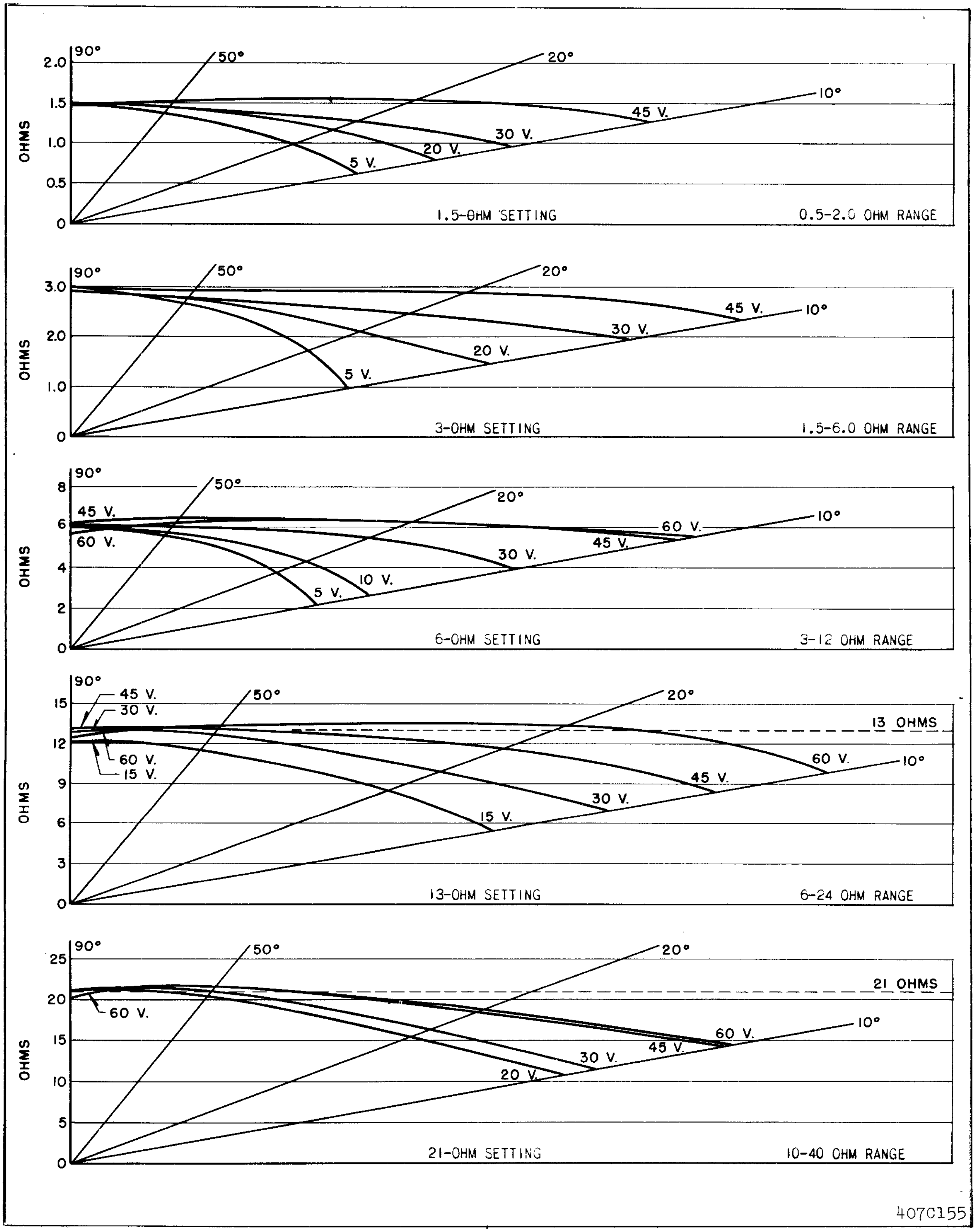

Fig. 15—Typical Reactance Characteristics.

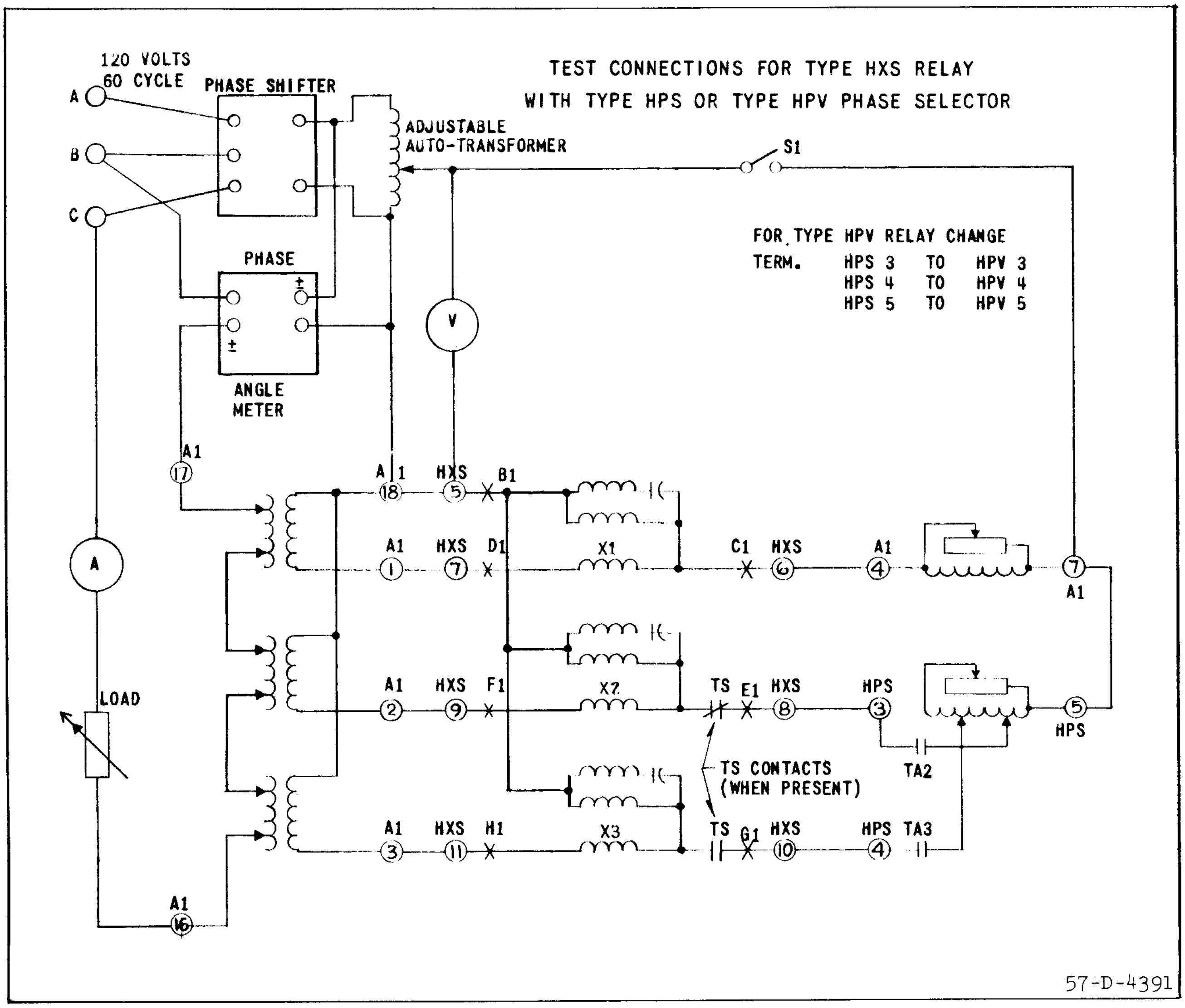

Fig. 16 — Test Connections for check of Reactance Curve.

time since the continuous rating is 60 v.d.c.

Reactance Element

The reactance curve can be checked with the circuit of Fig. 16. The zero-sequence taps and the line-drop compensator taps should be set at the values which will be used in service. Set the auto-transformer to 30 volts with the test current lagging the relay voltage by 90 degrees. With the switch S_1 closed, increase the current until the relay just trips. Then set the current to a slightly lower value and close the switch S_1 several times. If the beam does not trip every time, increase the current slightly and repeat the switch-closing procedure. In this manner, determine the lowest value of current at which the beam will trip for every switch operation. The reactance at the trip point can be calculated from the formula:

$$X_o = \frac{3E_{ag} \sin \theta}{I_a}$$

I_a = test current necessary to trip relay

θ = phase angle between E_{ag} and I_a

E_{ag} = voltage applied to relay from auto-transformer.

X_o = zero sequence ohmic reach of the relay

Change the phase angle θ between E_{ag} and I_a to 30 degrees and then 20 degrees and repeat this procedure. The reactance curve can then be plotted and compared with Fig. 15 which shows typical curves for all ohmic ranges, and the effect of voltage variation. The results obtained should generally follow these curves, although there will be some variation between individual relays.

Increase E_{ag} to 45 volts and repeat the previous check for zones 2 and 3. It will be necessary to bypass the TA contacts for this test. When checking zone 3, it will also be necessary to block the TS relay armature in the operated position so that the zone 3 coil circuits will be energized. This can be seen from an examination of Fig. 16.

If the actual operating conditions of the relay are known for faults at the balance point, it is, of course, advisable to test the relays with these conditions applied rather than the values recommended.

It will seldom be necessary to readjust the magnetic gaps of the beam-type reactance elements. These settings have been made at the factory; they are quite critical and should not be disturbed unless the reactance curve of the relay is unsatisfactory.

If the relay operation is only slightly outside the desired limits, a very small change in gap settings may be sufficient to correct it. When the relay is in approximately correct calibration, a change in the front or back gaps of only one or two thousandths of an inch will have an appreciable effect, particularly at small lagging angles (10° to 20°) and high relay voltages. Consequently, proceed with caution before making major changes in the relay gap settings.

If the relay has been disassembled and the previous gaps are not known, the following settings are recommended as a starting point for recalibrating the reactance units.

<u>Mechanical Adjustments (preliminary):</u>

1. Adjust the rear magnetic gap to 0.020 inch by moving the rear positioning screw until this clearance is measured between the beam and the rear of the pole piece with the beam in the reset position.

2. With the beam in the reset position, adjust the middle vertical gap to 0.010 inch and adjust both parts of the adjustable magnet so that the gaps are equal.

3. With the beam in the reset position, adjust front gap between the beam and the stop pin to approximately 0.020 inch.

4. Adjust stationary contacts for 0.015 inch separation and approximately 0.010 inch contact follow.

5. Mechanically balance the beam by moving the balance weight which is attached to the rear top surface of the beam. The position of the weight should just cause the beam to reset positively when the beam is pushed down by hand on the contact end and released. The above mechanical adjustments are all performed with the relay de-energized.

<u>Electrical Calibration:</u>

1. Set up a circuit according to Fig. 16 with the zero-sequence taps and the line-drop compensator taps on all three zones set at the values which will be used in service.

2. <u>Voltage Balance Adjustment</u> - Adjust the front core screw so that the beam just does not trip on voltage alone from zero to 70 volts. (It will generally be most susceptible to tripping around 45-50 volts.) Make this adjustment by turning up the front core screw until the beam just trips on the application of voltage, then back it off slightly so the beam just does not trip. Close and open switch S1 at least 10 times and note that the beam does not trip. If it is necessary to open the front gap to more than 0.030", reduce rear gap to not less than 0.015" and repeat until balance point is obtained with front gap between .020 and .030".

3. <u>Balance Weight Adjustment</u> - Energize the circuit and increase the current at 90°lagging until the beam trips, using 30 volts for the three lowest ranges and 45 volts for the two highest ranges. For the three lowest ranges, check the trip point at 5 volts, 90° lagging current, and readjust the balance weight so that the beam trips at one-sixth of the 30-volt 90° lag current. For the 10-40 ohm range at 5 volts, adjust for one-ninth the 45-volt cur-

rent. On the 6-24 ohm range, the beam is not balanced in this manner. Simply recheck the balance weight to be as far forward as possible and still reset when deenergized.

4. Reactance Calibration - With the relays and auxiliary box connected per Fig. 16 and with the taps to be used in service, apply 30 volts for the three lowest ranges or 45 for the two highest ranges (6-24 and 10-40), and a current at a 90° lagging angle.

To obtain the trip point, set the current at approximately the calculated value, and close the switch S1. Repeat the procedure described previously to obtain a consistent trip point. Readjust the front and rear gaps slightly to bring the 90° point within ±5 percent. Then check at 10° lagging current. The current to trip at this point will result in a reactance value approximately 65 percent of the 90° value. This is an inherent characteristic of the reactance unit at the calibrating voltage as shown in the curves of Fig. 15. If the current to trip is only slightly outside the ±5 percent limit at 90° or below the 65 percent point at 10°, it can be corrected by a small change in the rear gap setting. If the current to trip is considerably high, it may be necessary to increase the middle gap. Conversely, if the beam trips at too low a current, decrease the middle gap.
NOTE: It is more important that the 10° point be held up to at least 65 percent of the 90° point, than to hold the 90°point at a particular value. The ohmic reach of a properly adjusted HXS relay reactance unit depends primarily on the constants of the associated zero-sequence transformer. The actual shape of the reactance curve is determinded by the gap adjustments. The gaps are adjusted for the flattest reactance curve rather than for a particular value of reactance. The desired reactance value can then be obtained by proper selection of taps.

After the proper calibration has been obtained, recheck the balance weight setting and the voltage balance adjustments to be sure that (1) the beams reset when deenergized, (2) the beams do not trip when voltage only is switched on and off,and (3) that the reactance units have proper 5-volt calibration per paragraph #3.

5. Repeat the preceding calibration procedure for zones 2 and 3 using the appropriate voltage for the ohmic range. Note that the TA2 contact must be by-passed for testing zone 2. When testing zone 3, TA 3 and the normally-open contact of the TS switch must be by-passed, and the TS normally-closed contact open-circuited. This can easily be accomplished by blocking the TS armature in the operated position.

Adjustment of Selector Elements

With the relay in the vertical position, check the loop to see that it is free from friction, properly centered in the gap and free to swing.

Adjust the bearing screws so that there is about .010" end play on the loop. See that the loop does not bind or strike the iron or coil when pressed against either end jewel.

The adjustments consist of left and right hand loop stop screws to limit the travel of the loop and left and right hand spring tension adjusting screws.

Set the left and right hand loop stop screws so that the loop will have maximum travel but will not touch the magnet frame.

Left Hand Contact

With the loop in the normal de-energized position adjust the left contact tension spring screw so that the stationary contacts just touches the movable bridge. Since the bridge is free to turn it is important that both stationary contacts be aligned.

Right Hand Contacts

With loop in the vertical position adjust the right contact tension spring screw for .015 inch gap. The alignment of the bridging contact with the right-hand stationary contact should be checked electrically, using the circuit of Fig. 13 which simulates a phase A to ground fault. With minimum pick-up current (1.3 amperes) applied, the phase A selector should close to the right, and phase B and phase C selectors should have restraint torque to the left. The telephone relay TA should pick up at this energization; if not, the selector contacts should be realigned. For a phase-B-to-ground fault, connect the current source to terminal B of the filter and connect terminals A and C together. Similarly, a phase-C-to-ground fault can be simulated by introducing current into terminal C of the filter and paralleling terminals A and B.

For a more complete overall test, the following procedure is recommended.

1. Set up a circuit similar to Fig. 14 with the line-drop compensator taps on all three zones set at the values which will be used in service.

2. If possible, apply currents and voltages to the relay which duplicate actual operating conditions: if not, test the first zone at 30 volts and the second and third zones at 45 volts. Determine the current necessary to trip the relay. The ohmic reach can then be computed from the formula:

$$Z_R = \frac{3E_{ag} \underline{/\theta} - \frac{2I_a P_c S_c}{K_1} \underline{/\phi}}{I_a}$$

Z_R = relay ohmic reach--a complex number

E_{ag} = voltage applied to relay from auto-transformer

I_a = current necessary to trip relay

θ = phase angle between E_{ag} and I_a

ϕ = compensator angular setting

K_1 = constant from Fig. 11

$P_c S_c$ = line-drop compensator setting

A series of points taken for different values of θ will determine the reactance curve which should again fall approximately on the curves of Fig. 15.

Check of Line Drop Compensators (for all zones)

The line drop compensator is an air gap transformer with a relatively few primary turns energized by current, and a large number of secondary turns in which a voltage is induced. The angle between the primary current and the induced secondary voltage is essentially 90°. A resistor is included which can be connected across the secondary winding to reduce the angle to a value as low as 60° to match the positive sequence impedance angle of the line section. The compensator can be checked by the following formula:

$$I \times P_c \times S_c = E \pm 5\%$$

where P_c and S_c are the primary and secondary taps, I is the primary current, and E is the open-circuit secondary voltage measured with a high resistance voltmeter. The phase-angle resistor should be disconnected during this test.

When the phase-angle resistor is connected across the compensator secondary, the terminal voltage is reduced because of the loading effect of the resistor. Thus, the compensator must be set to a higher $P_c S_c$ setting by the factor K_1 as indicated under Settings and in Fig. 11. If the compensator is checked with the resistor connected, the relation between quantities will be as follows:

$$P_c S_c = ZK_1 = \frac{E}{I} K_1 \qquad \text{or} \qquad \frac{P_c S_c I}{K} = E \pm 5\%$$

where Z is the desired ohmic setting of the compensator

K_1 is the correctoin factor of Fig. 11

I is the primary current, and

E is the secondary terminal voltage.

If desired, the angle between the primary current and secondary voltage of a compensator can be checked using the circuit of Fig. 17. The procedure is the same for checking the first zone compensator in the auxiliary unit or the second and third zone compensator in the HPS relay.

The procedure is as follows:

1. Set the current I to the desired value (Calibration current is 2 amperes.)
2. Rotate the phase shifter for a minumum voltmeter reading (V).
3. Vary the adjustable auto-transformer to further decrease the voltmeter reading.
4. Repeat (2) and (3) to obtain the lowest possible voltmeter reading. Note - a low range voltmeter will be needed to obtain the final balance.
5. The angle between primary current and secondary voltage can now be read on the phase angle meter.

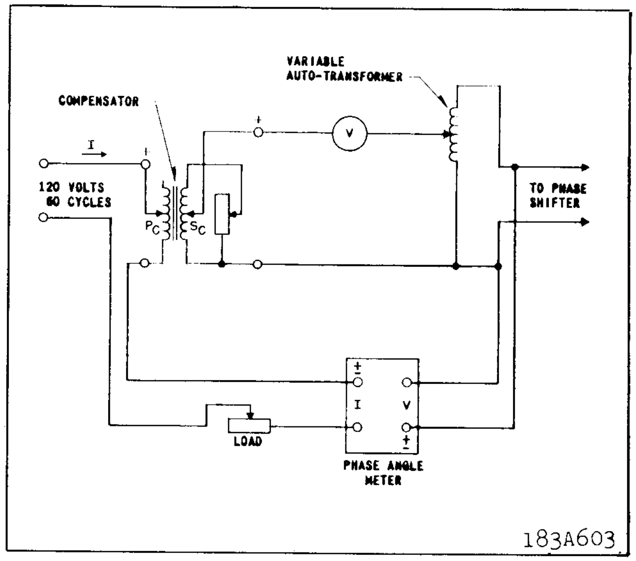

Fig. 17. Circuit for checking Phase Angle of Line Drop Compensator.

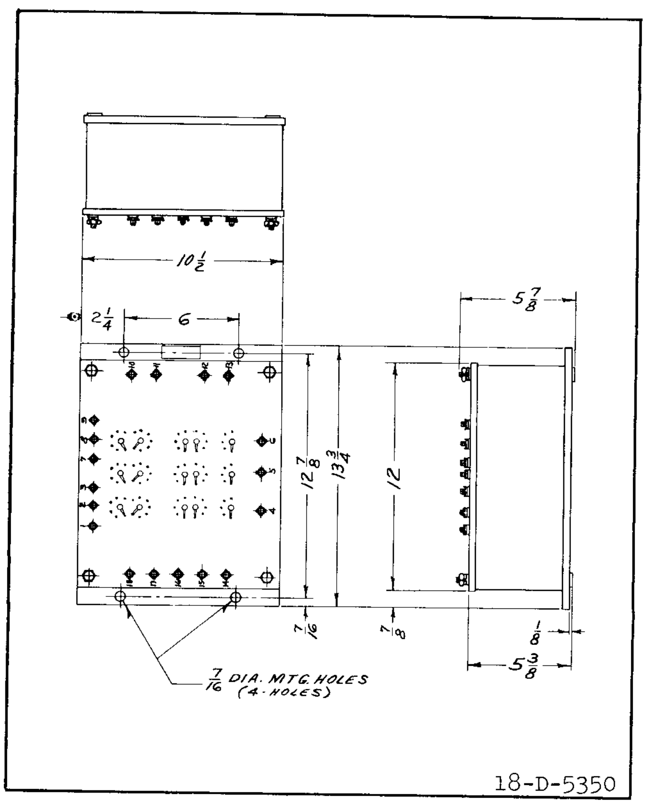

Fig. 18—Outline And Drilling Of The Auxiliary Unit.

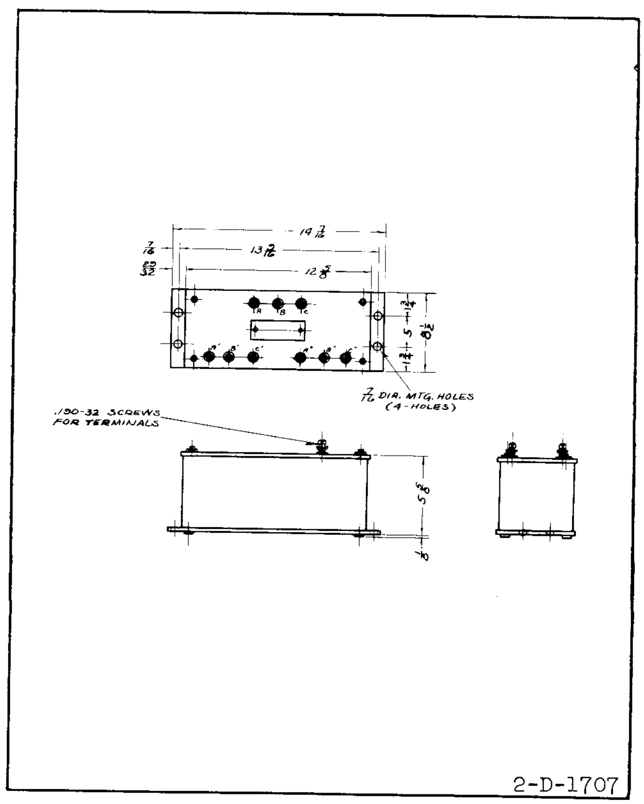

Fig. 19—Outline And Drilling Plan Of The Negative Sequence Filter.

STANDARD RELAY RANGES

The ranges are available in the following combinations:

	ZERO SEQUENCE REACTANCE			POSITIVE SEQUENCE COMPENSATOR	
	ZONE 1	ZONE 2	ZONE 3	ZONE 1	ZONES 2 & 3
low	0.5-2.0	1.5-6.0	3-12	0.1-1.0	0.3-6
medium	1.5-6.0	3-12	6-24	0.3-3.0	0.3-6
high	3-12	6-24	10-40	0.6-6.0	0.6-12

The second and third zone positive sequence compensator is available with 0.3-6.0 ohms or 0.6-12 ohms. (See Table III)

TABLE I

Zero Sequence Reactance

	Nominal Range				
	0.5-2.0	1.5-6.0	3-12	6-24	10-40
P_o Tap Marking					
A	0	0	0	0	0
B	.5	1.0	3.0	6.0	9
C	.75	2.0	4.50	9.5	15
D	1.0	3.0	6.0	13.0	21
E	1.25	4.0	7.50	16.5	27
F	1.50	5.0	9.0	20.0	33
G	1.75	6.0	10.50	23.5	39
S_o Tap Marking					
H	0	0	0	0	0
I	.1	.25	.5	.75	1.0
J	.2	.50	1.0	1.50	2.0
K	.3	.75	1.5	2.25	3.0
L	.4	1.0	2.0	3.0	4.0
M	.5	1.25	2.5	3.75	5.0

Values above are secondary ohms.

TABLE II

First Zone Positive and Negative Sequence Line Drop Compensators (In Auxiliary Unit)

	Nominal Range		
	.1-1.0	.3-3.0	.6-6.0
P_c Tap Marking			
F	.10	.30	.60
G	.17	.52	1.03
H	.30	.89	1.78
I	.51	1.53	3.05
J	.87	2.63	5.25
S_c Tap Marking			
A	1.12	1.12	1.12
B	1.24	1.24	1.24
C	1.36	1.36	1.36
D	1.48	1.48	1.48
E	1.60	1.60	1.60

Values above are in secondary ohms.

The following phase-angle taps are available for the first zone compensators:

$\phi_1 = 66°$, $\phi_2 = 72°$, $\phi_3 = 78°$, $\phi_4 = 84°$, $\phi_5 = 90°$ (approximately)

TABLE III

Second and Third Zone Positive Sequence Line Drop Compensators (In Type HPS Relay)

Primary Taps 0.3 - 6.0 P_c	Primary Taps 0.6 - 12 P_c	Tap Positions	+ Secondary Taps 0.3 - 6.0 S_c2	+ Secondary Taps 0.6 - 12 S_c2
.30	.57	1	1.0	1.0
.54	1.02	2	1.10	1.10
.97	1.94	3	1.20	1.20
1.75	3.54	4	1.30	1.30
3.25	6.30	5	1.40	1.40
		6	1.50	1.50
		7	1.60	1.60
		8	1.70	1.70
			S_c3	S_c3
		9	1.80	1.80
		10	1.91	1.91
		11	2.02	2.02
		12	2.13	2.13
		13	2.24	2.24
		14	2.35	2.35
		15	2.46	2.46
		16	2.57	2.57

P_c Values above are in secondary ohms

\+ Refer to Fig. 3.

ENERGY REQUIREMENTS

Types HXS Relay	Range Zero Sequence	Amps I	Burden in V. A. Min. Tap	Burden in V.A. Max Tap	Angle
	.5 - 2.0	5.0	.1	.65	53°
	1.5 - 6.0	5.0	.16	5.75	60°
	3.0 -12.0	5.0	1.44	22.0	70°
	6.0 -24.0	5.0	1.44	23.0	70°
	10.0 -40.0	5.0	4.00	65.0	70°

	Zone 1 Positive & Negative Sequence Compensator Range	I	Min.	Max.	Angle
	.1 - 1.0	5.0	.05	3.25	65°
	.3 - 3.0	5.0	.1	4.0	65°
	.6 - 6.0	5.0	.16	21.0	65°

Type HPS Relay	Zone 2 & 3 Positive & Negative Seq. Compensator Range	I	Min.	Max.	Angle
	.3 - 6.0	5.0	.1	10.0	68°
	.6 -12.0	5.0	.1	12.0	68°

	I	VA
Zero Sequence Segregating Transformers	5.0	9.0

Type HXS Relay	Potential Burden	Volts	VA	PF Angle
HXS Relay	Reactance elements including compensators	67	19.0	20° lag
HXS Relay	Directional element	67	1.25	20° lag

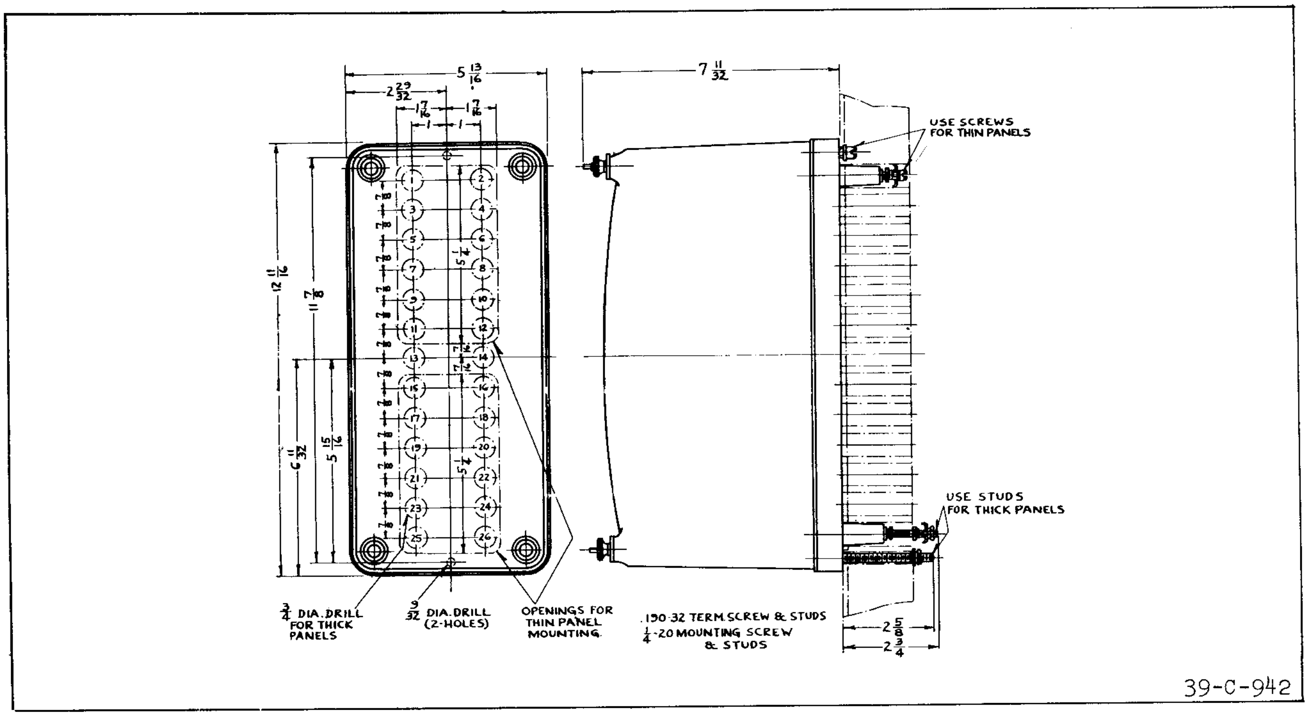

Fig. 20—Outline And Drilling Plan Of The Type HXS Relay And Type HPS Relay For The Standard Projection Case. For Reference Only.

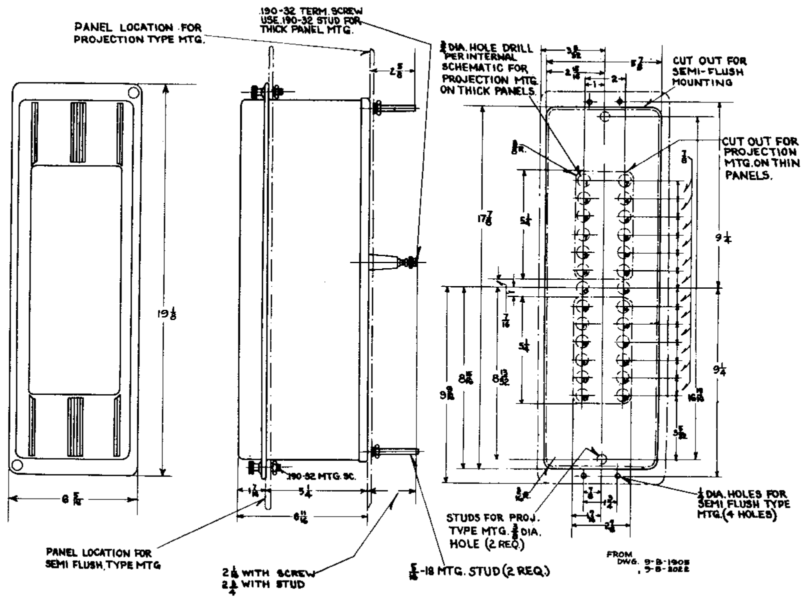

Fig. 21—Outline And Drilling Plan For The Type HXS Relay And Type HPS Relay For The Projection Or Semi-Flush Type FT Case. For Reference Only.

WESTINGHOUSE ELECTRIC CORPORATION

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