Westinghouse

TYPE HCB PILOT WIRE RELAY

INSTRUCTIONS*

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter:

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) figure 1 adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the output of the saturating transformer, and is marked in amperes required to operate the relay when the pilot wire is open or when equal amounts of current are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in figure 5. The rectox units are used to convert the a-c. output of the saturating transformer for use on the d-c. polar-type relay element. The use of a sensitive polar type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnet bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating

*SUPERSEDING I.L. 2723-E

and ordinate scales may be interpolated as follows to show the operating characteristics for other conditions using T = 4.

For ground faults using other R_o and R_1 taps multiply scales by:

$\frac{1.7}{R_o + R_1}$ Phase A to Ground Faults

$\frac{1.7}{R_o + j\ .577\ R_1}$ Phase B or C Ground Faults.

For three-phase faults multiply scales by:

$$\frac{1.7}{2\ R_1} = \frac{.85}{R_1}$$

For line - to - line faults multiply scales by:

$$\frac{\sqrt{3}\ 1.7}{2\ R_1} = \frac{1.47}{R_1}$$

The relay is normally shipped with the minimum restraint tap, T, connected as shown in upper left corner, figure 1. The maximum restraint tap, F, is available for use on maximum length pilot wires and when the current transformer ratios are not well-matched.

SETTINGS

The following nomenclature will be used throughout this section:

$I_{3\phi}$ = One-half the total minimum internal three phase fault current in the relay fed from both terminals of a two-terminal line. For three-terminal lines $I_{3\phi}$ is one-third the total from the three terminals.

I_{LL} = One-half the total minimum internal line-to-line fault current in the relay fed from both terminals of a two-terminal line. For three terminal lines, I_{LL} is one-third the total from the three terminals.

I_g = One-half the total minimum internal ground fault current in the relay (taking into account ground fault resistance) fed from both terminals of a two-terminal line. For three-terminal lines I_g is one third the total from the three terminals. (I_g equals three times the zero sequence current). (Average fault resistance is approximately 20 ohms.)

R_1 = The positive phase sequence filter resistance in ohms. (The positive sequence filter taps are expressed in R_1 ohms).

R_o = The zero-phase sequence filter resistance in ohms. (The zero sequence filter taps are expressed in R_o ohms).

T = The positive sequence current tap value. When R_1 = .10, T equals the balanced three phase or positive sequence minimum pick-up current in amperes. The minimum pick-up values of T for other R_1 taps are shown in Table I. (Minimum pick-up on two-terminal lines fed from one end only is 2 times tap T values; and for three terminal lines fed from one end only is 3 times tap T values. The multiplier may be increased somewhat for pilot wires of more than 1000 ohms resistance.

S_ϕ = Ratio of minimum phase fault current to minimum pick-up current of the relay.

S_g = Ratio of minimum ground fault current to minimum ground current pick-up of the relay. S_g should be greater than S_ϕ, as increased sensitivity of ground settings is generally required. The minimum pick-up of the relay on ground currents varies with the taps, T, R_1, and Ro, and is approximately equal to $2\ \frac{R_1}{Ro}\ T$. The values of T are selected from table 1.

The HCB relay protecting a transmission line system should be set to produce sufficient discriminating pilot wire voltage to correctly operate or block the relay at each of the terminals under all conditions of internal and external faults. This requires individual relay settings for operation on minimum internal (A) line-to-line and three phase faults, (B) line-to-ground faults. This is accomplished by setting each of three different taps:

1. The Positive Phase Sequence Current Taps (T)

   4 5 6 8 10 12 15

2. The Positive Phase Sequence Filter Taps (R_1 ohms)

   .075 .100 .150

3. The Zero Phase Sequence Filter Taps (R_o ohms)

   .025* .033* .05* .39 .51 .68 .90 1.2 1.6

* These taps are to be used with R_1 = .075, .10, and .15, respectively, to obtain response proportional to positive phase sequence currents only. The values are respectively 1/3 of R_1.

The setting with equal (Case I) and unequal (Case II) current transformer ratios for two-terminal lines, and the settings for a three terminal line (Case III) will be considered below. As discussed previously, all settings are based on the total fault current fed into minimum internal faults. The designation letters (A, B) and numbers (1, 2, 3) below refer to similar designation above.

CASE I - TWO TERMINAL LINE

(With equal current transformer ratios). The relay settings at each terminal will be the same.

A. Three Phase (Positive Sequence) Setting

1. Upper Tap Plate (T)

The nature of the sequence filter fixes the current setting for line-to-line faults at 1.73 times the three-phase setting which means that the three-phase trip settings must be 57% of the desired line-to-line current setting. Therefore, this setting should be made with regard to correct operation on line-to-line faults and the relay will trip for three-phase fault magnitudes 57% of the phase setting.

The settings on the upper tap plate should be made according to either of the following equations.

For minimum three-phase fault current values:

$$\text{Tap Setting (T)} = \frac{I_{3\phi} \times .86^* \times .57}{S_\phi} \quad (1)$$

Select the next lowest tap

* Line-to-line fault current is 86% of the three phase fault current when the positive phase sequence impedance equals the negative phase sequence impedance.

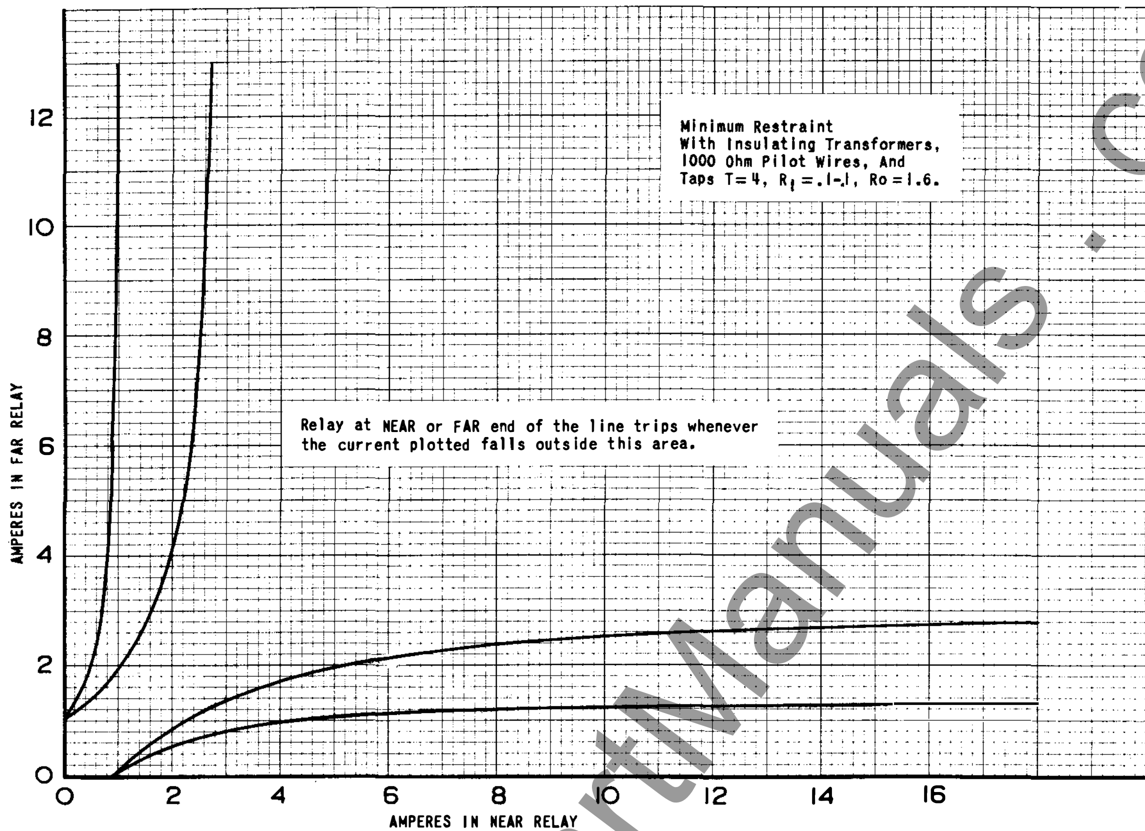

Figure 3
Typical Operating Characteristics on Phase A to Ground Faults with Currents in Phase.

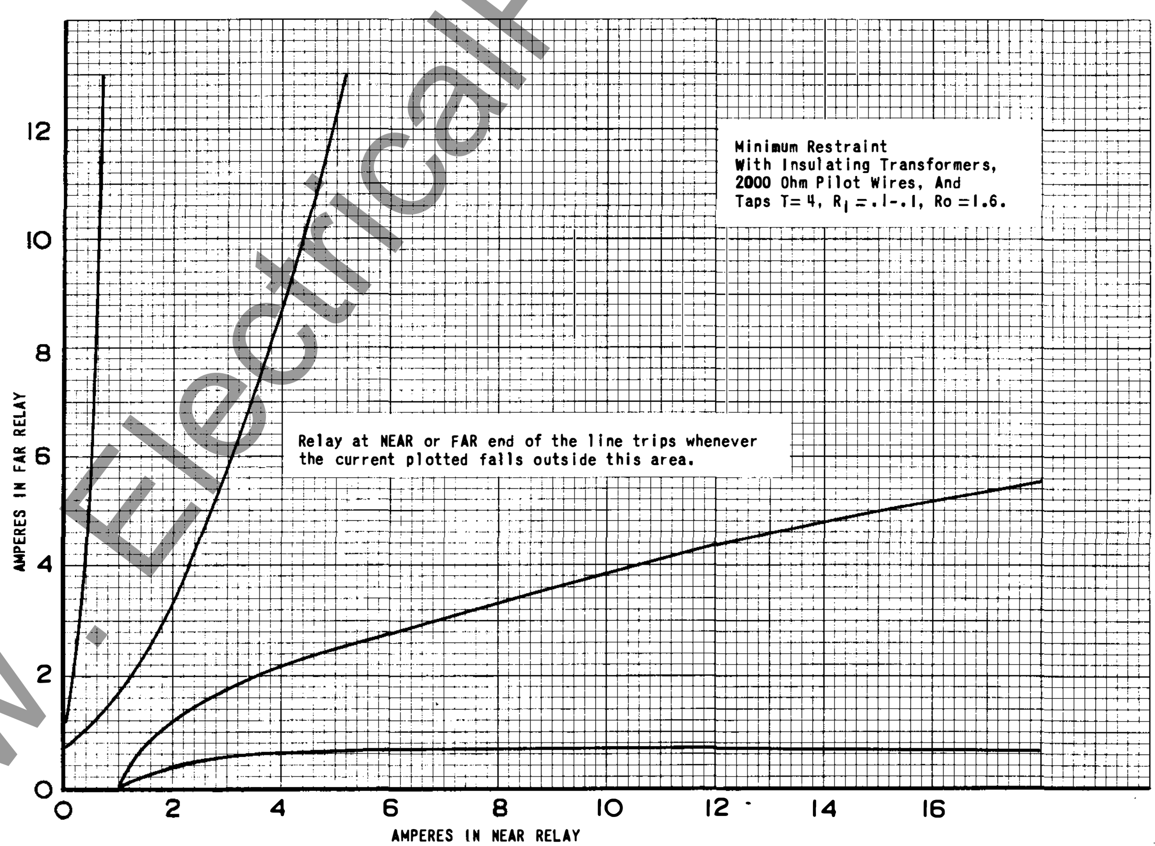

Figure 4
Typical Operating Characteristics on Phase A to Ground Faults with Currents in Phase.

For minimum line-to-line fault current value (I_{LL}):

$$\text{Tap Setting (T)} = \frac{I_{LL} \times .57}{S\phi} \qquad (2)$$

Select the next lower tap.

The value of S_ϕ is arbitrary and may be selected so that the relay minimum pick-up value is below maximum load with no danger of incorrect operation except when the pilot wires are opened. Then, as previously pointed out, the relays may trip under load conditions. To avoid incorrect operation on opened pilot wires choose S_ϕ so that the value of T will be above maximum load and as far below minimum fault current as possible.

The current tap (T) found from formulas (1) or (2) will be as marked on the upper tap plate except when R_1 is set on the .075 or .15 tap. In this case, consult Table I.

2. Lower Left Tap (R_1) Use R_1 = .1 for all cases except where values of T less than 4 are required. Consult Table I for calibration values of T on other values of R_1.

B. Ground (Zero Sequence) Setting

3. Lower Right Tap Plate (R_o)

The relay should be set more sensitive to ground currents than to phase currents. For lines with transformers of good quality (ratios matched and maintained during maximum thru faults) and with pilot wire circuits of 1000 ohms or less, it is recommended that the most sensitive ground tap (R_o = 1.6) be used in all cases without regard to the formulas that follow.

The limit to setting the ground tap sensitively depends on the current transformers used; since more sensitive ground setting means adding resistance (R_o type values are resistance in ohms) in the zero sequence branch of the filter which increases the energy requirement on the current transformers during ground faults.

In general, The ratio of the ground resistance tap (R_o) to the positive phase sequence resistance tap (R_1) can be selected to give the desired ground current setting by the following equation:

$$R_o = \frac{2\, R_1\, T\, S_g}{I_g} \qquad (3)$$

(select the next highest tap)

where T is the three-phase current tap setting selected above. S_g is an arbitrary constant, which should be larger than S_ϕ.

On lightly grounded systems, particularly those grounded thru a reactor, it may be necessary occasionally to reconnect the sequence filter for a negative K.* This is done as follows with reference to figure 1. Disconnect leads marked a, c, and d at the terminals A, C and D, respectively. Then reconnect lead a, to coil terminal D, lead c to terminal A, and lead d, to terminal C. This condition rarely occurs and requires special consideration beyond the scope of this leaflet.

* For further discussion of this problem reference is made to "A Single Element Pilot Wire Relay System" by E.L. Harder and M.A. Bostwick - Electric Journal, Nov. 1938.

Example for Case I (With equal current transformer ratios at all relay terminals).

HCB relays are to be set on a two terminal line section where the minimum fault currents (total from both ends) are 3000 amperes for a three-phase fault and 600 amperes for a line-to-ground fault (considering possible fault resistance). Maximum load current is 420 amperes. The current transformer ratio at both ends is 600/5. The setting for phase faults is as follows using equation (1).

$$I_{3\phi} = \frac{3000}{120 \times 2} = 12.5 \text{ amperes}$$

$$T = \frac{12.5 \times .86 \times .57}{1.5} = 4.1$$

Select Tap = 4. S_ϕ was selected 150% by inspection. Tap 4 is above maximum load to prevent tripping if the pilot wire accidentally opens.

The setting for ground faults using equation (3) is as follows: R_1 = .1 Tap.

$$I_g = \frac{600}{120 \times 2} = 2.5 \text{ amperes}$$

$$R_o = \frac{2 \times .1 \times 4 \times 3.00}{2.5} = .96$$

Select R_o Tap = 1.2. S_g = 300% was intentionally selected higher than S_ϕ = 150%. Note in this case the sensitivity to ground faults is less than that recommended above by using R_o = 1.6.

CASE II - TWO TERMINAL LINE

(With unequal current transformer ratios). The relay settings at each terminal will be different.

A. Three Phase (Positive Sequence Setting)

1. Upper Tap Plate (T).

The setting should be made in the same manner as described above under Case I, except that the taps should be picked from the following table, since values of R_1 other than .1 must be used.

As pointed out previously, the upper left-hand tap plate is calibrated and marked for three-phase current setting when R_1 = .1 on the lower left-hand tap plate. This table gives calibration values of the upper tap plate when R_1 is set on .075 and .15 taps.

	Value of R_1			Use Tap Marked
	.1	.075	.15	
Value of T in equations (1) & (2)	4	5.34	2.67	4
	5	6.67	3.33	5
	6	8.0	4.0	6
	8	10.7	5.34	8
	10	13.3	6.66	10
	12	16.0	8.0	12
	15	20.0	10.0	15

Table 1.

The table is used to determine the proper tap setting for calculated values of T from equation (1) and (2) when values of R_1 = .075,and .15 are used, that is, if T = 16.0 and R_1 = .075, the tap screw should be inserted in tap 12.

2. Lower Left Tap Plate (R_1)

The relay is supplied with taps (lower left-hand tap plate) which makes it possible to set the relay with the unequal current transformer ratios in the order of 2 to 1, 3 to 4 and 2 to 3. The example will best illustrate the section of R_1 for the unequal ratios.

B. Ground (Zero Sequence) Setting

3. Lower Right Tap Plate (R_o)

This setting should be made using the equation (3) as described under Case I (B).

When using the .15 R_1 tap, it is impossible to give equally sensitive settings for ground currents at all terminals, so that ground taps should be chosen to give as near equal sensitivity as possible. This will not cause incorrect operations, but limits the amount of permissible unbalance caused by saturation or unequal transformer characteristic.

Example for Case II (With unequal current transformer ratios at the relay terminals).

In the example of Case I the relay settings are to be given for current transformer ratios of 600/5 and 300/5.

As calculated above -

For the 600/5 Terminal

$I_{3\phi}$ = 12.5 amperes

I_g = 2.5 amperes

For the 300/5 Terminal

$I_{3\phi}$ = 25.0 amperes

I_g = 5.0 amperes

R_1 is to be chosen giving equal sensitivity for phase faults. (The ratio of the currents for the two terminals above is one to two so the R_1 taps should be chosen in the inverse ratio which is two to one; or

R_1 = .15 for the 600/5 Terminal

R_1 = .075 for the 300/5 Terminal

The value of T for three phase faults from equation (1).

For the 600/5 Terminal

$$T = \frac{12.5 \times .86 \times .57}{1.50} = 4.1$$

For the 300/5 Terminal

$$T = \frac{25 \times .86 \times .57}{1.50} = 8.16$$

and from Table 1 the taps chosen will be tap 6 for both terminals. In both cases $S\phi$ = 150% which gives values of T above maximum load.

NOTE: Equal current taps (T) must always be used.

The ground fault setting will be, using equation (3):

For the 600/5 Terminal

$$R_o = \frac{2 \times .15 \times 4 \times 3.00}{2.5} = 1.44$$

For the 300/5 Terminal

$$R_o = \frac{2 \times .075 \times 8 \times 3.00}{5.0} = .72$$

Choose ground taps 1.6 for the 600/5 Terminal and .9 for the 300/5 Terminal.

This does not give equal sensitivity as pointed out above, since there is not a 1.8 ground tap available. It will be observed that the range of the relay is considerably reduced by having unequal current transformer ratios.

CASE III - THREE TERMINAL LINE

The settings for this case are made the same as for Case I or II except $I_{3\phi}$ or I_{LL} and I_g values are 1/3 the total minimum fault current fed from the three terminals.

On three-terminal lines, the relay pick-up for feed from one terminal only is 3 times the tap (T) values as discussed above. The additional length of pilot wire increases the shunt pilot wire paths and consequently slightly more than 3 times tap value may be needed to operate the relays. This makes it desirable to use larger values of $S\phi$ in equations (1) or (2). On the other hand three-terminal lines are more susceptible to faulty operation on apparent ground currents set up by transformer ratio breakdown on heavy external faults. Thus, it may be desirable to limit the sensitivity of ground current settings. Consequently, on three-terminal lines it is necessary to use good quality transformers that will not saturate on maximum external faults.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs. Either of these studs may be utilized for grounding the metal base. 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.

The external connections are shown in figure 5. The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohms and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the lower lead on the front stationary contact of the switch and this lead should be fastened (dead ended) under the small filister-head screw located in the Micarta base of the switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms. The resistance of both coils in parallel is approximately 0.25 ohm.

ADJUSTMENTS AND MAINTENANCE

Caution

1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

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.

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed or the relay taken apart for repairs, the following instructions should be followed in reassembling and setting it.

Sequence Filter

There are no adjustments to be made in the filter.

Polar-Type Element

Back off the contact screws so that they do not make contact. Screw the magnetic shunts into the all-out position. The armature should remain against whichever side it is pushed with this adjustment.

Contact Adjustment: Adjust both left-hand (front view) contacts until they barely make a light circuit, when the armature is against the left stop. A flickering light is permissible. Give both the left-hand contact screws an additional 1/3 turn.

Calibration: Screw in the left-hand magnetic shunt so that only the top air gap is shunted. This increases the armature bias towards the right. The right-hand top air gap should not be shunted by the magnetic shunt. Energize the operating coil with .0078 ampere d-c. thru the right test link with the polarity as shown in figure 1. Then adjust the right-hand shunt by screwing it toward the left until the relay contacts close. The contacts should close with a snappy action. Check to see that the contacts reset when the coil is deenergized.

Close the right-hand operating coil test link and open the left-hand restraining coil test link. Energize the restraining coil with .10 ampere d-c. thru the restraining coil with polarity as shown in figure 1. The contacts should tend to move toward the right.

Overall Test

Close the test links and place the neon lamp in the circuit. Use taps R_0 = 1.6, R_1 = .1-.1, and T = 4. Connect a 1500 ohm resistor between terminals 15 and 16 to simulate the magnetizing impedance of the insulating transformer. Pass 6.95 amperes, 60 cycles, thru terminals 19 to 22 (figure 1). The relay should operate. It should also trip when .45 to .55 amperes, 60 cycles, are passed thru terminals 21 to 22.

If it is desired to calibrate the relay to actual pilot wire conditions, the insulating transformer should be connected across terminals 15 and 16 (figure 1) with one-half of the pilot wire capacitance connected across the high voltage terminals of the transformer. With these connections, the polarized element should be adjusted as outlined above. After calibrating in this manner, an equivalent pilot wire resistance can be determined by connecting a slide wire resistor across terminals 15 and 16 instead of the insulating transformer and by varying the magnitude until the same trip value is obtained. Then in the future this resistance can be used instead of the 1500 ohms suggested above.

The phase current trip setting on the relay may be made by passing 60 cycle current thru terminals 19 to 22 (Figure 1). The trip current should be 1.73 times the desired three phase magnitude. For the ground current settings, the relay should trip on the desired magnitude of ground current when 60 cycle current is passed thru terminals 19 and 21 (Figure 1).

Pilot Wire Polarity Check

The polarity of the pilot wires are most easily checked while the line is carrying load (1 ampere or more). This is done by short-circuiting the current transformers to create an apparent zero sequence current thru the relays and observing the relay operation. The procedure is as follows: Set R_0 tap on 1.6 and tap T on 4. At one end short-circuit the phase A current transformer and then disconnect the lead to terminal 20. At the other end short circuit either phase B or C current transformers and then disconnect the corresponding lead to the relay (either terminal 19 or 22, respectively). If the pilot wire is properly connected to the relays, the relays should trip. Reconnect the lead to either terminal 19 or 22 and remove the short across B or C phase. Now short phase A current transformer and remove the lead to terminal 20. The relays should not operate with correct polarity.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This canbe done by turning the relay up-side-down and screwing up the core screw of the switch until the contacts just separate. Then back up 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c. is passed thru the coil.

Operation Indicators

Adjust the indicators to operate at 0.2 ampere d-c. gradually increased. Test for sticking after 5 amperes d-c. has been applied.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used.

The burdens are approximately equal to I^2R_1 where R_1 is the positive sequence tap used and I is the balanced three-phase current used. To illustrate the following burdens were measured at a balanced three-phase current of 5 amperes:

For tap 4 R_1 = .075 and R_0 = .39

Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_0 = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.

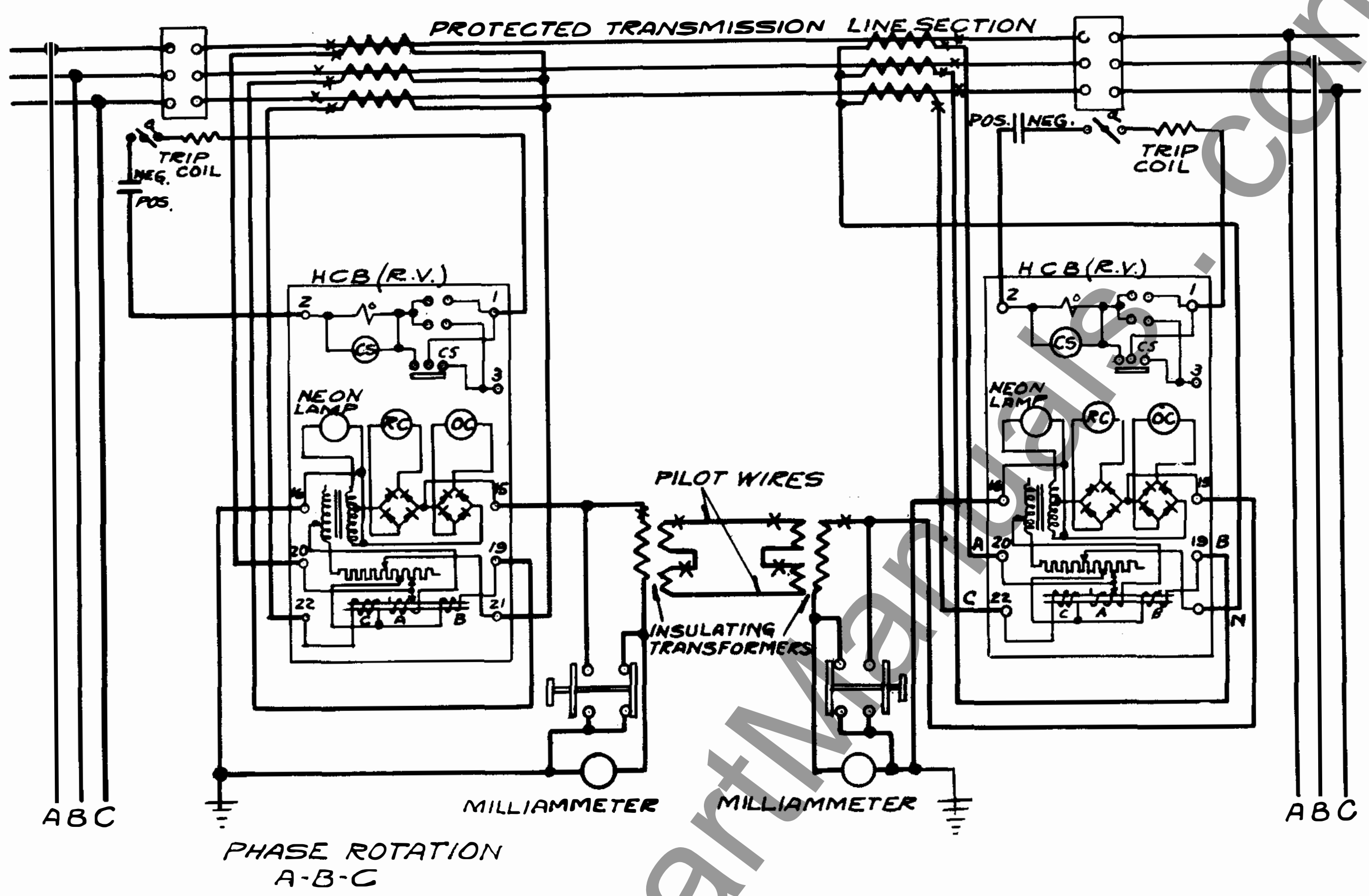

Figure 5
External Connections of the Type HCB Relay for a Two Terminal Line.

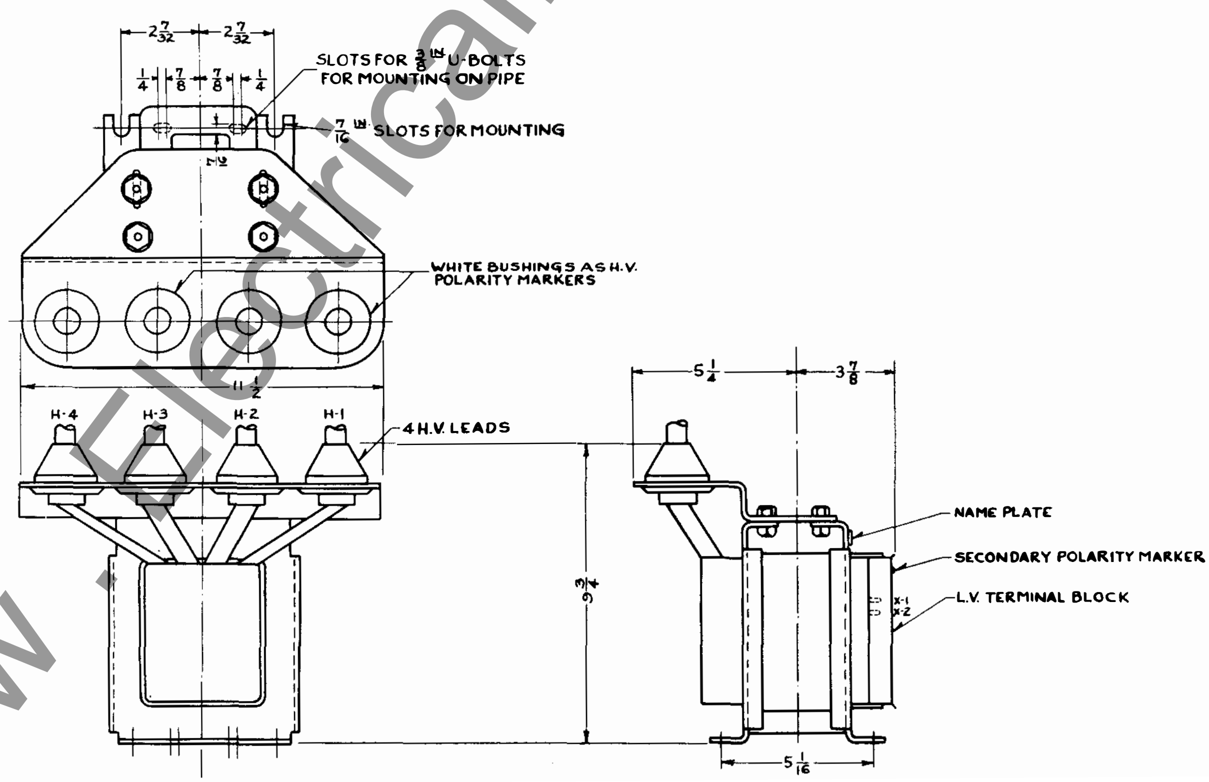

Figure 6
Outline and Drilling Plan of the Insulating Transformer.

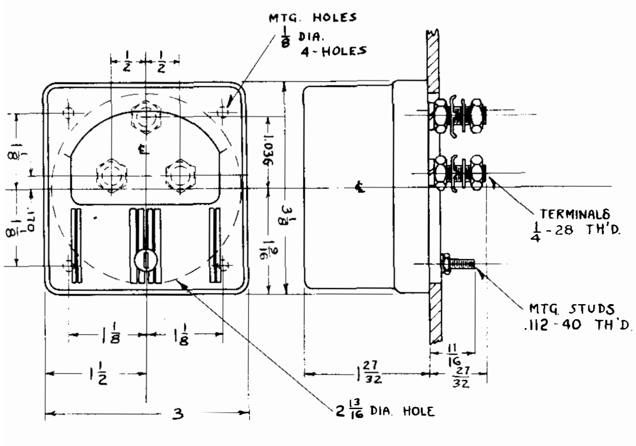

Figure 7
Outline and Drilling Plan of the Test Milliammeter for 1/8" panel Mounting.

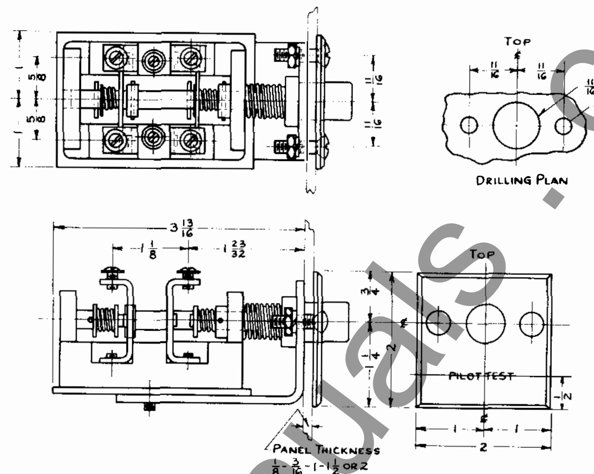

Figure 8
Outline and Drilling Plan of the Test Switch.

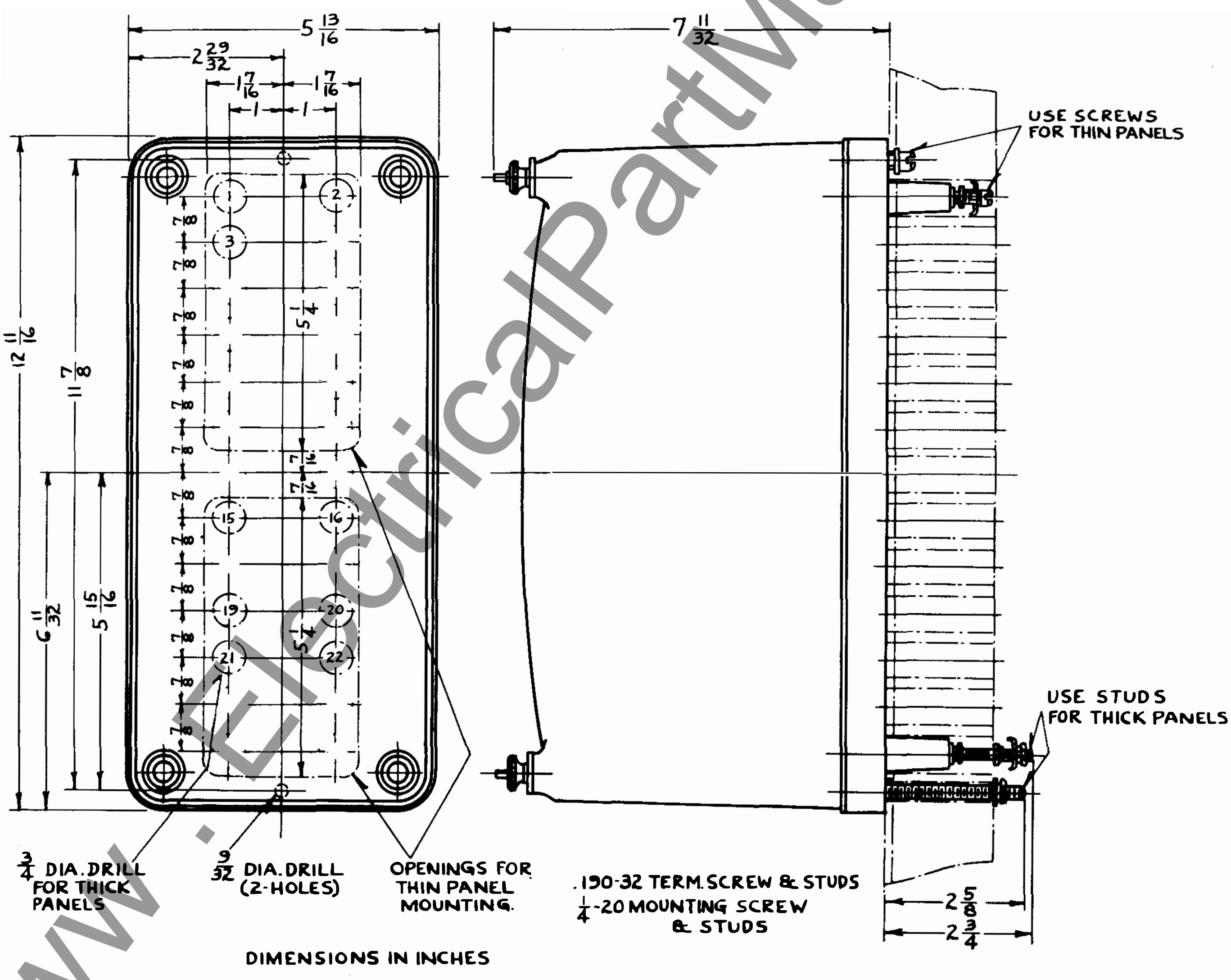

Figure 9
Oultine and Drilling Plan for the Standard Projection Type Case.

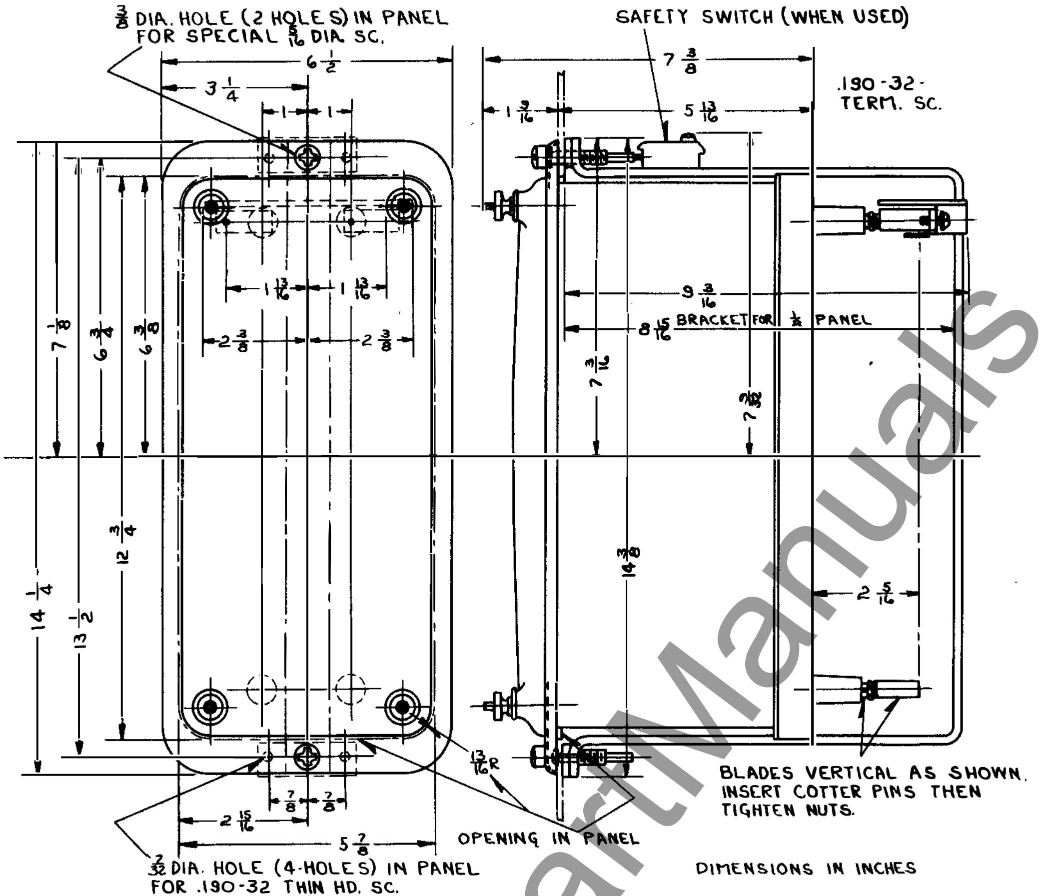

Figure 10
Outline and Drilling Plan for the Standard Flush Type Case.

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TYPE HCB PILOT WIRE RELAY

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The type HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

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The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

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The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) figure 1 adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the output of the saturating transformer, and is marked in amperes required to operate the relay when the pilot wire is open or when equal amounts of current are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in figure 9. The rectox units are used to convert the a-c. output of the saturating transformer for use on the d-c. polar-type relay element. The use of a sensitive polar type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnet bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating winding produces a magnetic field which acts to move the armature in the contact closing direction. The restraining winding is tapped and the leads are brought out to taps at the upper left of the relay. The taps are marked T and F signifying Tapped and Full winding, respectively.

The moving contacts are fastened on the free end of the leaf spring. Two stationary contact screws are mounted to the left (front view) of the moving contact assembly and are adjusted for normally open contacts.

Insulating Transformer

The insulating transformer is connected as shown in figure 9 and serves to isolate the terminal equipment from the pilot wire. This avoids interconnection of station grounds that may have large differences of potentials between them. The mid-taps of the parallel-wound secondary windings are brought out separately to provide a means of connecting supervisory relays symmetrically within the pilot wire circuit. When auxiliary supervisory relays are not used, these mid-taps are to be connected together and may be grounded to drain the voltages induced along the length of the pilot wires when these voltages approach the voltage limit of the cable. This is discussed further under Pilot Wire below.

The transformers have a 4/1 ratio and are insulated for 5000 volts.

Pilot Wire

One pair of pilot wires connecting the secondaries of the insulating transformers is required to provide a continuous circuit between the relays. For the pilot wires a lead-covered twisted pair of No. 19 wire or larger is recommended; however, open wires may be used. The following points should be considered in selecting pilot wire circuits.

1. The total circuit resistance between terminals of the Type HCB relays exclusive of the insulating transformers and expressed in terms of the pilot wire voltage must not exceed 2000 ohms.

2. The shunt capacity between pilot wires should not exceed 0.75 microfarads per pilot wire terminal. In cases where this value is exceeded, auxiliary reactors may be required to reduce the shunt currents which tend to desensitize the relay.

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. However, the requirement of 15 volts difference must be maintained.

b. For more serious induction two winding neutralizing transformers can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing transformers should be used. Transformers are available for 1000 and 2000 volt neutralization.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in figure 9. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault currents fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted pilot wire mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by a continuously-operated supervisory circuit supplied as extra equipment.

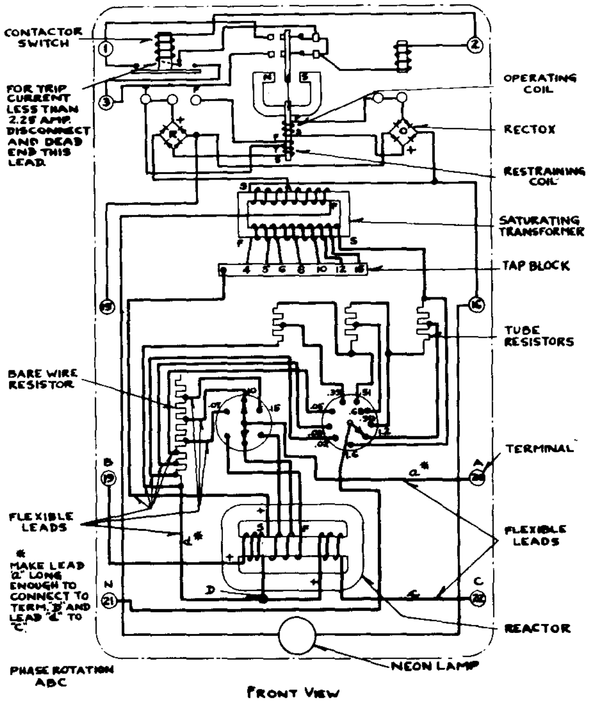


Figure 1
Internal Connections of the Type HCB Relay For Projection Mounting.

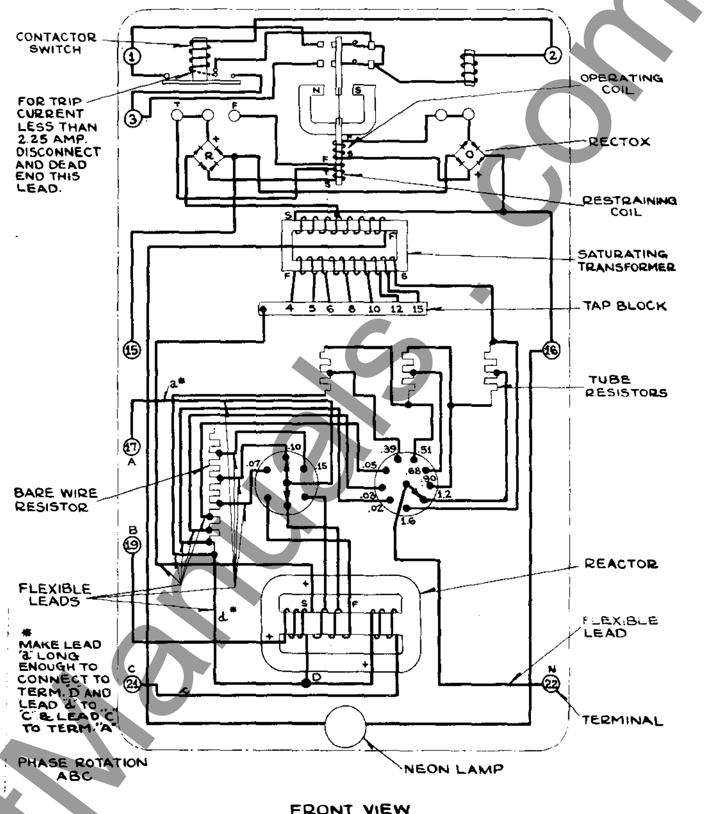


Figure 2
Internal Connection of The Type HCB Relay For Projection Detachzble And All Flush Type Mounting.

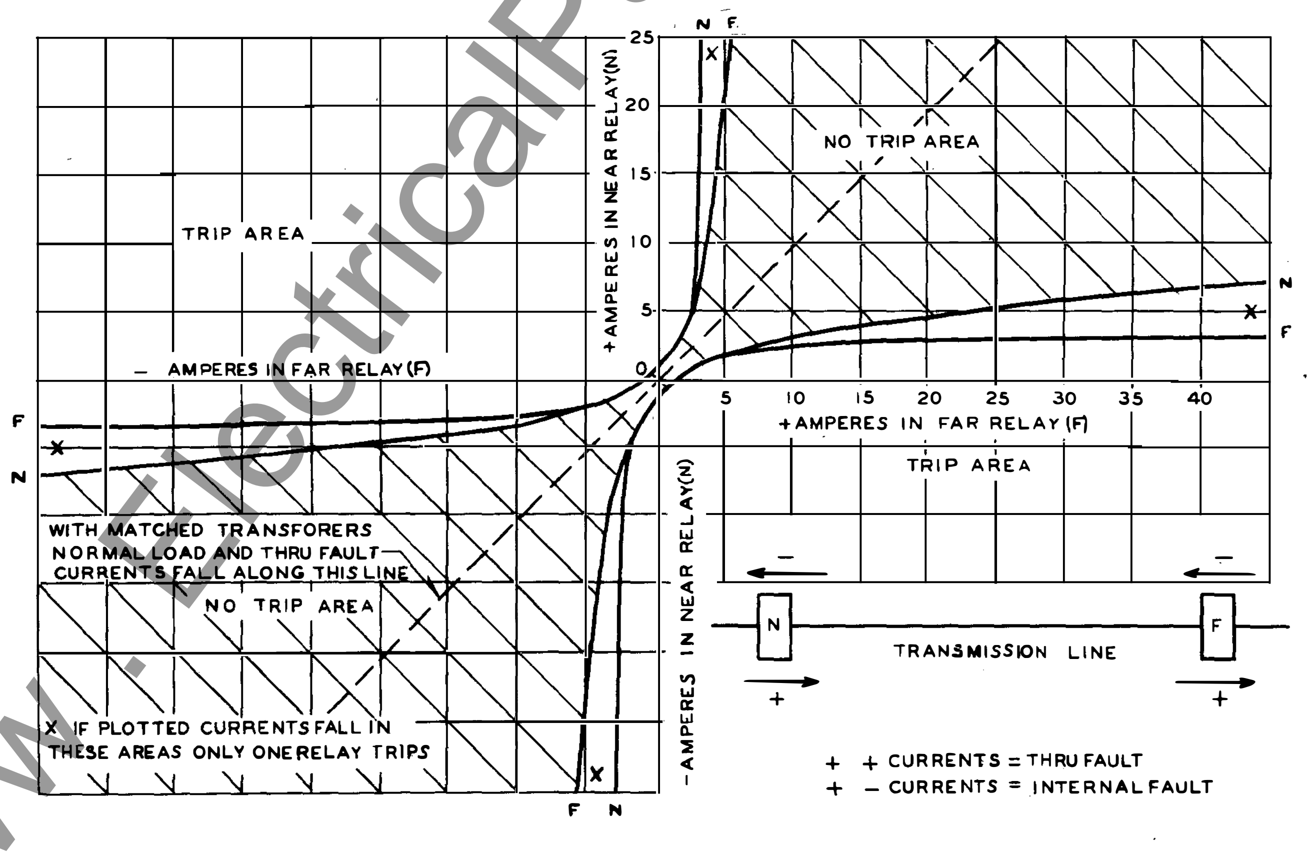


Figure 3
Typical Operating Characteristics on Phase A to Ground Faults with Currents thru the Two Terminals 30° Out of Phase. Maximum Restraint With Insulating Transformers And 2000 Ohm Pilot Wires. Taps 4, .1-.1, and 1.6.

Checking the condition of the pilot wire under normal load conditions by the test switch and milliammeter may be done as follows:

1. Press the push button part way to open the short-circuit around the meter and the meter reading will indicate the magnitude of pilot wire current being circulated.

2. Press the push button all the way to short the near end of the pilot wire and the meter will indicate the magnitude of current that is sent over the pilot wires from the far relay.

A comparison of these readings will indicate the condition of the pilot wire. With normal pilot wires the second readings will be somewhat less than the first reading. When the pilot wires are shorted, the second reading will be reduced to zero. In the event the second reading is considerably less than expected, a high resistance fault between wires is indicated. If a pilot wire is open, both readings will be zero. It should be noted that the relays are made inoperative when the test switch is fully depressed.

CHARACTERISTICS

The overall operating characteristics of the relay are illustrated in figure 3. The general shape of these curves are similar for other types of faults, relay settings, and pilot wire lengths. Figures 4 and 5 are enlarged first quadrants of figure 3 taken under the condition noted on the curve. The ampere abscissa and ordinate scales may be interpolated as follows to show the operating characteristics for other conditions using T = 4.

For ground faults using other R_0 and R_1 taps multiply scales by:

$$\frac{1.7}{R_0 + R_1} \quad \text{Phase A to Ground Faults}$$

$$\frac{1.7}{R_0 + j\ .577R_1} \quad \text{Phase B or C Ground Faults}$$

For three-phase faults multiply scales by:

$$\frac{1.7}{2\ R_1} = \frac{.85}{R_1}$$

For line - to - line faults multiply scales by:

$$\frac{1.7\sqrt{3}}{2R_1} = \frac{1.47}{R_1}$$

The relay is normally shipped with the minimum restraint tap, T , connected as shown in upper left corner, figures 1 & 2. The maximum restraint tap, F, is available for use on maximum length pilot wires and when the current transformer ratios are not well-matched.

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (taps are actually marked .07, .10, and .15 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of R_1 = .10 is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with R_1 = .10. Where the current transformers are different at the different terminals, select the value of R_1 which is most nearly proportional to the current transformer ratios. For example, assume ratio of 300/5 at one terminal and 600/5 at another terminal. Set R_1 = .075 at the 300/5 terminal and R_1 = .15 at the 600/5 terminal. The same procedure applies to three terminal lines.

Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12, and 15. This tap should be selected to assure operation on minimum internal line to line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line to line faults is given by the equation:

$$T = 5.7\ I_{LL}\ R_1 \qquad (1)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

The factor "5.7" is used as the operation of the positive sequence filter and is such that the relay requires 1.73 times as much current for operation on a line-te-line fault as on a three phase fault, which means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T must be divided by 0.1 thereby obtaining the factor "5.7".

Where line-to-line fault currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\ (.86)\ (I_{3\phi})\ R_1 \qquad (1a)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

Equation (1) and (1a) give the upper limit of "T" which must not be exceeded to obtain operation on line-to-line faults. The actual setting should always be below the values obtained from equation (1) or (1a). The minimum limits for this setting are discussed below.

The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10\ R_1\ I_{Load} \qquad (2)$$

where "I_{Load}" is the maximum secondary

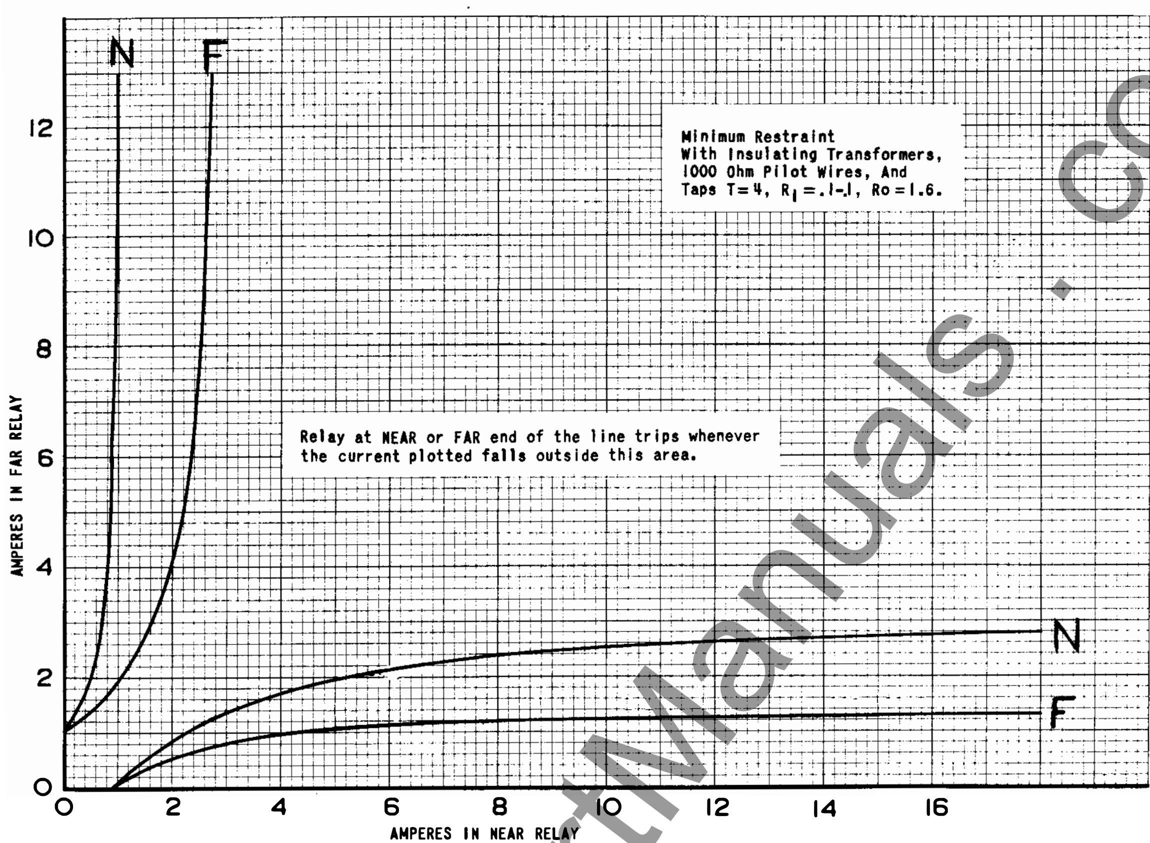


Figure 4
Typical Operating Characteristics On Phase A to Ground Faults with Currents in Phase.

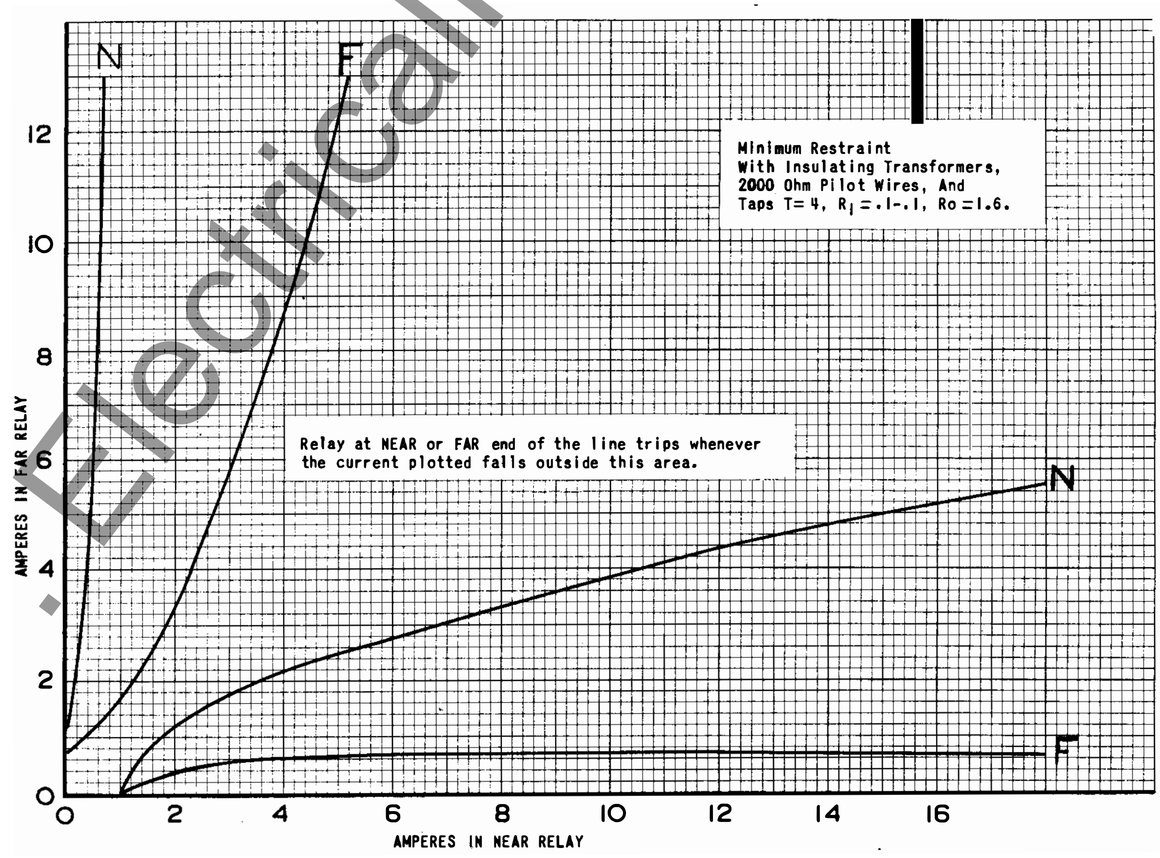


Figure 5
Typical Operating Characteristics On Phase A to Ground Faults with Currents in Phase

full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (2) if the relay is not to operate on load current with the pilot wires open circuited.

This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents, or if supervisory relays are installed and connected to block the HCB on the occurrence of pilot wire failures. If supervisory relays are installed to block HCB operation under heavy load conditions with the pilot wires opened, it is necessary to introduce a time delay of approximately one cycle by interposing an auxiliary relay in the trip circuit at each terminal to allow the supervisory relays time to coordinate with the high speed of the HCB relay.

It is recommended that "T" be set reasonably below the value obtained from equation (1) without causing incorrect operation on load current in the event of a pilot wire failure. Such a selection assures abundant energy for the simultaneously tripping of all relays on light internal faults.

NOTE: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_o) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. The first two taps are actually marked .02 and .03 because of space limitations.) The three lowest taps are not used in applications where sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_o is set to equal to 1/3 R_1.

Maximum sensitivity to ground faults is obtained with $R_o = 1.6$. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_o should be selected which are most nearly proportional to the transformer ratios.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_o = \frac{0.2T}{Ig} \qquad (3)$$

where Ig is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals.
And where "T" is the actual tap selected (not the value calculated from equation (1) or (1a).

It is recommended that "R_o" be set as high above the value obtained from equation (3) as possible keeping the value of R_o approximately proportional to the current transformer ratios. It is further recommended that "R_o" be set with a greater safety factor than "T". That is, the value obtained from equation (1) or (1a) divided by the actual tap selected for "T" equals the safety factor $S\phi$. The actual value of R_o selected divided by the value obtained from equation (3) equals the safety factor Sg. Sg should be larger than $S\phi$ to obtain greater sensitivity to minimum ground faults than to minimum phase faults.

NOTE: R_o at various terminals should be selected which are most nearly proportional to the current transformer ratios.

Restraint Tap:

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is shipped from the factory with the connection to the tap to obtain minimum restraint. This connection is recommended for most applications but the additional restraint is available where needed for special applications.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on minimum internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R_1 at station 2 = 0.075.

Positive Sequence Current Tap

From equation 1

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissable setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (2).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75 \quad \text{or}$$

$$T = \frac{10 \times 0.75 \times 300 \times 5}{300} = 3.75$$

Select T at both stations = 6

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation 3.

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6
And R_o at station 2 = 1.2

The factor of safety on phase faults ($S\phi$) = 6/3.75 = 160%.
The factor of safety on ground faults (Sg) = 1.6/.48 = 334%.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs. Either of these studs may be utilized for grounding the metal base. 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.

The external connections are shown in figures 9, 10, 11, 12. The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohms and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the switch and this lead should be fastened (dead ended) under the small filister-head screw located in the Micarta base of the switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms. The resistance of both coils in parallel is approximately 0.25 ohm.

ADJUSTMENTS AND MAINTENANCE

Caution

1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

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.

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed or the relay taken apart for repairs, the following instructions should be followed in reassembling and setting it.

Sequence Filter

There are no adjustments to be made in the filter.

Polar-Type Element

Back off the contact screws so that they do not make contact. Screw the magnetic shunts into the all-out position. The armature should remain against whichever side it is pushed with this adjustment.

Contact Adjustment: Adjust both left-hand (front view) contacts until they barely make a light circuit, when the armature is against the left stop. A flickering light is permissible. Give both the left-hand contact screws an additional 1/3 turn.

Calibration: Screw in the left-hand magnetic shunt so that only the top air gap is shunted. This increases the armature bias towards the right. The right-hand top air gap should not be shunted by the magnetic shunt. Energize the operating coil with .0078 ampere d-c. thru the right test link with the polarity as shown in figure 1. Then adjust the right-hand shunt by screwing it toward the left until the relay contacts close. The contacts should close with a snappy action. Check to see that the contacts reset when the coil is deenergized.

Close the right-hand operating coil test link and open the left-hand restraining coil test link. Energize the restraining coil with .10 ampere d-c. Thru the restraining coil with polarity as shown in figure 1. The contacts should tend to move toward the right.

Overall Test

Close the test links and place the neon lamp in the circuit. Use taps $R_o = 1.6$, $R_1 = .1-.1$, and T = 4. Connect a 1500 ohm resistor between terminals 15 and 16 to simulate the magnetizing impedance of the insulating transformer. Pass 6.95 amperes, 60 cycles, thru terminals 19 to 22 (figure 1). The relay should operate. It should also trip when .45 to .55 amperes, 60 cycles, are passed thru trrminals 21 to 22.

If it is desired to calibrate the relay to actual pilot wire conditions, the insulating transformer should be connected across terminals 15 and 16 (figure 1) with one-half of the pilot wire capacitance connected across the high voltage terminals of the transformer. With these connection , the polarized element should be adjusted as outlined above. After calibrating in this manner, an equivalent pilot wire resistance can be determined by connecting a slide wire resistor across terminals 15 and 16 instead of the insulating transformer and by varying the magnitude until the same trip value is obtained. Then in the future this resistance can be used instead of the 1500 ohms suggested above.

The phase current trip setting on the relay may be made by passing 60 cycle current thru terminals 19 to 22 (figure 1). The trip current should be 1.73 times the desired three phase magnitude. For the ground current settings, the relay should trip on the desired magnitude of ground current when 60 cycle current is passed thru terminals 19 and 21 (Figure 1).

Pilot Wire Polarity Check

The polarity of the pilot wires are most easily checked while the line is carrying load (1 ampere or more). This is done by short-circuiting the current transformers to create an apparent zero sequence current thru the relays and observing the relay operation. The procedure is as follows: Set R_o tap on 1.6 and tap T on 4. At one end short-circuit the phase A current transformer and then disconnect the lead to terminal 20. At the other end short circuit either phase B or C current transformers and then disconnect the corresponding lead to the relay (either terminal 19 or 22, respectively). If the pilot wire is properly connected to the relays, the relays should trip. Reconnect the lead to either terminal 19 or 22. and remove the short across B or C phase. Now short phase A current transformer and remove the lead to terminal 20. The relays should not operate with correct polarity.

Contactor Switch

Adjust the stationary core of the

switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down and screwing up the core screw of the switch until the contacts just separate. Then back up 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c. is passed thru the coil.

Operation Indicators

Adjust the indicators to operate at 0.2 ampere d-c. gradually increased. Test for sticking after 5 amperes d-c. has been applied.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three-phase current of 5 amperes:

For tap 4 R_1 = .075 and R_o = .39

Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_o = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.

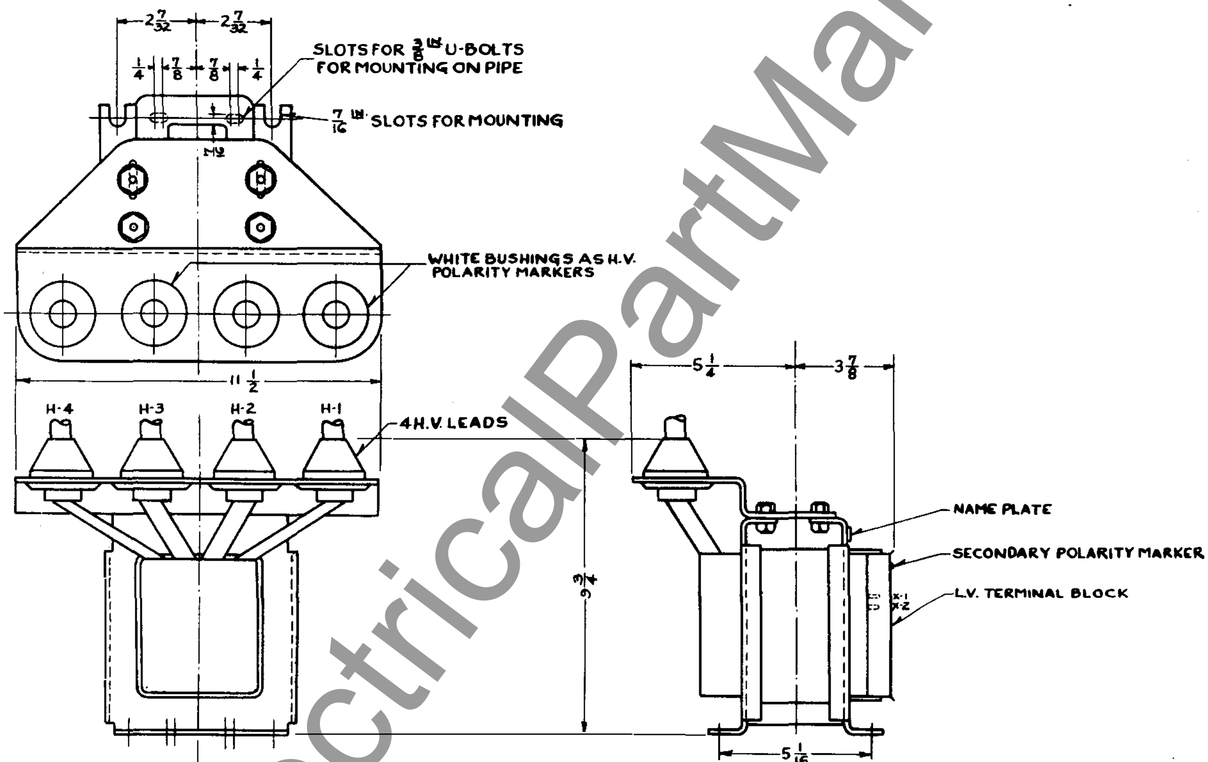
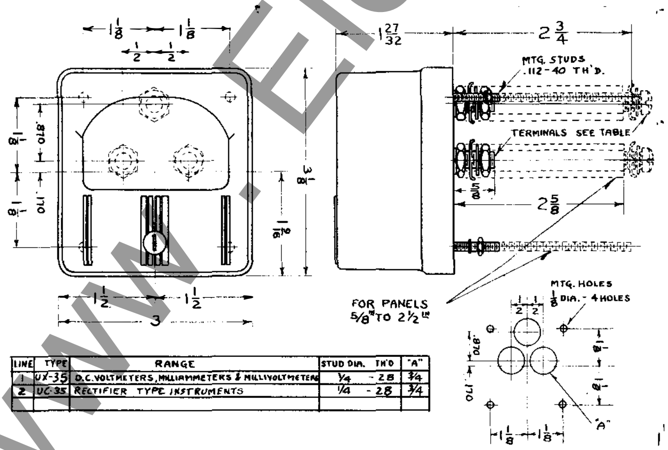


Figure 6
Outline and Drilling Plan of the Insulating Transformer.



LINE	TYPE	RANGE	STUD DIA. TH'D	"A"
1	UX-35	D.C. VOLTMETERS, MILLIAMMETERS & MILLIVOLTMETERS	1/4 - 28	3/4
2	UC-35	RECTIFIER TYPE INSTRUMENTS	1/4 - 28	3/4

Figure 7
Outline & Drilling Plan of the Test Milliammeter for 1/8" Panel Mounting.

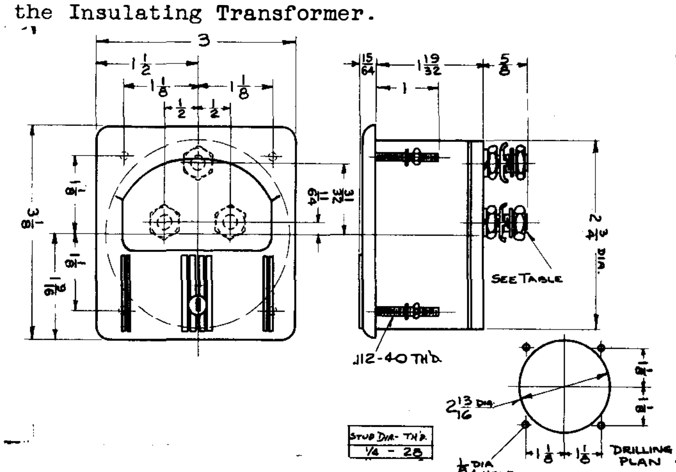


Figure 8
Outline & Drilling Plan of the Test Milliammeter for Flush Type Mounting.

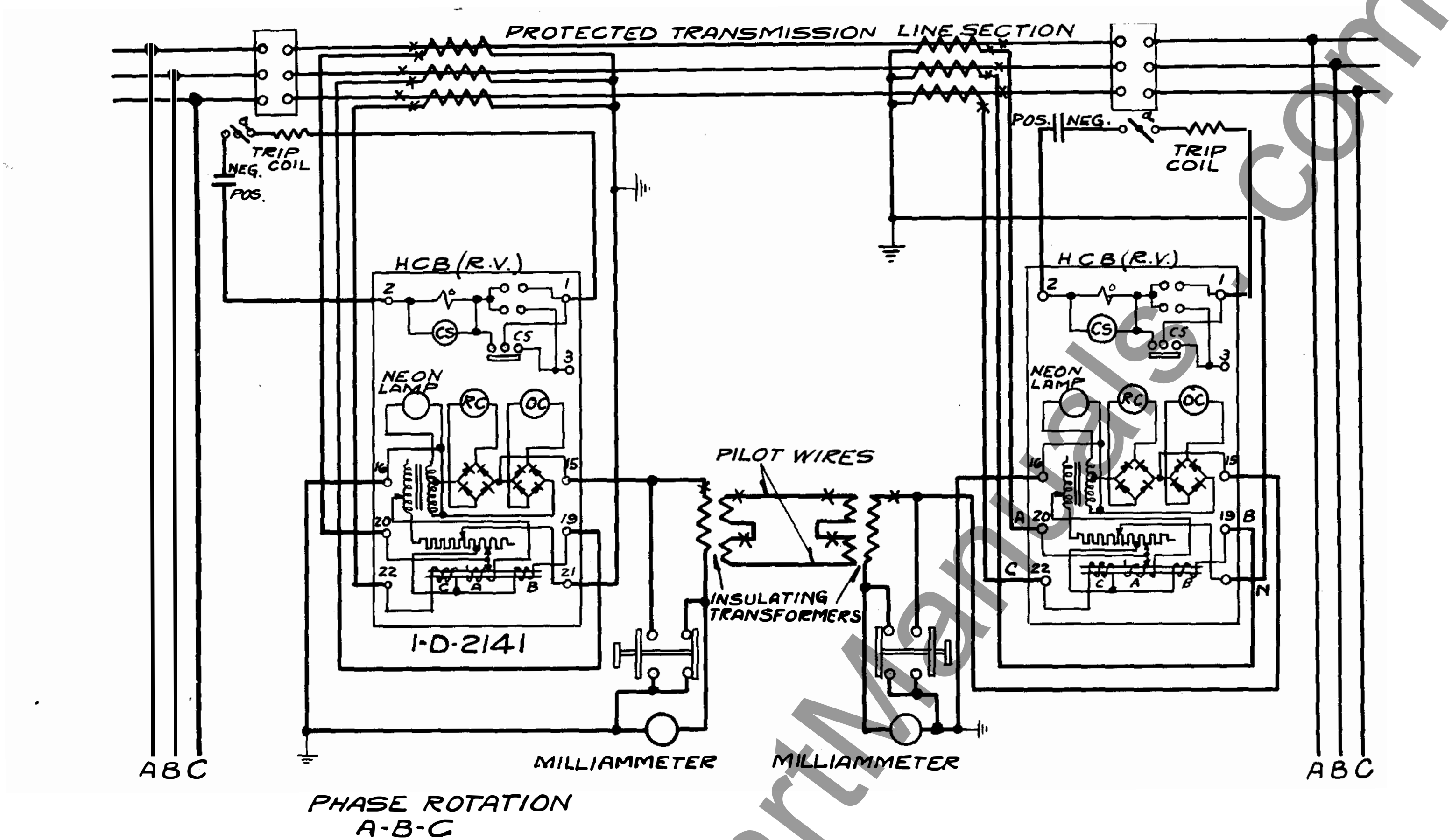


Figure 9
External Connections of the Type HCB Relays For Phase and Ground Fault Protection of a Two-Terminal Line.

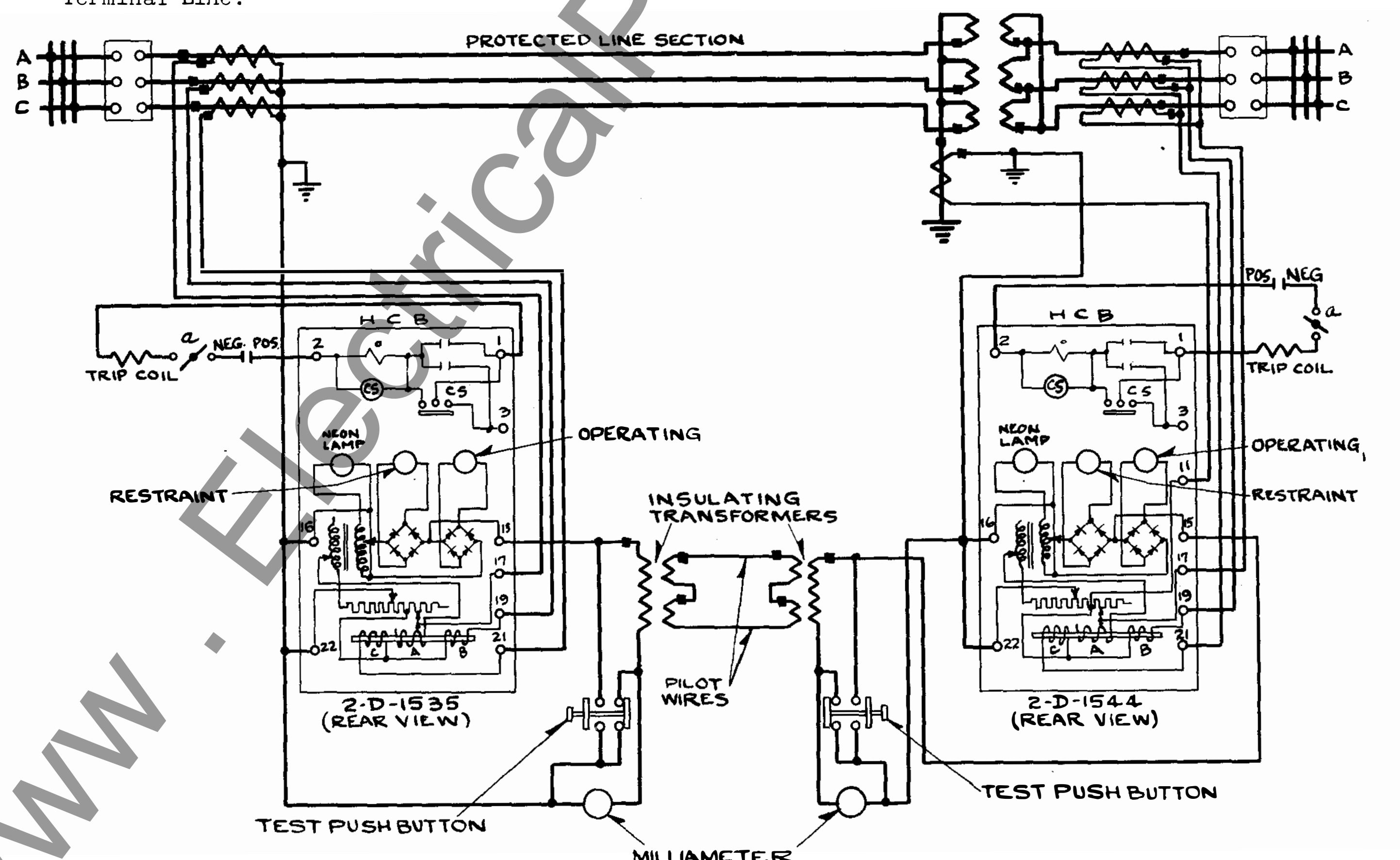


Figure 10
External Connections of the Type HCB Relays For Phase and Ground Fault Protection of a two-Terminal Line Thru a Star-Delta Transformer Bank at One End.

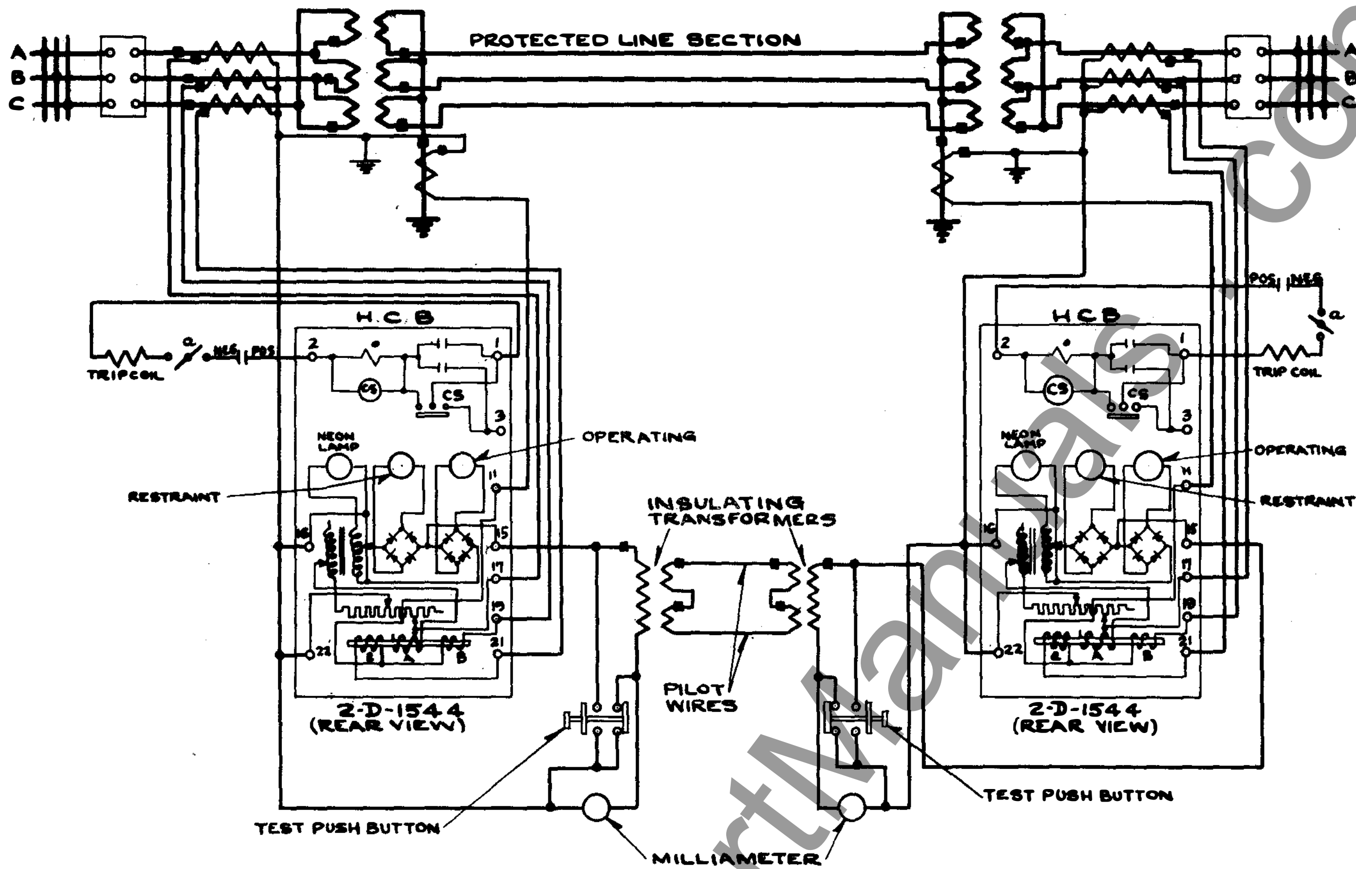


Figure 11
External Connections of the Type HCB Relays for Phase and Ground Fault Protection of a Two-Terminal Line Thru Two Star Delta Transformer Banks.

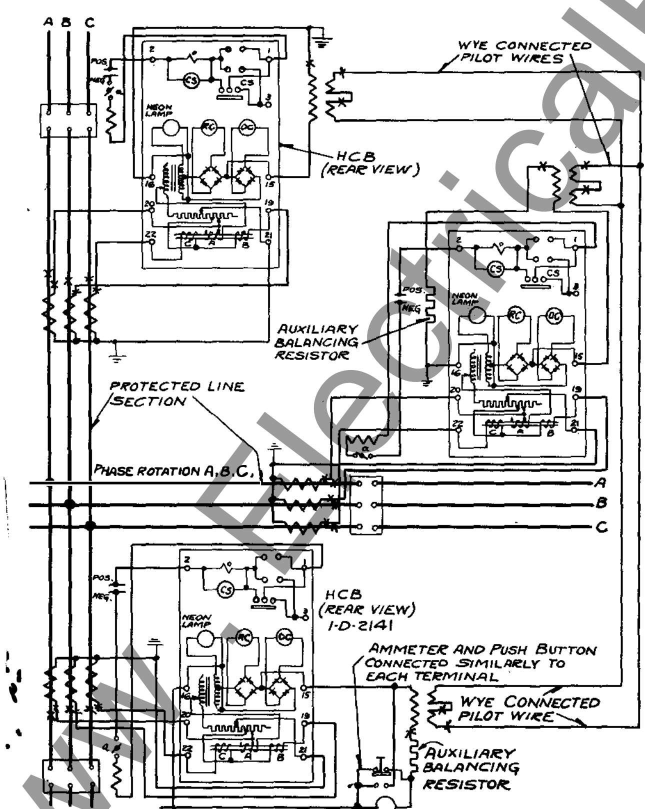


Figure 12
External Connections of the Type HCB Relays for Phase and Ground Protection of a Three Terminal Line.

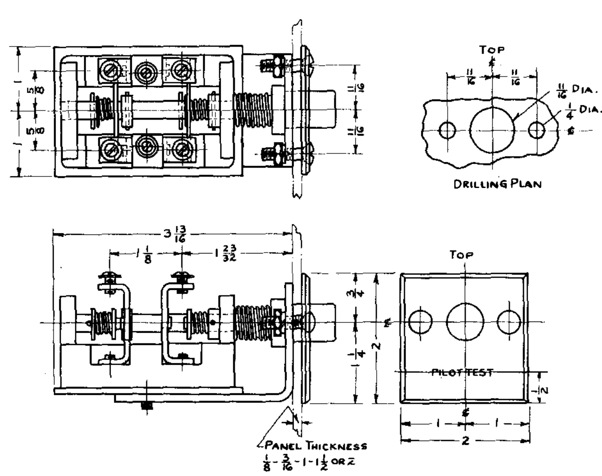


Figure 13
Outline And Drilling Plan of the Test Switch

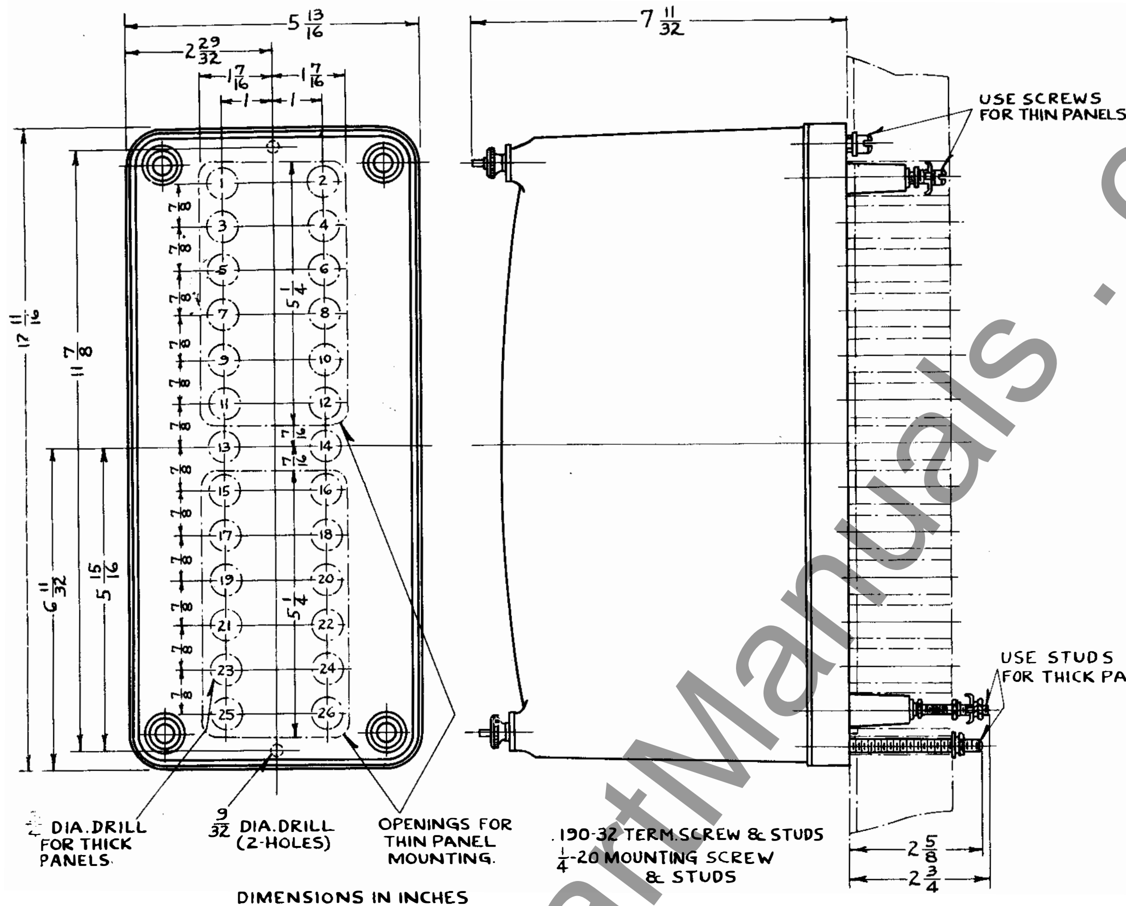


Figure 14
Outline and Drilling Plan for The Standard Projection Type Case. (See Internal and External Connections For Terminal Supplied.)

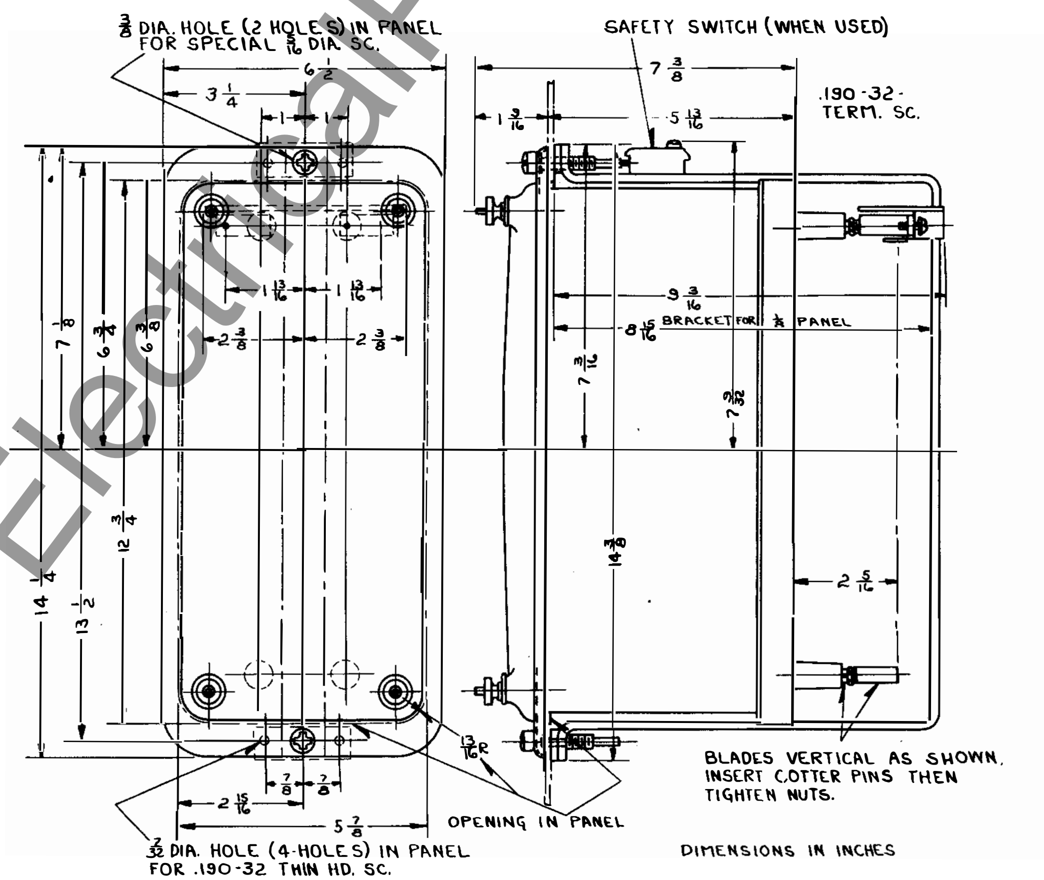


Figure 15
Outline And Drilling Plan For The Standard Detachable Type Case for 1/8" Panel Mounting.

Westinghouse Electric & Manufacturing Company
Newark Works, Newark, N. J.

Westinghouse

TYPE HCB PILOT WIRE RELAY

INSTRUCTIONS

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line, three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test push button. The construction of these components is as follows:

Sequence Filter

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the output of the saturating transformer, and is marked in amperes required to operate the relay when the pilot wire is open or when equal amounts of current are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in Figure 8. The rectox units are used to convert the a-c output of the saturating transformer to d-c for use on the d-c polar-type relay element. The use of a sensitive polar type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnet bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a mag-

WESTINGHOUSE

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HCB PILOT WIRE RELAY

Supersed by IL 41-658D Jan 1949.

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

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CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter

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The upper tap plate changes the out-put of

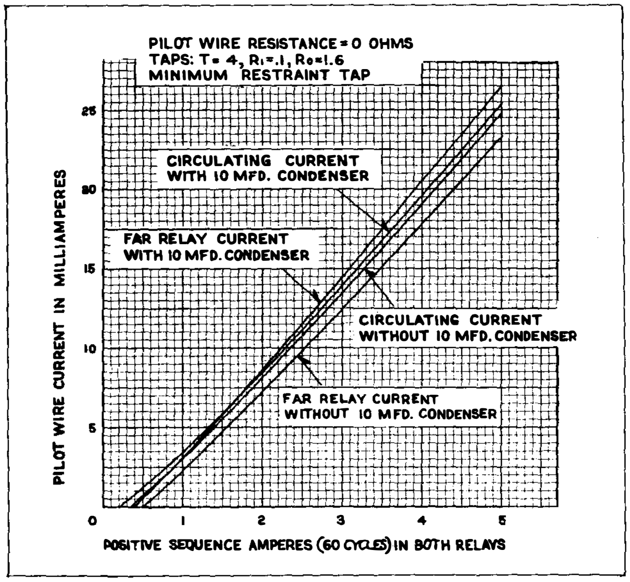


Fig. 4—Typical Test Output Vs. Input Relay Current In A Two Terminal Line With Zero Pilot Wire Resistance.

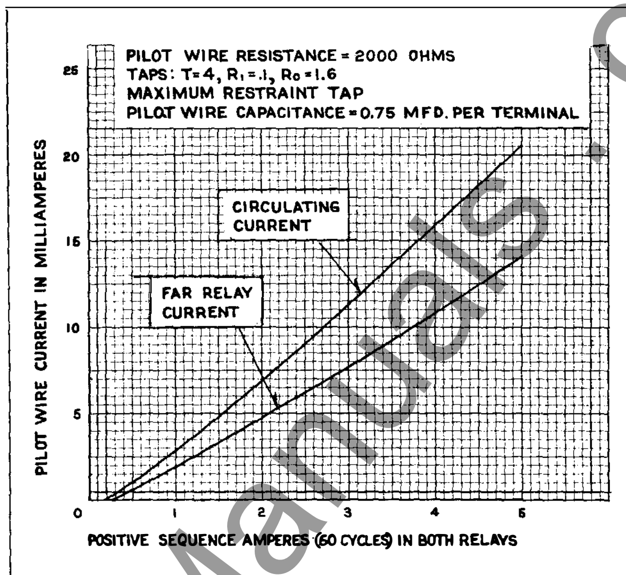


Fig. 5—Typical Test Output Vs. Input Relay Current In A Two Terminal Line With 2000 Ohm Pilot Wire Resistance With or Without the 10 MFD. Condenser.

2. The shunt capacity between pilot wires should not exceed 0.75 microfarads per pilot wire terminal for two terminal lines (0.60 mfd. per terminal for three terminal lines). In cases where this value is exceeded, auxiliary reactors may be required to reduce the shunt currents which tend to desensitize the relay.

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. However, the requirement of 15 volts difference must be maintained.

b. For more serious induction two winding neutralizing transformers can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing transformers should be used. Transformers are available for 1000 and 2000 volt neutralization.

c. Another method consists of connecting a suitable two winding reactor and a protector tube, such as the type KX642, to the pilot wires at suitable points. The arrangement is such that when the tube flashes because of high extraneous voltages, both wires are connected to ground, through the reactor and the tube. The impedance to ground is low, but the impedance between wires is kept high to avoid interfering with the operation of the HCB relays.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in Figure 8. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault current fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay. However, if the short circuit on the pilot wire is so placed that it is 1000 or more pilot wire ohms from one of the two relays, then that relay will not be blocked.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted wire pilot mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by continuously-operated supervisory relays supplied as extra equipment.

The condition of the pilot wire under normal load conditions may be determined by reading the pilot wire current by means of the test switch and milliammeter.

A comparison of the readings obtained with the typical values of Figures 4 & 5 will indicate the condition of the pilot wire. It should be noted that, when the far relay current is being read, the near relay is short circuited, and the far relay is shunted by the resistance of the pilot wires plus the impedance of the near relay insulating transformers.

CHARACTERISTICS

Typical overall operating characteristics of the relay are illustrated in Figures 6 and 7. The general shape of these curves is similar for other types of faults, relay settings, and pilot wire lengths. The ampere abscissa and

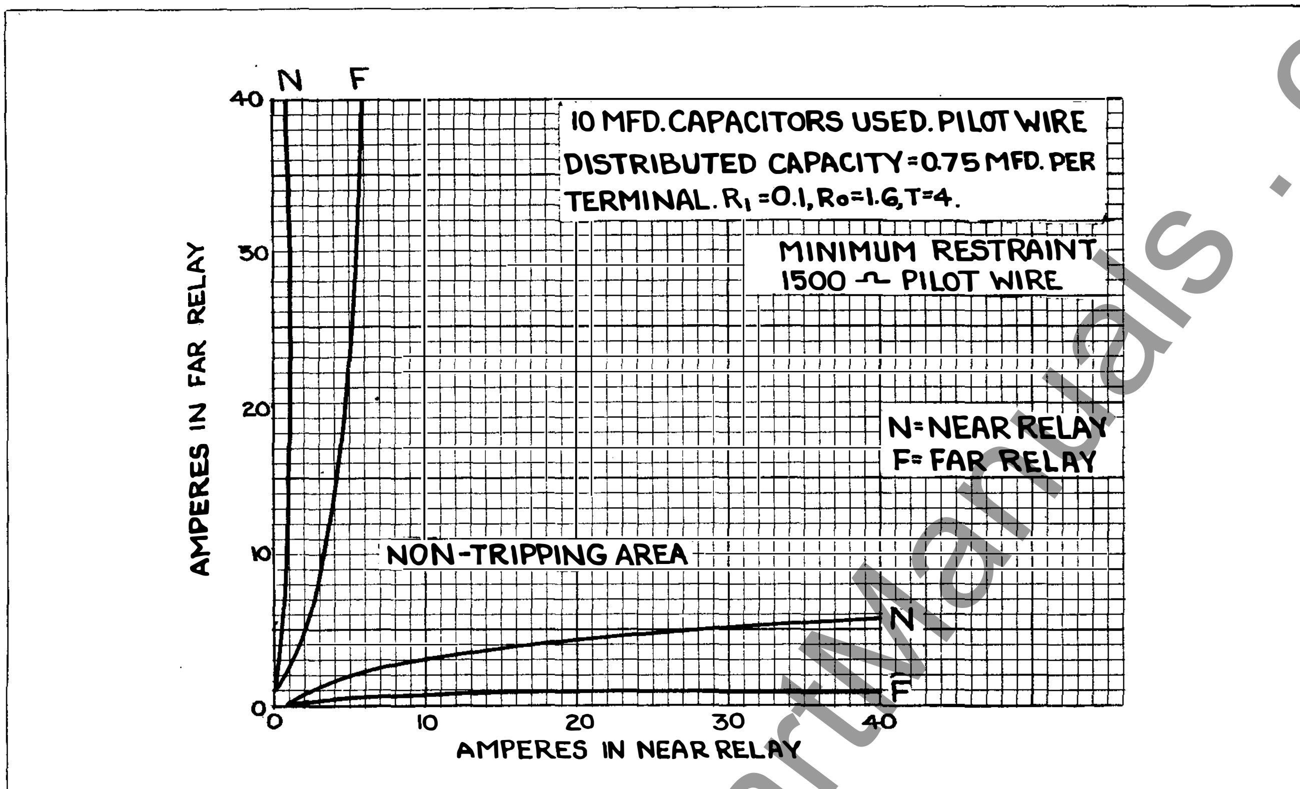


Fig. 6—Typical Operating Characteristics On Phase A to Ground Faults With Currents In Phase and 1500 Ohm Pilot Wire.

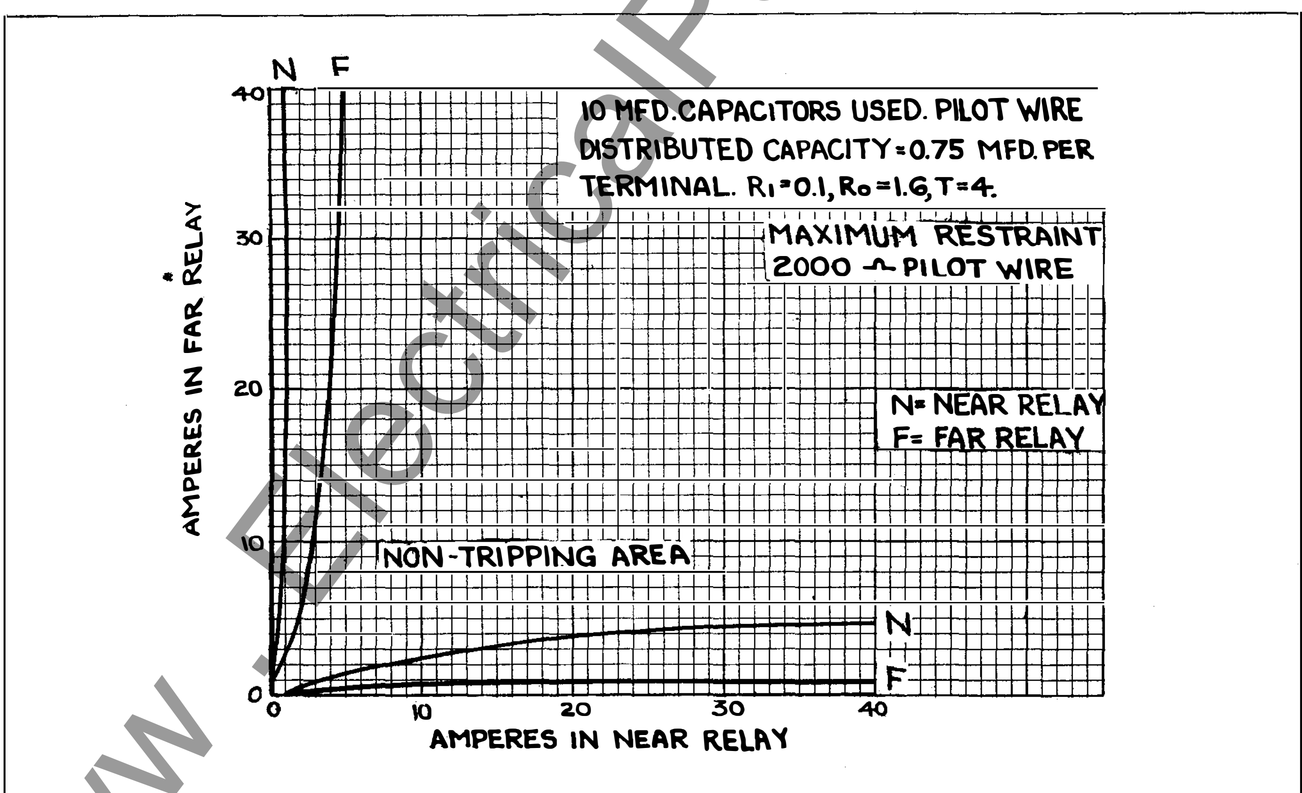
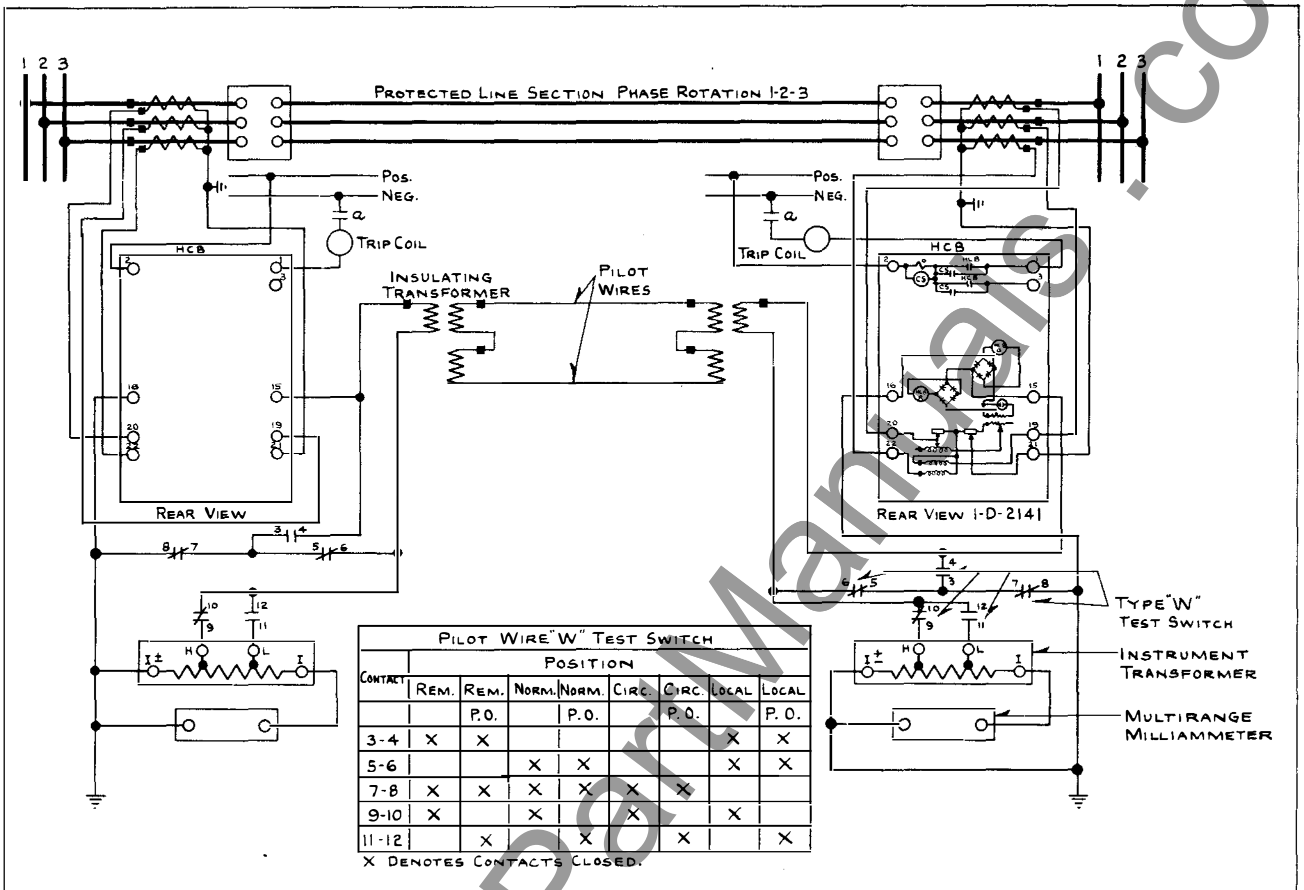


Fig. 7—Typical Operating Characteristics On Phase A to Ground Faults With Currents in Phase and 2000 Ohm Pilot Wire.



PILOT WIRE "W" TEST SWITCH								
CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
3-4	X	X					X	X
5-6			X	X			X	X
7-8	X	X	X	X	X	X		
9-10	X		X		X		X	
11-12		X		X		X		X

X DENOTES CONTACTS CLOSED.

Fig. 8—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Two Terminal Line.

ordinate scales may be interpolated as follows to show the operating characteristics for other conditions using T = 4.

For ground faults using other R_o and R_1 taps multiply scales by:

$$\frac{1.7}{R_o + R_1} \quad \text{Phase A to Ground Faults}$$

$$\frac{1.7}{R_o + j\ .577\ R_1} \quad \text{Phase B or C Ground Faults}$$

For three-phase faults multiply scales by:

$$\frac{1.7}{2\ R_1} = \frac{.85}{R_1}$$

For line-to-line faults multiply scales by:

$$\frac{1.7\sqrt{3}}{2R_1} = \frac{1.47}{R_1}$$

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude. That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (the .075 tap is actually marked .07 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of $R_1 = .10$ is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with $R_1 = .10$. Where the current transformers are different at the different terminals, select the value of R_1 which is proportional to the current transformer ratios. For example, assume a ratio of 300/5 at one terminal and 600/5 at another terminal. Set $R_1 = .075$ at the 300/5 terminal and $R_1 = .15$ at the 600/5 terminal. The ratios obtainable are 1/1, 2/1, 3/2, and 4/3. The same procedure applies to three terminal lines.

Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12 and 15. This tap should be selected to assure operation on minimum internal line-to-line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line-to-line faults is given by the equation:

$$T = 5.7\ I_{LL}\ R_1 \qquad (1)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

The factor "5.7" is used as the operation of the positive sequence filter is such that the relay requires 1.73 times as much current for operation on a line-to-line fault as on a three phase fault. This means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T, must be divided by 0.1 thereby obtaining the factor "5.7".

Where line-to-line currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\ (.86)\ (I_{3\phi})\ R_1 \qquad (1a)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

Equation (1) and (1a) give the upper limit of "T" which must not be exceeded to obtain operation on the line-to-line faults. The actual setting should always be below the values obtained from equation (1) or (1a). The minimum limits for this setting are discussed below.

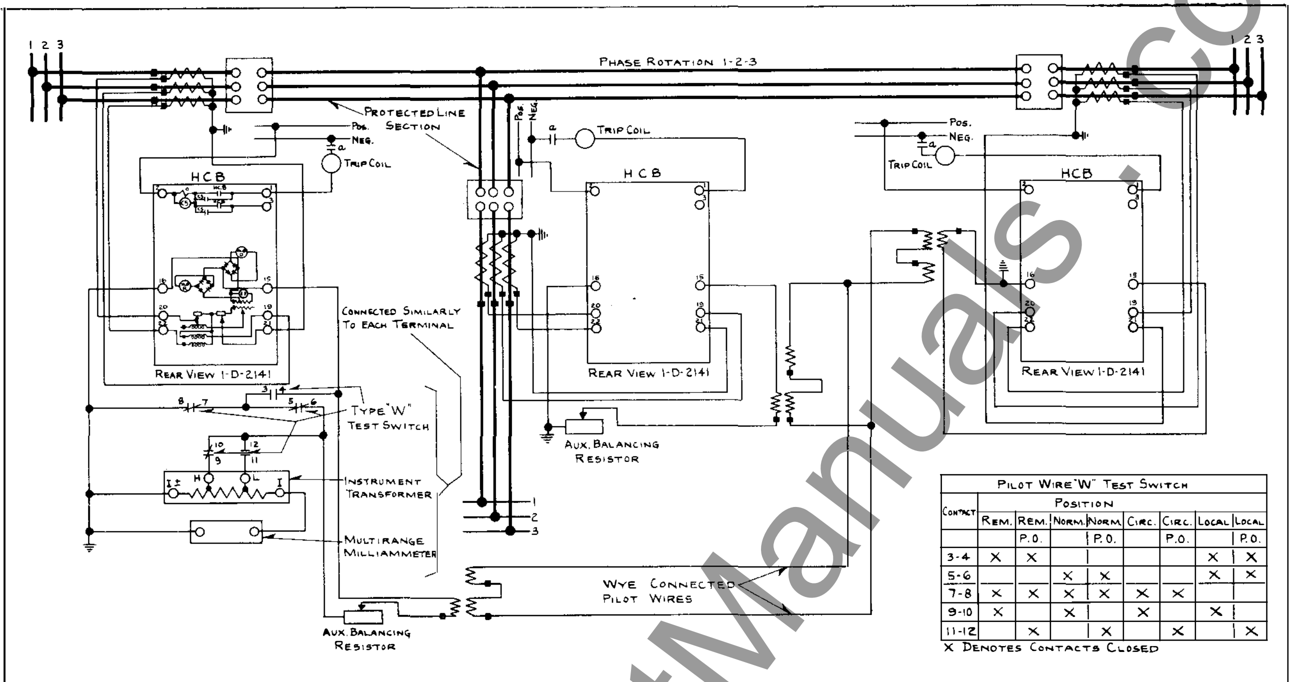
The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10\ R_1\ I_{Load} \qquad (2)$$

where "I_{Load}" is the maximum secondary full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (2) if the relay is not to operate on load current with the pilot wires open circuited.

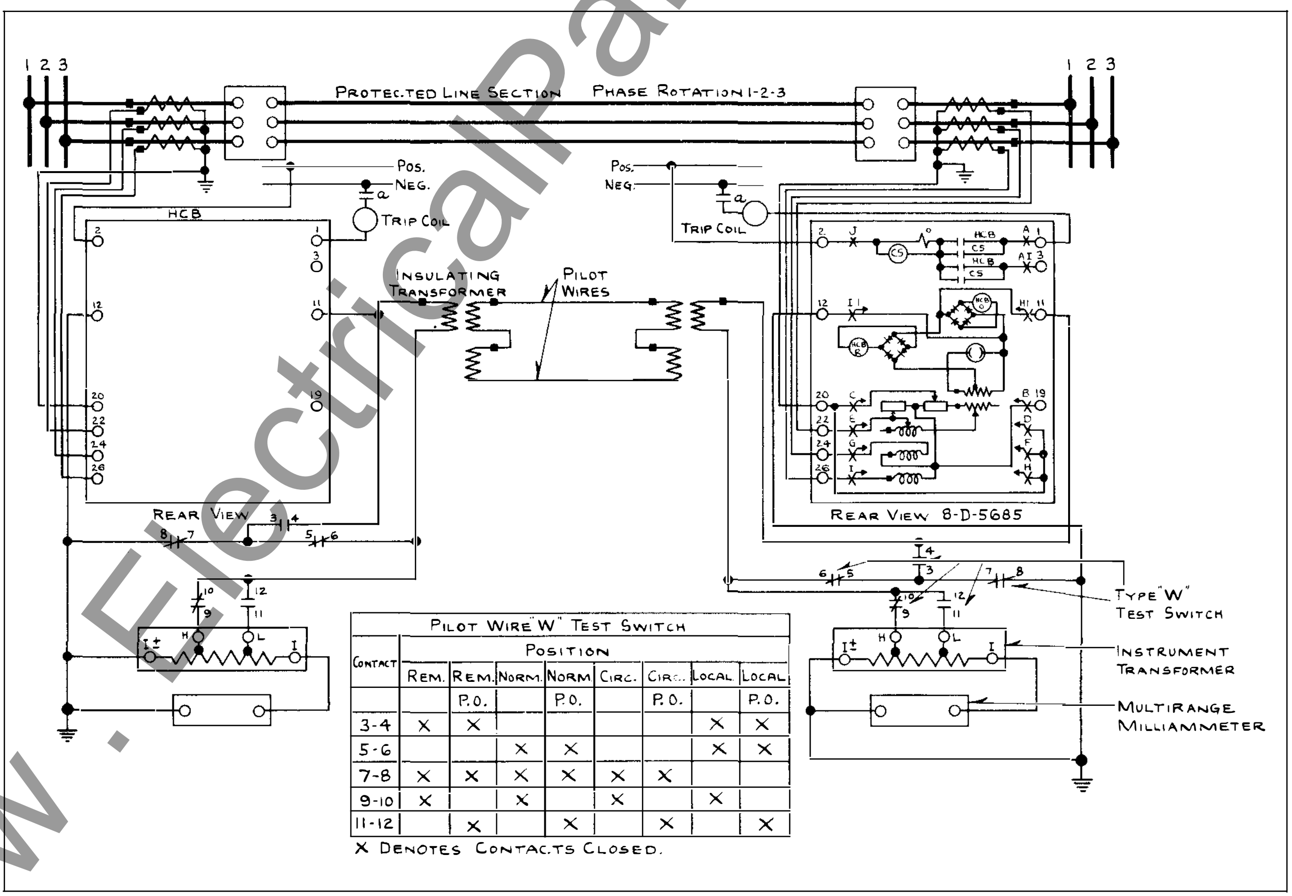
This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents, or if supervisory relays are installed and connected to block the HCB on the occurrence of pilot wire failures. If supervisory relays are installed to block HCB oper-



Pilot Wire "W" Test Switch								
Contact	Position							
	Rem.	Rem. P.O.	Norm.	Norm. P.O.	Circ.	Circ. P.O.	Local	Local P.O.
3-4	X	X					X	X
5-6			X	X			X	X
7-8	X	X	X	X	X	X		
9-10	X		X		X		X	
11-12		X		X		X		X

X Denotes Contacts Closed

Fig. 9—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Three Terminal Line.



Pilot Wire "W" Test Switch								
Contact	Position							
	Rem.	Rem. P.O.	Norm.	Norm. P.O.	Circ.	Circ. P.O.	Local	Local P.O.
3-4	X	X					X	X
5-6			X	X			X	X
7-8	X	X	X	X	X	X		
9-10	X		X		X		X	
11-12		X		X		X		X

X Denotes Contacts Closed.

Fig. 10—External Connections of the Type HCB Relay in the Type FT Case and Ground Protection of a Two Terminal Line.

ation under heavy load conditions with the pilot wires opened, it is necessary to introduce a time delay of approximately one cycle by interposing an auxiliary relay in the trip circuit at each terminal to allow the supervisory relays time to coordinate with the high speed of the HCB relay.

Note: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_o) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. (The first two taps are actually marked .02 and .03 because of space limitations). The three lowest taps are not used in applications where high sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_o is set to equal to 1/3 R_1.

Maximum sensitivity to ground faults is obtained with $R_o = 1.6$. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_o should be selected which are most nearly proportional to the transformer ratios. When the ratio of the R_o taps can not be made to exactly match the ratio of the R_1 taps, pick the ratio to match as closely as possible, and use maximum restraint tap.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_o = \frac{0.2T}{I_g} \quad (3)$$

where I_g is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals, and where "T" is the actual tap selected (not the value calculated from equation (1) or (1a).

It is recommended that "R_o" be set as high above the value obtained from equation (3) as possible keeping the value of R_o approximately proportional to the current transformer ratios.

Restraint Tap

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is normally shipped with the restraint tap link connected in the maximum restraint position. This link is in the upper left hand corner of the panel carrying the polar element. The link is connected to the left for minimum restraint, and to the right for maximum restraint. Maximum restraint should be used with pilot wires of 1500 to 2000 ohms.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on minimum internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R_1 at station 2 = 0.075.

Positive Sequence Current Tap

From Equation 1

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissible

setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (2).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75$$

or

$$T = \frac{10 \times .075 \times 300 \times 5}{300} = 3.75$$

Select T at both stations = 6.

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation 3.

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6
And R_o at station 2 = 1.2

RELAYS IN TYPE FT CASE

The type FT cases are dust-proof enclosures combining relay elements and knife-blade test switches in the same case. This combination provides a compact flexible assembly easy to maintain, inspect, test and adjust. There are three main units of the type FT case: the case, cover and chassis. The case is an all welded steel housing containing the hinge half of the knife-blade test switches and the terminals for external connections. The cover is a drawn steel frame with a clear window which fits over the front of the case with the switches closed. The chassis is a frame that supports the relay elements and the contact jaw half of the test switches. This slides in and out of the case. The electrical connections between the base and chassis are completed through the closed knife-blades.

Removing Chassis

To remove the chassis, first remove the cover by unscrewing the captive nuts at the corners. This exposes the relay elements and all the test switches for inspection and testing. The next step is to open the test switches. Always open the elongated red handle switches first before any of the black handle switches or the cam action latches. This opens the trip circuit to prevent accidental trip out. Then open all the remaining switches. The order of opening the remaining switches is not important. In opening the test switches they should be moved all the way back against the stops. With all the switches fully opened, grasp the two cam action latch arms and pull outward. This releases the chassis from the case. Using the latch arms as handles, pull the chassis out of the case. The chassis can be set on a test bench in a normal upright position as well as on its top, back or sides for easy inspection, maintenance and test.

After removing the chassis a duplicate chassis may be inserted in the case or the blade protion of the switches can be closed and the cover put in place without the chassis. The chassis operated shorting switch located behind the short circuiting test switch prevents open circuiting that circuit when the short circuiting type test switches are closed.

When the chassis is to be put back in the case, the above procedure is to be followed in the reversed order. The elongated red handle switch should not be closed until after the chassis has been latched in place and all of the black handle switches closed.

Electrical Circuits

Each terminal in the base connects thru a test switch to the relay elements in the chassis as shown on the internal schematic diagrams. The relay terminal is identified by numbers marked on both the inside and outside of the base. The test switch positions are identified by letters marked on the top and bottom surface of the moulded blocks. These letters can be seen when the chassis is removed from the case.

The potential and control circuits thru the relay are disconnected from the external circuit by opening the associated test switches. Opening the short circuiting test switch short-circuits that circuit and disconnects one side of the relay coil but leaves the other side of the coil connected to the external circuit thru the current test jack jaws. This circuit can be isolated by inserting the current test plug (without external connections) by inserting the ten circuit test plug, or by inserting a piece of insulating material approximately 1/32" thick into the current test jack jaws. Both switches of the current test switch pair must be open when using the current test plug or insulating material in this manner to short-circuit the current transformer secondary.

A cover operated switch can be supplied with its contacts wired in series with the trip circuit. This switch opens the trip circuit when the cover is removed. This switch can be added to the existing type FT cases at any time.

Testing

The relays can be tested in service, in the case but with the external circuits isolated or out of the case as follows:

Testing in Service

The ammeter test plug can be inserted in the current test jaws after opening the knife-blade switch to check the current thru the relay. This plug consists of two conducting strips separated by an insulating strip. The ammeter is connected to these strips by terminal screws and the leads are carried out thru holes in the back of the insulated handle.

Voltages between the potential circuits can be measured conveniently by clamping #2 clip leads on the projecting clip lead lug on the contact jaw.

Testing in Case

With all blades in the full open position, the ten circuit test plug can be inserted in the contact jaws. This connects the relay elements to a set of binding posts and completely isolates the relay circuits from the external connections by means of an insulating barrier on the plug. The external test circuits are connected to these binding posts. The plug is inserted in the bottom test jaws with the binding posts up and in the top test switch jaws with the binding posts down.

The external test circuits may be made to the relay elements by #2 test clip leads instead of the test plug. When connecting an external test circuit to the current elements using clip leads, care should be taken to see that the current test jack jaws are open so that the relay is completely isolated from the external circuits. Suggested means for isolating this circuit are outlined above, under "Electrical Circuits."

Testing Out of Case

With the chassis, removed from the base, relay elements may be tested by using the ten circuit test plug or by #2 test clip leads as described above. The factory calibration is made with the chassis in the case and removing the chassis from the case will change the calibration values by a small percentage. It is recommended that the relay be checked in position as a final check on calibration.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs for the standard cases 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.

The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohm and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the contactor switch. This lead should be fastened (dead ended) under the small filister-head screw located in the Micarta base of the contactor switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms.

ADJUSTMENTS AND MAINTENANCE

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if 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.

CAUTION 1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

Sequence Filter

There are no adjustments to be made in the filter.

Polar-Type Element

Contact Adjustment: Adjust both left-hand (front view) contacts until they barely make a light circuit, when the armature is against the left stop. A flickering light is permissible. Give both the left-hand contact screws an additional 1/3 turn, and lock in position with the lock nuts provided.

Calibration: Connect the restraint tap link in the position in which it will be used. Connect the low voltage terminals of the insulating transformer across the pilot wire terminals of the relay. (If this is not available, use a 1500 ohm resistor.) Connect the relay taps on $T = 4$, $R_1 = .1$, $R_o = 1.6$.

Screw in the left-hand magnetic shunt all the way and lock it in position by means of the locking screw provided. Adjust the right-hand magnetic shunt in or out, as required, until the relay just closes contacts at 6.9 to 7.0 amperes phase B to phase C current. When this adjustment has been made, and checked with both magnetic shunts locked in position, change the input current connections to phase A to neutral. The relay should trip for phase A to neutral current between .45 and .55 amperes.

Restraining Coil: The effectiveness of the restraining coil of the relay element, and the performance of the Rectox units, may be checked as follows, if desired: Connect a variable resistor across the high voltage terminals of the insulating transformer, and connect d-c milliammeters in series with the operating and restraining coils of the element, by opening these circuits at the test links provided for this purpose. These milliammeters should have low resistance, and should be capable of reading in the order of 20 to 25 ma. in the operating coil and 100 to 150 ma. in the restraining circuit. Using $T=4$, $R=.1$, $R_o=1.6$, pass 10 amperes 60 cycles from phase A to neutral in the relay, and increase the variable resistance across the insulating transformer high voltage terminals until the relay just trips. Read the d-c current (milliamperes) in the operating and restraining coils at this point. The values obtained should conform substantially to the following equations.

For Minimum Restraint

$$I_o = .12\ I_R + 8$$

For Maximum Restraint

$$I_o = .16\ I_R + 8$$

where I_o and I_R are operating and restraining coil currents, respectively, in milliamperes. The results are subject to slight variations between individual relays.

The polarity of the connections to the pilot wires, and the correct "Phasing out" of A, B, C phases at the two stations may be checked by the six tests outlined on Page 15.

Pilot Wire Current

The pilot wire current which should flow under normal load conditions is given in Figures 4 and 5. If the relay taps in use differ from those indicated in these figures, suitable conversion factors must be used as given in the text. The pilot wire current will vary inversely with T and directly with R_1.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down or by disconnecting the switch and turning it up-side-down. Then screw up the core screw until the moving core starts rotating. Now, back off the core screw until the moving core stops rotating. This indicates the points where the play in the assembly is taken up, and where the moving core just separates from the stationary core screw. 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c have been passed through the coil.

Operation Indicator

Adjust the indicator to operate at 0.2 ampere d-c gradually applied by loosening the two screws on the under side of the assembly, and moving the bracket forward or backward. If the two helical springs which reset the armature are replaced by new springs, they should be weakened slightly by stretching to obtain the 1 ampere calibration. The coil resistance is approximately 2.8 ohms.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three - phase current of 5 amperes:

For tap 4 R_1 = .075 and R_o = .39

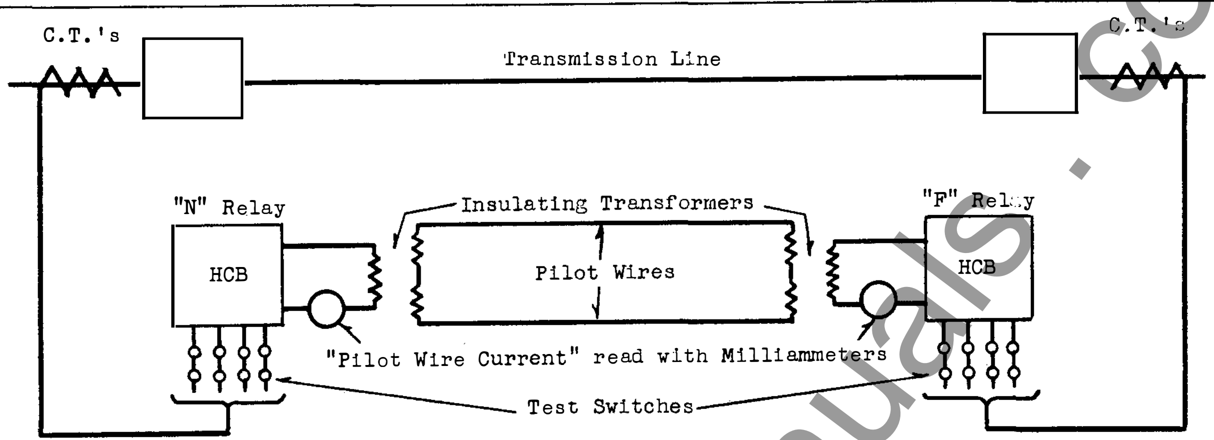
Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_o = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.



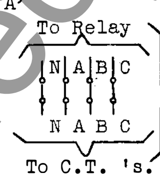
Note: The line should be carrying through load c rrent amounting to at least 1.5 amperes as measured in the secondary of the Current Transformers. This test is based on the ratio of the C.T.'s being the same at each end of the line, in which case set the taps of both relays to $R_1 = .1$; $R_0 = 1.6$; $T = 4$ for this test.

	RELAY "N"					RELAY "F"				
Test No.	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay F	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay N
1		A,B,C,N	No	(1)	(1)		A,B,C,N	No	(1)	(1)
2		A,C,B,N	No	(2)	(2)		A,C,B,N	No	(2)	(2)
3		A,N	Yes	(3)	(3)		0	Yes	(3)	(3) (4)
4		0	Yes	(3)	(3) (4)		A,N	Yes	(3)	(3)
5		A,N	No	(3)	(3)		A,N	No	(3)	(3)
6		A,N	Yes	(6)			B,C,N	Yes	(6)	

REMARKS

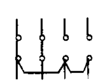
Tests 1 and 2 are to check normal positive sequence rotation of phases. The test switch connections of test #2 may be made readily with relays in the Flexitest case by using clip leads and insulating barriers in the ammeter test jacks. However, care should be used to avoid accidentally open-circuiting the current transformer circuits.
Tests 3 and 4 simulate internal Phase A to Ground fault with single end feed.
Test 5 simulates an external Phase A to Ground fault. (5)
Test 6 simulates an internal Phase A to Ground fault, with equal feed from the two ends, since $I_B + I_C = - I_A$, with balanced load.

LEGEND OF TEST SWITCH SYMBOLS:



Normal Connection. All Currents to Relay.

EXAMPLE



Phase A current from C.T. 's to Relay. Phase B and C C.T.'s shorted to neutral.

(1) The "pilot wire current" will vary depending upon the magnitude of the through load current and the characteristics of the pilot wire. See Figures 6 and 7.
(2) Since the relay is temporarily connected for negative sequence, it should have practically zero output in this test.
(3) These readings may be "off scale" depending upon the magnitude of the load current.
(4) The relay at this station should reset when the "far" current is being read because the local relay will be receiving no current from either the pilot wire or the current transformers.
(5) Test 4 and 5 can be repeated using phase B to neutral current, and again with phase C to neutral current, but this is not strictly necessary on the basis that, having proved the phase sequence with tests 1 and 2, and having proved the correspondence of phase A at the two ends of the line with test 5, then phases B and C must be correct.
(6) Some pilot wire current will be read, depending upon the magnitude of the distributed capacity of the pilot wire in combination with the magnetizing impedance of the insulating transformer.

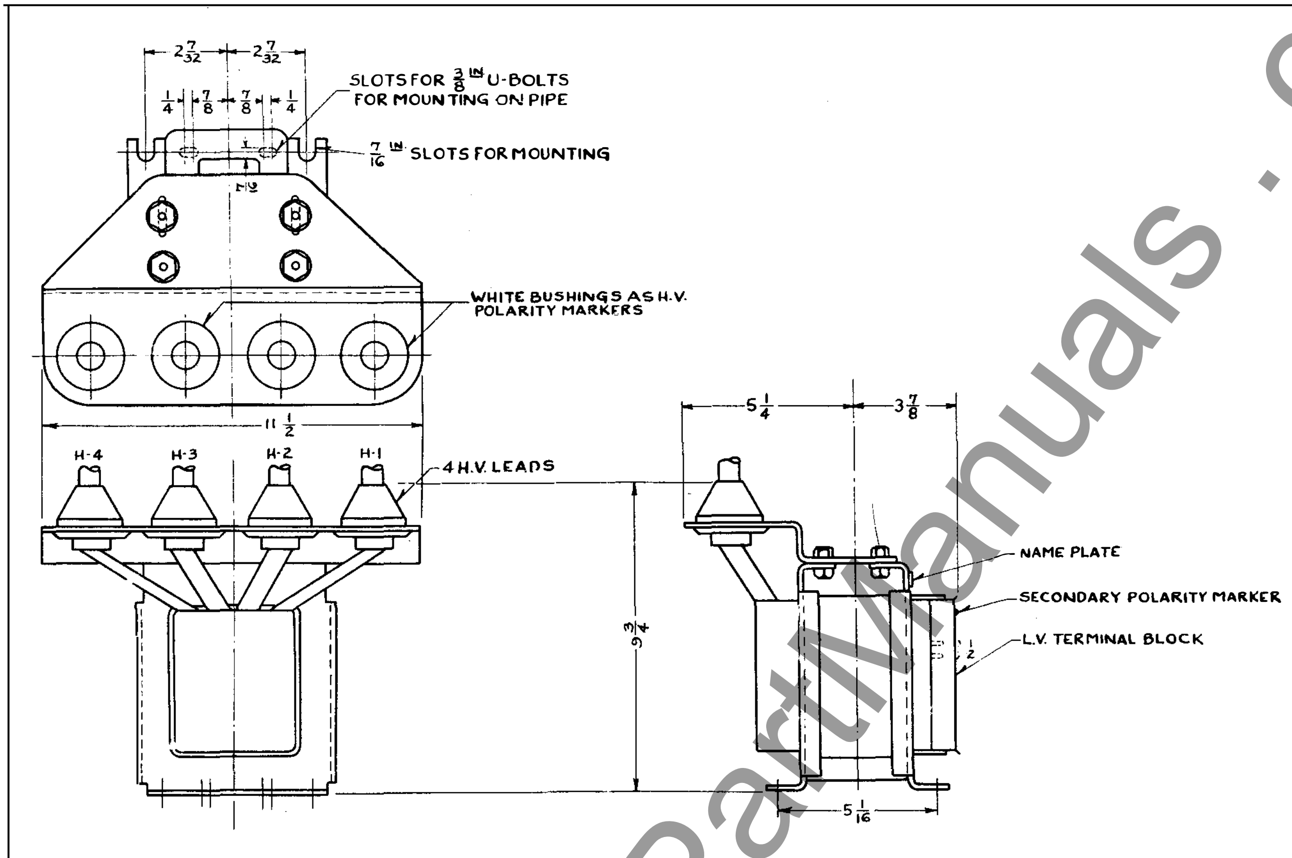


Fig. 11—Outline and Drilling Plan of the Insulating Transformer. For Reference Only.

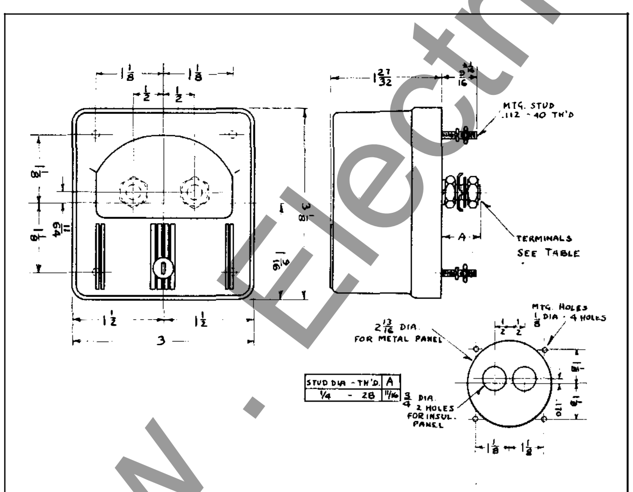


Fig. 12—Outline and Drilling Plan of the Projection Type Test Milliammeter. For Reference Only.

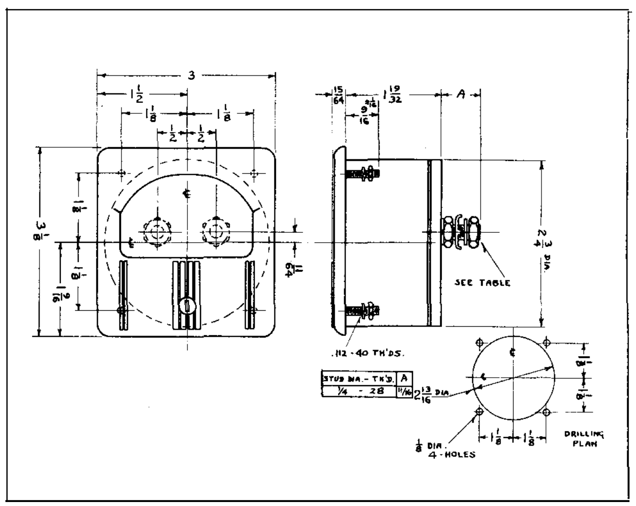


Fig. 13—Outline and Drilling Plan of the Semi-flush Type Test Milliammeter. For Reference Only.

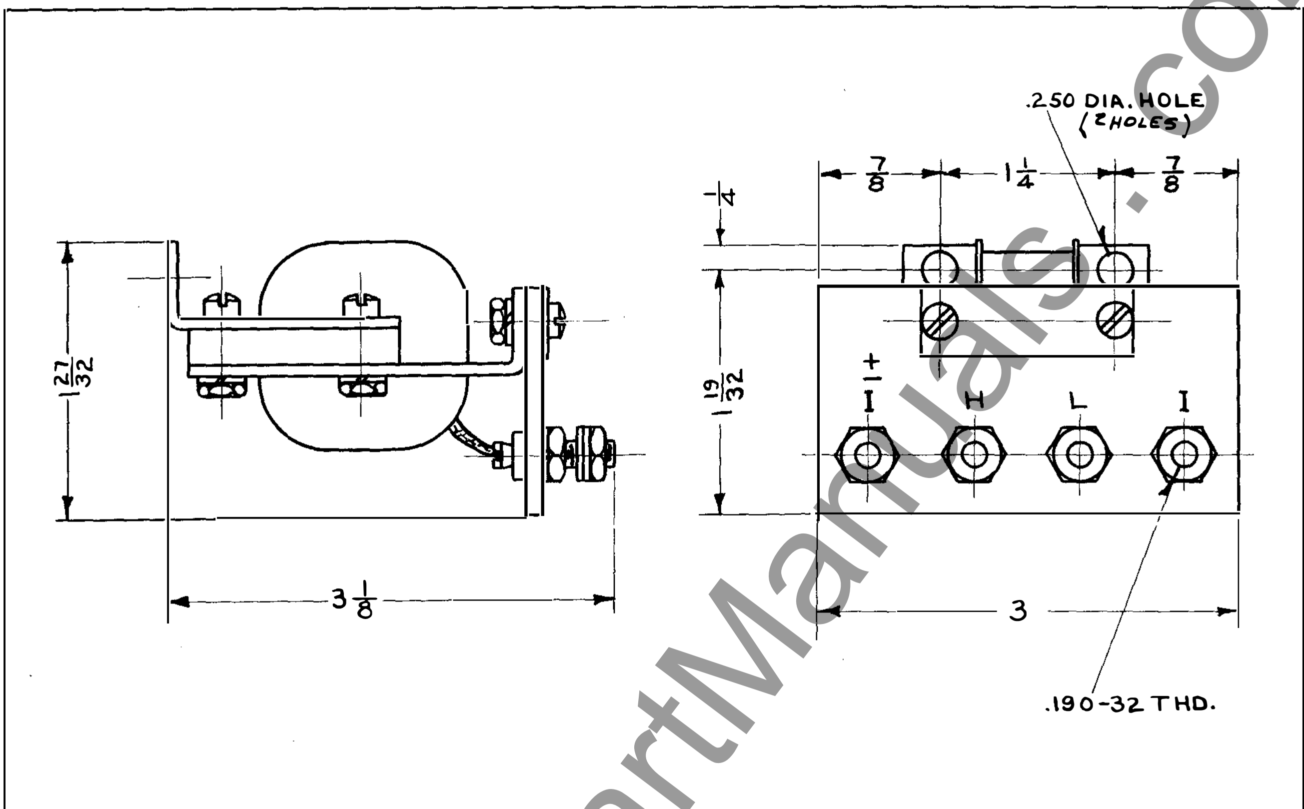
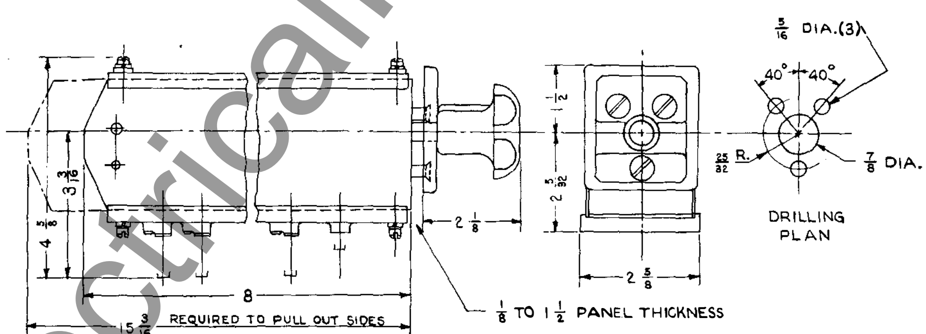


Fig. 14—Outline of the Test Milliammeter Auxiliary Transformer. For Reference Only.



SWITCH POSITION TABULATION

CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
3 - 4	X	X					X	X
5 - 6			X	X			X	X
7 - 8	X	X	X	X	X	X		
9 - 10	X		X		X		X	
11 - 12		X		X		X		X

X DENOTES CONTACTS CLOSED

NAMEPLATE ENGRAVING

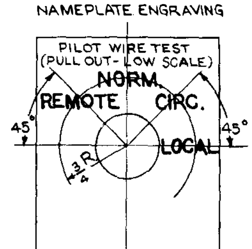


Fig. 15—Outline and Drilling Plan of the Type W Test Switch. For Reference Only.

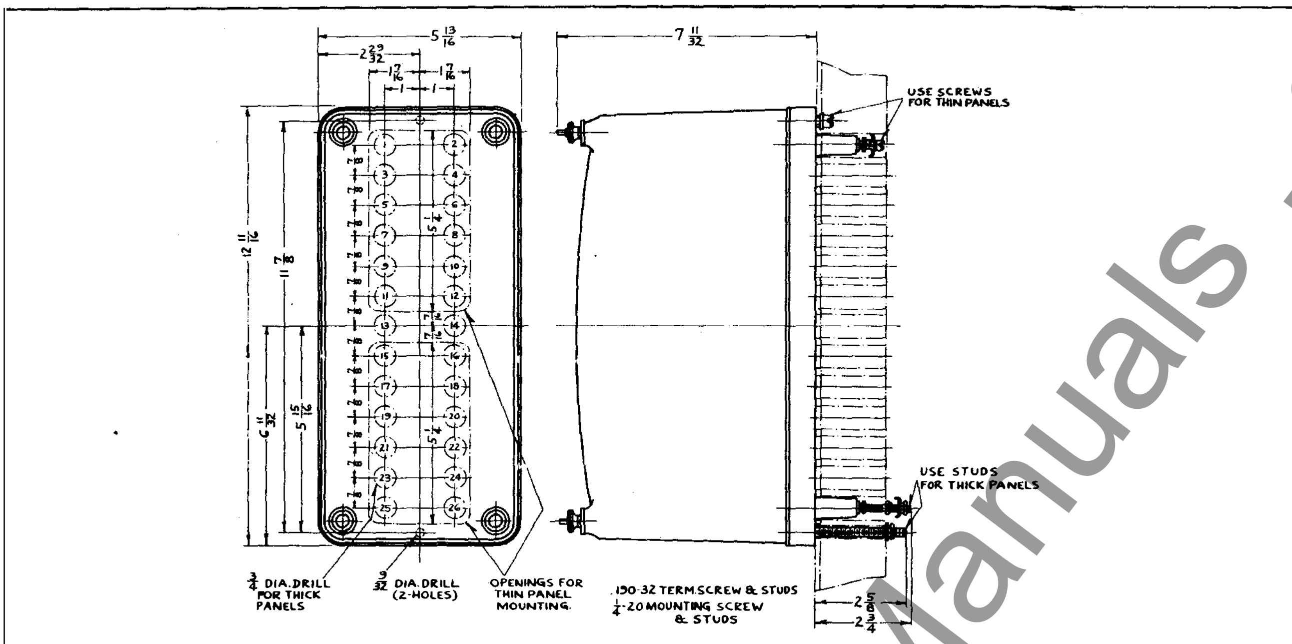


Fig 16—Outline and Drilling Plan For the Projection Type Standard Case. See the Internal Schematics For The Terminals Supplied. For Reference Only.

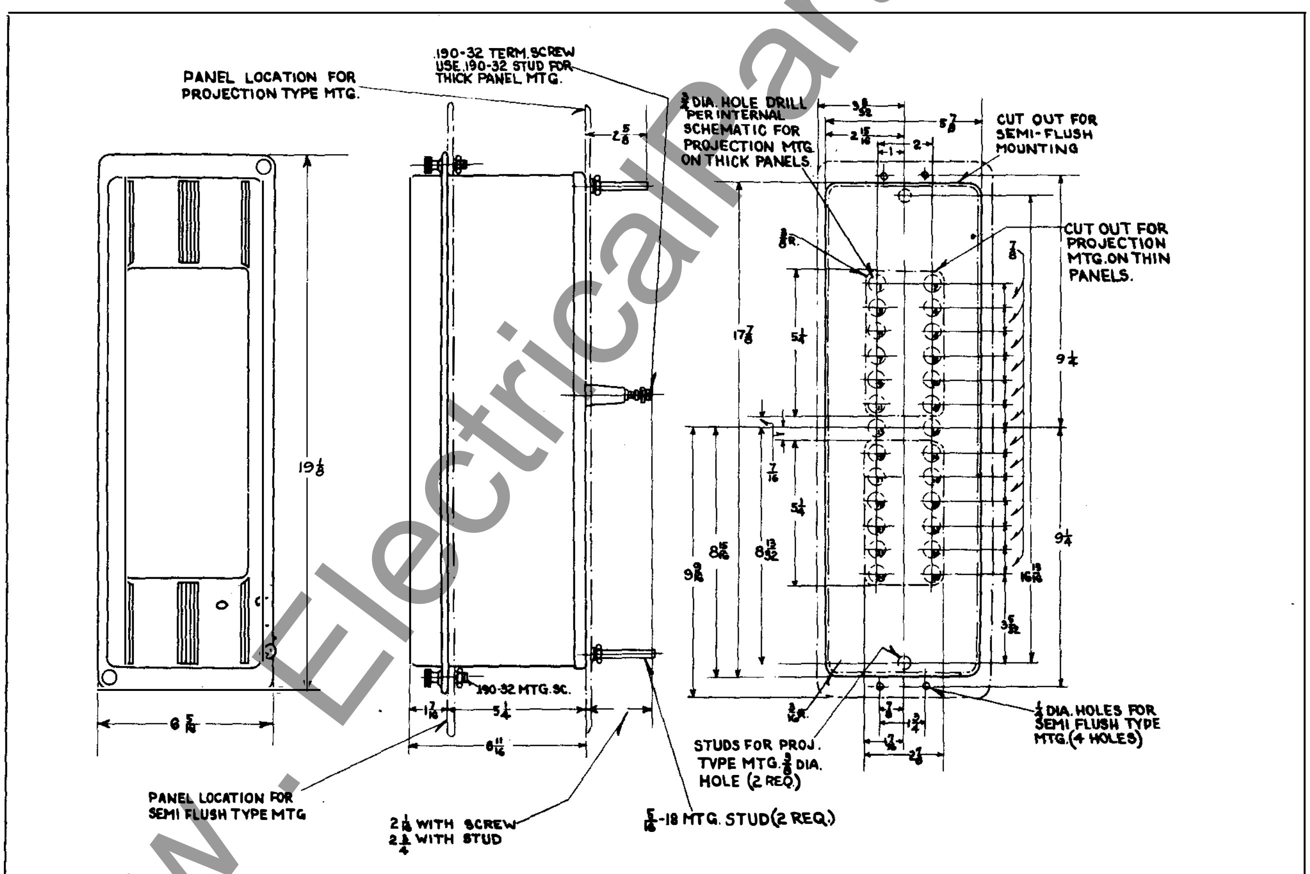


Fig. 17—Outline and Drilling Plan for The M-20 Projection or Semi-Flush Type FT Case. See the Internal Schematic for the Terminals Supplied. For Reference Only.

WESTINGHOUSE ELECTRIC CORPORATION

METER DIVISION **NEWARK, N.J.**

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HCB PILOT WIRE RELAY

Superseded by I.L. 41-658 E 5/49

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line, three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the out-put of the saturating transformer, and is marked in amperes required to operate the relay when the

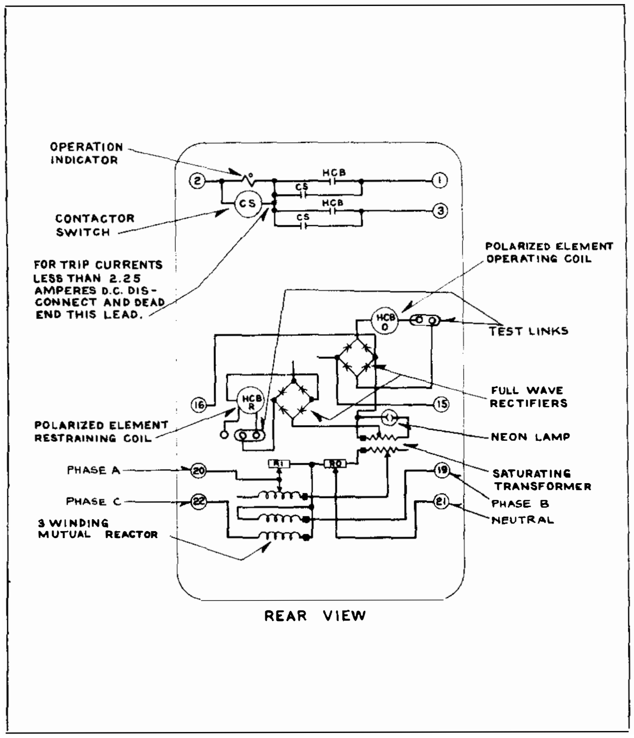


Fig. 1—Internal Schematic of the Type HCB Relay in the Standard Case.

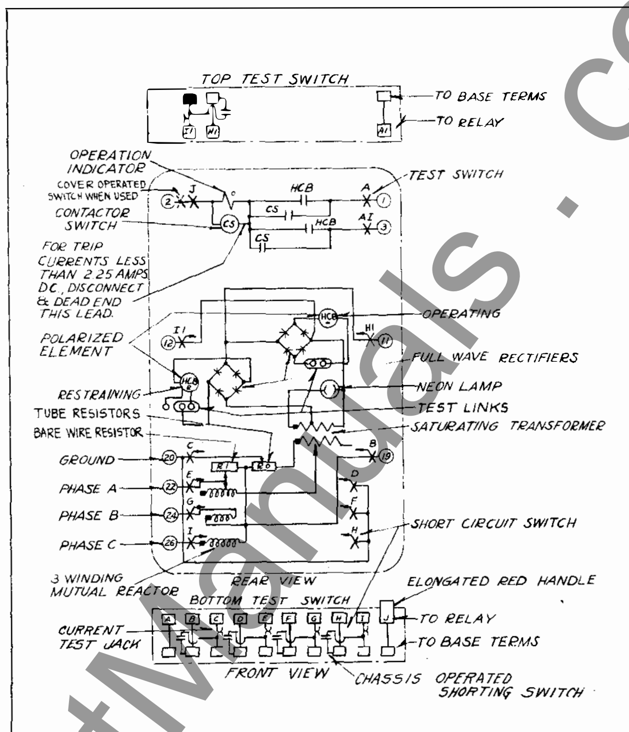


Fig. 2—Internal Schematic of the Type HCB Relay in the Type FT Case.

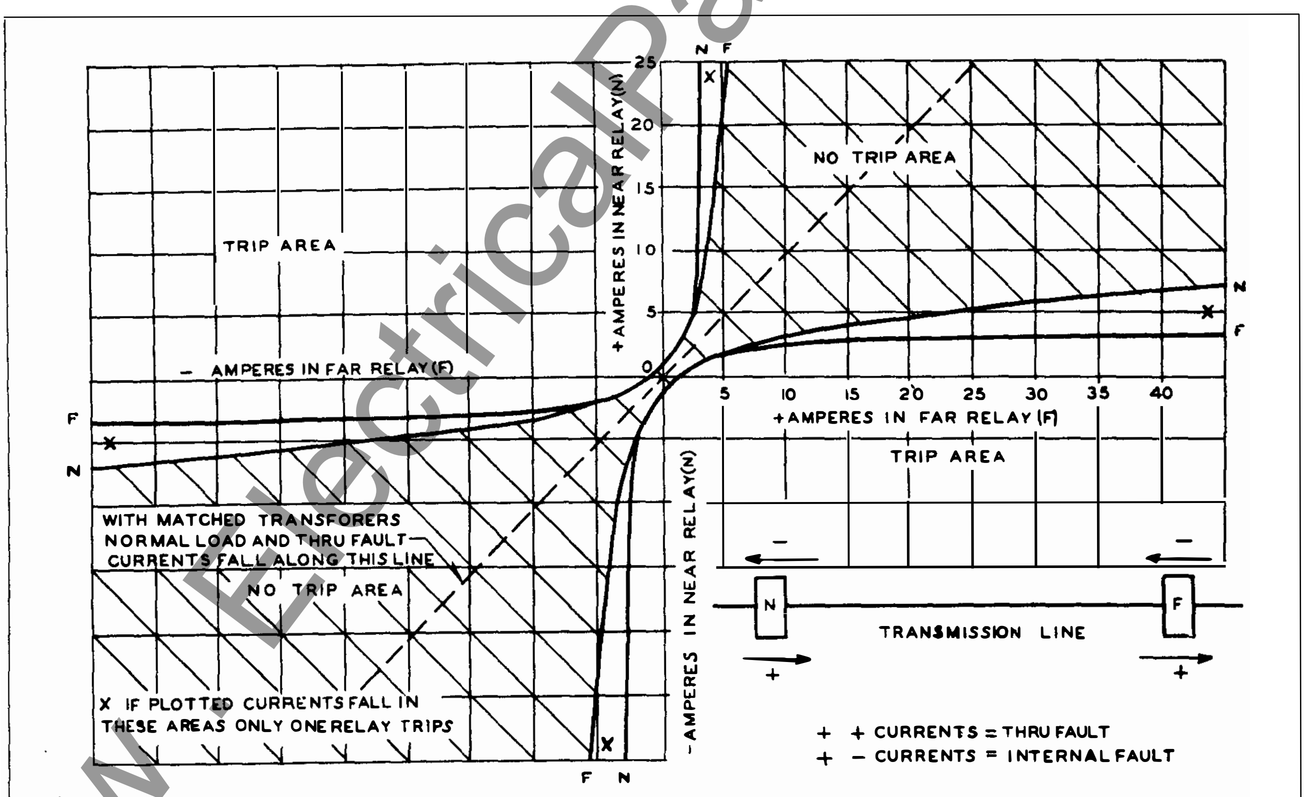


Fig. 3—Typical Operating Characteristics on Phase A to Ground Faults With Currents Thru the Two Terminals 30° Out of Phase. Maximum Restraint With Insulating Transformers and 2000 Ohm Pilot Wires. Taps T = 4, R_1 = .1, R_0 = 1.6.

pilot wire is open or when equal amounts of currents are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in Figure 8. The rectox units are used to convert the a-c output of the saturating transformer to d-c for use on the d-c polar-type relay element. The use of a sensitive polar-type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polary-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnetic bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating winding produces a magnetic field which acts to move the armature in the contact closing direction. The restraining winding is tapped and the leads are brought out to taps at the upper left of the relay. The taps are marked T and F signifying Tapped and Full winding, respectively.

The moving contacts are fastened on the free end of the leaf spring. Two stationary contact screws are mounted to the left (front view) of the moving contact assembly and are adjusted for normally open contacts.

Insulating Transformer

The insulating transformer is connected as shown in Figure 8 and serves to isolate the terminal equipment from the pilot wire. This avoids interconnection of station grounds that may have large differences of potentials between them. The mid-taps of the parallel-wound secondary windings are brought out separately to provide a means of connecting supervisory relays symmetrically within the pilot wire circuit. When auxiliary supervisory relays are not used, these mid-taps are to be connected together and may be grounded to drain the voltages induced along the length of the pilot wires when these voltages approach the voltage limit of the cable. This is discussed further under Pilot Wire below.

The transformers have a 4/1 ratio and are insulated for 5000 volts.

Pilot Wire

One pair of pilot wires connecting the secondaries of the insulating transformers is required to provide a continuous circuit between the relays. For the pilot wires a lead-covered twisted pair of No. 19 wire or larger is recommended, however, open wires may be used. The following points should be considered in selecting pilot wire circuits.

1. The total circuit resistance (including neutralizing transformers when used) between terminals of the Type HCB relays exclusive of the insulating transformers and expressed in terms of the pilot wire voltage must not exceed 2000 ohms for two terminal lines (500 ohms per wye branch for three terminal lines).

2. The shunt capacity between pilot wires should not exceed 0.75 microfarads per pilot wire terminal for two terminal lines (0.60 mfd. per terminal for three terminal lines). In cases where this value is exceeded, auxiliary reactors may be required to reduce the shunt currents which tend to desensitize the

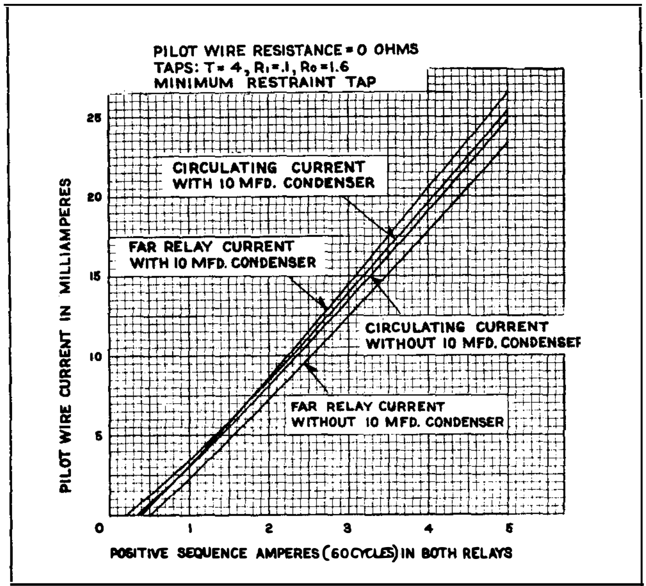


Fig. 4—Typical Test Output Vs. Input Relay Current in A Two Terminal Line With Zero Pilot Wire Resistance.

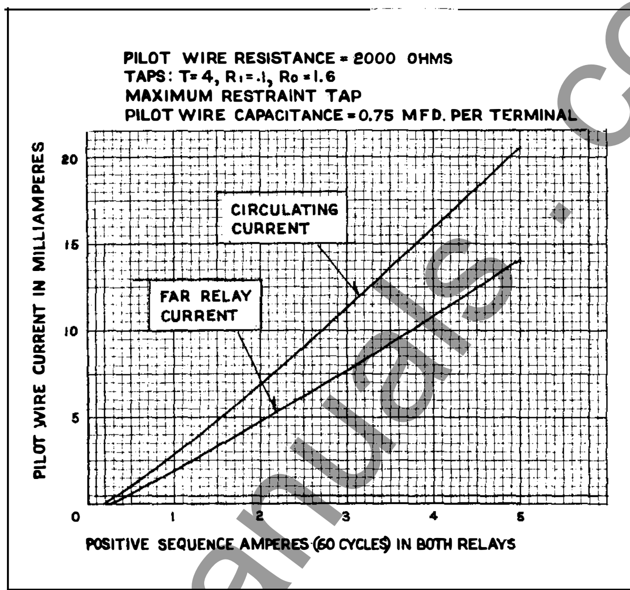


Fig. 5—Typical Test Output Vs. Input Relay Current In A Two Terminal Line With 2000 Ohm Pilot Wire Resistance With or Without the 10 MFD. Condenser.

relay, except that, when the relays are calibrated in place, connected to the pilot wires, the values may be increased to 1.0 mfd. for two terminal lines. See "Adjustments".

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. However, the requirement of 15 volts difference must be maintained.

b. For more serious induction two winding neutralizing transformers can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing transformers should be used. Transformers are available for 1000 and 2000 volt neutralization.

c. Another method consists of connecting a suitable two winding reactor and a protector tube, such as the type KX642, to the pilot wires at suitable points. The arrangement is such that when the tube flashes because of high extraneous voltages, both wires are connected to ground, through the reactor and the tube. The impedance to ground is low, but the impedance between wires is kept high to avoid interfering with the operation of the HCB relays.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in Figure 8. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault current fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay. However, if the short circuit on the pilot wire is so placed that it is 1000 or more pilot wire ohms from one of the two relays, then that relay will not be blocked.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted wire pilot mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by continuously-operated supervisory relays supplied as extra equipment.

The condition of the pilot wire under normal load conditions may be determined by reading the pilot wire current by means of the test switch and milliammeter.

A comparison of the readings obtained with the typical values of Figures 4 & 5 will indicate the condition of the pilot wire. It should be noted that, when the far relay current is being read, the near relay is short circuited, and the far relay is shunted by the resistance of the pilot wires plus the impedance of the near relay insulating transformers.

CHARACTERISTICS

Typical overall operating characteristics of the relay are illustrated in Figures 6 and 7. The general shape of these curves is similar for other types of faults, relay settings, and pilot wire lengths. The ampere abscissa and ordinate scales may be interpolated to show the operating characteristics for other conditions and tap settings by the use of the following equation:

$$I_{an} = \frac{2.35}{T}\left\{ 2\mathring{I}_{a1}R_1 + \mathring{I}_{ao}\,(R_1 + 3R_o)\right\} \quad (1)$$

where I_{an} is the value to read on the curve (Figures 6 and 7).

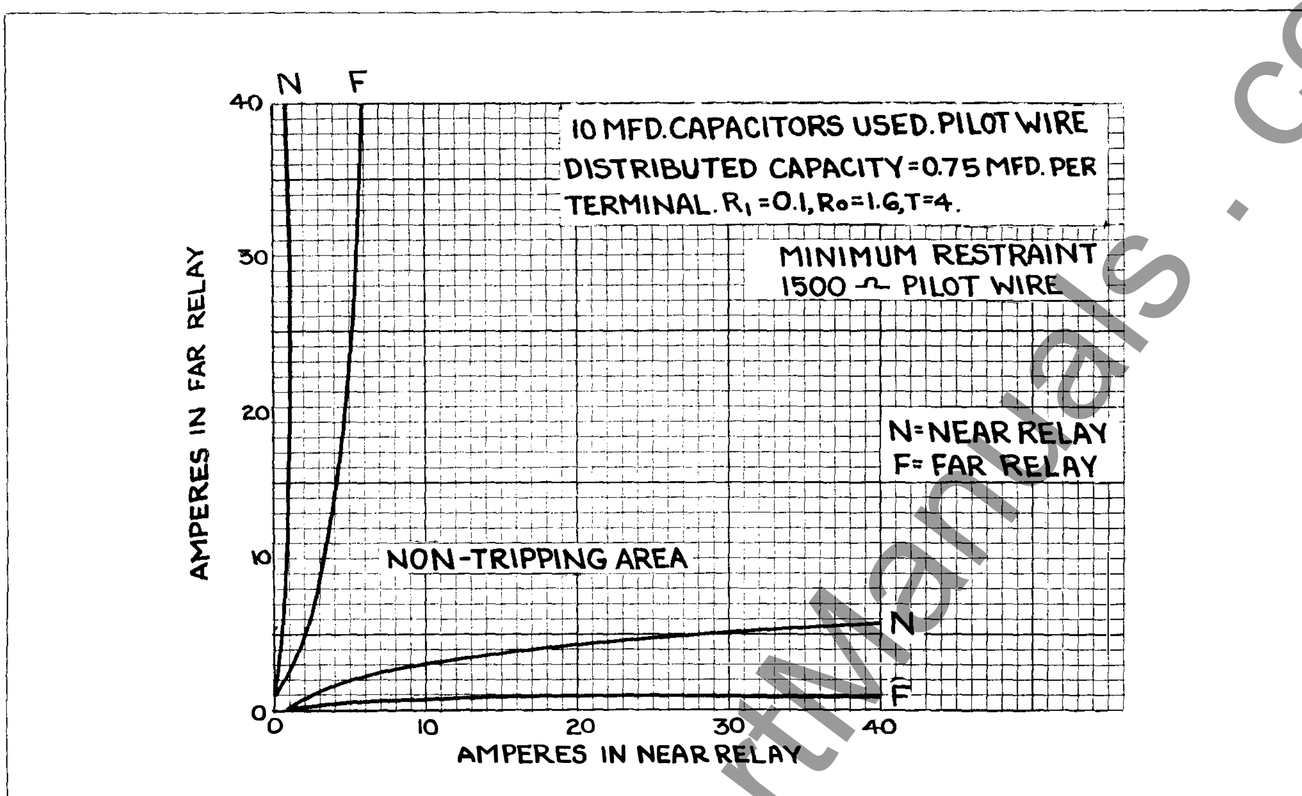


Fig. 6—Typical Operating Characteristics On Phase A to Ground Faults With Currents In Phase and 1500 Ohm Pilot Wire.

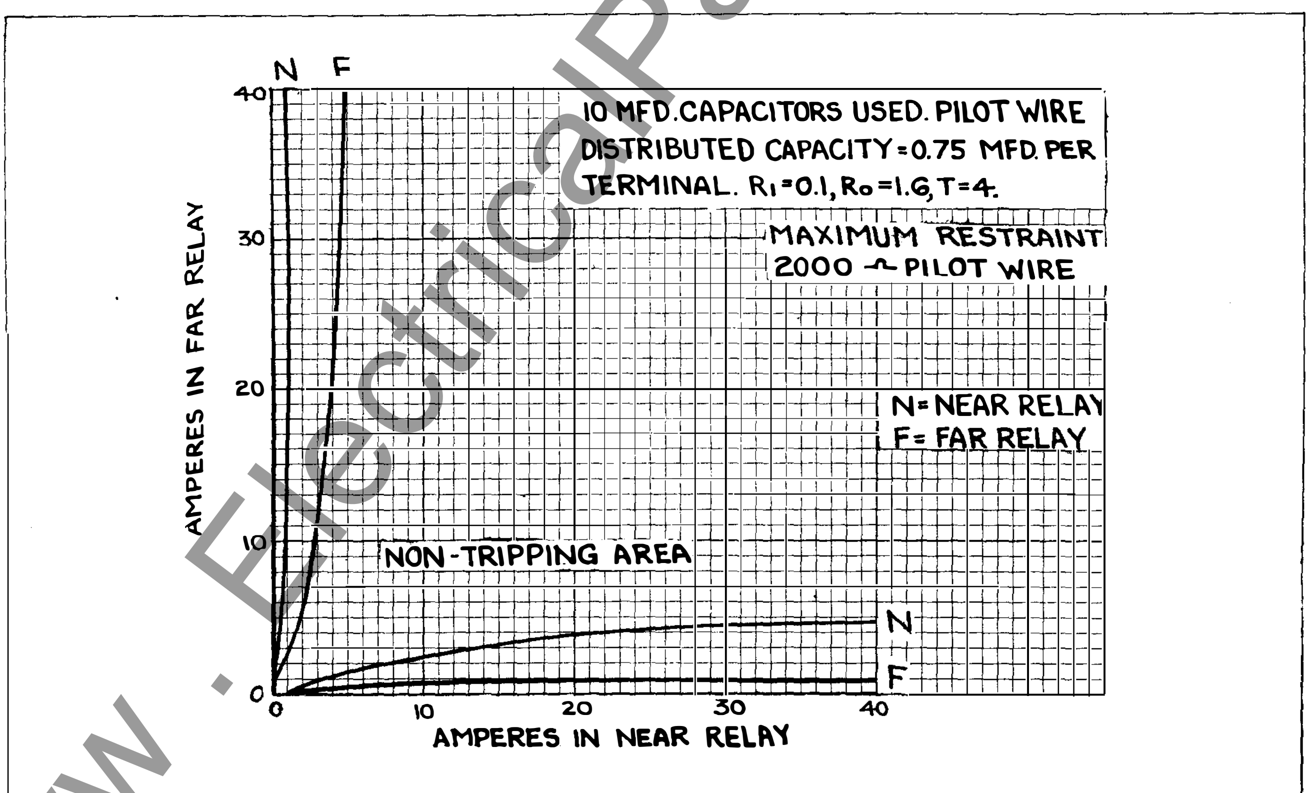
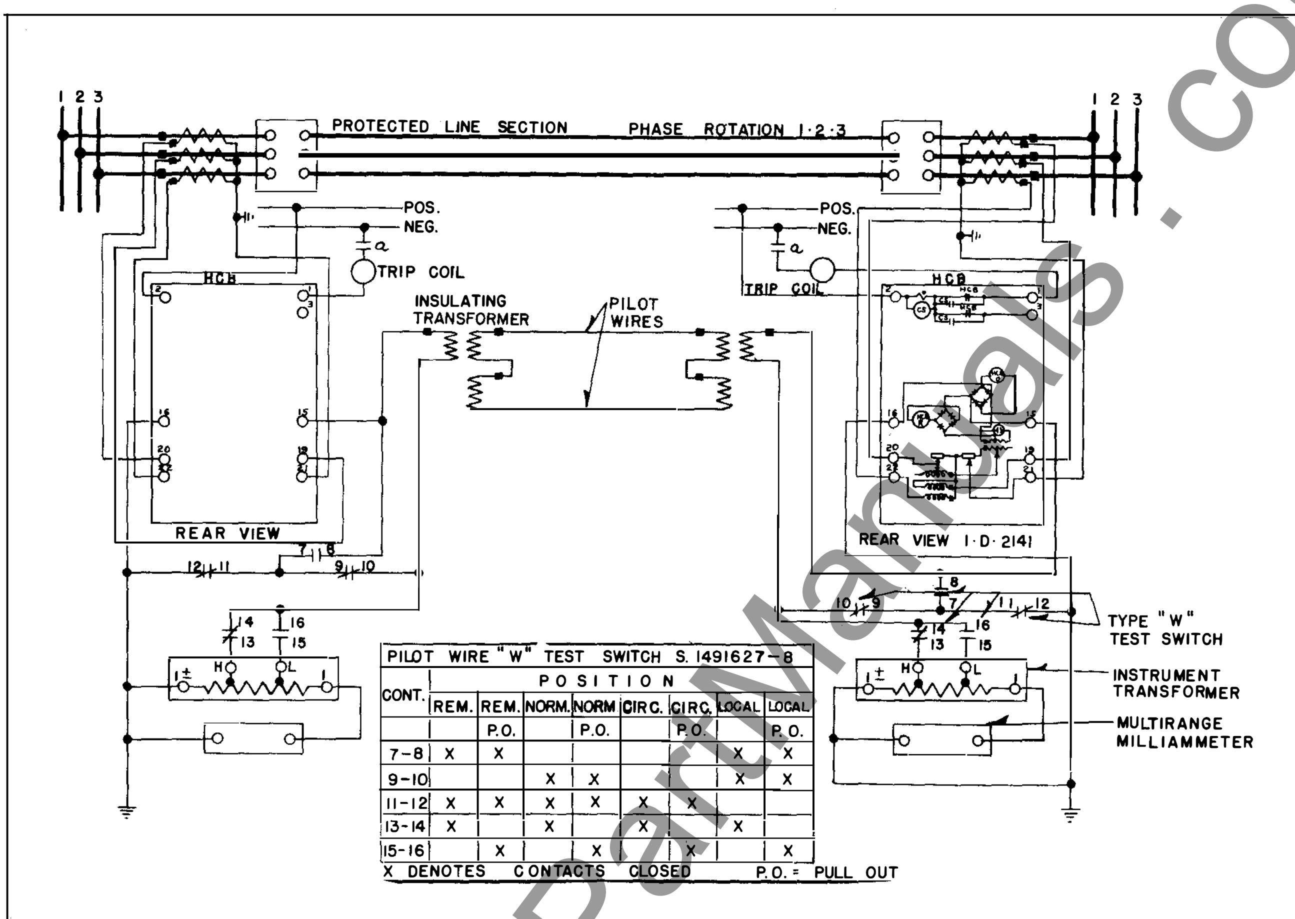


Fig. 7—Typical Operating Characteristics On Phase A to Ground Faults With Currents in Phase and 2000 Ohm Pilot Wire.



PILOT WIRE "W" TEST SWITCH S. 1491627-8

CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 8—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Two Terminal Line.

For example, assume relay tap settings of $T = 6$, $R_1 = .1$, $R_o = .68$, and also assume that a phase b to ground fault occurs, for which the "near" relay components are as follows:

$$I_{a1} = 10 + j0 \qquad (2)$$

$$I_{ao} = .9a^2(I_{a1}) \qquad (3)$$

In equation (3), the factor .9 was arbitrarily used as a reminder that the distribution factors for positive and zero sequence components are not necessarily equal for any given system. Also, the operator a^2 signifies that I_{ao} is 240° leading I_{ao} for a phase b to ground fault, neglecting dissimilarities in the sequence networks. First substituting the particular condition of equation (3) in equation (1) gives

$$I_{an} = \frac{2.35}{T} I_{a1}\left\{2R_1 + .9a^2 (R_1 + 3R_o)\right\} \qquad (4)$$

Substituting values for the several taps in (4) gives

$$I_{an} = \frac{2.35}{6} I_{a1}\left\{\begin{matrix} 2 \times .1 + .9 (-.5-j.866) \\ (.1 + 3 \times .68) \end{matrix}\right\} \qquad (5)$$

$$I_{an} = .392\ I_{a1}\left\{-.763-j1.67\right\} \qquad (6)$$

$$I_{an} = I'_{a1}\ .718\ \underline{|245.4°} \qquad (7)$$

Substituting the numberical value for I_{a1} given by equation (2) results in a numerical value for I'_{an} of

$$I_{an} = .718 \times 10 = 7.18 \text{ amperes.}$$

This is the value to read on the curve for the typical values chosen for the taps R_1, R_o, and T at the particular phase b to ground fault values indicated by equations (2) and (3). It should be noted that the total phase b current to the "near" relay is $I_b = I_{b1} + I_{b2} + I_{bo}$ = 29 amperes, assuming $I_{b2} = I_{b1}$.

For a phase to phase fault, there is no zero sequence current, and the phase current, I_{LL}, is equal in magnitude to $\sqrt{3}\, I_{a1}$. Hence, for phase to phase faults, equation (1) reduces to:

$$I_{an} = \frac{2.35}{T}\left\{2\frac{I_{LL}}{\sqrt{3}}R_1\right\} \qquad (8)$$

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude. That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (the .075 tap is actually marked .07 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of R_1 = .10 is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with R_1 = .10. Where the current transformers are different at the different terminals, select the value of R_1 which is proportional to the current transformer ratios. For example, assume a ratio of 300/5 at one terminal and 600/5 at another terminal. Set R_1 = .075 at the 300/5 terminal and R_1 = .15 at the 600/5 terminal. The ratios obtainable are 1/1, 2/1, 3/2, and 4/3. The same procedure applies to three terminal lines.

Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12 and 15. This tap should be selected to assure operation on minimum internal line-to-line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line-to-line faults is given by the equation :

$$T = 5.7\, I_{LL}\, R_1 \qquad (9)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

The factor "5.7" is used as the operation of the positive sequence filter is such that the relay requires 1.73 times as much current for operation on a line-to-line fault as on a three phase fault. This means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T, must be divided by 0.1 thereby obtaining the factor "5.7".

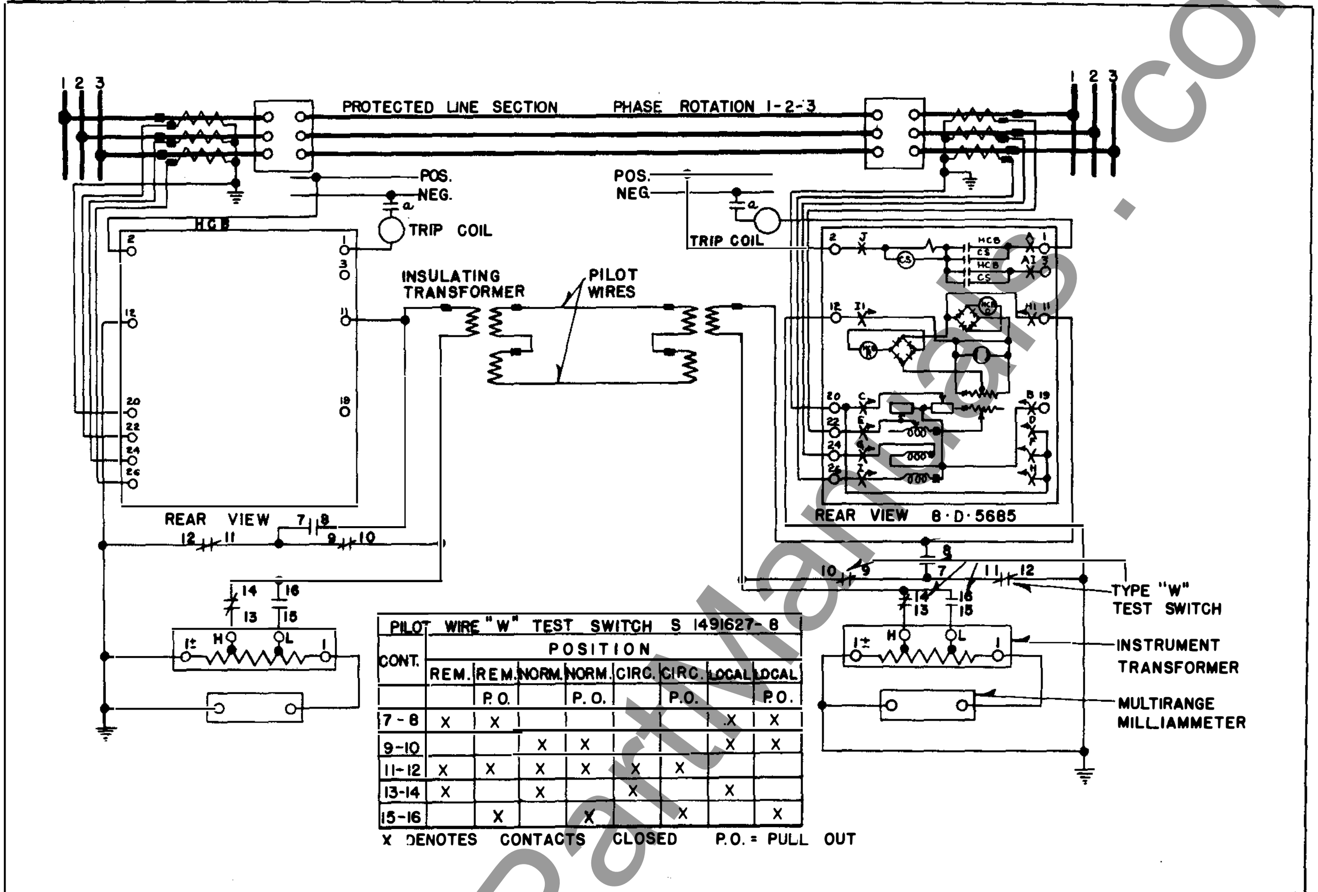
Where line-to-line currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\,(.86)\,(I_{3\phi})\,R_1 \qquad (10)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

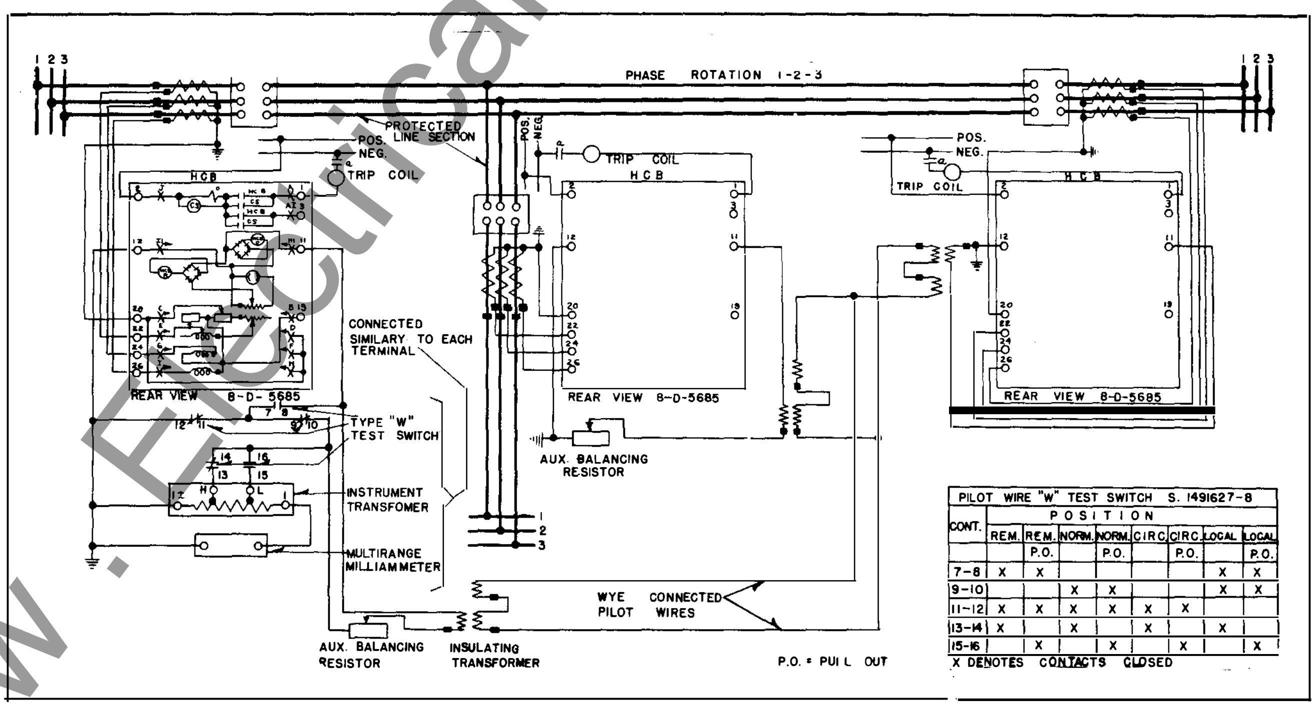
Equation (9) and (10) give the upper limit of "T" which must not be exceeded to obtain operation on the line-to-line faults. The



PILOT WIRE "W" TEST SWITCH S 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

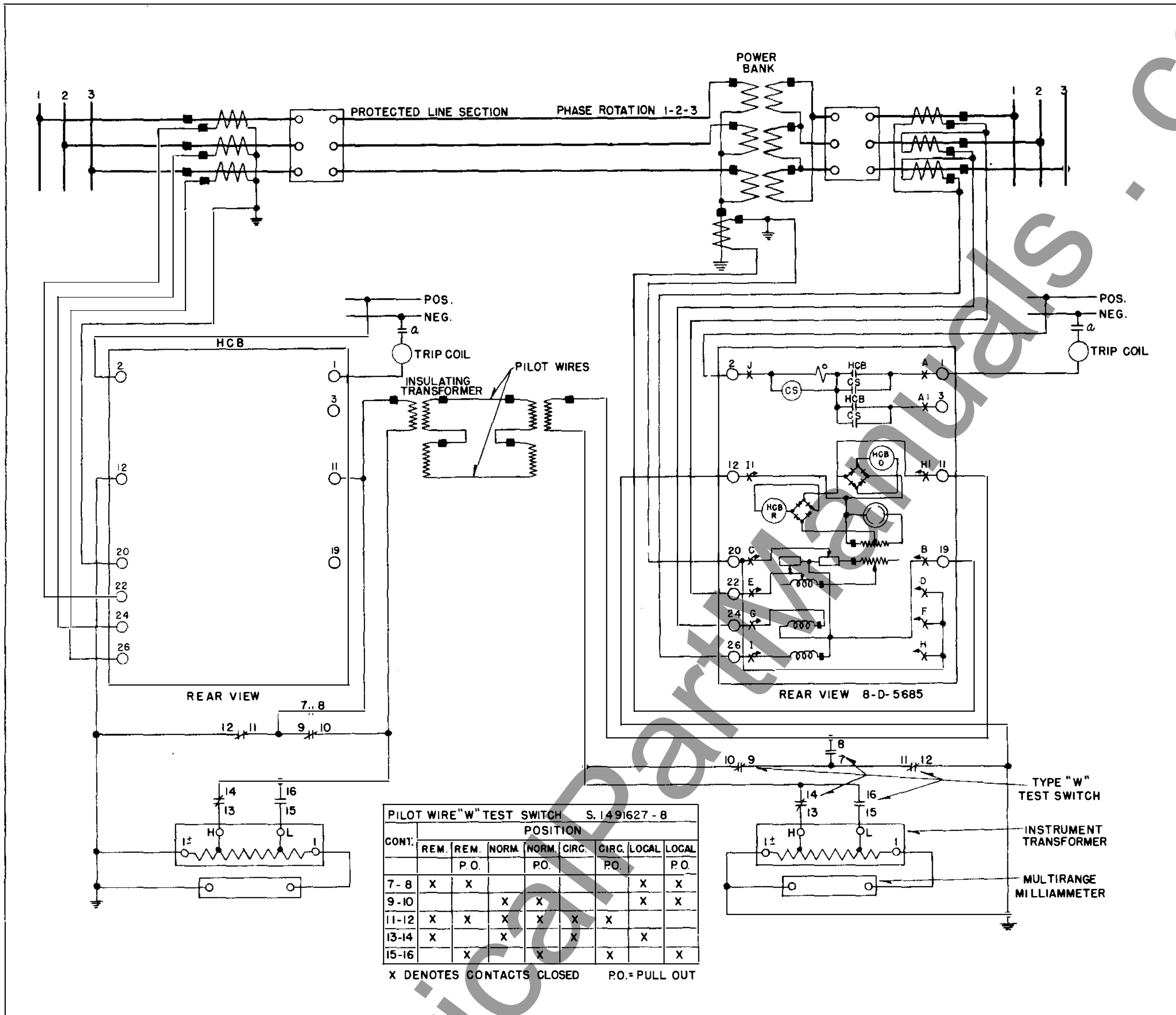
Fig. 9—External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 10—External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of A Three Terminal Line.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 11—External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line With a Transformer Bank.

actual setting should always be below the values obtained from equation (9) or (10). The minimum limits for this setting are discussed below.

The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10\ R_1\ I_{Load} \qquad (11)$$

where "I_{Load}" is the maximum secondary full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (11) if the relay is not to operate on load current with the pilot wires open circuited.

This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents, or if supervisory relays are installed and connected to block the HCB on the occurrence of pilot wire failures. If supervisory relays are installed to block HCB operation under heavy load conditions with the pilot wires opened, it is necessary to introduce a time delay of approximately one cycle by interposing an auxiliary relay in the trip circuit at each terminal to allow the supervisory relays time to coordinate with the high speed of the HCB relay.

Note: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_0) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. (The first two taps are actually marked .02 and .03 because of space limitations). The three lowest taps are not used in applications where high sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_o is set to equal to 1/3 R_1.

Maximum sensitivity to ground faults is obtained with $R_0 = 1.6$. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_0 should be selected which are most nearly proprotional to the transformer ratios. When the ratio of the R_0 taps can not be made to exactly match the ratio of the R_1 taps, pick the ratio to match as closely as possible, and use maximum restraint tap.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_0 = \frac{0.2T}{I_g} \qquad (12)$$

where I_g is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals, and where "T" is the actual tap selected (not the value calculated from equation (9) or (10).

It is recommended that "R_o" be set as high above the value obtained from equation (12) as possible keeping the value of R_o approximately proportional to the current transformer ratios.

Restraint Tap

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is normally shipped with the restraint tap link connected in the maximum restraint position. This link is in the upper left hand corner of the panel carrying the polar element. The link is connected to the left for minimum restraint, and to the right for maximum restraint. Maximum restraint should be used with pilot wires of 1500 to 2000 ohms.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on minimum internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R at station 2 = 0.075.

Positive Sequence Current Tap

From equation (9)

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissable setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (11).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75$$

or

$$T = \frac{10 \times 0.75 \times 300 \ 5}{300} = 3.75$$

Select T at both stations = 6.

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation (12).

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6
And R_o at station 2 = 1.2

RELAYS IN TYPE FT CASE

The type FT cases are dust-proof enclosures combining relay elements and knife-blade test switches in the same case. This combination provides a compact flexible assembly easy to maintain, inspect, test and adjust. There are three main units of the type FT case: the case, cover and chassis. The case is an all welded steel housing containing the hinge half of the knife-blade test switches and the terminals for external connections. The cover is a drawn steel frame with a clear window which fits over the front of the case with the switches closed. The chassis is a frame that supports the relay elements and the contact jaw half of the test switches. This slides in and out of the case. The electrical connections between the base and chassis are completed through the closed knife-blades.

Removing Chassis

To remove the chassis, first remove the cover by unscrewing the captive nuts at the corners. This exposes the relay elements and all the test switches for inspection and testing. The next step is to open the test switches. Always open the elongated red handle switches first before any of the black handle switches or the cam action latches. This opens the trip circuit to prevent accidental trip out. Then open all the remaining switches. The order of opening the remaining switches is not important. In opening the test switches they should be moved all the way back against the stops. With all the switches fully opened, grasp the two cam action latch arms and pull outward. This releases the chassis from the case. Using the latch arms as handles, pull the chassis out of the case. The chassis can be set on a test bench in a normal upright position as well as on its top, back or sides for easy inspection, maintenance and test.

After removing the chassis a duplicate chassis may be inserted in the case or the blade portion of the switches can be closed and the cover put in place without the chassis. The chassis operated shorting switch located behind the short circuiting test switch prevents open circuiting that circuit when the short circuiting type test switches are closed.

When the chassis is to be put back in the case, the above procedure is to be followed in the reversed order. The elongated red handle switch should not be closed until after the chassis has been latched in place and all of the black handle switches closed.

Electrical Circuits

Each terminal in the base connects thru a test switch to the relay elements in the chassis as shown on the internal schematic diagrams. The relay terminal is identified by numbers marked on both the inside and outside of the base. The test switch positions are identified by letters marked on the top and bottom surface of the moulded blocks. These letters can be seen when the chassis or removed from the case.

The potential and control circuits thru the relay are disconnected from the external circuit by opening the associated test switches. Opening the short circuiting test switch short-circuits that circuit and disconnects one side of the relay coil but leaves the other side of the coil connected to the external circuit thru the current test jack jaws. This circuit can be isolated by inserting the current test plug (without external connections) by inserting the ten circuit test plug, or by inserting a piece of insulating material approximately 1/32" thick into the current test jack jaws. Both switches of the current test switch pair must be open when using the current test plug or insulating material in this manner to short-circuit the current transformer secondary.

A cover operated switch can be supplied with its contacts wired in series with the trip circuit. This switch opens the trip circuit when the cover is removed. This switch can be added to the existing type FT cases at any time.

Testing

The relays can be tested in service, in the case but with the external circuits isolated or out of the case as follows:

Testing In Service

The ammeter test plug can be inserted in the current test jaws after opening the knife-blade switch to check the current thru the relay. This plug consists of two conducting strips separated by an insulating strip. The ammeter is connected to these strips by terminal screws and the leads are carried out thru holes in the back of the insulated handle.

Voltages between the potential circuits can be measured conveniently by clamping #2 clip leads on the projecting clip lead lug on the contact jaw.

Testing In Case

With all blades in the full open position, the ten circuit test plug can be inserted in the contact jaws. This connects the relay elements to a set of binding posts and completely isolates the relay circuits from the external connections by means of an insulating barrier on the plug. The external test circuits are connected to these binding posts. The plug is inserted in the bottom test jaws with the binding posts up and in the top test switch jaws with the binding posts down.

The external test circuits may be made to the relay elements by #2 test clip leads instead of the test plug. When connecting an external test circuit to the current elements using clip leads, care should be taken to see that the current test jack jaws are open so that the relay is completely isolated from the external circuits. Suggested means for isolating this circuit are outlined above, under "Electrical Circuits."

Testing Out of Case

With the chassis, removed from the base, relay elements may be tested by using the ten circuit test plug or by #2 test clip leads as described above. The factory calibration is made with the chassis in the case and removing the chassis from the case will change the calibration values by a small percentage. It is recommended that the relay be checked in position as a final check on calibration.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs for the standard cases 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.

The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohm and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the contactor switch. This lead should be fastened (dead ended) under the small filister-head screw located in the Micarta base of the contactor switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms.

ADJUSTMENTS AND MAINTENANCE

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if 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.

CAUTION 1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the ~~spare~~ tap screw should be inserted before removing the other tap screw.

Sequence Filter

There are no adjustments to be made in the zero sequence resistor. The taps on the R_1 resistor are adjustable, however, but this is a factory calibration which should not ordinarily be disturbed. To check the positive sequence current filter, pass a current I = 6.94 amperes through a pair of phase terminals, for example, in at phase B, out of phase C (see Figure 2) and measure the open circuit filter voltage with a high resistance voltmeter. This may be done by removing the positive sequence current tap screw, T, and connecting the voltmeter across the open circuit thus formed. The voltage should be $8R_1$ plus or minus 5% for each of the three phase-to-phase combinations, AB, BC, or CA. For example, at I = 6.94 amperes and R_1 = .1, the voltage should be 0.8 volts.

Polar-Type Element

Contact Adjustment: Adjust both left-hand (front view) contacts until they barely make a light circuit, when the armature is against the left stop. A flickering light is permissible. Give both the left-hand contact screws an additional 1/3 turn, and lock in position with the lock nuts provided.

Calibration: Connect the restraint tap link in the position in which it will be used. Connect the low voltage terminals of the insulating tramsformer across the pilot wire terminals of the relay. Connect the relay taps on T = 4, R_1 = .1, R_o = 1.6.

Screw in the left-hand magnetic shunt all the way and lock it in position by means of the locking screw provided. Adjust the right-hand magnetic shunt in or out, as required, unitl the relay just closes contacts at 6.9 to 7.0 amperes phase B to phase C current. When this adjustment has been made, and checked with both magnetic shunts locked in position, change the input current connections to phase A to neutral. The relay should trip for phase A to neutral current between .45 and .55 amperes.

The above is given as a laboratory calibration on an individual relay with its insulating transformer. This does not take into consideration the characteristics of the pilot wire circuit between the relays, so that the following calibration in place is recommended, particularly when the distributed capacity of the pilot wires approaches the upper limit for the application.

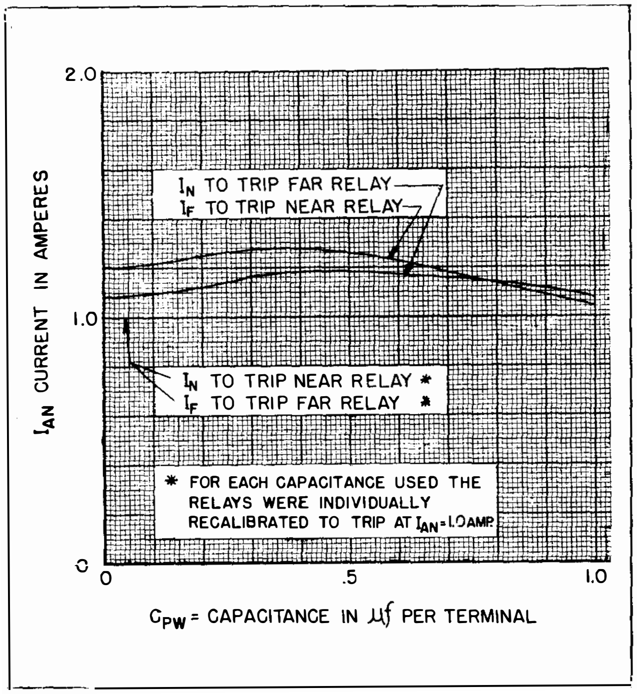


Fig. 12—Typical Curves Showing the Effect of Pilot Wire Capacitance on Operation of the Type HCB Relay.

With both relays set on taps T = 4, R_1 = .1, R_O = 1.6, and the restraint tap which will be used, adjust the "near" relay to trip at 2 x .47 = .94 amperes, phase A to Neutral, This is based on two considerations. First, .47 amperes is the value of phase A to Neutral amperes which is equivalent in the relay filter to 4 amperes positive sequence only, with the taps as specified above. Secondly, with both relays connected to the pilot wires the total internal fault current to trip the two relays is substantially two times the current required for one relay only, thus accounting for the factor of 2. A suitable tolerance to allow in the adjustment for .94 amperes may be considered, for example, as between the limits of .9 and 1.0 ampere. Once the "near" relay is adjusted, or calibrated, in line with the above, it becomes necessary to repeat the procedure for the "far" relay.

It does not necessarily follow that when the "near" relay is being calibrated as above, that the "far" relay, when calibrated, will trip at the same current value in the "near" relay that trips the "near" relay, because, being energized over the pilot wires, its condition of energization is different. The current in the "near" relay to trip the "far" relay, and vice versa, requires observers at both locations. The curve, Figure 12, is typical of a 2000 ohm pilot wire and is typical of the variation to be expected with different values of distributed capacity.

Restraining Coil: The effectiveness of the restraining coil of the relay element, and the performance of the Rectox units, may be checked as follows, if desired: Connect a variable non-inductive resistor across the high voltage terminals of the insulating transformer, and connect d-c milliammeters in series with the operating and restraining coils of the element, by opening these circuits at the test links provided for this purpose. These milliammeters should have low resistance, and should be capable of reading in the order of 20 to 25 ma. in the operating coil and 100 to 150 ma. in the restraining circuit. Using T = 4, R = .1, R_O = 1.6, pass 10 amperes 60 cycles from phase A to Neutral in the relay, and increase the variable resistance across the insulating transformer high voltage terminals until the relay just trips. This should be in the order of 1400 to 2000 ohms when maximum restraint is used. Read the d-c current (milliamperes) in the operating and restraining coils at this point. The values obtained should conform substantially to the following equations.

For Minimum Restraint

$$I_O = .12\ I_R + 8$$

For Maximum Restraint

$$I_O = .16\ I_R + 8$$

where I_O and I_R are operating and restraining coil currents, respectively, in milliamperes. The results are subject to slight variations between individual relays.

The polarity of the connections to the pilot wires, and the correct "Phasing out" of A, B, C phases at the two stations may be checked by the six tests outlined on Page 17.

Pilot Wire Current

The pilot wire current which should flow under normal load conditions is given in Figures 4 and 5. If the relay taps in use differ from those indicated in these figures, suitable conversion factors must be used as given in the text. The pilot wire current will vary inversely with T and directly with R_1.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down or by disconnecting the switch and turning it up-side-down. Then screw up the core screw until the moving core starts rotating. Now, back off the core screw until the moving core stops rotating. This indicates the points where the play in the assembly is taken up, and where the moving core just separates from the stationary core screw. 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c have been passed through the coil.

Operation Indicator

Adjust the indicator to operate at 0.2 ampere d-c gradually applied by loosening the two screws on the under side of the assembly, and moving the bracket forward or backward. If the two helical springs which reset the armature are replaced by new springs, they should be weakened slightly by stretching to obtain the 1 ampere calibration. The coil resistance is approximately 2.8 ohms.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three - phase current of 5 amperes:

For tap 4 R_1 = .075 and R_o = .39

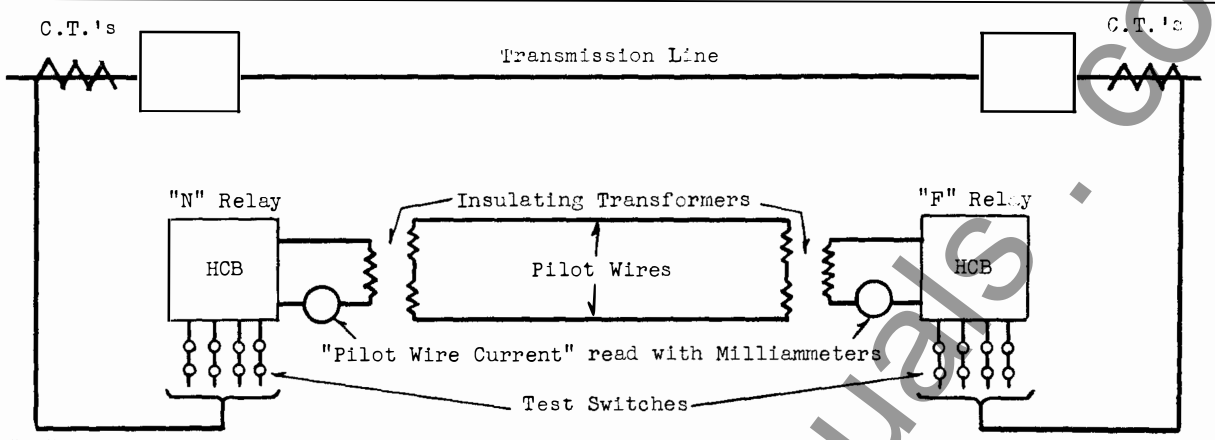
Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_o = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.



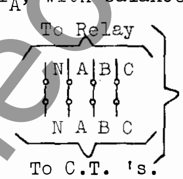
Note: The line should be carrying through load current amounting to at least 1.5 amperes as measured in the secondary of the Current Transformers. This test is based on the ratio of the C.T.'s being the same at each end of the line, in which case set the taps of both relays to $R_1 = .1$; $R_o = 1.6$; $T = 4$ for this test.

	RELAY "N"					RELAY "F"				
Test No.	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay F	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay N
1		A,B,C,N	No	(1)	(1)		A,B,C,N	No	(1)	(1)
2		A,C,B,N	No	(2)	(2)		A,C,B,N	No	(2)	(2)
3		A,N	Yes	(3)	(3)		0	Yes	(3)	(3) (4)
4		0	Yes	(3)	(3) (4)		A,N	Yes	(3)	(3)
5		A,N	No	(3)	(3)		A,N	No	(3)	(3)
6		A,N	Yes	(6)			B,C,N	Yes	(6)	

REMARKS

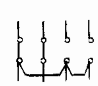
Tests 1 and 2 are to check normal positive sequence rotation of phases. The test switch connections of test #2 may be made readily with relays in the Flexitest case by using clip leads and insulating barriers in the ammeter test jacks. However, care should be used to avoid accidentally open-circuiting the current transformer circuits.
Tests 3 and 4 simulate internal Phase A to Ground fault with single end feed.
Test 5 simulates an external Phase A to Ground fault. (5)
Test 6 simulates an internal Phase A to Ground fault, with equal feed from the two ends, since $I_B + I_C = - I_A$, with balanced load.

LEGEND OF TEST SWITCH SYMBOLS:



Normal Connection. All Currents to Relay.

EXAMPLE



Phase A current from C.T. 's to Relay. Phase B and C C.T.'s shorted to neutral.

(1) The "pilot wire current" will vary depending upon the magnitude of the through load current and the characteristics of the pilot wire. See Figures 4 and 5.
(2) Since the relay is temporarily connected for negative sequence, it should have practically zero output in this test.
(3) These readings may be "off scale" depending upon the magnitude of the load current.
(4) The relay at this station should reset when the "far" current is being read because the local relay will be receiving no current from either the pilot wire or the current transformers.
(5) Test 4 and 5 can be repeated using phase B to neutral current, and again with phase C to neutral current, but this is not strictly necessary on the basis that, having proved the phase sequence with tests 1 and 2, and having proved the correspondence of phase A at the two ends of the line with test 5, then phases B and C must be correct.
(6) Some pilot wire current will be read, depending upon the magnitude of the distributed capacity of the pilot wire in combination with the magnetizing impedance of the insulating transformer.

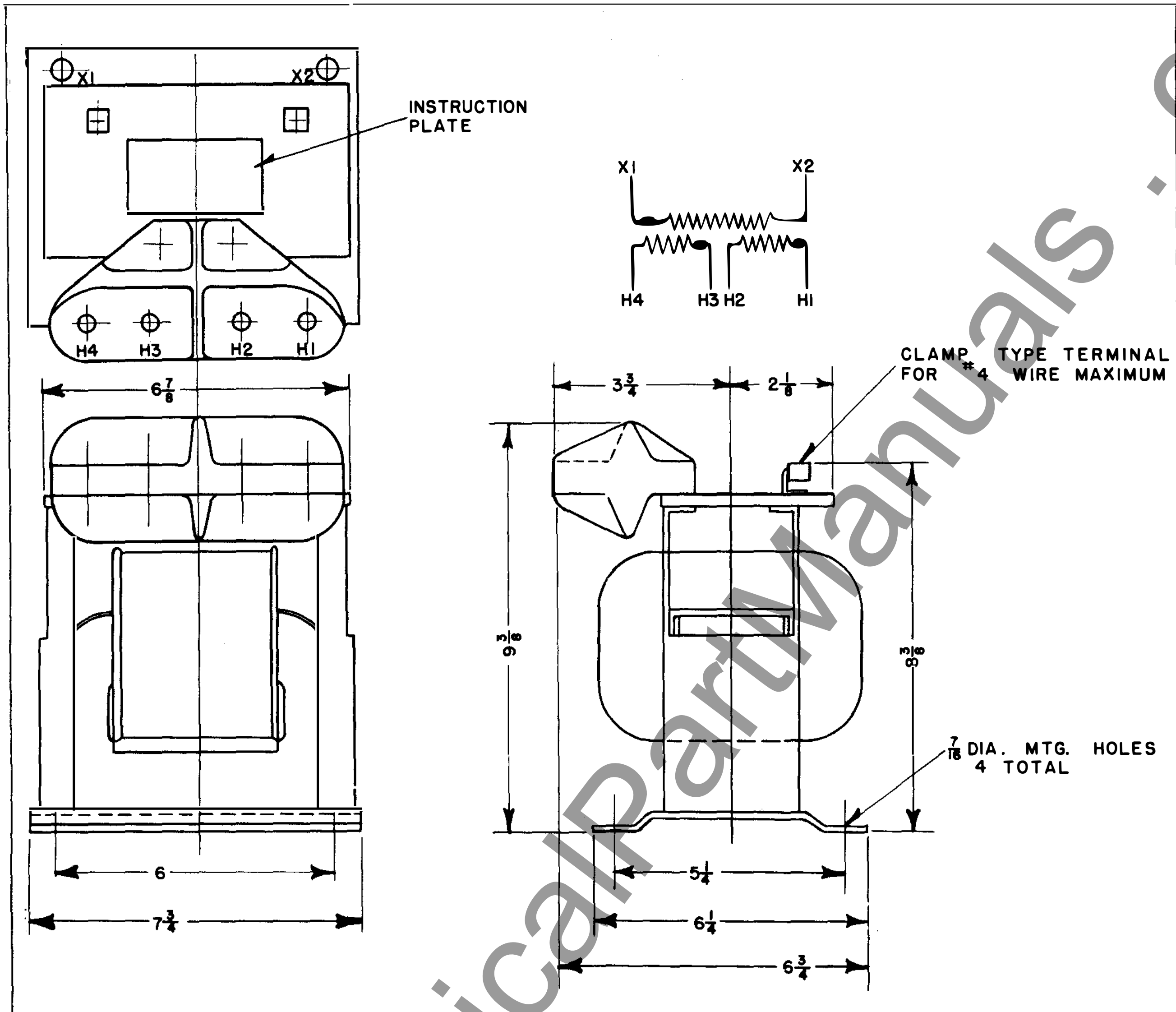


Fig. 13—Outline and Drilling Plan of the Insulating Transformer. For Reference Only.

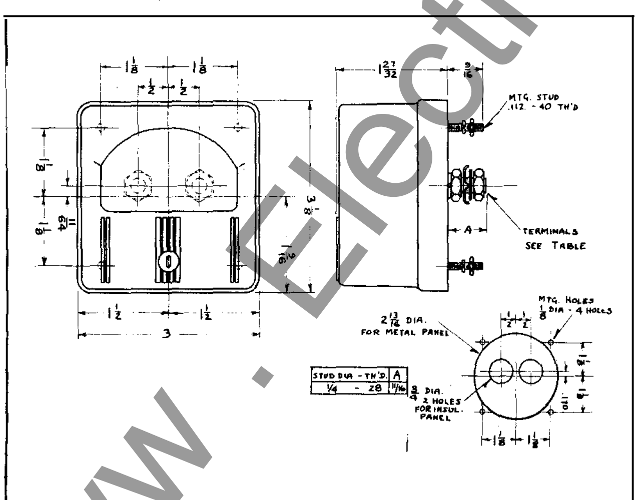


Fig. 14—Outline and Drilling Plan of the Projection Type Test Milliammeter. For Reference Only.

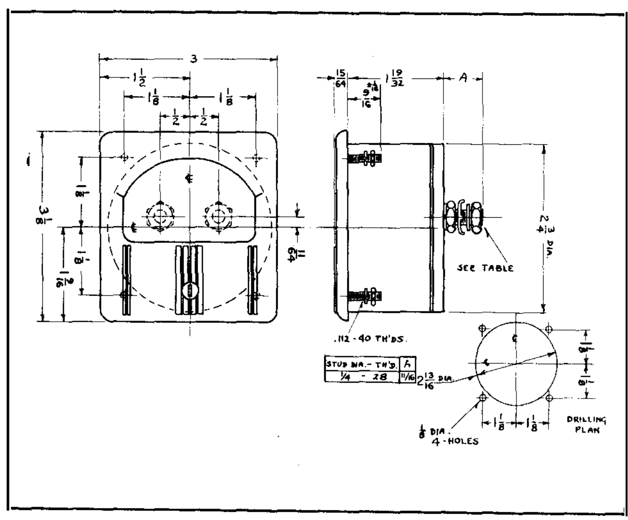


Fig. 15—Outline and Drilling Plan of the Semi-flush Type Test Milliammeter. For Reference Only.

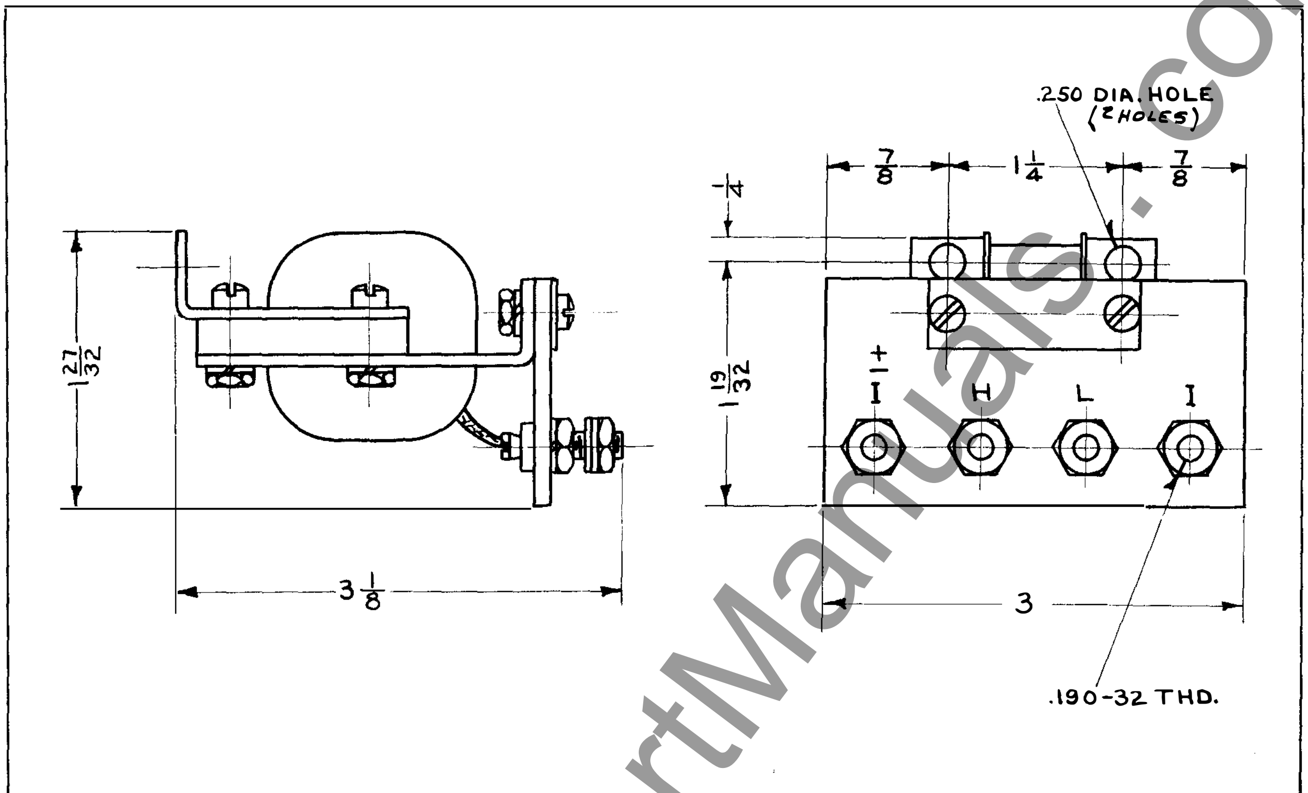
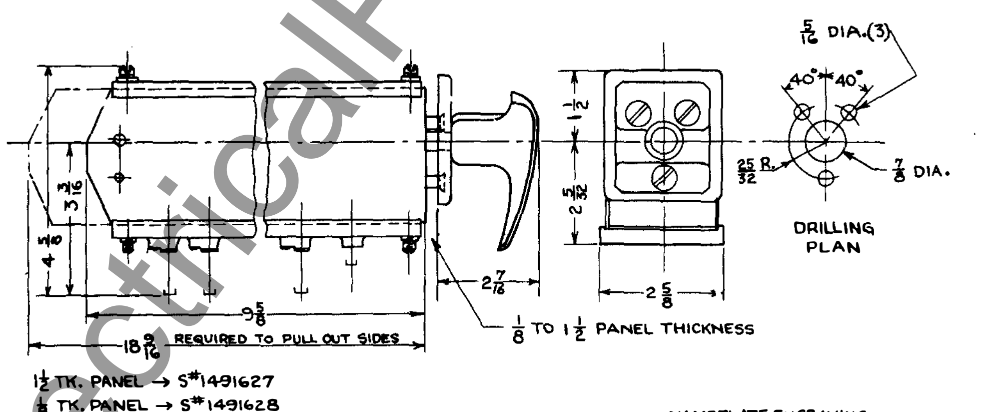


Fig. 16—Outline of the Test Milliammeter Auxiliary Transformer. For Reference Only.

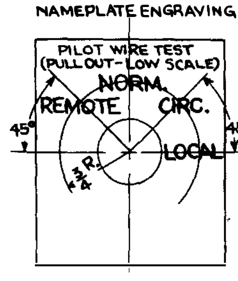


SWITCH POSITION TABULATION

CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X-DENOTES CONTACTS CLOSED

NAMEPLATE ENGRAVING



SPRING RETURN
MODERN PISTOL HANDLE

Fig. 17—Outline and Drilling Plan of the Type W Test Switch. For Reference Only.

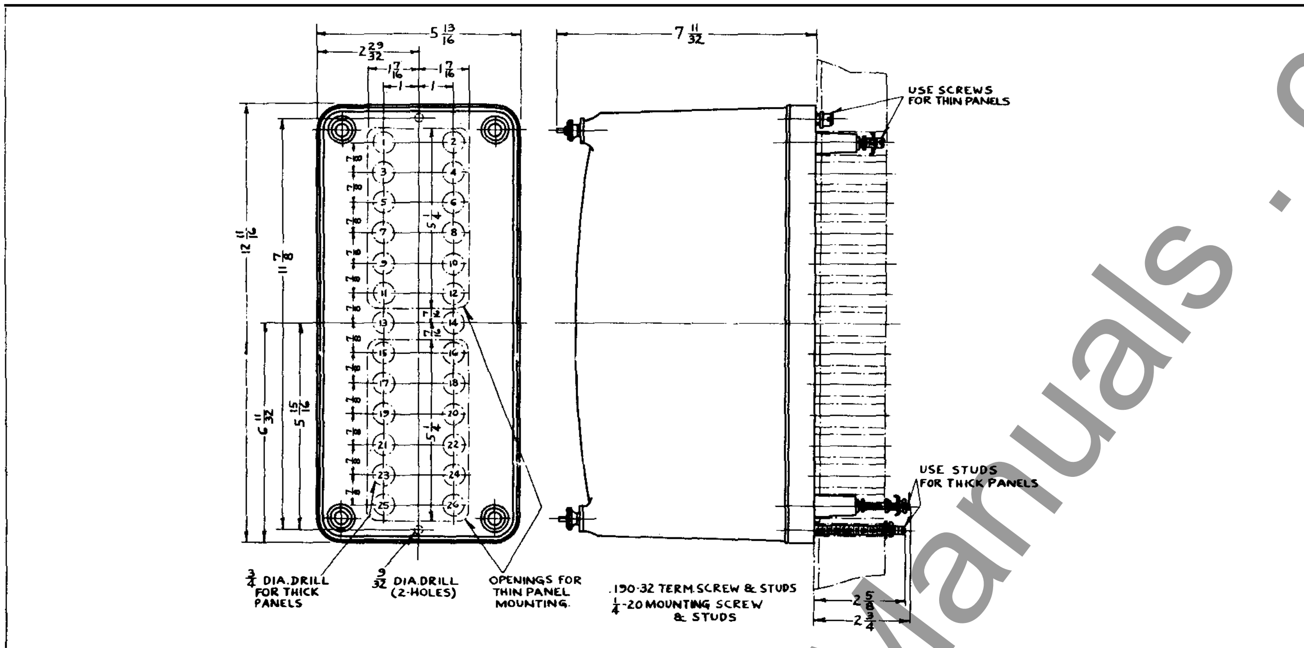


Fig. 18—Outline and Drilling Plan For the Projection Type Standard Case. See the Internal Schematics For The Terminals Supplied. For Reference Only.

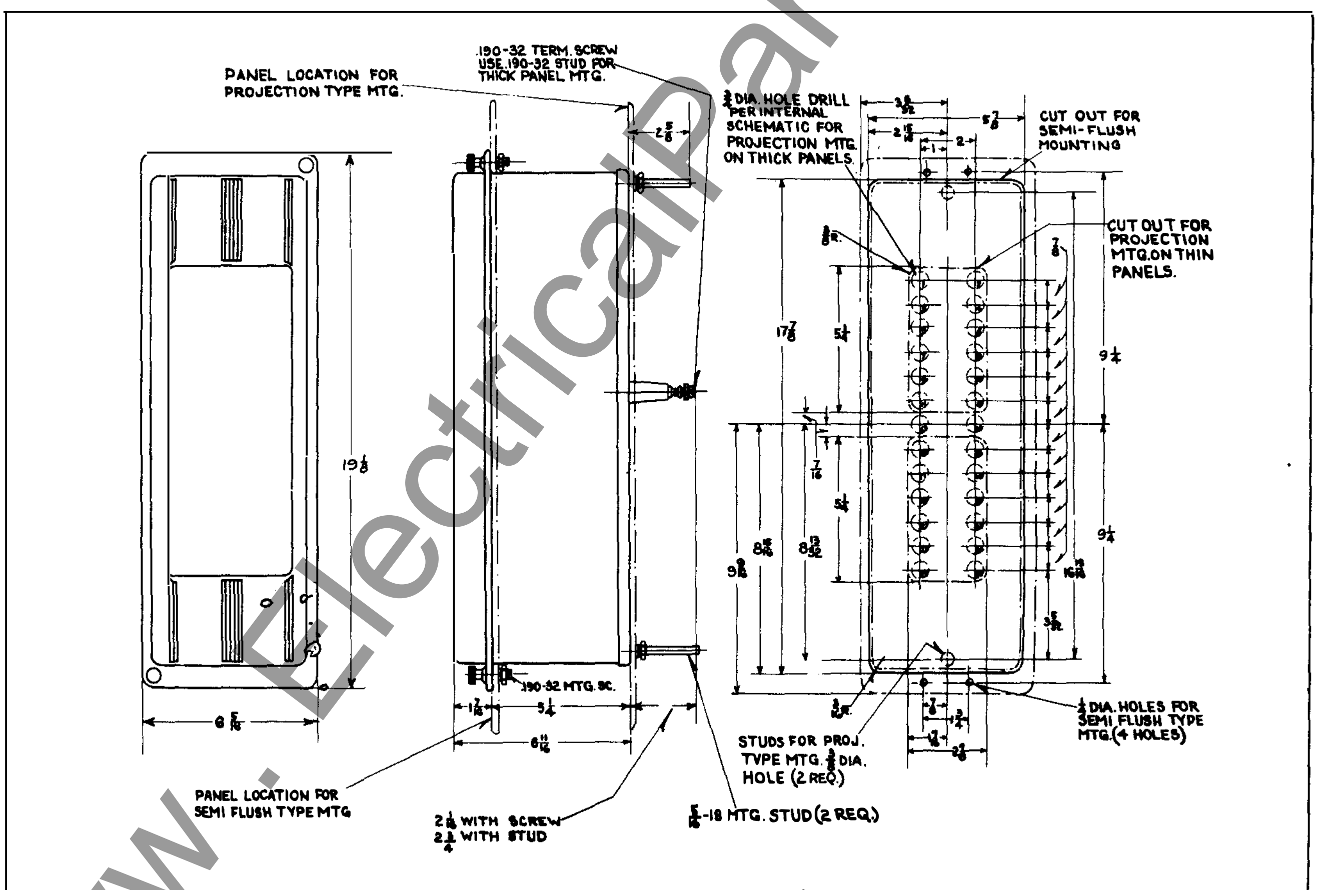


Fig. 19—Outline and Drilling Plan for the M-20 Projection or Semi-Flush Type FT Case. See the Internal Schematic for the Terminals Supplied. For Reference Only.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HCB PILOT WIRE RELAY

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line, three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the out-put of the saturating transformer, and is marked in amperes required to operate the relay when the

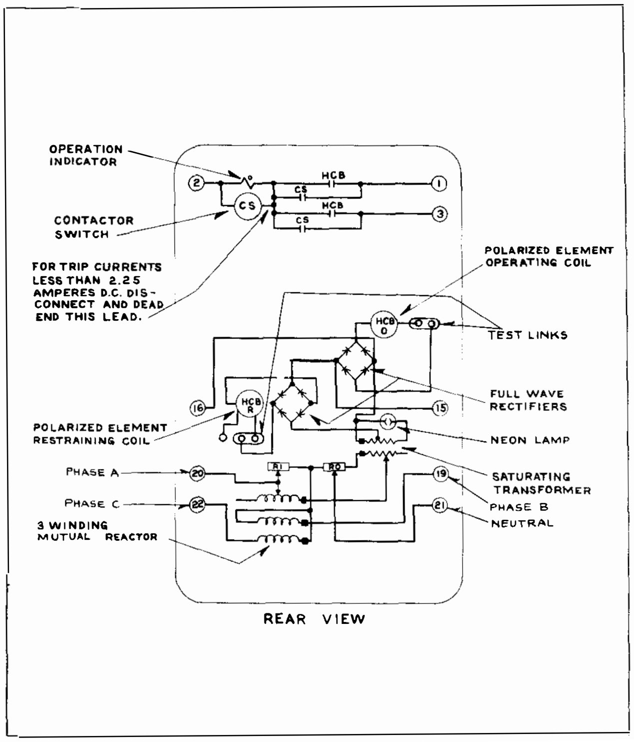


Fig. 1—Internal Schematic of the Type HCB Relay in the Standard Case.

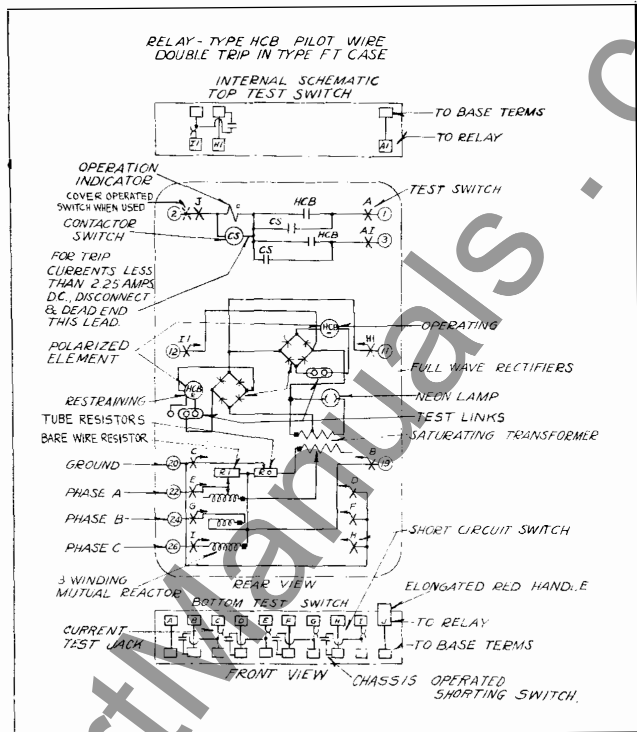


Fig. 2—Internal Schematic of the Type HCB Relay in the Type FT Case.

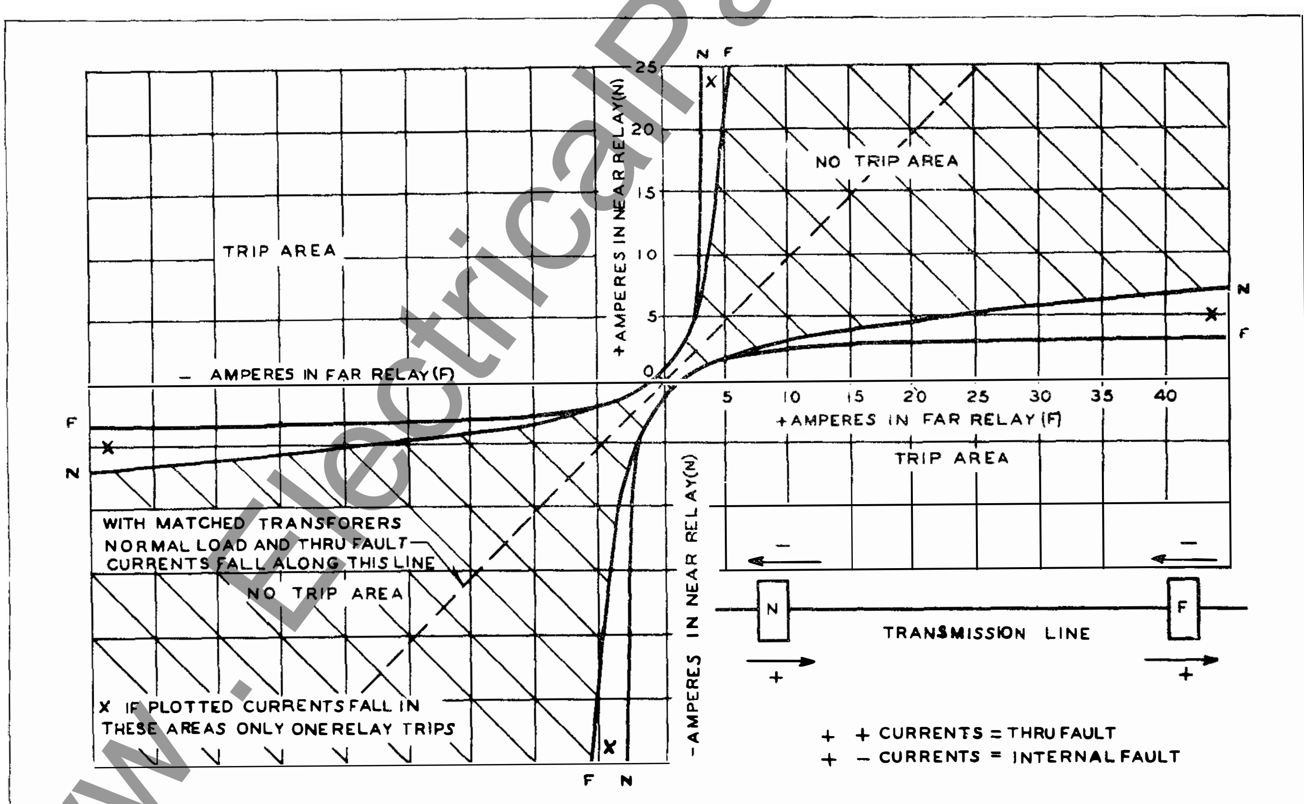


Fig. 3—Typical Operating Characteristics on Phase A to Ground Faults With Currents Thru the Two Terminals 30° Out of Phase. Maximum Restraint With Insulating Transformers and 2000 Ohm Pilot Wires. Taps T = 4, R_I = .1, R_O = 1.6.

pilot wire is open or when equal amounts of currents are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in Figure 9. The rectox units are used to convert the a-c output of the saturating transformer to d-c for use on the d-c polar-type relay element. The use of a sensitive polar-type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar -Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnetic bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating winding produces a magnetic field which acts to move the armature in the contact closing direction. The restraining winding is tapped and the leads are brought out to taps at the upper left of the relay. The left hand position of the test link is the minimum restraint connection, and the right hand position is the maximum restraint connection.

The moving contacts are fastened on the free end of the leaf spring. Two stationary contact screws are mounted to the left (front view) of the moving contact assembly and are adjusted for normally open contacts.

Insulating Transformer

The insulating transformer is connected as shown in Figure 9 and serves to isolate the terminal equipment from the pilot wire. This avoids interconnection of station grounds that may have large differences of potentials between them. The mid-taps of the parallel-wound secondary windings are brought out separately to provide a means of connecting supervisory relays symmetrically within the pilot wire circuit. When auxiliary supervisory relays are not used, these mid-taps are to be connected together and may be grounded to drain the voltages induced along the length of the pilot wires when these voltages approach the voltage limit of the cable. This is discussed further under Pilot Wire below.

The transformers have a 4/1 ratio and are insulated for 5000 volts.

Pilot Wire

One pair of pilot wires connecting the secondaries of the insulating transformers is required to provide a continuous circuit between the relays. For the pilot wires a lead-covered twisted pair of No. 19 wire or larger is recommended, however, open wires may be used. The following points should be considered in selecting pilot wire circuits.

1. The total circuit resistance (including neutralizing reactors when used) between terminals of the Type HCB relays exclusive of the insulating transformers and expressed in terms of the pilot wire voltage must not exceed 2000 ohms for two terminal lines (500 ohms per wye branch for three terminal lines).

2. The shunt capacity between pilot wires should not exceed 0.75 microfarad per pilot wire terminal for two terminal lines (0.60 mfd. per leg. for three terminal lines). In cases where this value is exceeded, compensating reactors will be required to reduce the

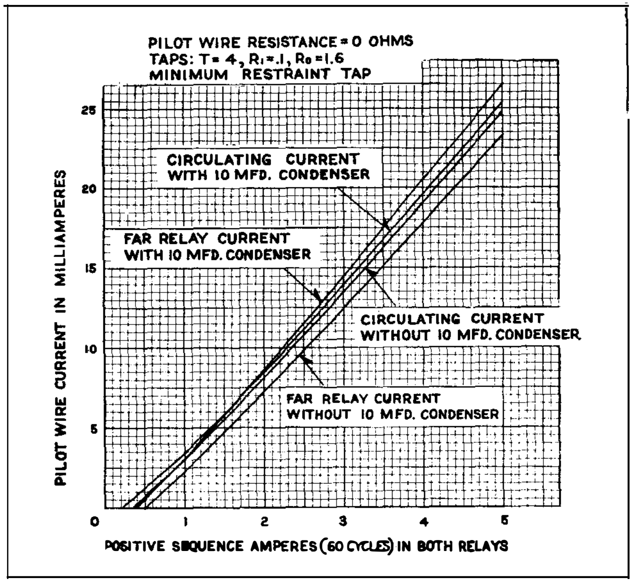


Fig. 4—Typical Test Output Vs. Input Relay Current in A Two Terminal Line With Zero Pilot Wire Resistance.

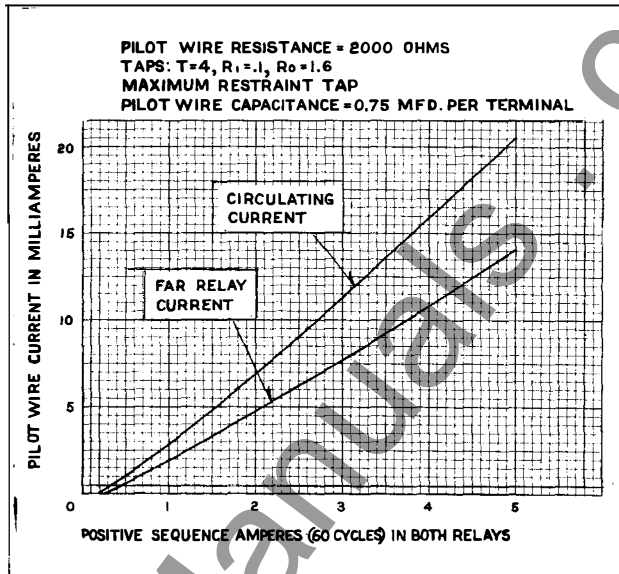


Fig. 5—Typical Test Output Vs. Input Relay Current In A Two Terminal Line With 2000 Ohm Pilot Wire Resistance With or Without the 10 MFD. Condenser.

shunt currents which tend to desensitize the relay.

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. However, the requirement of 15 volts difference must be maintained.

b. For more serious induction two winding neutralizing reactors can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing reactors should be used. Reactors are available for 1000 and 2000 volt neutralization.

c. Another method consists of connecting a suitable two winding drainage reactor and a protector tube, such as the type KX642, to the pilot wires at suitable points. The arrangement is such that when the tube flashes because of high extraneous voltages, both wires are connected to ground, through the reactor and the tube. The impedance to ground is low, but the impedance between wires is kept high to avoid interfering with the operation of the HCB relays.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in Figure 9. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault current fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay. However, if the short circuit on the pilot wire is so placed that it is 1000 or more pilot wire ohms from one of the two relays, then that relay will not be blocked.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted wire pilot mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by continuously-operated supervisory relays supplied as extra equipment.

The condition of the pilot wire under normal load conditions may be determined by reading the pilot wire current by means of the test switch and milliammeter.

A comparison of the readings obtained with the typical values of Figures 4 & 5 will indicate the condition of the pilot wire. It should be noted that, when the far relay current is being read, the near relay is short circuited, and the far relay is shunted by the resistance of the pilot wires plus the impedance of the near relay insulating transformers.

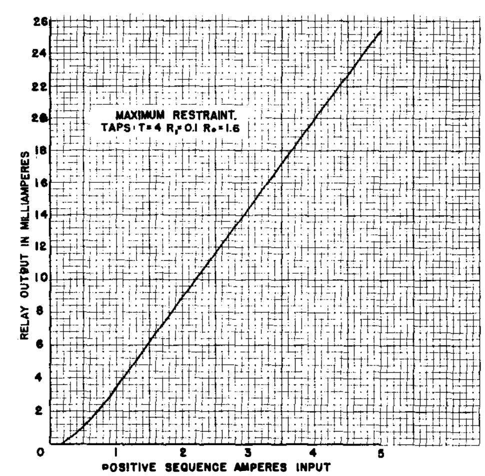


Fig. 6—Typical Curve of Relay Output vs. Positive Sequence Amperes Input.

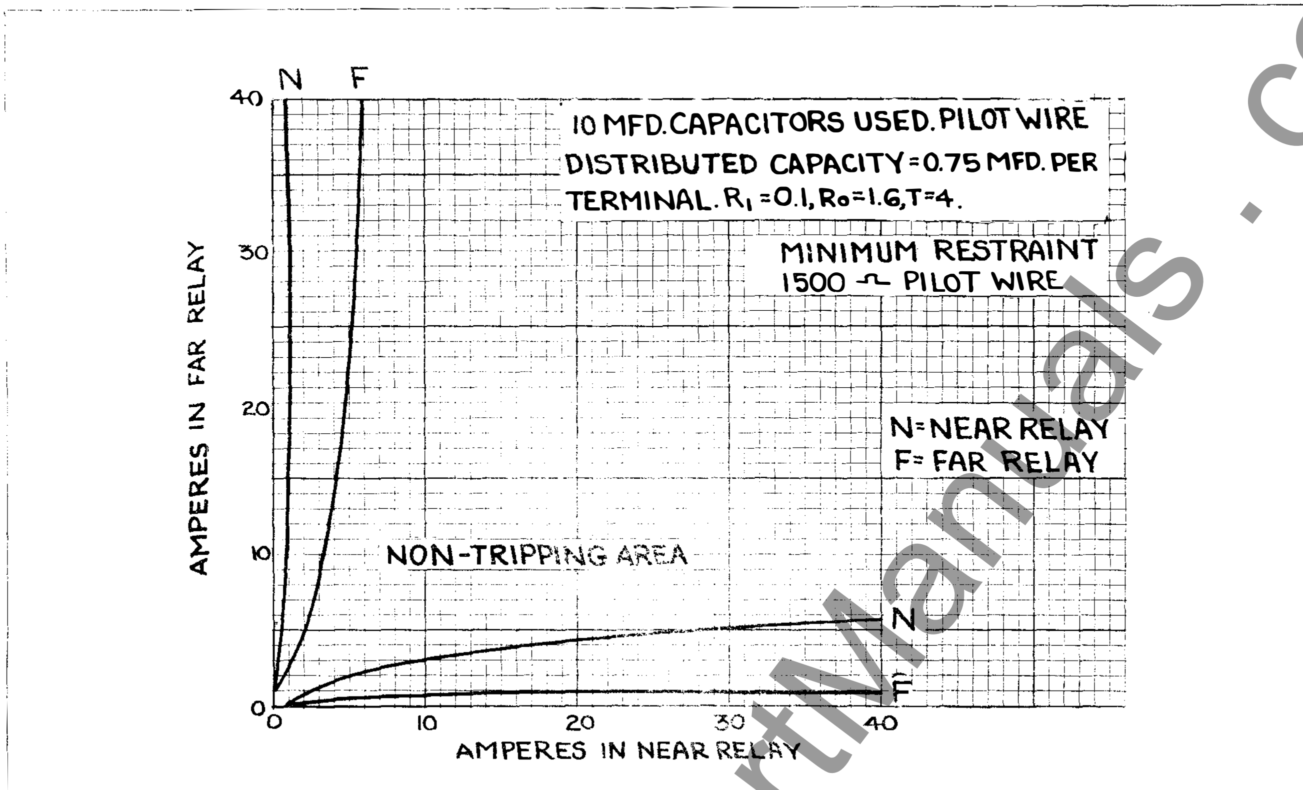


Fig. 7—Typical Operating Characteristics On Phase A to Ground Faults With Currents In Phase and 1500 Ohm Pilot Wire.

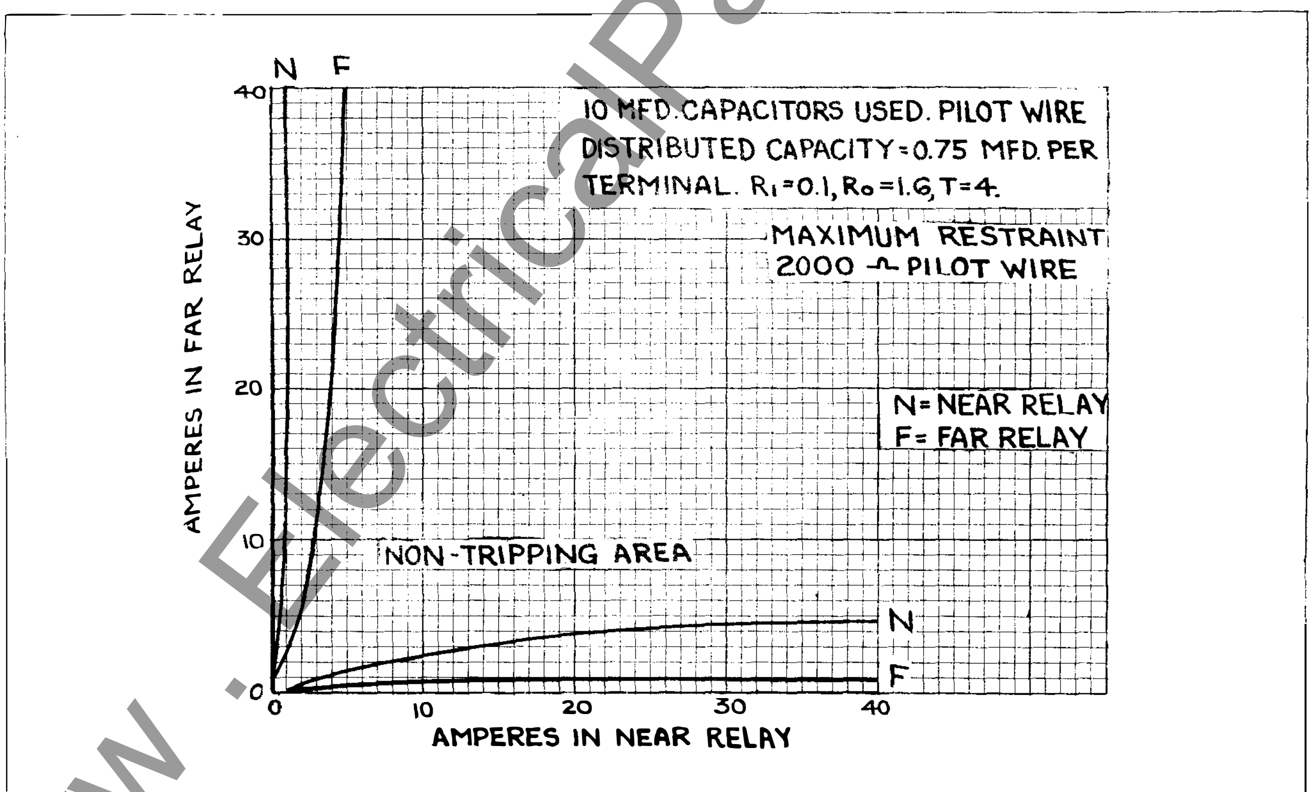
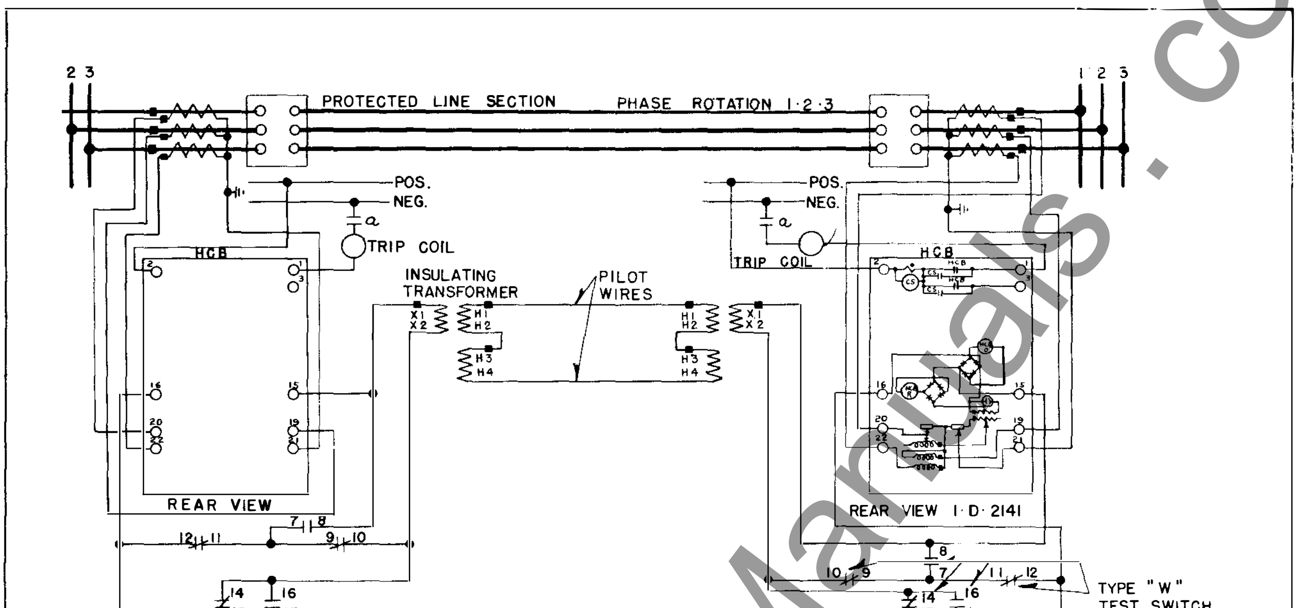


Fig. 8—Typical Operating Characteristics On Phase A to Ground Faults With Currents in Phase and 2000 Ohm Pilot Wire.



PILOT WIRE "W" TEST SWITCH S. 1491627-8

CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 9—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Two Terminal Line.

Figure 6 shows typical values for relay output current vs. positive sequence input current. For this test, the insulating transformer is short circuited on the low voltage side so that the milliammeter is connected directly across the relay output terminals.

CHARACTERISTICS

Typical overall operating characteristics of the relay are illustrated in Figures 7 and 8. The general shape of these curves is similar for other types of faults, relay settings, and pilot wire lengths. The ampere abscissa and ordinate scales may be interpolated to show the operating characteristics for other conditions and tap settings by the use of the following equation:

$$I_{an} = \frac{2.35}{T}\left\{2\dot{I}_{a1}R_1 + \dot{I}_{ao}\,(R_1 + 3R_o)\right\} \quad (1)$$

where I_{an} is the value to read on the curve (Figures 7 and 8).

For example, assume relay tap settings of $T = 6$, $R_1 = .1$, $R_o = .68$, and also assume that a phase b to ground fault occurs, for which the "near" relay components are as follows:

$$\dot{I}_{a1} = 10 + j0 \quad (2)$$

$$\dot{I}_{ao} = .9a^2(I_{a1}) \quad (3)$$

In equation (3), the factor .9 was arbitrarily used as a reminder that the distribution factors for positive and zero sequence components are not necessarily equal for any given system. Also, the operator a^2 signifies that I_{ao} is 240° leading I_{a1} for a phase b to ground fault, neglecting dissimilarities in the sequence networks. First substituting the particular condition of equation (3) in equation (1) gives

$$I_{an} = \frac{2.35}{T} I_{a1}\left\{2R_1 + .9a^2\,(R_1 + 3R_o\,)\right\} \quad (4)$$

Substituting values for the several taps in (4) gives

$$I_{an} = \frac{2.35}{.6} \dot{I}_{a1} \left\{ \begin{matrix} 2 \times .1 + .9\,(-.5-j.866) \\ (.1 + 3 \times .68) \end{matrix} \right\} \quad (5)$$

$$I_{an} = .392\, \dot{I}_{a1} \left\{ -.763-j1.67 \right\} \quad (6)$$

$$I_{an} = \overset{\circ}{I}_{a1}\, .718\, \underline{|245.4°} \quad (7)$$

Substituting the numberical value for I_{a1} given by equation (2) results in a numerical value for I_{an} of

$I_{an} = .718 \times 10 = 7.18$ amperes.

This is the value to read on the curve for the typical values chosen for the taps R_1, R_o, and T at the particular phase b to ground fault values indicated by equations (2) and (3). It should be noted that the total phase b current to the "near" relay is $I_b = I_{b1} + I_{b2} + I_{bo} = 29$ amperes, assuming $I_{b2} = I_{b1}$.

For a phase to phase fault, there is no zero sequence current, and the phase current, I_{LL}, is equal in magnitude to $\sqrt{3}\, I_{a1}$. Hence, for phase to phase faults, equation (1) reduces to:

$$I_{an} = \frac{2.35}{T} \left\{ .2 \frac{I_{LL}}{\sqrt{3}} R_1 \right\} \quad (8)$$

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude. That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (the .075 tap is actually marked .07 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of $R_1 = .10$ is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with $R_1 = .10$. Where the current transformers are different at the different terminals, select the value of R_1 which is proportional to the current transformer ratios. For example, assume a ratio of 300/5 at one terminal and 600/5 at another terminal. Set $R_1 = .075$ at the 300/5 terminal and $R_1 = .15$ at the 600/5 terminal. The ratios obtainable are 1/1, 2/1, 3/2, and 4/3. In the event that the ratio of the R_1 taps is not 1/1 it will be necessary to compensate for the unbalance by increasing the minimum trip calibration 25% above its normal value or by neutralizing the distributed capacitance of the pilot wire. The same procedure applies to three terminal lines.

Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12 and 15. This tap should be selected to assure operation on minimum internal line-to-line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line-to-line faults is given by the equation :

$$T = 5.7\, I_{LL}\, R_1 \quad (9)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

The factor "5.7" is used as the operation of the positive sequence filter is such that the relay requires 1.73 times as much current for operation on a line-to-line fault as on a three phase fault. This means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the

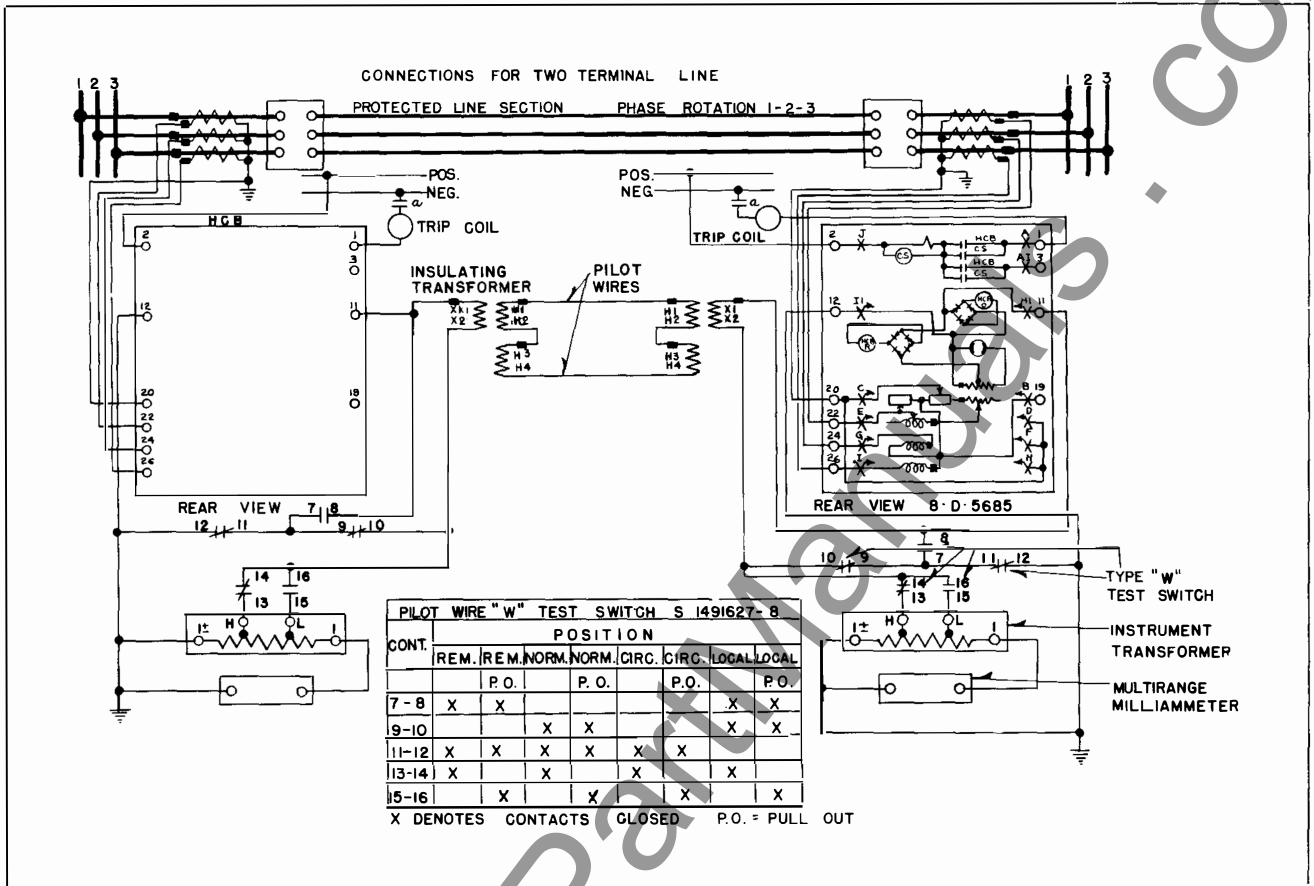


Fig. 10– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line.

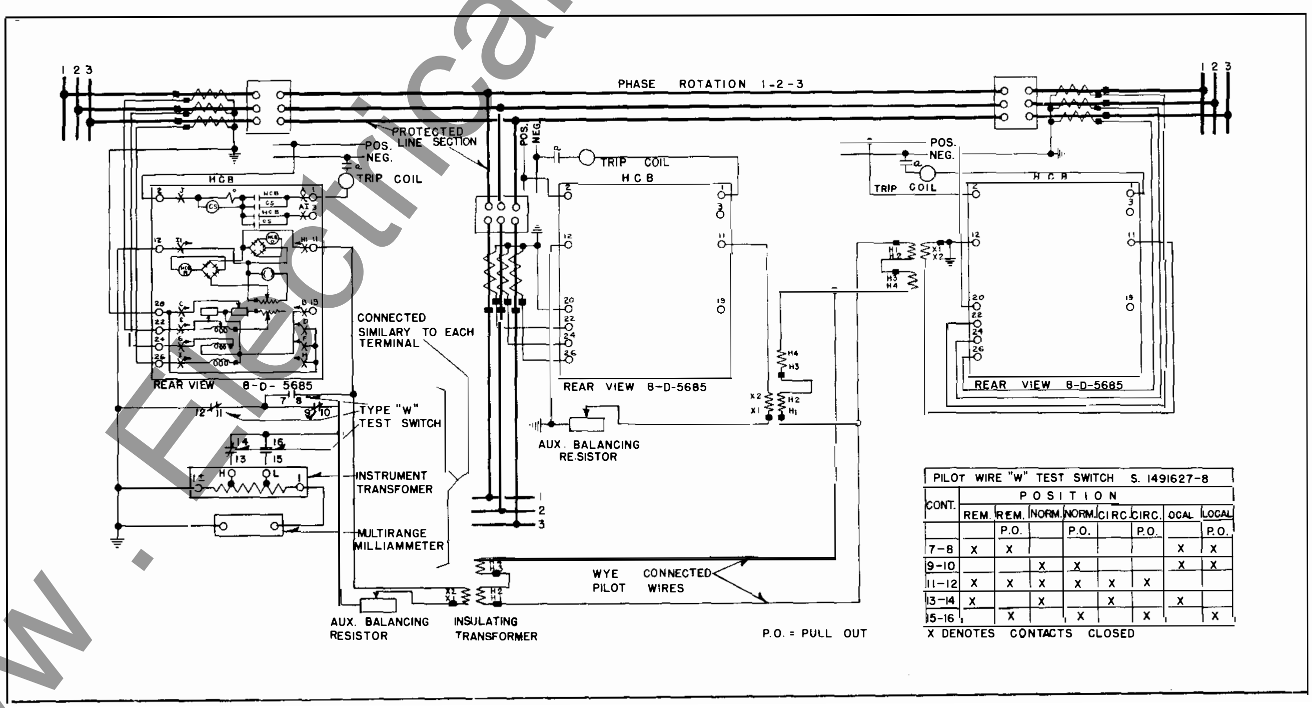
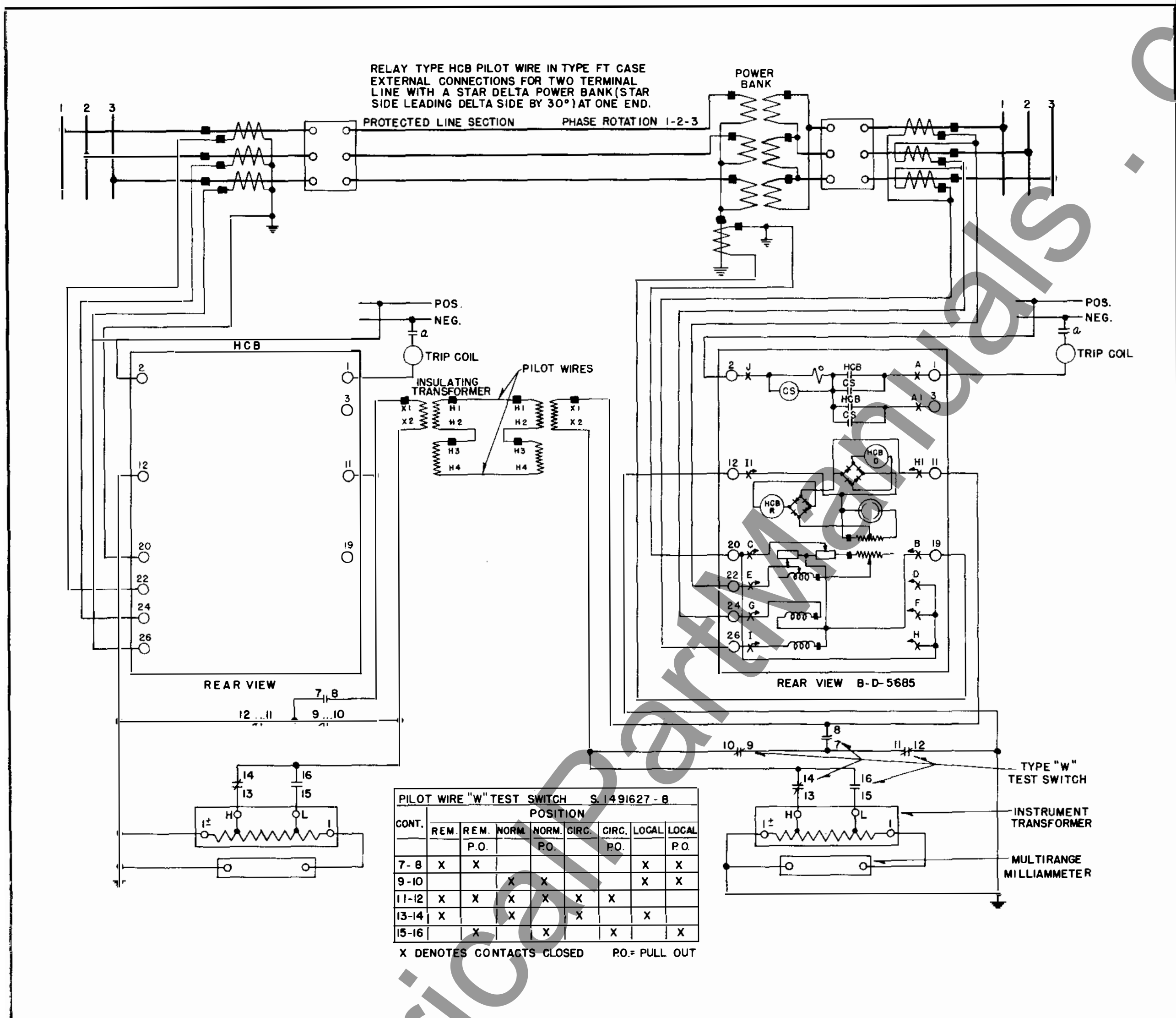


Fig. 11– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of A Three Terminal Line.



CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O.= PULL OUT

Fig. 12—External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line With a Transformer Bank.

numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T, must be divided by 0.1 thereby obtaining the factor "5.7".

Where line-to-line currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\ (.86)\ (I_{3\phi})\ R_1 \qquad (10)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

Equation (9) and (10) give the upper limit of "T" which must not be exceeded to obtain operation on the line-to-line faults. The actual setting should always be below the values obtained from equation (9) or (10). The minimum limits for this setting are discussed below.

The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10 R_1 I_{Load} \tag{11}$$

where "I_{Load}" is the maximum secondary full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (11) if the relay is not to operate on load current with the pilot wires open circuited.

This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents, or if supervisory relays are installed and connected to block the HCB on the occurrence of pilot wire failures. If supervisory relays are installed to block HCB operation under heavy load conditions with the pilot wires opened, it is necessary to introduce a time delay of approximately one cycle by interposing an auxiliary relay in the trip circuit at each terminal to allow the supervisory relays time to coordinate with the high speed of the HCB relay.

Note: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_0) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. (The first two taps are actually marked .02 and .03 because of space limitations). The three lowest taps are not used in applications where high sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_0 is set to equal to 1/3 R_1.

Maximum sensitivity to ground faults is obtained with R_0 = 1.6. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_0 should be selected which are most nearly proprotional to the transformer ratios. When the ratio of the R_0 taps can not be made to exactly match the ratio of the R_1 taps, pick the ratio to match as closely as possible, and use maximum restraint tap.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_0 = \frac{0.2T}{I_g} \tag{12}$$

where I_g is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals, and where "T" is the actual tap selected (not the value calculated from equation (9) or (10).

It is recommended that "R_0" be set as high above the value obtained from equation (12) as possible keeping the value of R_0 approximately proportional to the current transformer ratios.

Restraint Tap

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is normally shipped with the restraint tap link connected in the maximum restraint position. This link is in the upper left hand corner of the panel carrying the polar element. The link is connected to the left for minimum restraint, and to the right for maximum restraint. Maximum restraint should be used with pilot wires of 1500 to 2000 ohms.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on minimum

internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R_1 at station 2 = 0.075.

Positive Sequence Current Tap

From equation (9)

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissable setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (11).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75$$

or

$$T = \frac{10 \times 0.75 \times 300\ 5}{300} = 3.75$$

Select T at both stations = 6.

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation (12).

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6
And R_o at station 2 = 1.2

RELAYS IN TYPE FT CASE

The type FT cases are dust-proof enclosures combining relay elements and knife-blade test switches in the same case. This combination provides a compact flexible assembly easy to maintain, inspect, test and adjust. There are three main units of the type FT case: the case, cover and chassis. The case is an all welded steel housing containing the hinge half of the knife-blade test switches and the terminals for external connections. The cover is a drawn steel frame with a clear window which fits over the front of the case with the switches closed. The chassis is a frame that supports the relay elements and the contact jaw half of the test switches. This slides in and out of the case. The electrical connections between the base and chassis are completed through the closed knife-blades.

Removing Chassis

To remove the chassis, first remove the cover by unscrewing the captive nuts at the corners. This exposes the relay elements and all the test switches for inspection and testing. The next step is to open the test switches. Always open the elongated red handle switches first before any of the black handle switches or the cam action latches. This opens the trip circuit to prevent accidental trip out. Then open all the remaining switches. The order of opening the remaining switches is not important. In opening the test switches they should be moved all the way back against the stops. With all the switches fully opened, grasp the two cam action latch arms and pull outward. This releases the chassis from the case. Using the latch arms as handles, pull the chassis out of the case. The chassis can be set on a test bench in a normal upright position as well as on its top, back or sides for easy inspection, maintenance and test.

After removing the chassis a duplicate chassis may be inserted in the case or the blade portion of the switches can be closed and the cover put in place without the chassis. The chassis operated shorting switch located behind the short circuiting

test switch prevents open circuiting that circuit when the short circuiting type test switches are closed.

When the chassis is to be put back in the case, the above procedure is to be followed in the reversed order. The elongated red handle switch should not be closed until after the chassis has been latched in place and all of the black handle switches closed.

Electrical Circuits

Each terminal in the base connects thru a test switch to the relay elements in the chassis as shown on the internal schematic diagrams. The relay terminal is identified by numbers marked on both the inside and outside of the base. The test switch positions are identified by letters marked on the top and bottom surface of the moulded blocks. These letters can be seen when the chassis or removed from the case.

The potential and control circuits thru the relay are disconnected from the external circuit by opening the associated test switches. Opening the short circuiting test switch short-circuits that circuit and disconnects one side of the relay coil but leaves the other side of the coil connected to the external circuit thru the current test jack jaws. This circuit can be isolated by inserting the current test plug (without external connections) by inserting the ten circuit test plug, or by inserting a piece of insulating material approximately 1/32" thick into the current test jack jaws. Both switches of the current test switch pair must be open when using the current test plug or insulating material in this manner to short-circuit the current transformer secondary.

A cover operated switch can be supplied with its contacts wired in series with the trip circuit. This switch opens the trip circuit when the cover is removed. This switch can be added to the existing type FT cases at any time.

Testing

The relays can be tested in service, in the case but with the external circuits isolated or out of the case as follows:

Testing In Service

The ammeter test plug can be inserted in the current test jaws after opening the knife-blade switch to check the current thru the relay. This plug consists of two conducting strips separated by an insulating strip. The ammeter is connected to these strips by terminal screws and the leads are carried out thru holes in the back of the insulated handle.

Voltages between the potential circuits can be measured conveniently by clamping #2 clip leads on the projecting clip lead lug on the contact jaw.

Testing In Case

With all blades in the full open position, the ten circuit test plug can be inserted in the contact jaws. This connects the relay elements to a set of binding posts and completely isolates the relay circuits from the external connections by means of an insulating barrier on the plug. The external test circuits are connected to these binding posts. The plug is inserted in the bottom test jaws with the binding posts up and in the top test switch jaws with the binding posts down.

The external test circuits may be made to the relay elements by #2 test clip leads instead of the test plug. When connecting an external test circuit to the current elements using clip leads, care should be taken to see that the current test jack jaws are open so that the relay is completely isolated from the external circuits. Suggested means for isolating this circuit are outlined above, under "Electrical Circuits."

Testing Out of Case

With the chassis, removed from the base,

relay elements may be tested by using the ten circuit test plug or by #2 test clip leads as described above. The factory calibration is made with the chassis in the case and removing the chassis from the case will change the calibration values by a small percentage. It is recommended that the relay be checked in position as a final check on calibration.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs for the standard cases 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.

The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohm and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the contactor switch. This lead should be fastened (dead ended) under the small fillister-head screw located in the Micarta base of the contactor switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms.

ADJUSTMENTS AND MAINTENANCE

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if 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.

CAUTION 1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

Sequence Filter

There are no adjustments to be made in the zero sequence resistor. The taps on the R_1 resistor are adjustable, however, but this is a factory calibration which should not ordinarily be disturbed. To check the positive sequence current filter, pass a current I = 6.94 amperes through a pair of phase terminals, for example, in at phase B, out of phase C (see Figure 2) and measure the open circuit filter voltage with a high resistance voltmeter. This may be done by removing the positive sequence current tap screw, T, and connecting the voltmeter across the open circuit thus formed. The voltage should be $8R_1$ plus or minus 5% for each of the three phase-to-phase combinations, AB, BC, or CA. For example, at I = 6.94 amperes and R_1= .1, the voltage should be 0.8 volts.

Polar-Type Element

Contact Adjustment: Adjust the left-hand (front view) contacts until they just make a light circuit, when the armature rivet touches the left-hand pole face. Give both the left-hand contact screws two additional turns, and lock in position with the lock nuts provided. This moves the armature rivet away from the left-hand pole face and provides contact

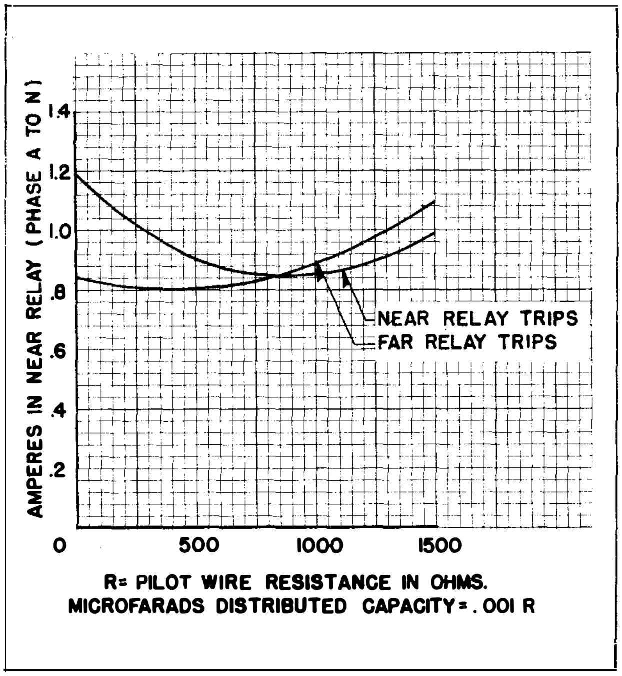


Fig. 13—Typical Curves Showing the Effect of Pilot Wires Resistance and Capacitance on Minimum Trip Current With Minimum Restraint.

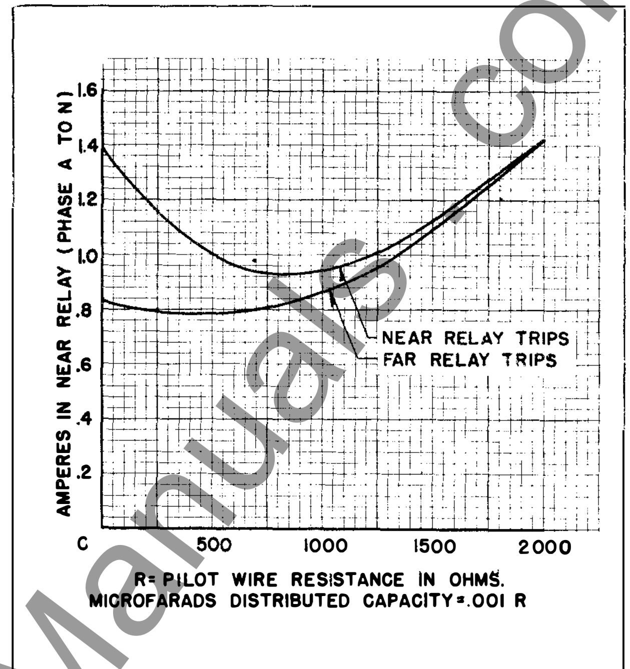


Fig. 14—Typical Curves Showing the Effect of Pilot Wire Resistance and Capacitance on Minimum Trip Current With Maximum Restraint.

follow. Now adjust the right-hand backstop screws until they just touch the moving contacts when the moving contacts are in the contact closing position as above. Back off each backstop screw two turns and lock in position.

Calibration: Connect the restraint tap link in the position in which it will be used. Connect the low voltage terminals of the insulating transformer across the pilot wire terminals of the relay. Connect the relay taps on T = 4, R_1 = .1, R_o = 1.6.

Screw in the left-hand magnetic shunt all the way. Adjust the right-hand magnetic shunt in or out, as required, until the relay just closes contacts at 6.9 to 7.0 amperes phase B to phase C current. When this adjustment has been made, change the input current connections to phase A to neutral. The relay should trip for phase A to neutral current between .45 and .55 amperes.

The above is given as a laboratory calibration on an individual relay with its insulating transformer. This does not take into consideration the characteristics of the pilot wire circuit between the relays.

Figures 13 and 14 show typical variations of minimum trip current for various lengths of pilot wire circuits up to the limiting values of 1500 ohms for relays operating on minimum restraint (Fig. 13) and 2000 ohms for relays operating on maximum restraint (Fig. 14).

For these curves, both relays are set on taps T = 4, R_1 = 0.1, R_o = 1.6. Each relay is originally calibrated to trip on a current of .47 amperes, phase A to neutral, with the high side of the insulating transformer open-circuited. This value of current is equivalent in the relay filter to 4 amperes positive sequence only, with the taps as specified above.

Restraining Coil: The effectiveness of the restraining coil of the relay element, and the performance of the Rectox units, may be checked as follows, if desired. Connect a variable non-inductive resistor across tthe high voltage terminals of the insulating transformer, and connect d-c milliammeters in series with the operating and restraining coils of the element, by opening these circuits at the test links provided for this purpose. These milliammeters should have low resistance, and should be capable of reading in the order of 20 to 25 ma. in the operating coil and 100 to 150 ma. in the restraining circuit. Using T = 4, R_1 = .1, R_0 = 1.6, pass 10 amperes 60 cycles from phase A to Neutral in the relay, and increase the variable resistance across the insulating transformer high voltage terminals until the relay just trips. This should be in the order of 1400 to 2000 ohms when maximum restraint is used. Read the d-c current (milliamperes) in the operating and restraining coils at this point. The values obtained should conform substantially to the following equations.

For Minimum Restraint

$$I_O = .12\ I_R + 8$$

For Maximum Restraint

$$I_O = .16\ I_R + 8$$

where I_O and I_R are operating and restraining coil currents, respectively, in milliamperes. The results are subject to slight variations between individual relays.

The polarity of the connections to the pilot wires, and the correct "Phasing out" of A, B, C phases at the two stations may be checked by the six tests outlined on Page 17.

Pilot Wire Current

The pilot wire current which should flow under normal load conditions is given in Figures [illegible] and 5. If the relay taps in use differ from those indicated in these figures, suitable conversion factors must be used. The pilot wire current will vary inversely with T and directly with R_1.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down or by disconnecting the switch and turning it up-side-down. Then screw up the core screw until the moving core starts rotating. Now, back off the core screw until the moving core stops rotating. This indicates the points where the play in the assembly is taken up, and where the moving core just separates from the stationary core screw. 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c have been passed through the coil.

Operation Indicator

Adjust the indicator to operate at 0.2 ampere d-c gradually applied by loosening the two screws on the under side of the assembly, and moving the bracket forward or backward. If the two helical springs which reset the armature are replaced by new springs, they should be weakened slightly by stretching to obtain the 0.2 ampere calibration. The coil resistance is approximately 2.8 ohms.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three - phase current of 5 amperes:

For tap 4 R_1 = .075 and R_O = .39

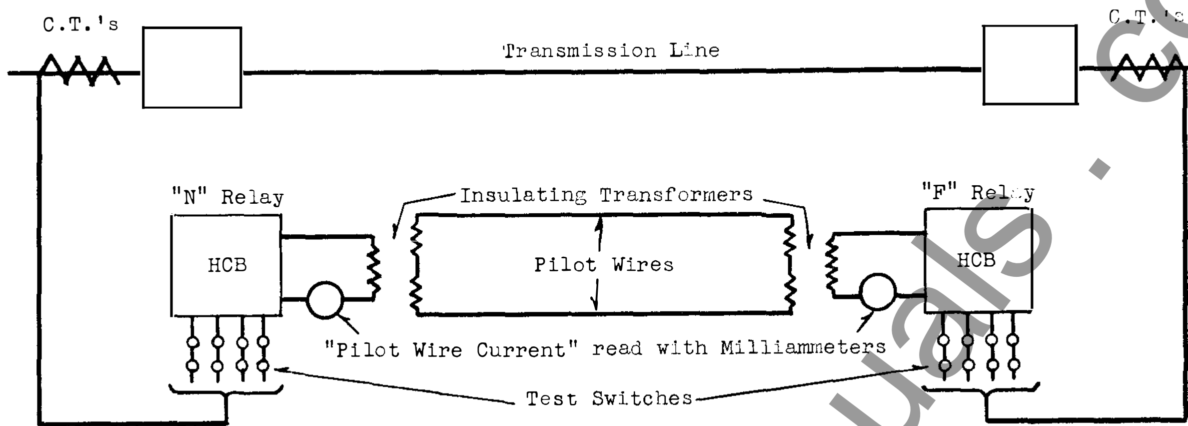
Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_O = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.



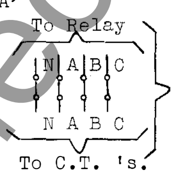
Note: The line should be carrying through load current amounting to at least 1.5 amperes as measured in the secondary of the Current Transformers. This test is based on the ratio of the C.T.'s being the same at each end of the line, in which case set the taps of both relays to $R_1 = .1$; $R_0 = 1.6$; T = 4 for this test.

	RELAY "N"					RELAY "F"				
Test No.	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay F	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay N
1		A,B,C,N	No	(1)	(1)		A,B,C,N	No	(1)	(1)
2		A,C,B,N	No	(2)	(2)		A,C,B,N	No	(2)	(2)
3		A,N	Yes	(3)	(0)		0	Yes	(3)	(3) (4)
4		0	Yes	(3)	(3) (4)		A,N	Yes	(3)	(0)
5		A,N	No	(3)	(3)		A,N	No	(3)	(3)
6		A,N	Yes	(6)			B,C,N	Yes	(6)	

REMARKS

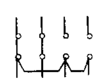
Tests 1 and 2 are to check normal positive sequence rotation of phases. The test switch connections of test #2 may be made readily with relays in the Flexitest case by using clip leads and insulating barriers in the ammeter test jacks. However, care should be used to avoid accidentally open-circuiting the current transformer circuits.
Tests 3 and 4 simulate internal Phase A to Ground fault with single end feed.
Test 5 simulates an external Phase A to Ground fault. (5)
Test 6 simulates an internal Phase A to Ground fault, with equal feed from the two ends, since $I_B + I_C = -I_A$, with balanced load.

LEGEND OF TEST SWITCH SYMBOLS:



Normal Connection. All Currents to Relay.

EXAMPLE



Phase A current from C.T.'s to Relay. Phase B and C C.T.'s shorted to neutral.

(1) The "pilot wire current" will vary depending upon the magnitude of the through load current and the characteristics of the pilot wire. See Figures 4 and 5.
(2) Since the relay is temporarily connected for negative sequence, it should have practically zero output in this test.
(3) These readings may be "off scale" depending upon the magnitude of the load current.
(4) The relay at this station should reset when the "far" current is being read because the local relay will be receiving no current from either the pilot wire or the current transformers.
(5) Test 4 and 5 can be repeated using phase B to neutral current, and again with phase C to neutral current, but this is not strictly necessary on the basis that, having proved the phase sequence with tests 1 and 2, and having proved the correspondence of phase A at the two ends of the line with test 5, then phases B and C must be correct.
(6) Some pilot wire current will be read, depending upon the magnitude of the distributed capacity of the pilot wire in combination with the magnetizing impedance of the insulating transformer.

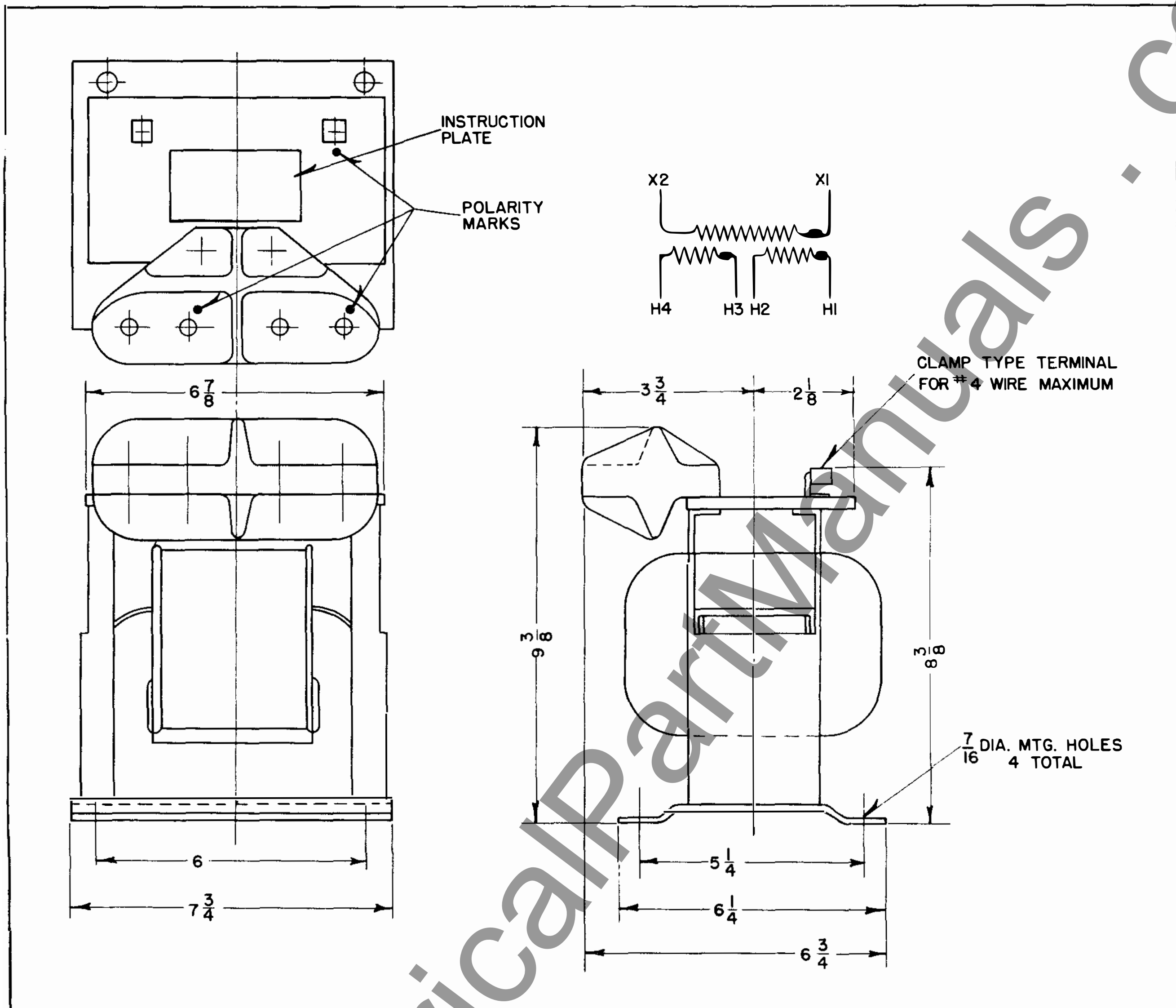


Fig. 15—Outline and Drilling Plan of the Insulating Transformer. For Reference Only.

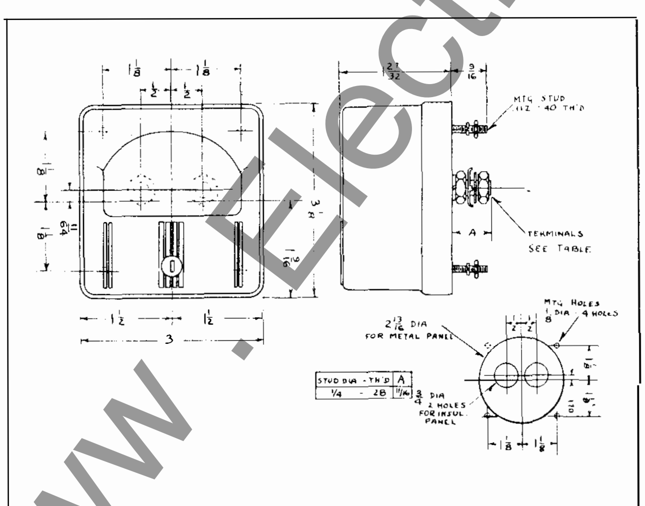


Fig. 16—Outline and Drilling Plan of the Projection Type Test Milliammeter. For Reference Only.

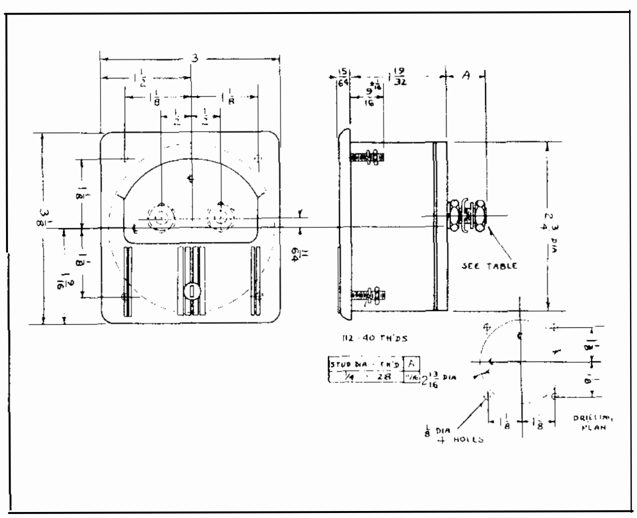


Fig. 17—Outline and Drilling Plan of the Semi-flush Type Test Milliammeter. For Reference Only.

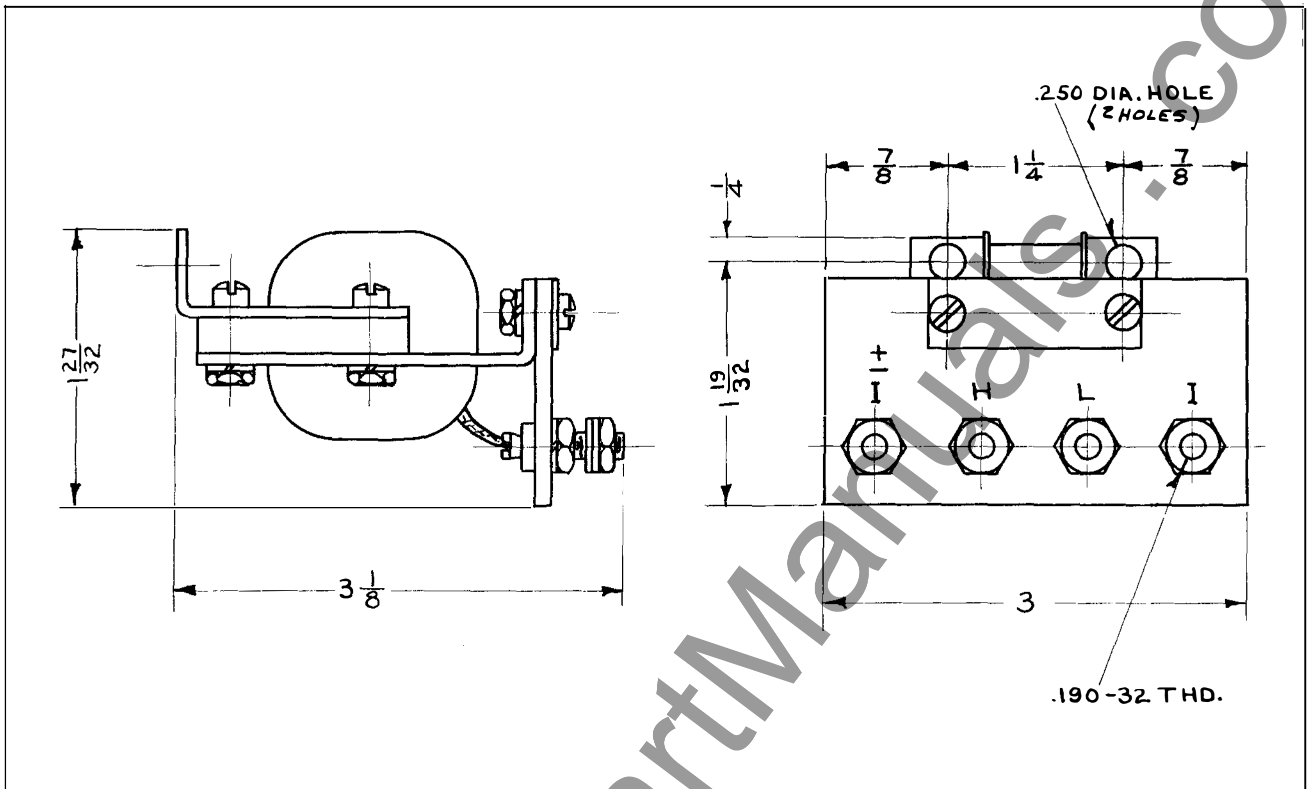
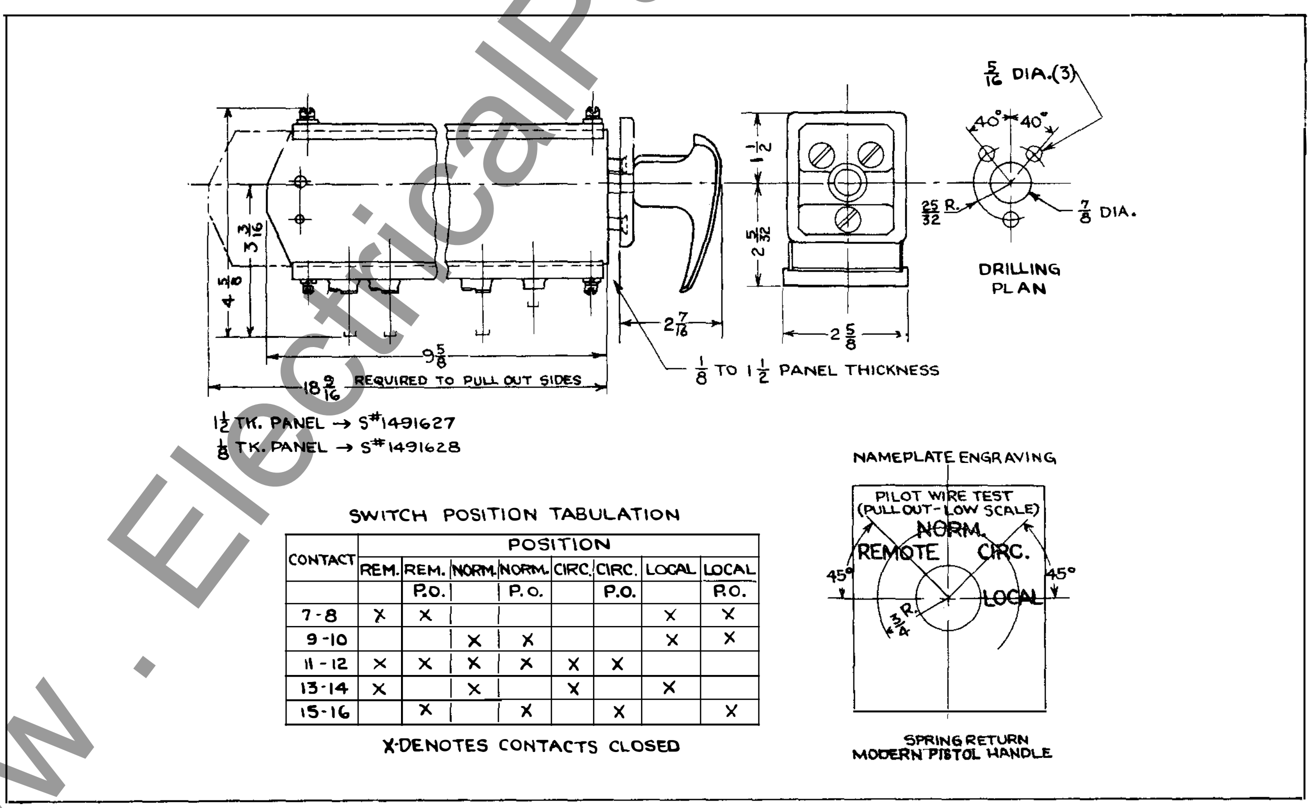


Fig. 18—Outline of the Test Milliammeter Auxiliary Transformer. For Reference Only.



SWITCH POSITION TABULATION

CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X-DENOTES CONTACTS CLOSED

Fig. 19—Outline and Drilling Plan of the Type W Test Switch. For Reference Only.

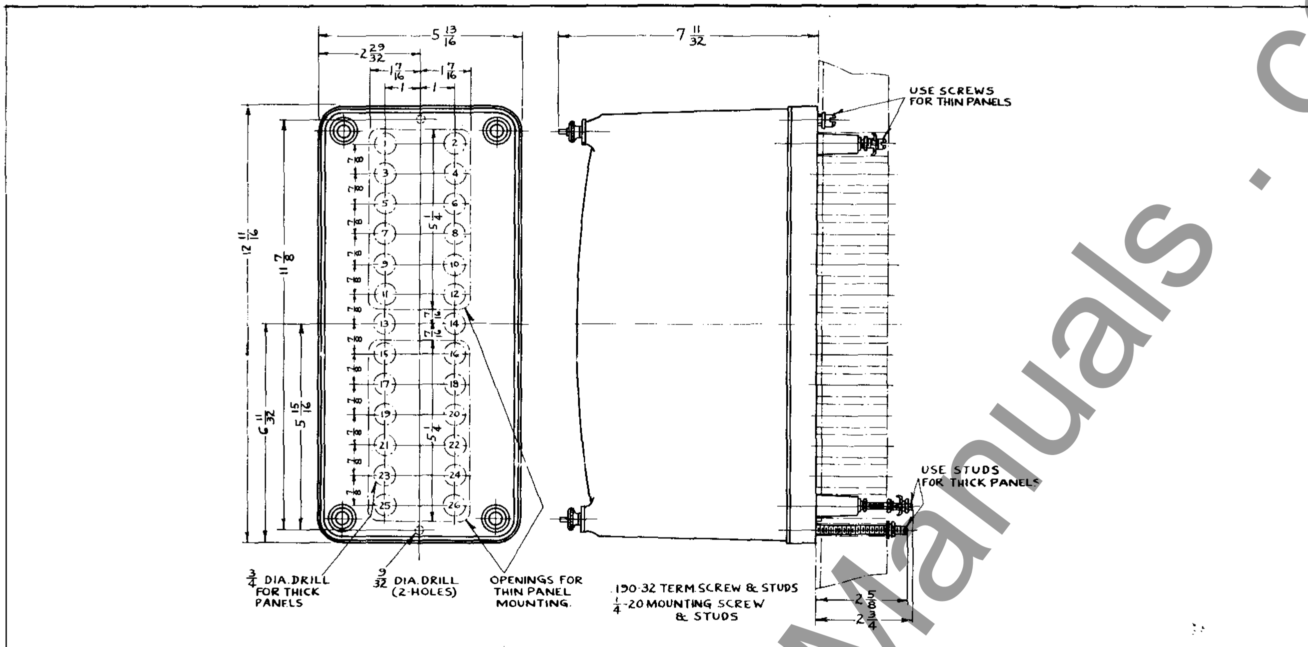


Fig. 20– Outline and Drilling Plan For the Projection Type Standard Case. See the Internal Schematics For The Terminals Supplied. For Reference Only.

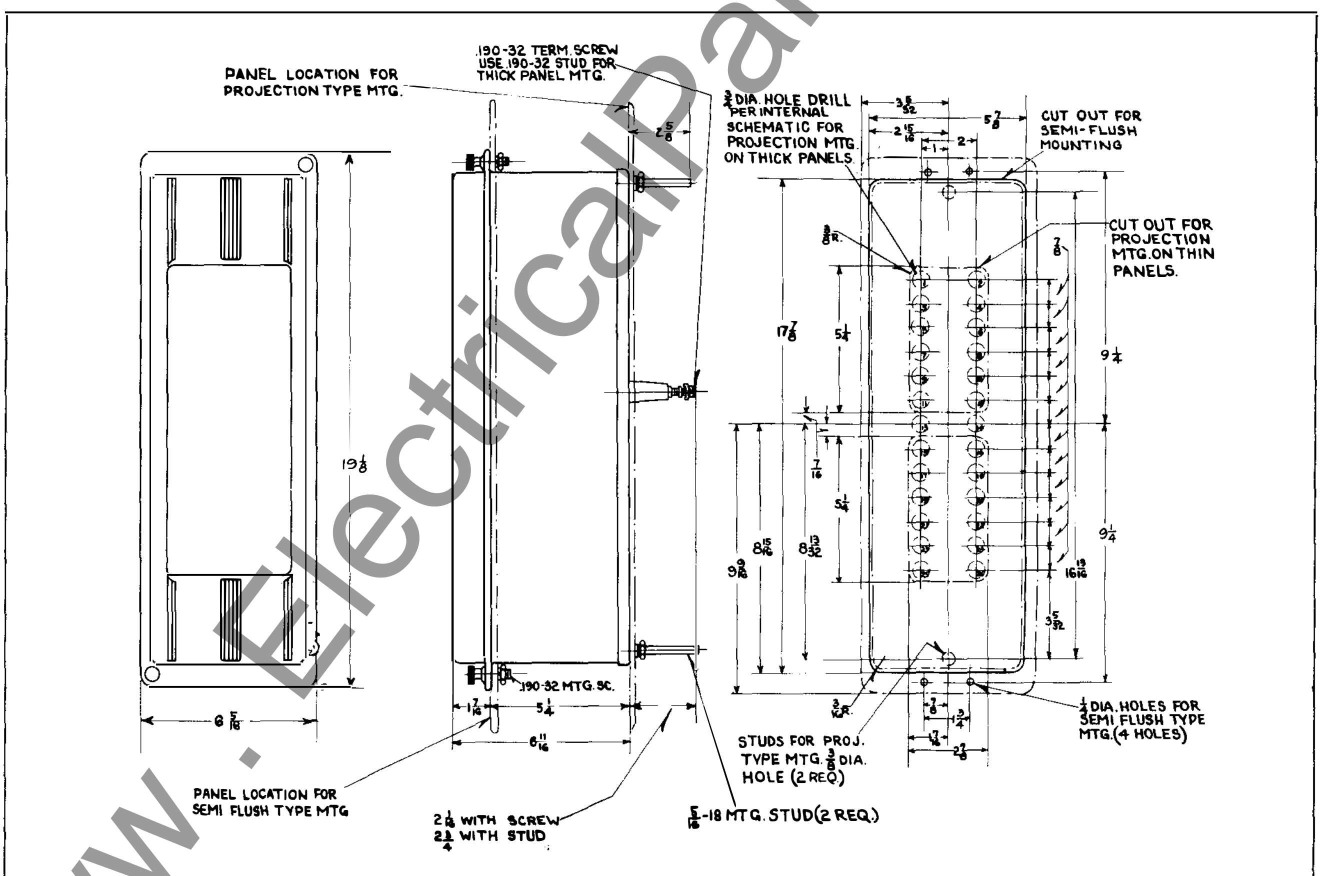


Fig. 21--Outline and Drilling Plan for the M-20 Projection or Semi-Flush Type FT Case. See the Internal Schematic for the Terminals Supplied. For Reference Only.

WESTINGHOUSE ELECTRIC CORPORATION

METER DIVISION **NEWARK, N.J.**

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HCB PILOT WIRE RELAY

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line, three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the out-put of the saturating transformer, and is marked in amperes required to operate the relay when the

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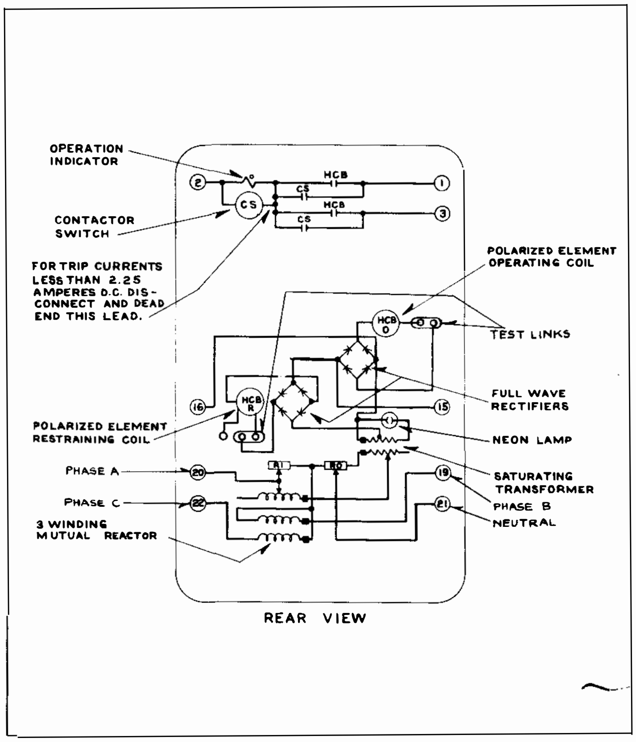


Fig. 1—Internal Schematic of the Type HCB Relay in the Standard Case.

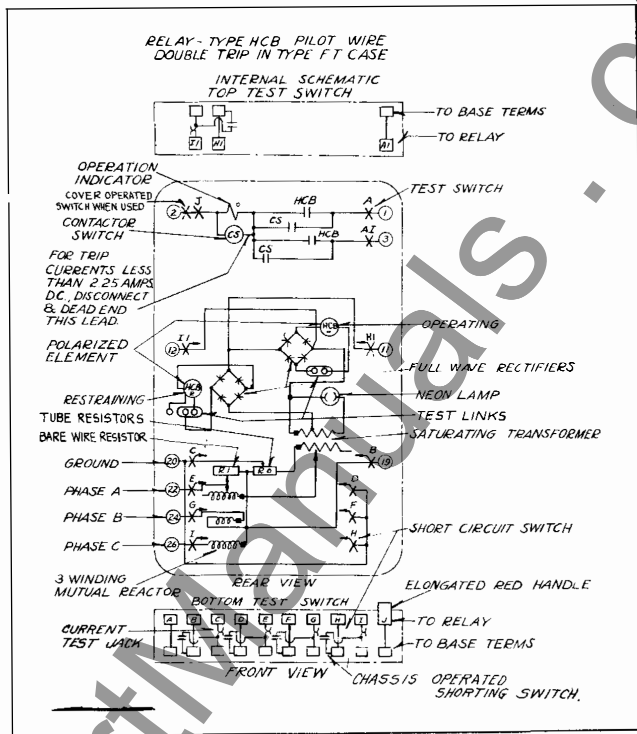


Fig. 2—Internal Schematic of the Type HCB Relay in the Type FT Case.

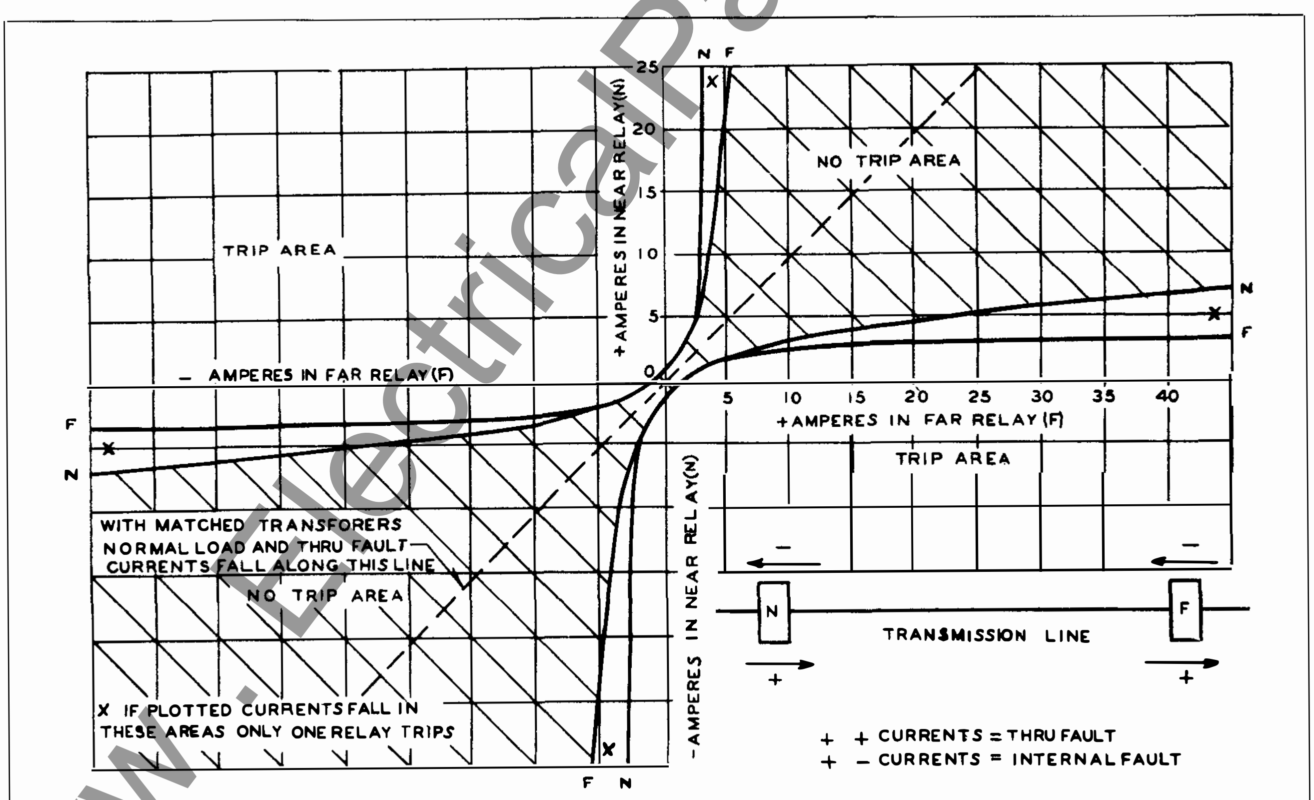


Fig. 3—Typical Operating Characteristics on Phase A to Ground Faults With Currents Thru the Two Terminals 30° Out of Phase. Maximum Restraint With Insulating Transformers and 2000 Ohm Pilot Wires. Taps T = 4, R_1 = .1, R_0 = 1.6.

pilot wire is open or when equal amounts of currents are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in Figure 9. The rectox units are used to convert the a-c output of the saturating transformer to d-c for use on the d-c polar-type relay element. The use of a sensitive polar-type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnetic bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating winding produces a magnetic field which acts to move the armature in the contact closing direction. The restraining winding is tapped and the leads are brought out to taps at the upper left of the relay. The left hand position of the test link is the minimum restraint connection, and the right hand position is the maximum restraint connection.

The moving contacts are fastened on the free end of the leaf spring. Two stationary contact screws are mounted to the left (front view) of the moving contact assembly and are adjusted for normally open contacts.

Insulating Transformer

The insulating transformer is connected as shown in Figure 9 and serves to isolate the terminal equipment from the pilot wire. This avoids interconnection of station grounds that may have large differences of potentials between them. The mid-taps of the parallel-wound secondary windings are brought out separately to provide a means of connecting supervisory relays symmetrically within the pilot wire circuit. When auxiliary supervisory relays are not used, these mid-taps are to be connected together and may be grounded to drain the voltages induced along the length of the pilot wires when these voltages approach the voltage limit of the cable. This is discussed further under Pilot Wire below.

The transformers have a 4/1 ratio and are insulated for 5000 volts.

Pilot Wire

One pair of pilot wires connecting the secondaries of the insulating transformers is required to provide a continuous circuit between the relays. For the pilot wires a lead-covered twisted pair of No. 19 wire or larger is recommended, however, open wires may be used. The following points should be considered in selecting pilot wire circuits.

1. The total circuit resistance (including neutralizing reactors when used) between terminals of the Type HCB relays exclusive of the insulating transformers and expressed in terms of the pilot wire voltage must not exceed 2000 ohms for two terminal lines (500 ohms per wye branch for three terminal lines).

2. The shunt capacity between pilot wires should not exceed 0.75 microfarad per pilot wire terminal for two terminal lines (0.60 mfd. per leg. for three terminal lines). In cases where this value is exceeded, compensating reactors will be required to reduce the

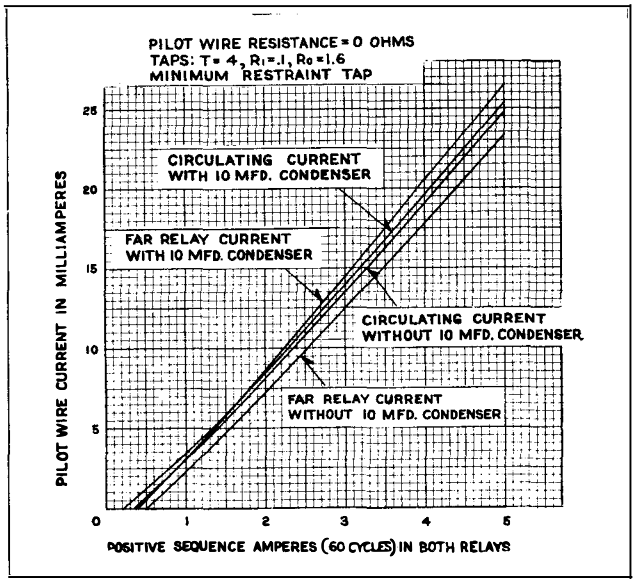


Fig. 4—Typical Test Output Vs. Input Relay Current in A Two Terminal Line With Zero Pilot Wire Resistance.

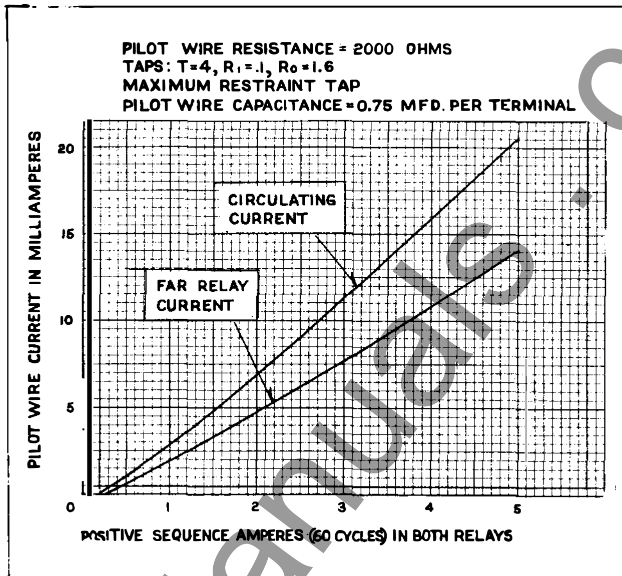


Fig. 5—Typical Test Output Vs. Input Relay Current In A Two Terminal Line With 2000 Ohm Pilot Wire Resistance With or Without the 10 MFD. Condenser.

shunt currents which tend to desensitize the relay.

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. However, the voltage between pilot wires must not exceed 15 volts.

b. For more serious induction two winding neutralizing reactors can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing reactors should be used. Reactors are available for 1000 and 2000 volt neutralization.

c. Another method consists of connecting a suitable two winding drainage reactor and a protector tube, such as the type KX642, to the pilot wires at suitable points. The arrangement is such that when the tube flashes because of high extraneous voltages, both wires are connected to ground, through the reactor and the tube. The impedance to ground is low, but the impedance between wires is kept high to avoid interfering with the operation of the HCB relays.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in Figure 9. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault current fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay. However, if the short circuit on the pilot wire is so placed that it is 1000 or more pilot wire ohms from one of the two relays, then that relay will not be blocked.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted wire pilot mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by continuously-operated supervisory relays supplied as extra equipment.

The condition of the pilot wire under normal load conditions may be determined by reading the pilot wire current by means of the test switch and milliammeter.

A comparison of the readings obtained with the typical values of Figures 4 & 5 will indicate the condition of the pilot wire. It should be noted that, when the far relay current is being read, the near relay is short circuited, and the far relay is shunted by the resistance of the pilot wires plus the impedance of the near relay insulating transformers.

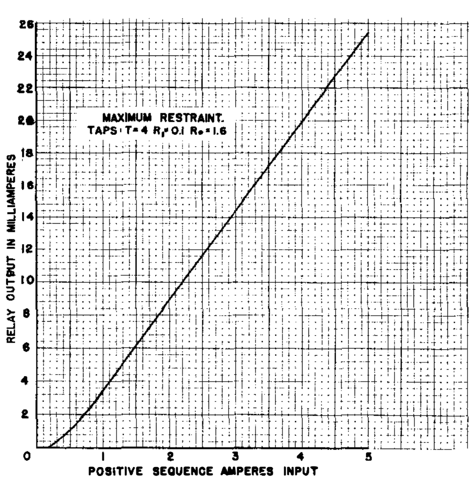


Fig. 6—Typical Curve of Relay Output vs. Positive Sequence Amperes Input.

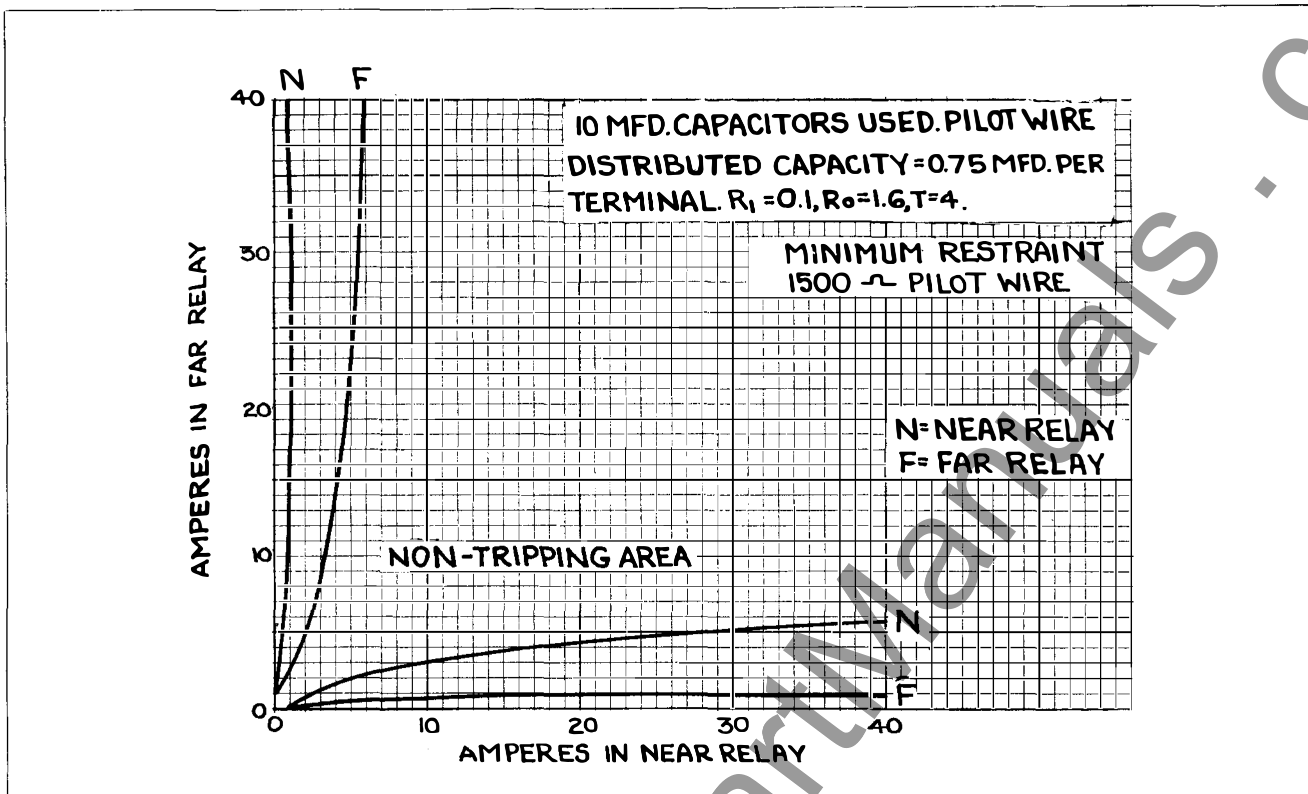


Fig. 7—Typical Operating Characteristics On Phase A to Ground Faults With Currents In Phase and 1500 Ohm Pilot Wire.

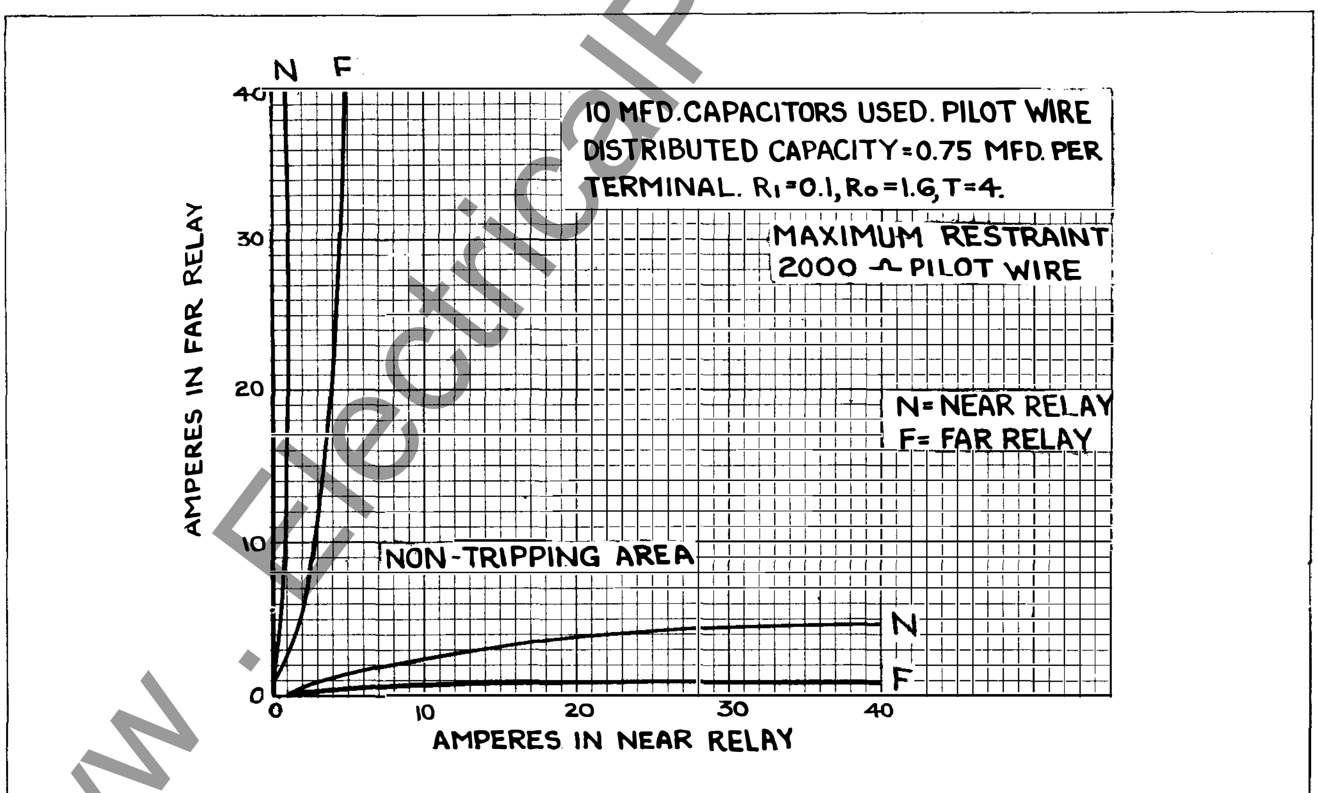
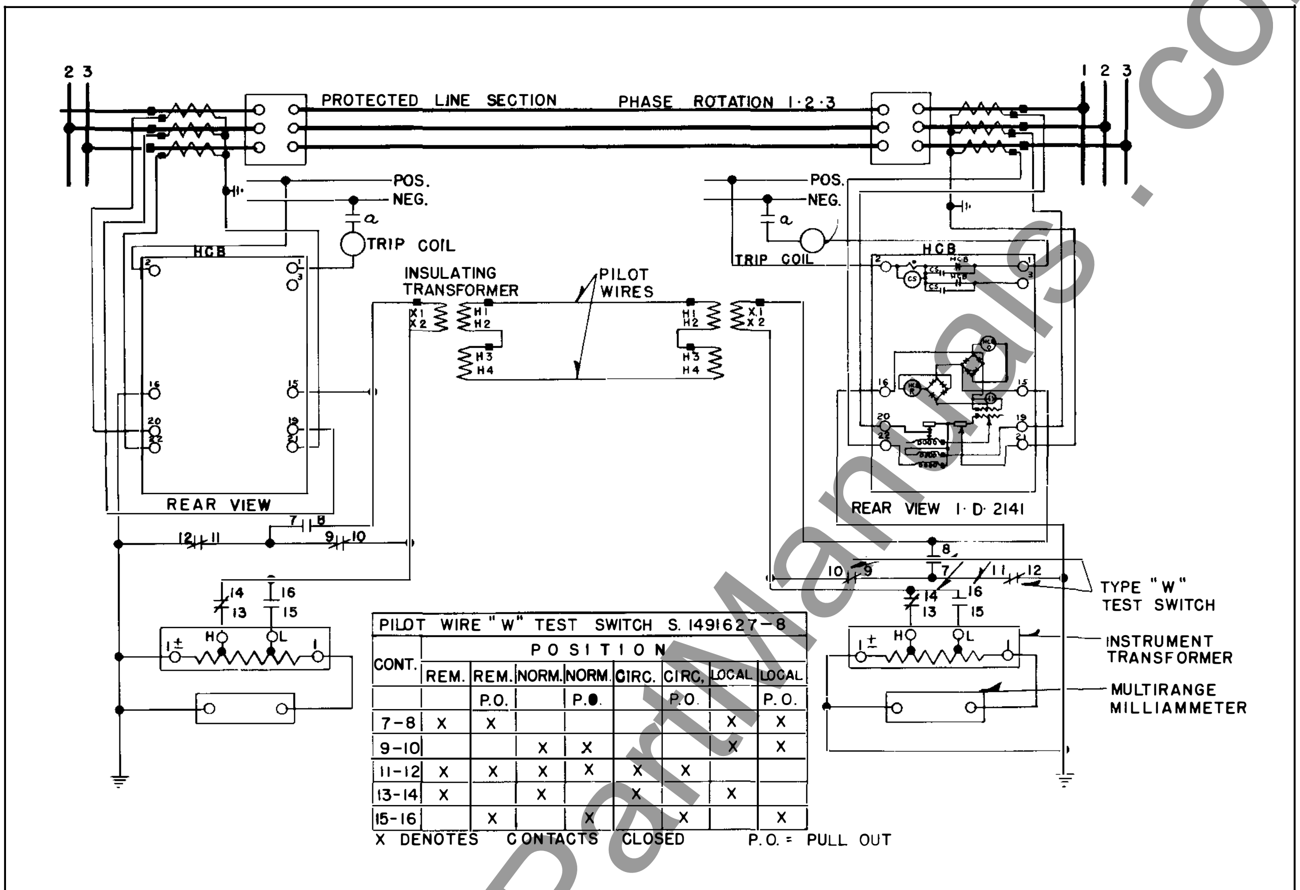


Fig. 8—Typical Operating Characteristics On Phase A to Ground Faults With Currents in Phase and 2000 Ohm Pilot Wire.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 9—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Two Terminal Line.

Figure 6 shows typical values for relay output current vs. positive sequence input current. For this test, the insulating transformer is short circuited on the low voltage side so that the milliammeter is connected directly across the relay output terminals.

CHARACTERISTICS

Typical overall operating characteristics of the relay are illustrated in Figures 7 and 8. The general shape of these curves is similar for other types of faults, relay settings, and pilot wire lengths. The ampere abscissa and ordinate scales may be interpolated to show the operating characteristics for other conditions and tap settings by the use of the following equation:

$$I_{an} = \frac{2.35}{T}\left\{2\mathring{I}_{a1}R_1 + \mathring{I}_{ao}(R_1 + 3R_o)\right\} \quad (1)$$

where I_{an} is the value to read on the curve (Figures 7 and 8).

For example, assume relay tap settings of $T = 6$, $R_1 = .1$, $R_o = .68$, and also assume that a phase b to ground fault occurs, for which the "near" relay components are as follows:

$$\dot{I}_{a1} = 10 + jo \quad (2)$$

$$\dot{I}_{ao} = .9a^2(I_{a1}) \quad (3)$$

In equation (3), the factor .9 was arbitrarily used as a reminder that the distribution factors for positive and zero sequence components are not necessarily equal for any given system. Also, the operator a^2 signifies that I_{ao} is 240° leading I_{a1} for a phase b to ground fault, neglecting dissimilarities in the sequence networks. First substituting the particular condition of equation (3) in equation (1) gives

$$I_{an} = \frac{2.35}{T} I_{a1}\left\{2R_1 + .9a^2(R_1 + 3R_o)\right\} \quad (4)$$

Substituting values for the several taps in (4) gives

$$I_{an} = \frac{2.35}{6} \dot{I}_{a1} \begin{Bmatrix} 2 \times .1 + .9 \ (-.5 - j.866) \\ (.1 + 3 \times .68) \end{Bmatrix} \quad (5)$$

$$I_{an} = .392 \ \dot{I}_{a1} \left\{ -.763 - j1.67 \right\} \quad (6)$$

$$I_{an} = \mathring{I}_{a1} \ .718 \ \underline{|245.4°} \quad (7)$$

Substituting the numberical value for I_{a1} given by equation (2) results in a numerical value for I_{an} of

$I_{an} = .718 \times 10 = 7.18$ amperes.

This is the value to read on the curve for the typical values chosen for the taps R_1, R_o, and T at the particular phase b to ground fault values indicated by equations (2) and (3). It should be noted that the total phase b current to the "near" relay is $I_b = I_{b1} + I_{b2} + I_{bo} = 29$ amperes, assuming $I_{b2} = I_{b1}$.

For a phase to phase fault, there is no zero sequence current, and the phase current, I_{LL}, is equal in magnitude to $\sqrt{3}\ I_{a1}$. Hence, for phase to phase faults, equation (1) reduces to:

$$I_{an} = \frac{2.35}{T} \left\{ 2 \frac{I_{LL}}{\sqrt{3}} R_1 \right\} \quad (8)$$

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude. That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (the .075 tap is actually marked .07 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of $R_1 = .10$ is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with $R_1 = .10$. Where the current transformers are different at the different terminals, select the value of R_1 which is proportional to the current transformer ratios. For example, assume a ratio of 300/5 at one terminal and 600/5 at another terminal. Set $R_1 = .075$ at the 300/5 terminal and $R_1 = .15$ at the 600/5 terminal. The ratios obtainable are 1/1, 2/1, 3/2, and 4/3. In the event that the ratio of the R_1 taps is not 1/1 it will be necessary to compensate for the unbalance by increasing the minimum trip calibration 25% above its normal value or by neutralizing the distributed capacitance of the pilot wire. The same procedure applies to three terminal lines.

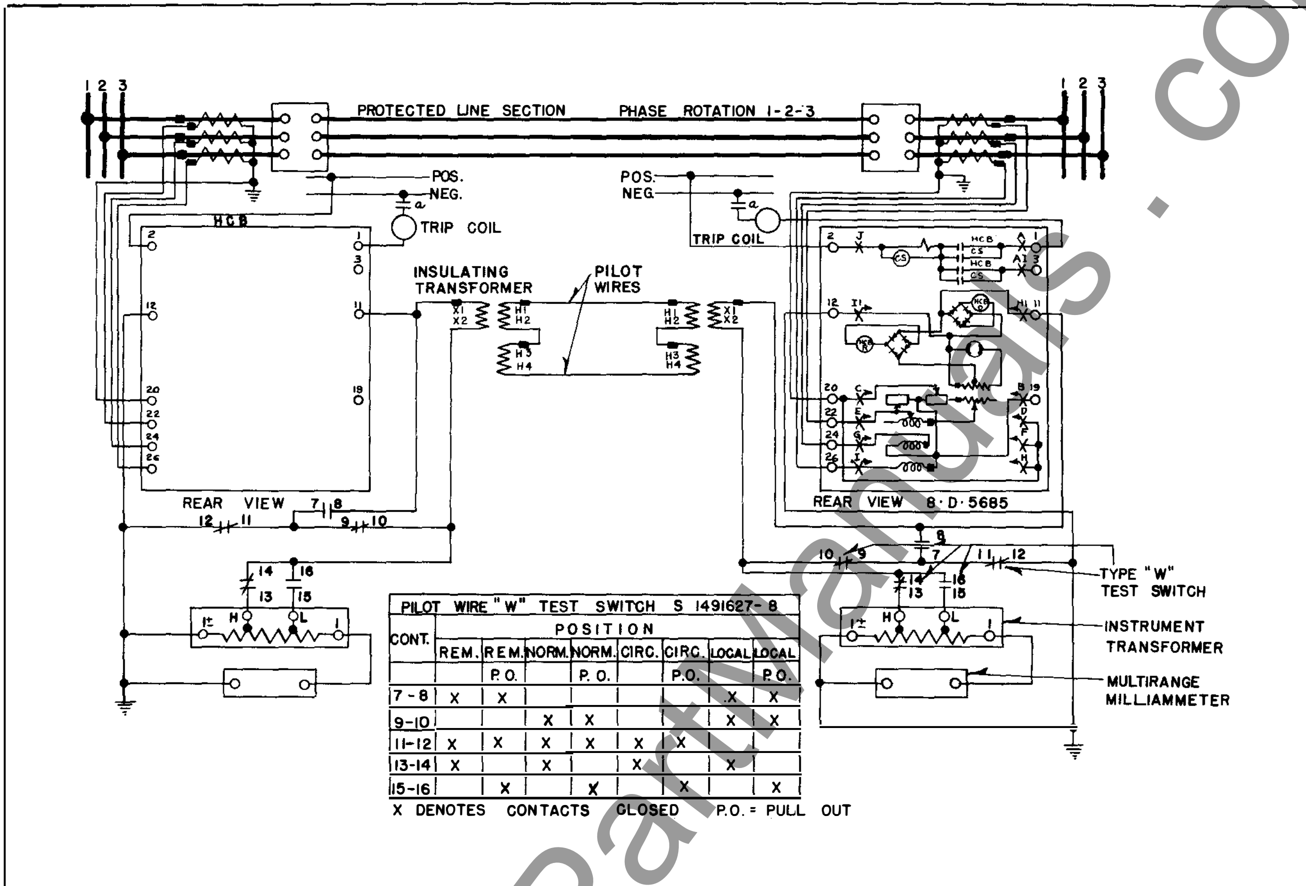
Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12 and 15. This tap should be selected to assure operation on minimum internal line-to-line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line-to-line faults is given by the equation :

$$T = 5.7 \ I_{LL} \ R_1 \quad (9)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

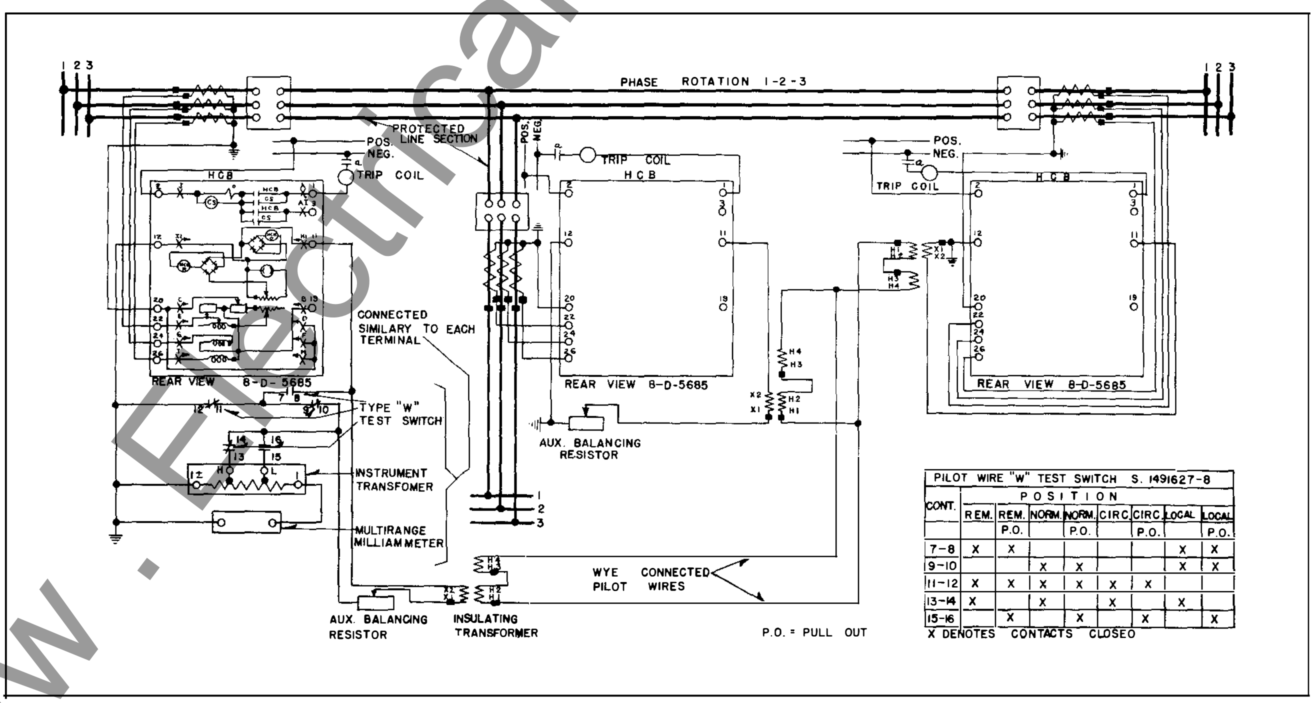
The factor "5.7" is used as the operation of the positive sequence filter is such that the relay requires 1.73 times as much current for operation on a line-to-line fault as on a three phase fault. This means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the



PILOT WIRE "W" TEST SWITCH S 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

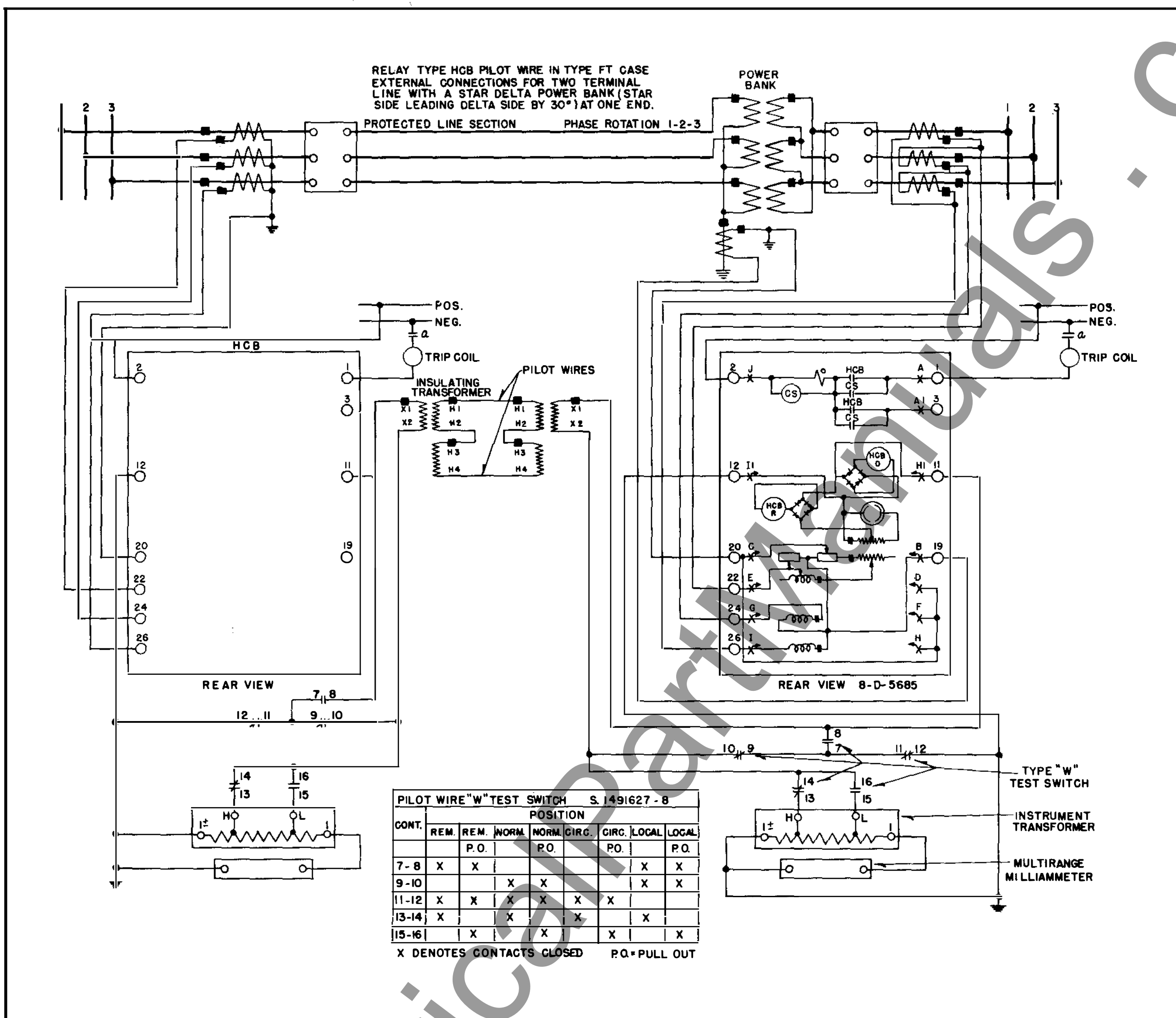
Fig. 10– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSEO

Fig. 11–External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of A Three Terminal Line.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM.	NORM.	NORM.	CIRC.	CIRC.	LOCAL	LOCAL
		P.O.		P.O.		P.O.		P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 12—External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line With a Transformer Bank.

numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T, must be divided by 0.1 thereby obtaining the factor "5.7".

Where line-to-line currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\ (.86)\ (I_{3\phi})\ R_1 \qquad (10)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

Equation (9) and (10) give the upper limit of "T" which must not be exceeded to obtain operation on the line-to-line faults. The actual setting should always be below the values obtained from equation (9) or (10). The minimum limits for this setting are discussed below.

The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10\ R_1 . I_{Load} \qquad (11)$$

where "I_{Load}" is the maximum secondary full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (11) if the relay is not to operate on load current with the pilot wires open circuited.

This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents,

Note: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_o) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. (The first two taps are actually marked .02 and .03 because of space limitations). The three lowest taps are not used in applications where high sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_o is set to equal to 1/3 R_1

Maximum sensitivity to ground faults is obtained with R_o = 1.6. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_o should be selected which are most nearly proprotional to the transformer ratios. When the ratio of the R_o taps can not be made to exactly match the ratio of the R_1 taps, pick the ratio to match as closely as possible, and use maximum restraint tap.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_o = \frac{0.2T}{I_g} \qquad (12)$$

where I_g is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals, and where "T" is the actual tap selected (not the value calculated from equation (9) or (10).

It is recommended that "R_o" be set as high above the value obtained from equation (12) as possible keeping the value of R_o approximately proportional to the current transformer ratios.

Restraint Tap

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is normally shipped with the restraint tap link connected in the maximum restraint position. This link is in the upper left hand corner of the panel carrying the polar element. The link is connected to the left for minimum restraint, and to the right for maximum restraint. Maximum restraint should be used with pilot wires of 1500 to 2000 ohms.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on minimum

internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R_1 at station 2 = 0.075.

Positive Sequence Current Tap

From equation (9)

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissable setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (11).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75$$

or

$$T = \frac{10 \times 0.75 \times 300\ 5}{300} = 3.75$$

Select T at both stations = 6.

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation (12).

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6

And R_o at station 2 = 1.2

RELAYS IN TYPE FT CASE

The type FT cases are dust-proof enclosures combining relay elements and knife-blade test switches in the same case. This combination provides a compact flexible assembly easy to maintain, inspect, test and adjust. There are three main units of the type FT case: the case, cover and chassis. The case is an all welded steel housing containing the hinge half of the knife-blade test switches and the terminals for external connections. The cover is a drawn steel frame with a clear window which fits over the front of the case with the switches closed. The chassis is a frame that supports the relay elements and the contact jaw half of the test switches. This slides in and out of the case. The electrical connections between the base and chassis are completed through the closed knife-blades.

Removing Chassis

To remove the chassis, first remove the cover by unscrewing the captive nuts at the corners. This exposes the relay elements and all the test switches for inspection and testing. The next step is to open the test switches. Always open the elongated red handle switches first before any of the black handle switches or the cam action latches. This opens the trip circuit to prevent accidental trip out. Then open all the remaining switches. The order of opening the remaining switches is not important. In opening the test switches they should be moved all the way back against the stops. With all the switches fully opened, grasp the two cam action latch arms and pull outward. This releases the chassis from the case. Using the latch arms as handles, pull the chassis out of the case. The chassis can be set on a test bench in a normal upright position as well as on its top, back or sides for easy inspection, maintenance and test.

After removing the chassis a duplicate chassis may be inserted in the case or the blade portion of the switches can be closed and the cover put in place without the chassis. The chassis operated shorting switch located behind the short circuiting

test switch prevents open circuiting that circuit when the short circuiting type test switches are closed.

When the chassis is to be put back in the case, the above procedure is to be followed in the reversed order. The elongated red handle switch should not be closed until after the chassis has been latched in place and all of the black handle switches closed.

Electrical Circuits

Each terminal in the base connects thru a test switch to the relay elements in the chassis as shown on the internal schematic diagrams. The relay terminal is identified by numbers marked on both the inside and outside of the base. The test switch positions are identified by letters marked on the top and bottom surface of the moulded blocks. These letters can be seen when the chassis or removed from the case.

The potential and control circuits thru the relay are disconnected from the external circuit by opening the associated test switches. Opening the short circuiting test switch short-circuits that circuit and disconnects one side of the relay coil but leaves the other side of the coil connected to the external circuit thru the current test jack jaws. This circuit can be isolated by inserting the current test plug (without external connections) by inserting the ten circuit test plug, or by inserting a piece of insulating material approximately 1/32" thick into the current test jack jaws. Both switches of the current test switch pair must be open when using the current test plug or insulating material in this manner to short-circuit the current transformer secondary.

A cover operated switch can be supplied with its contacts wired in series with the trip circuit. This switch opens the trip circuit when the cover is removed. This switch can be added to the existing type FT cases at any time.

Testing

The relays can be tested in service, in the case but with the external circuits isolated or out of the case as follows:

Testing In Service

The ammeter test plug can be inserted in the current test jaws after opening the knife-blade switch to check the current thru the relay. This plug consists of two conducting strips separated by an insulating strip. The ammeter is connected to these strips by terminal screws and the leads are carried out thru holes in the back of the insulated handle.

Voltages between the potential circuits can be measured conveniently by clamping #2 clip leads on the projecting clip lead lug on the contact jaw.

Testing In Case

With all blades in the full open position, the ten circuit test plug can be inserted in the contact jaws. This connects the relay elements to a set of binding posts and completely isolates the relay circuits from the external connections by means of an insulating barrier on the plug. The external test circuits are connected to these binding posts. The plug is inserted in the bottom test jaws with the binding posts up and in the top test switch jaws with the binding posts down.

The external test circuits may be made to the relay elements by #2 test clip leads instead of the test plug. When connecting an external test circuit to the current elements using clip leads, care should be taken to see that the current test jack jaws are open so that the relay is completely isolated from the external circuits. Suggested means for isolating this circuit are outlined above, under "Electrical Circuits."

Testing Out of Case

With the chassis, removed from the base,

relay elements may be tested by using the ten circuit test plug or by #2 test clip leads as described above. The factory calibration is made with the chassis in the case and removing the chassis from the case will change the calibration values by a small percentage. It is recommended that the relay be checked in position as a final check on calibration.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs for the standard cases 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.

The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohm and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the contactor switch. This lead should be fastened (dead ended) under the small filister-head screw located in the Micarta base of the contactor switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms.

ADJUSTMENTS AND MAINTENANCE

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if 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.

CAUTION 1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

Sequence Filter

There are no adjustments to be made in the zero sequence resistor. The taps on the R_1 resistor are adjustable, however, but this is a factory calibration which should not ordinarily be disturbed. To check the positive sequence current filter, pass a current $I = 6.94$ amperes through a pair of phase terminals, for example, in at phase B, out of phase C (see Figure 2) and measure the open circuit filter voltage with a high resistance voltmeter. This may be done by removing the positive sequence current tap screw, T, and connecting the voltmeter across the open circuit thus formed. The voltage should be $8R_1$ plus or minus 5% for each of the three phase-to-phase combinations, AB, BC, or CA. For example, at $I = 6.94$ amperes and $R_1 = .1$, the voltage should be 0.8 volts.

Polar-Type Element

Contact Adjustment: Adjust the left-hand (front view) contacts until they just make a light circuit, when the armature rivet touches the left-hand pole face. Give both the left-hand contact screws four to five additional turns, and lock in position with the lock nuts provided. This moves the armature rivet away from the left-hand pole face and provides

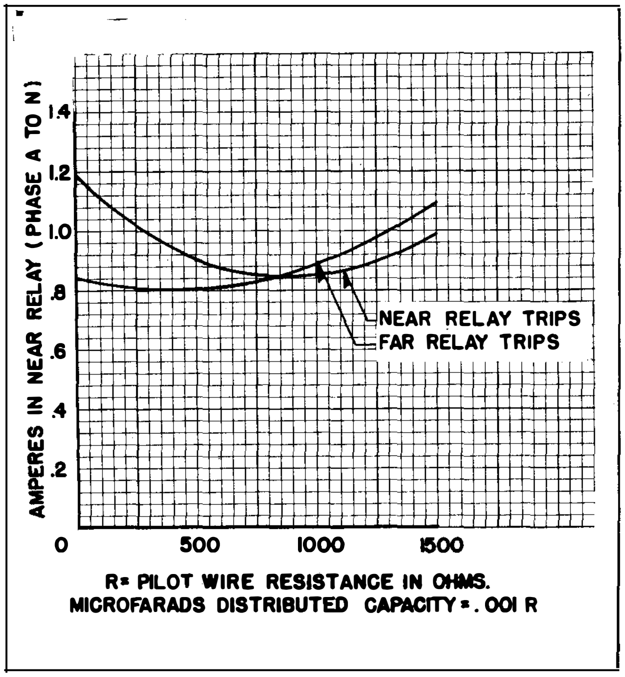


Fig. 13—Typical Curves Showing the Effect of Pilot Wires Resistance and Capacitance on Minimum Trip Current With Minimum Restraint.

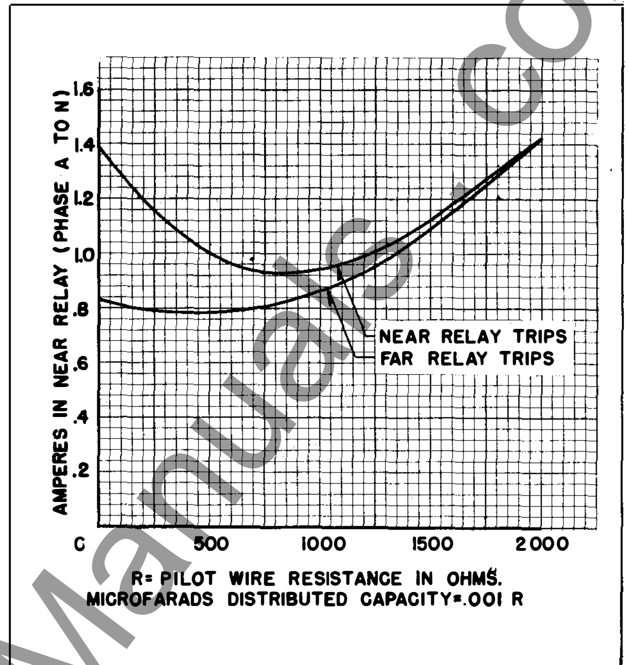


Fig. 14—Typical Curves Showing the Effect of Pilot Wire Resistance and Capacitance on Minimum Trip Current With Maximum Restraint.

contact follow. Now adjust the right-hand backstop screws until they just touch the moving contacts when the moving contacts are in the contact closing position as above. Back off each backstop screw two turns and lock in position.

Calibration: Connect the restraint tap link in the position in which it will be used. Connect the low voltage terminals of the insulating transformer across the pilot wire terminals of the relay. Connect the relay taps on T = 4, R_1 = .1, R_o = 1.6.

Adjust the right-hand magnetic shunt in or out, as required, until the relay just closes contacts at 6.9 to 7.0 amperes phase B to phase C current. When this adjustment has been made, change the input current connections to phase A to neutral. The relay should trip for phase A to neutral current between .45 and .55 ampers.

The above is given as a laboratory calibration on an individual relay with its insulating transformer. This does not take into consideration the characteristics of the pilot wire circuit between the relays.

Figures 13 and 14 show typical variations of minimum trip current for various lengths of pilot wire circuits up to the limiting values of 1500 ohms for relays operating on minimum restraint (Fig. 13) and 2000 ohms for relays operating on maximum restraint (Fig. 14).

For these curves, both relays are set on taps T = 4, R_1 = 0.1, R_o = 1.6. Each relay is originally calibrated to trip on a current of .47 amperes, phase A to neutral, with the high side of the insulating transformer open-circuited. This value of current is equivalent in the relay filter to 4 amperes positive sequence only, with the taps as specified above.

Restraining Coil: The effectiveness of the restraining coil of the relay element, and the performance of the Rectox units, may be checked as follows, if desired. Connect a variable non-inductive resistor across tthe high voltage terminals of the insulating transformer, and connect d-c milliammeters in series with the operating and restraining coils of the element, by opening these circuits at the test links provided for this purpose. These milliammeters should have low resistance, and should be capable of reading in the order of 20 to 25 ma. in the operating coil and 100 to 150 ma. in the restraining circuit. Using T = 4, R_1 = .1, R_o = 1.6, pass 10 amperes 60 cycles from phase A to Neutral in the relay, and increase the variable resistance across the insulating transformer high voltage terminals until the relay just trips. This should be in the order of 1400 to 2000 ohms when maximum restraint is used. Read the d-c current (milliamperes) in the operating and restraining coils at this point. The values obtained should conform substantially to the following equations.

For Minimum Restraint

$$I_O = .12\ I_R + 8$$

For Maximum Restraint

$$I_O = .16\ I_R + 8$$

where I_O and I_R are operating and restraining coil currents, respectively, in milliamperes. The results are subject to slight variations between individual relays.

The polarity of the connections to the pilot wires, and the correct "Phasing out" of A, B, C phases at the two stations may be checked by the six tests outlined on Page 17.

Pilot Wire Current

The pilot wire current which should flow under normal load conditions is given in Figures 4 and 5. If the relay taps in use differ from those indicated in these figures, suitable conversion factors must be used. The pilot wire current will vary inversely with T and directly with R_1.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down or by disconnecting the switch and turning it up-side-down. Then screw up the core screw until the moving core starts rotating. Now, back off the core screw until the moving core stops rotating. This indicates the points where the play in the assembly is taken up, and where the moving core just separates from the stationary core screw. 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c have been passed through the coil.

Operation Indicator

Adjust the indicator to operate at 0.2 ampere d-c gradually applied by loosening the two screws on the under side of the assembly, and moving the bracket forward or backward. If the two helical springs which reset the armature are replaced by new springs, they should be weakened slightly by stretching to obtain the 0.2 ampere calibration. The coil resistance is approximately 2.8 ohms.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three - phase current of 5 amperes:

For tap 4 R_1 = .075 and R_o = .39

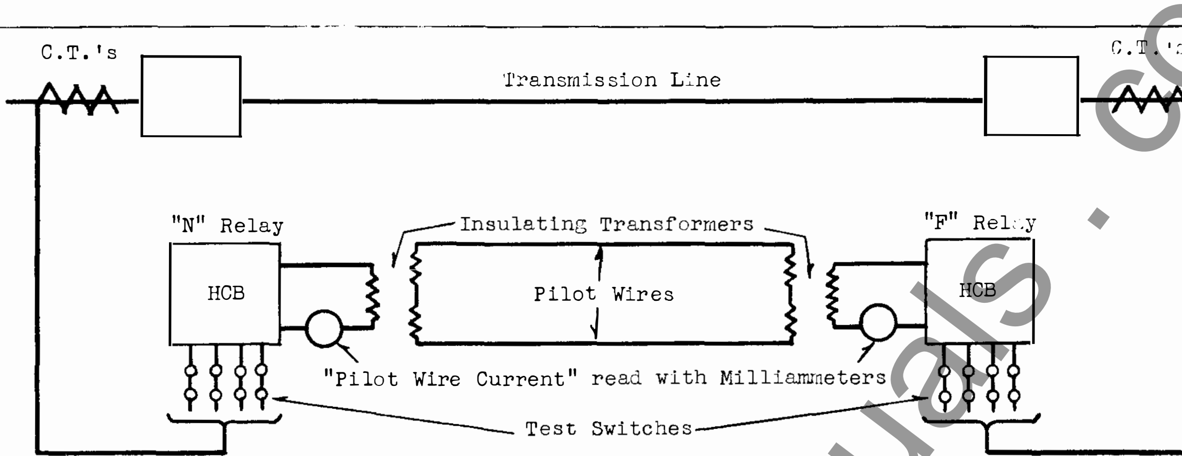
Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_o = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.



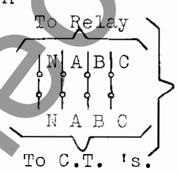
Note: The line should be carrying through load current amounting to at least 1.5 amperes as measured in the secondary of the Current Transformers. This test is based on the ratio of the C.T.'s being the same at each end of the line, in which case set the taps of both relays to $R_1 = .1$; $R_0 = 1.6$; $T = 4$ for this test.

	RELAY "N"					RELAY "F"				
Test No.	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	Relay F	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	Relay N
1		A,B,C,N	No	(1)	(1)		A,B,C,N	No	(1)	(1)
2		A,C,B,N	No	(2)	(2)		A,C,B,N	No	(2)	(2)
3		A,N	Yes	(3)	(0)		0	Yes	(3)	(3) (4)
4		0	Yes	(3)	(3) (4)		A,N	Yes	(3)	(0)
5		A,N	No	(3)	(3)		A,N	No	(3)	(3)
6		A,N	Yes	(6)			B,C,N	Yes	(6)	

REMARKS

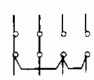
Tests 1 and 2 are to check normal positive sequence rotation of phases. The test switch connections of test #2 may be made readily with relays in the Flexitest case by using clip leads and insulating barriers in the ammeter test jacks. However, care should be used to avoid accidentally open-circuiting the current transformer circuits.
Tests 3 and 4 simulate internal Phase A to Ground fault with single end feed.
Test 5 simulates an external Phase A to Ground fault. (5)
Test 6 simulates an internal Phase A to Ground fault, with equal feed from the two ends, since $I_B + I_C = - I_A$, with balanced load.

LEGEND OF TEST SWITCH SYMBOLS:



Normal Connection. All Currents to Relay.

EXAMPLE



Phase A current from C.T.'s to Relay. Phase B and C C.T.'s shorted to neutral.

(1) The "pilot wire current" will vary depending upon the magnitude of the through load current and the characteristics of the pilot wire. See Figures 4 and 5.
(2) Since the relay is temporarily connected for negative sequence, it should have practically zero output in this test.
(3) These readings may be "off scale" depending upon the magnitude of the load current.
(4) The relay at this station should reset when the "far" current is being read because the local relay will be receiving no current from either the pilot wire or the current transformers.
(5) Test 4 and 5 can be repeated using phase B to neutral current, and again with phase C to neutral current, but this is not strictly necessary on the basis that, having proved the phase sequence with tests 1 and 2, and having proved the correspondence of phase A at the two ends of the line with test 5, then phases B and C must be correct.
(6) Some pilot wire current will be read, depending upon the magnitude of the distributed capacity of the pilot wire in combination with the magnetizing impedance of the insulating transformer.

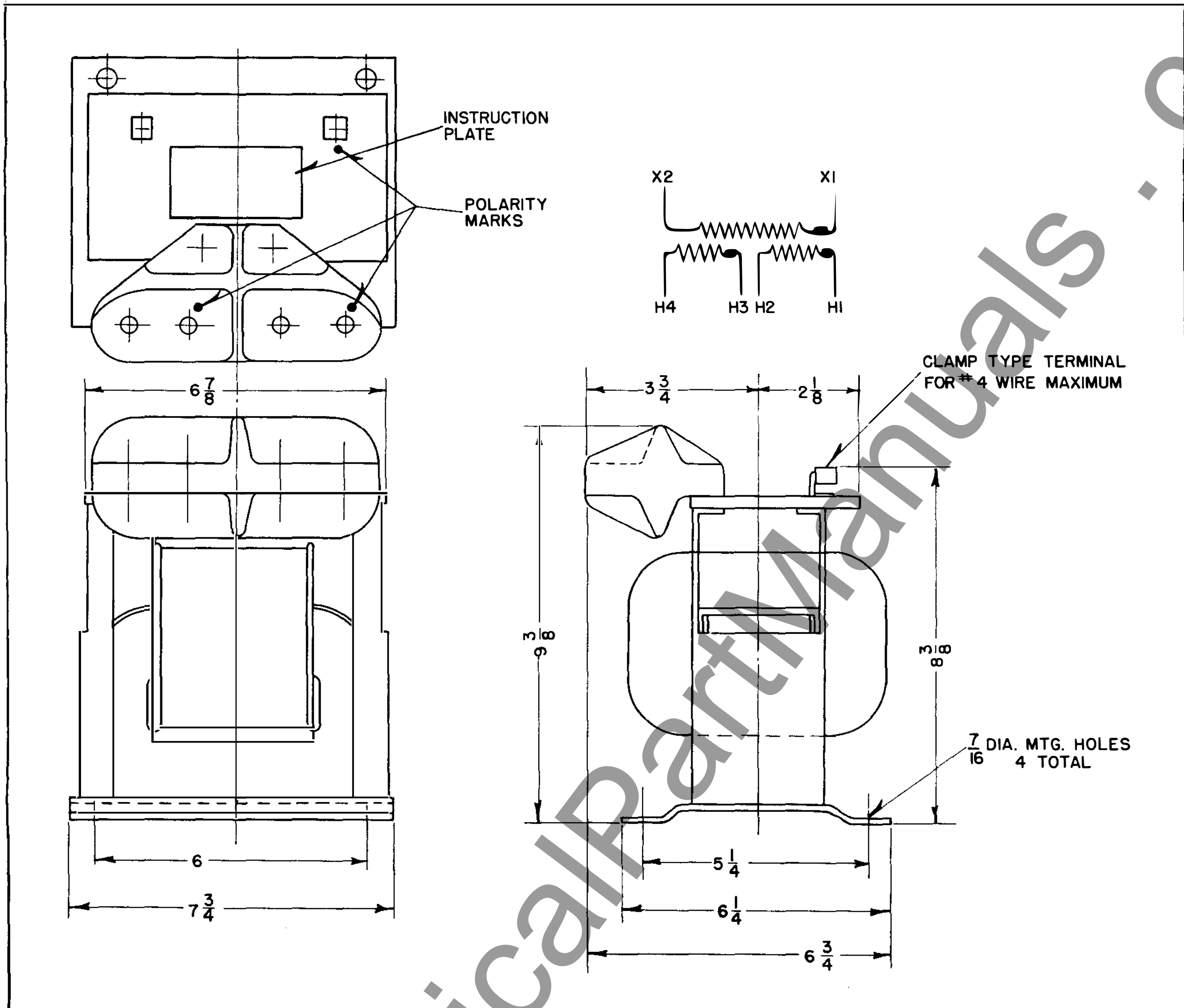


Fig. 15—Outline and Drilling Plan of the Insulating Transformer. For Reference Only.

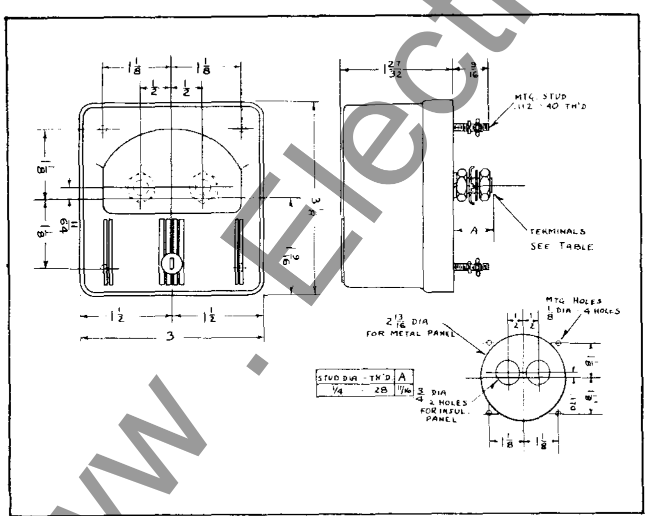


Fig. 16—Outline and Drilling Plan of the Projection Type Test Milliammeter. For Reference Only.

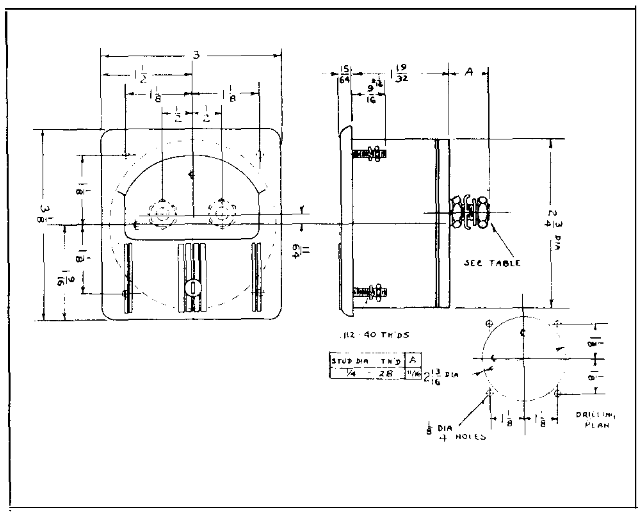


Fig. 17—Outline and Drilling Plan of the Semi-flush Type Test Milliammeter. For Reference Only.

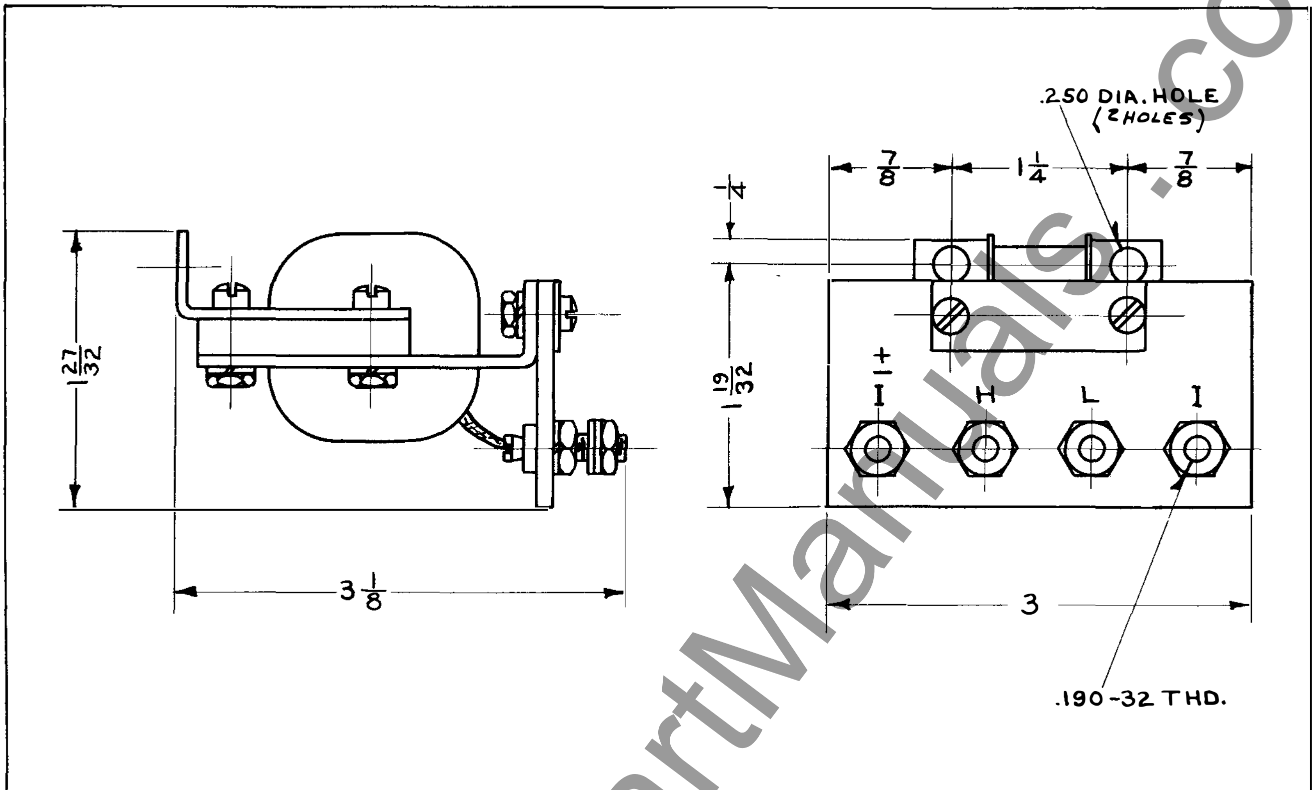
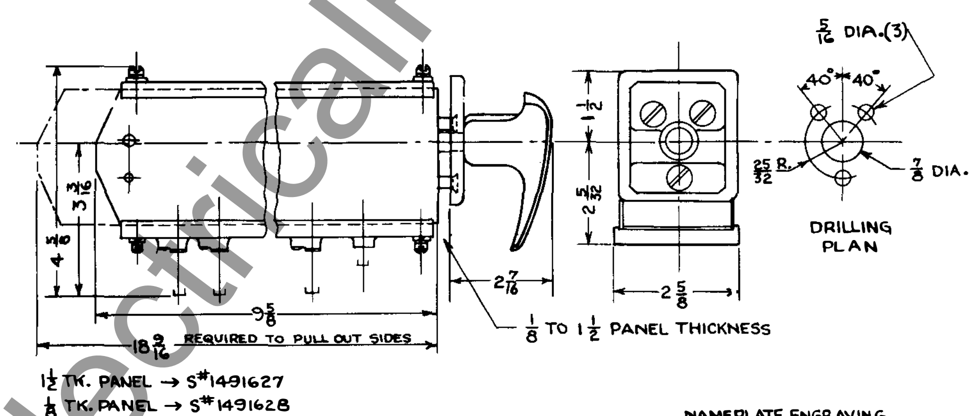


Fig. 18—Outline of the Test Milliammeter Auxiliary Transformer. For Reference Only.

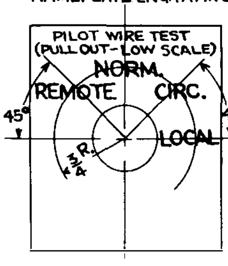


SWITCH POSITION TABULATION

CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X-DENOTES CONTACTS CLOSED

NAMEPLATE ENGRAVING



SPRING RETURN
MODERN PISTOL HANDLE

Fig. 19—Outline and Drilling Plan of the Type W Test Switch. For Reference Only.

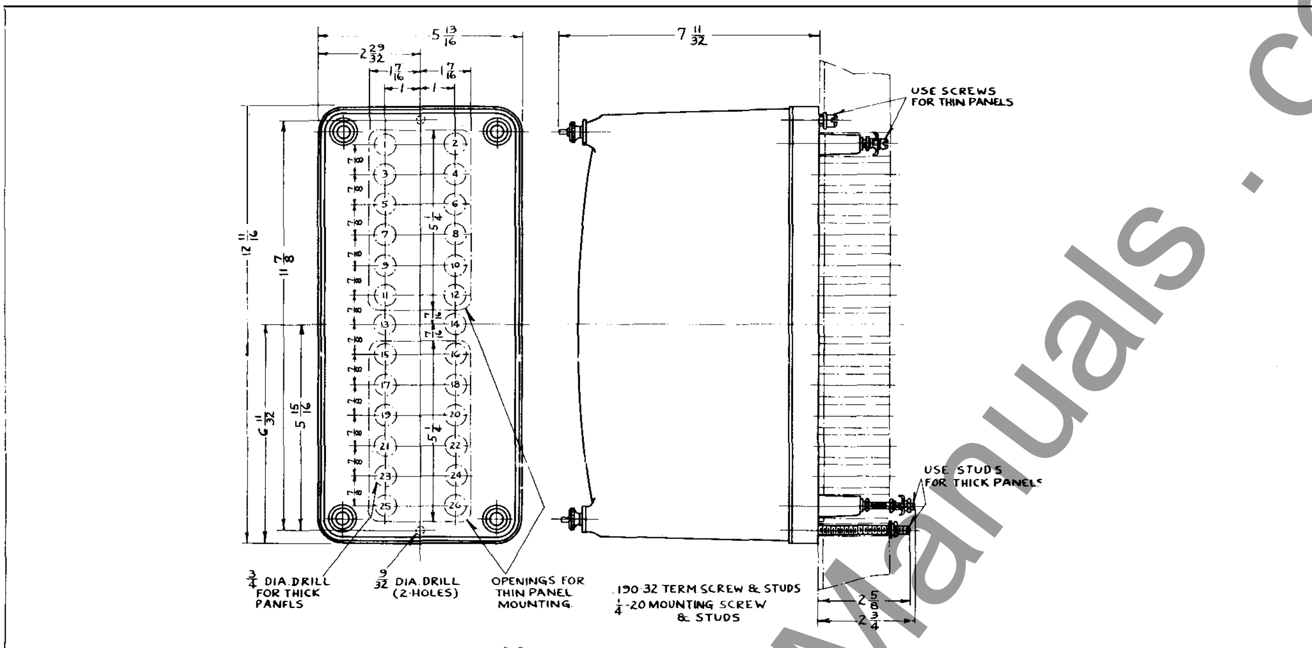


Fig. 20– Outline and Drilling Plan For the Projection Type Standard Case. See the Internal Schematics For The Terminals Supplied. For Reference Only.

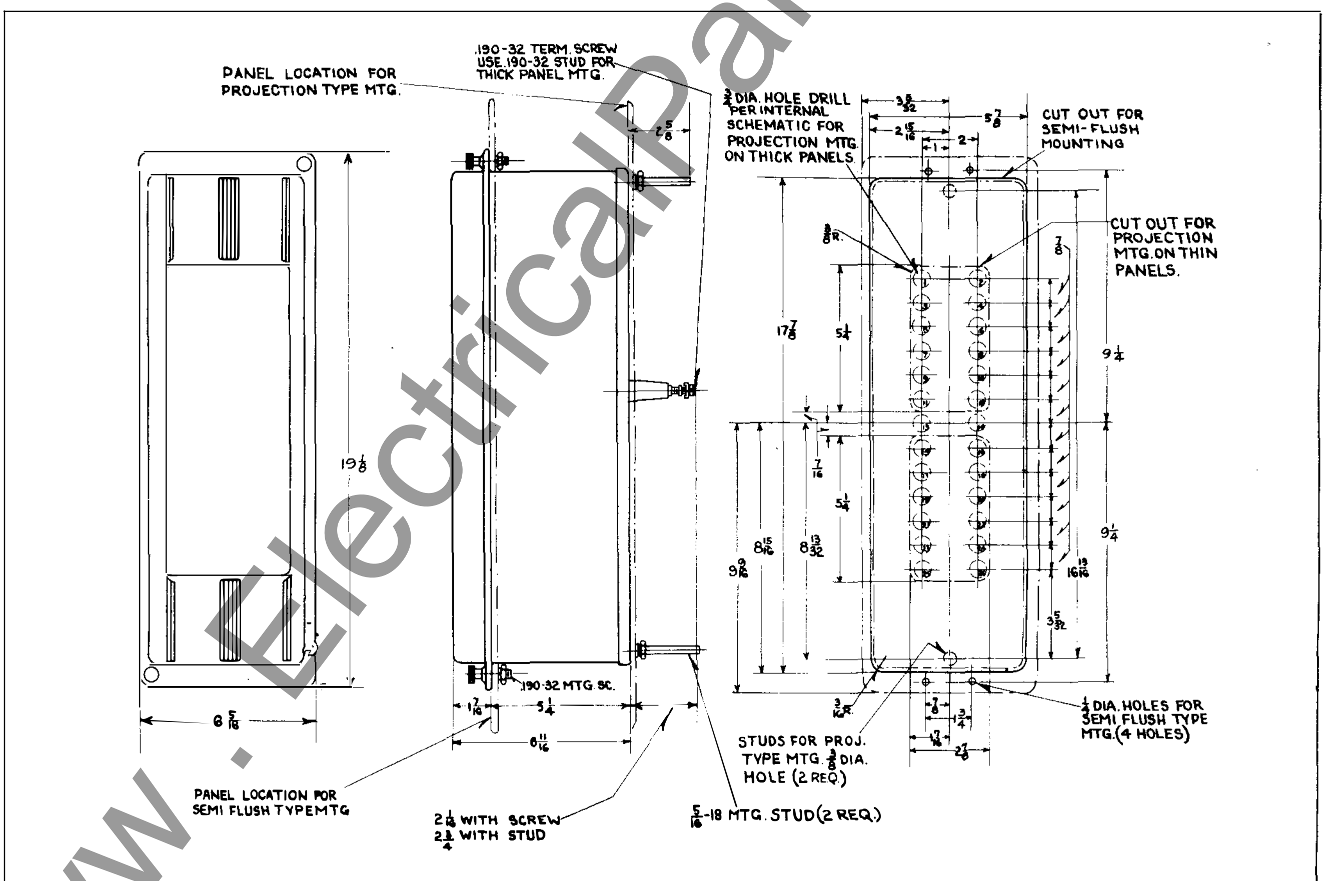


Fig. 21—Outline and Drilling Plan for the M-20 Projection or Semi-Flush Type FT Case. See the Internal Schematic for the Terminals Supplied. For Reference Only.

WESTINGHOUSE ELECTRIC CORPORATION
METER DIVISION **NEWARK, N.J.**

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE HCB PILOT WIRE RELAY

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 HCB relay is a high speed pilot wire relay designed for the complete phase and ground protection of two and three terminal transmission lines. Simultaneous tripping of the relay at each terminal is obtained in about 1/60 of a second for all faults. A complete installation for a two terminal line consists of two relays, two insulating transformers, and an interconnecting pilot wire circuit. For a three terminal line, three relays, three insulating transformers, and a wye-connected pilot wire circuit with branches of equal impedances are required.

CONSTRUCTION

The relay consists of a combination positive and zero phase sequence filter, a saturating auxiliary transformer, two rectox units, a polar type relay unit, and a neon lamp all mounted in a single case. The external equipment normally supplied with the relay consists of an insulating transformer, a milliammeter and test switch. The construction of these components is as follows:

Sequence Filter

The currents from the current transformer secondaries are passed thru a filter consisting of a three winding iron core reactor and two resistors. The secondary of the three winding reactor and the resistors are tapped to obtain settings for various fault conditions. The output of this filter provides a voltage across the primary of the saturating transformer proportional to the positive sequence current plus a constant times the zero sequence current. This combination is selected as the discriminating function because it can be adjusted to have definite values lying in a comparatively small range for all types of phase and ground faults. Thus, a single operating element can be used for all types of faults. The two lower tap dials provide the adjustment of the relative amounts of positive and zero sequence currents that are combined to produce the required discriminating voltage. The right-hand lower tap dial (front view) adjusts the sensitivity to ground fault currents. The left-hand lower tap dial adjusts the positive phase sequence sensitivity when the ratio of the current transformers at the terminals of the line are not equal.

Saturating Auxiliary Transformer

The voltage from the filter is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer is used to limit the voltage impressed on the pilot wire, and to provide a small range of voltage for a large variation of maximum to minimum fault currents. Thus, high operating energy is obtained for very light faults and limited operating energy for heavy faults. The relay operating characteristic changes from percentage differential at low current values to approximately directional characteristics at high current values.

The upper tap plate changes the out-put of the saturating transformer, and is marked in amperes required to operate the relay when the

SUPERSEDES I.L. 41-658 J
* Denotes change from superseded issue.

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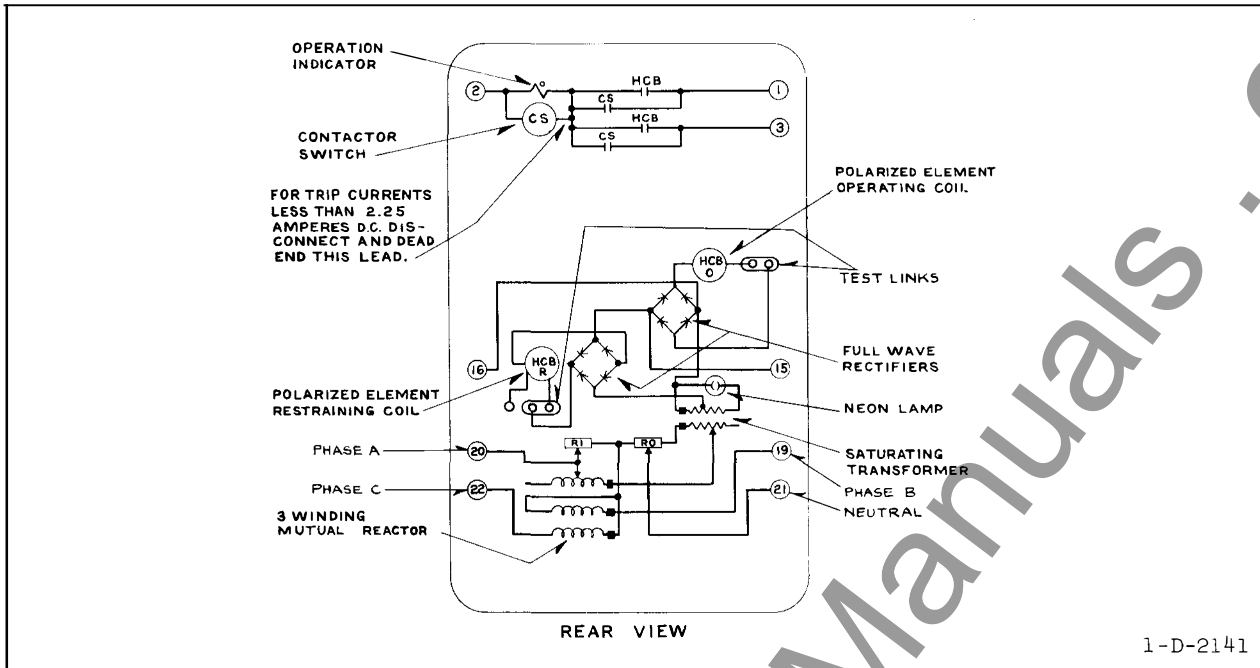


Fig. 1—Internal Schematic of the Type HCB Relay in the Standard Case.

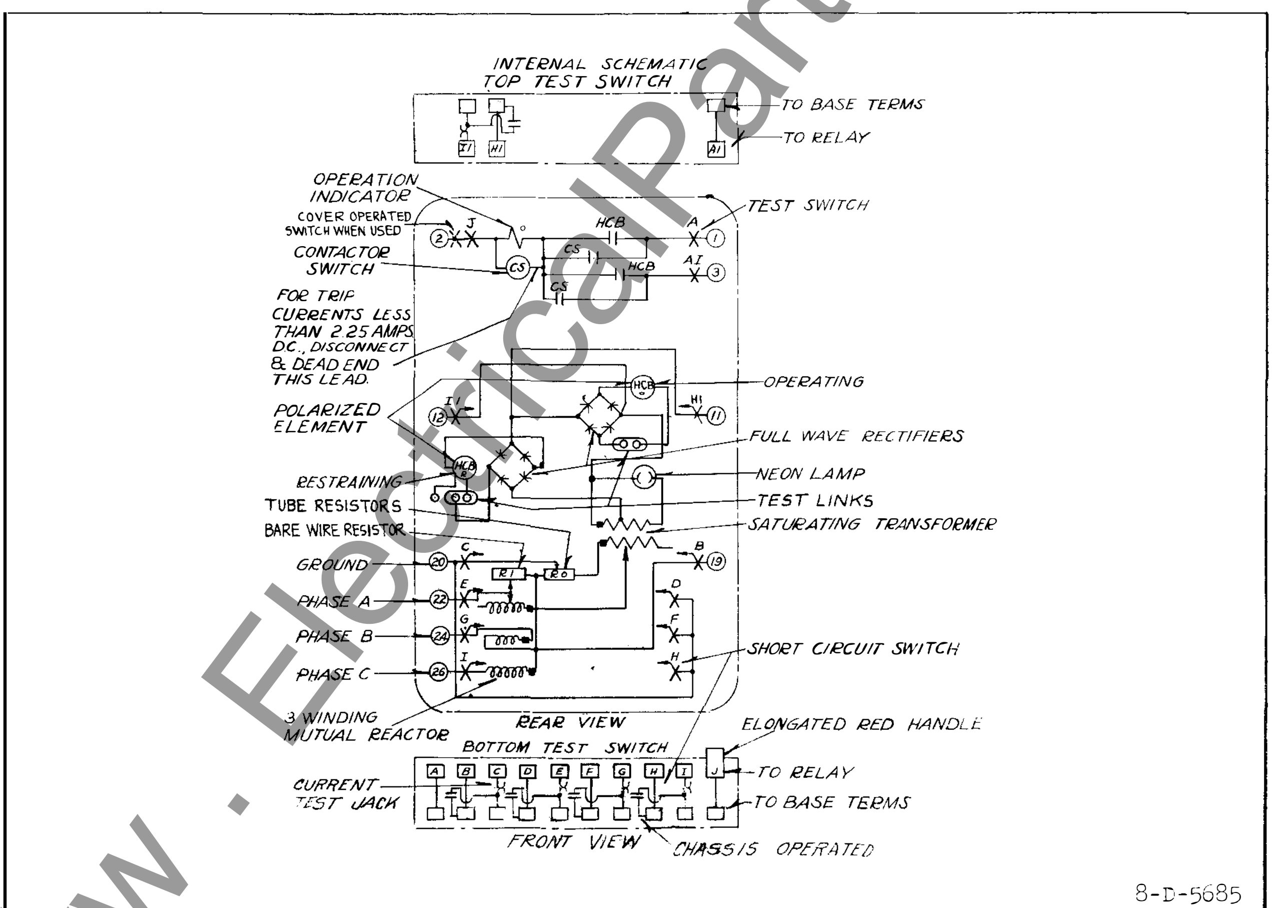


Fig. 2—Internal Schematic of the Type HCB Relay in the Type FT Case.

pilot wire is open or when equal amounts of currents are fed to an internal fault thru the line terminals. For further discussion, see section entitled, "Settings".

Rectox Units

The secondary of the saturating transformer feeds the two rectox units, the insulating transformer, and the pilot wire, as shown schematically in Figure 9. The rectox units are used to convert the a-c output of the saturating transformer to d-c for use on the d-c polar-type relay element. The use of a sensitive polar-type relay, requiring a small amount of energy, keeps the volt-ampere burden on the current transformers very low.

Polar-Type Relay

This element consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature with a double set of contacts. The poles of the permanent magnet clamp directly to each side of the magnetic frame. Flux from the permanent magnet divides into two paths, one path across the air gap at the front of the element in which the armature is located, the other across two gaps at the base of the frame. Two adjustable shunts are located across the rear air gaps. These change the reluctance of the magnetic path so as to force some of the flux thru the moving armature which is fastened to the leaf spring and attached to the frame midway between the two rear air gaps. Flux in the armature polarizes it and creates a magnetic bias causing it to move towards one or the other of the poles, depending upon the adjustment of the magnetic shunts. Two concentric coils are placed around the armature and within the magnetic frame. The coils are connected in opposition with one used as a restraining winding and the other as an operating winding. The restraining winding sets up a magnetic field, which, in conjunction with the field from the permanent magnet holds the contact in the normal open position. The operating winding produces a magnetic field which acts to move the armature in the contact closing direction. The restraining winding is tapped and the leads are brought out to taps at the upper left of the relay. The left hand position of the test link is the minimum restraint connection, and the right hand position is the maximum restraint connection.

The moving contacts are fastened on the free end of the leaf spring. Two stationary contact screws are mounted to the left (front view) of the moving contact assembly and are adjusted for normally open contacts.

Insulating Transformer

The insulating transformer is connected as shown in Figure 9 and serves to isolate the terminal equipment from the pilot wire. This avoids interconnection of station grounds that may have large differences of potentials between them. The mid-taps of the parallel-wound secondary windings are brought out separately to provide a means of connecting supervisory relays symmetrically within the pilot wire circuit. When auxiliary supervisory relays are not used, these mid-taps are to be connected together and may be grounded to drain the voltages induced along the length of the pilot wires when these voltages approach the voltage limit of the cable. This is discussed further under Pilot Wire below.

The transformers have a 4/1 ratio and are insulated for 5000 volts.

Pilot Wire

One pair of pilot wires connecting the secondaries of the insulating transformers is required to provide a continuous circuit between the relays. For the pilot wires a lead-covered twisted pair of No. 19 wire or larger is recommended, however, open wires may be used. The following points should be considered in selecting pilot wire circuits.

1. The total circuit resistance (including neutralizing reactors when used) between terminals of the Type HCB relays exclusive of the insulating transformers and expressed in terms of the pilot wire voltage must not exceed 2000 ohms for two terminal lines (500 ohms per wye branch for three terminal lines).

2. The shunt capacity between pilot wires should not exceed 0.75 microfarad per pilot wire terminal for two terminal lines (0.60 mfd. per leg. for three terminal lines). In cases where this value is exceeded, compensating reactors will be required to reduce the

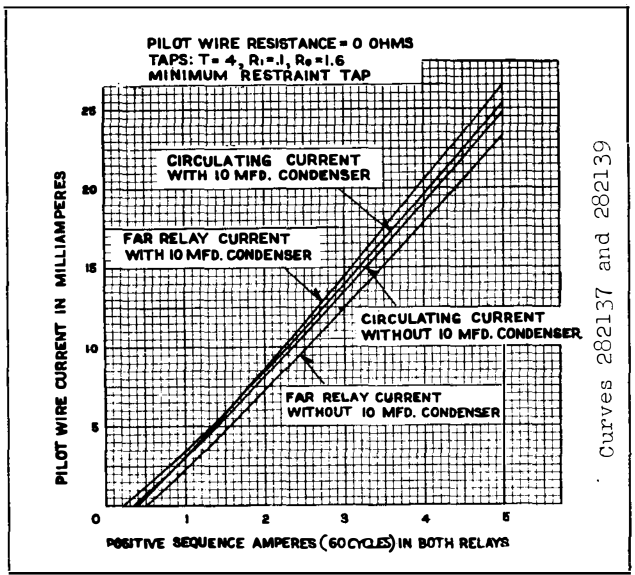


Fig. 3—Typical Test Output Vs. Input Relay Current in A Two Terminal Line With Zero Pilot Wire Resistance.

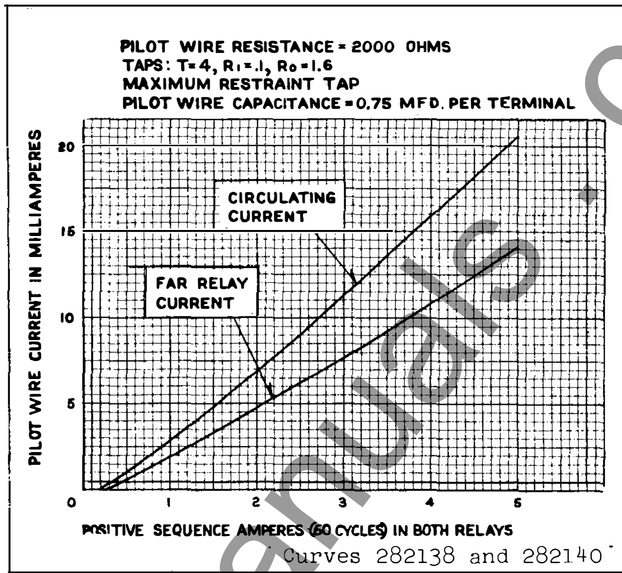


Fig. 4 —Typical Test Output Vs. Input Relay Current In A Two Terminal Line With 2000 Ohm Pilot Wire Resistance With or Without the 10 MFD. Condenser.

shunt currents which tend to desensitize the relay.

3. The difference in the longitudinal induced voltage which appears between wires should not exceed 15 volts total (7.5 volts per relay).

4. The induced voltage to ground which occurs on the pilot wires during maximum fault conditions should not exceed the rating of the pilot wires or insulating transformers. The transformers are insulated for 5000 volts. In general, the pilot wires will be insulated for a much lower voltage.

Induced voltages and differences between station ground potentials which appear along the pilot wire may be reduced to safe limits by the following means:

a. Excessive voltages can be reduced by grounding the mid-taps of the insulating transformers and allowing current to circulate over the pilot wires to ground. The voltage between pilot wires must not exceed 15 volts.

b. For more serious induction two winding neutralizing reactors can be used to limit the voltages. In cases where the sheath current may be sufficient to cause damage the sheath must be insulated from ground and three winding neutralizing reactors should be used. Reactors are available for 1000 and 2000 volt neutralization.

c. Another method consists of connecting a suitable two winding drainage reactor and a protector tube, such as the type KX642, to the pilot wires at suitable points. The arrangement is such that when the tube flashes because of high extraneous voltages, both wires are connected to ground, through the reactor and the tube. The impedance to ground is low, but the impedance between wires is kept high to avoid interfering with the operation of the HCB relays.

OPERATION

The HCB pilot wire relay operates as a percentage differential device when the fault currents are small, and has essentially directional characteristics, comparing the direction of current flow at the terminals of the protected section when the fault currents are large.

The voltage appearing across the secondary of the saturating transformer is balanced against a similar voltage at the opposite end of the protected line section, thru the restraint winding of each relay, the insulating transformers and the pilot wires, as shown in Figure 9. On external faults, a flow of fault power thru the protected line section, produces voltages across the secondaries of the saturating transformers which are essentially equal and in series. These voltages act to circulate current thru the restraining coil of each relay which is connected in series with pilot wire. Under this condition the operating coils connected across the pilot wires do not receive sufficient current to overcome the restraint and so tripping does not occur.

For internal faults with equal feed-in from the terminals, the voltages across the saturating transformers are in opposition. This results in all of the current flowing thru the restraining and operating coils in series and none thru the pilot wires. The relays at the ends of the section operate under this condition to give simultaneous tripping of the breakers at the terminals of the protected section.

The impedance of the filter and the operating coil can be adjusted so that the sum of the minimum trip currents from all terminals, when fed in from only one terminal, is sufficient to trip the relays simultaneously. This is affected somewhat by very low or very high pilot wire impedance, since in this case energy to trip any terminal not supplying current to the fault, must be carried over the pilot wire. Consequently, settings are based on total fault current fed in from all terminals disregarding the current distribution from the terminals.

If the pilot wire becomes open circuited, all of the current in the restraining coil will also flow thru the operating coil. While this condition exists the relay operates as an overcurrent device and will trip on all faults and also on heavy loads greater than the relay setting. A short circuit on the pilot wires will prevent tripping, since it short circuits the operating winding of the relay. However, if the short circuit on the pilot wire is so placed that it is 1000 or more pilot wire ohms from one of the two relays, then that relay will not be blocked.

The current and voltage impressed on the pilot wire do not exceed 100 milliamperes and 60 volts. The wave form and magnitude of the pilot wire current is such that telephone interference is within the limits allowed by the Bell Telephone Company. This permits the use of leased telephone lines as a pilot wire channel.

SUPERVISION

A faulted pilot wire mentioned above may be detected by the milliammeter and test switch (supplied with the relay) or by continuously-operated supervisory relays supplied as extra equipment.

The condition of the pilot wire under normal load conditions may be determined by reading the pilot wire current by means of the test switch and milliammeter.

A comparison of the readings obtained with the typical values of Figures 4 & 5 will indicate the condition of the pilot wire. It should be noted that, when the far relay current is being read, the near relay is short circuited, and the far relay is shunted by the resistance of the pilot wires plus the impedance of the near relay insulating transformers.

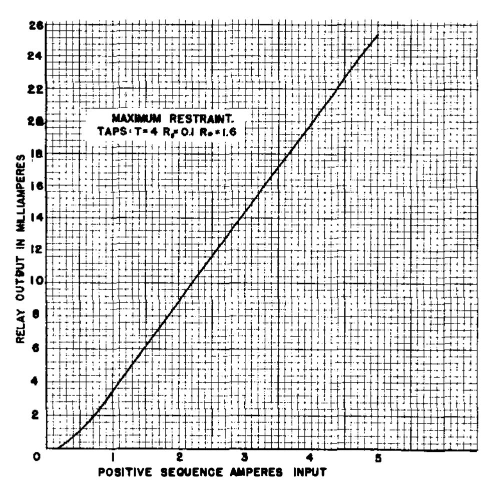


Fig. 5—Typical Curve of Relay Output vs. Positive Sequence Amperes Input.

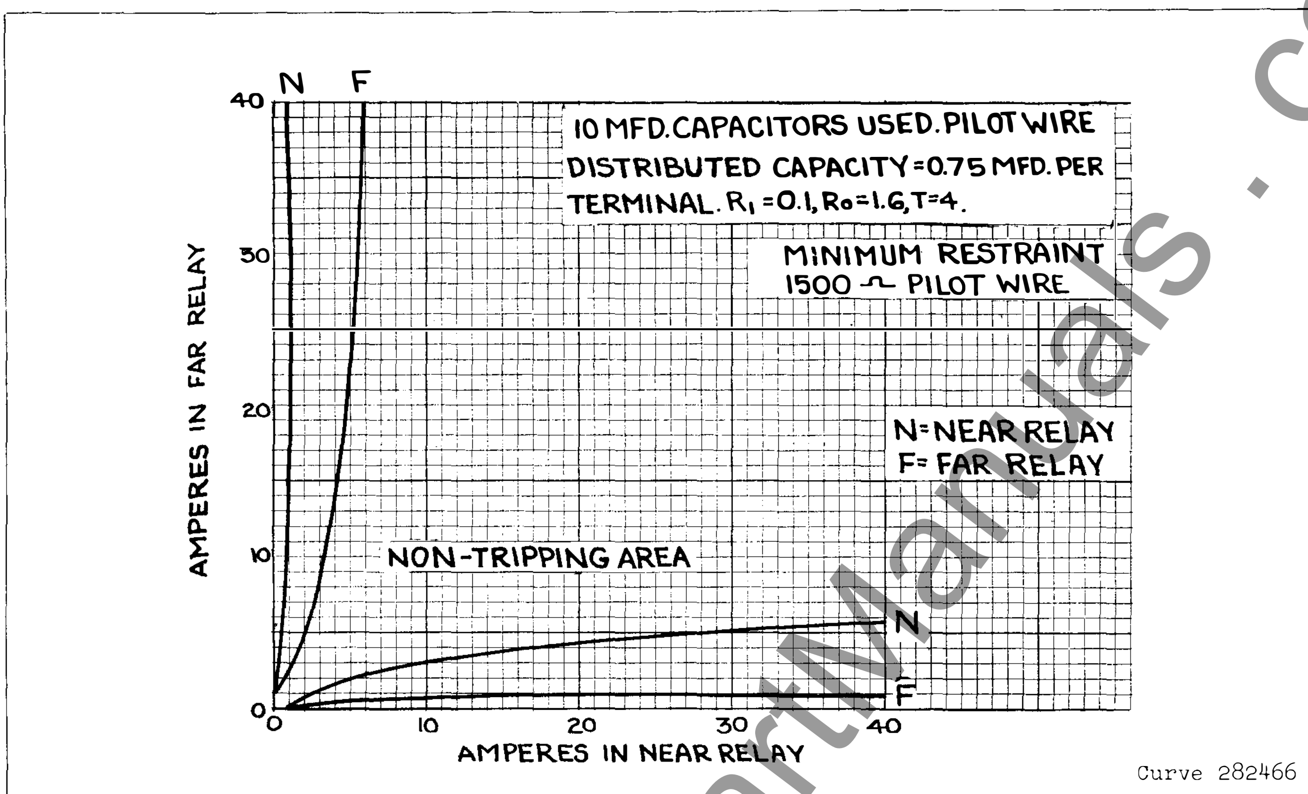


Fig. 6— Typical Operating Characteristics On Phase A to Ground Faults With Currents In Phase and 1500 Ohm Pilot Wire.

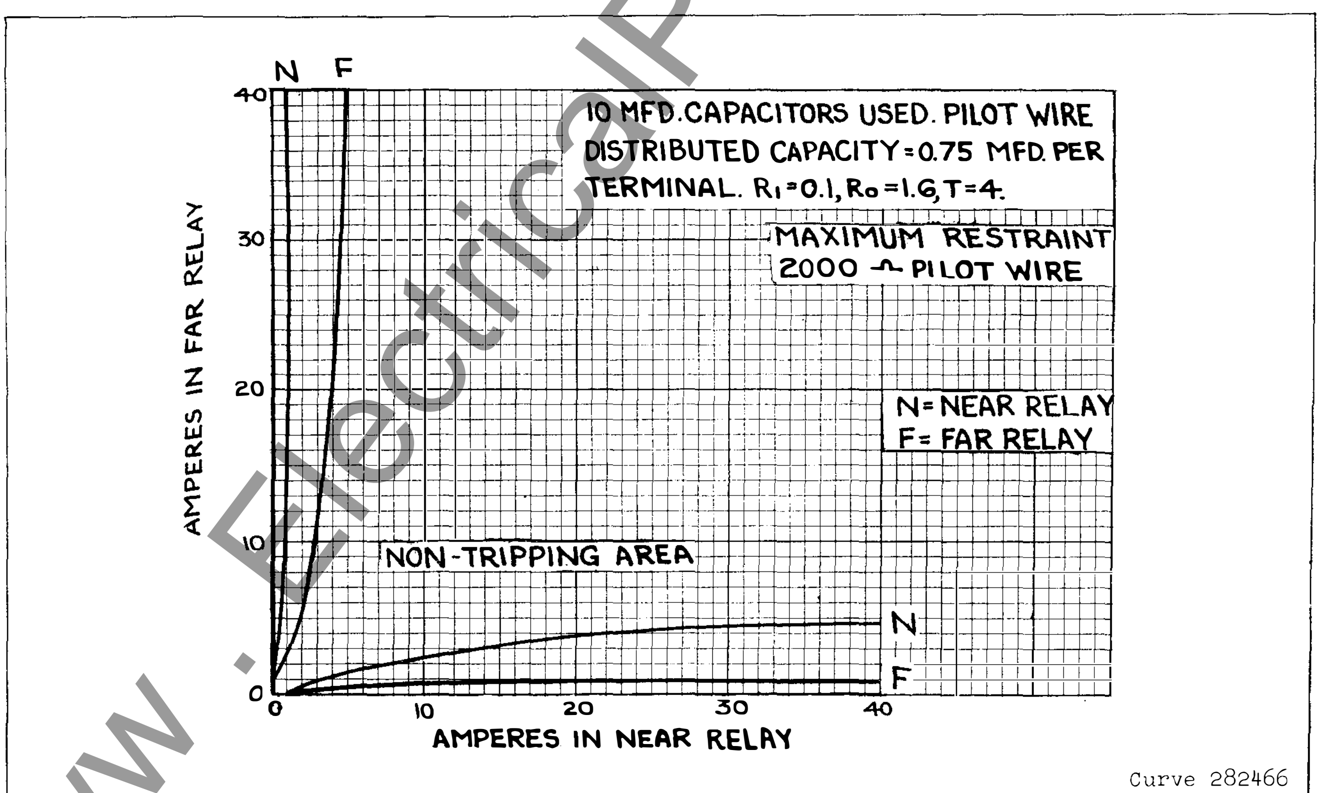
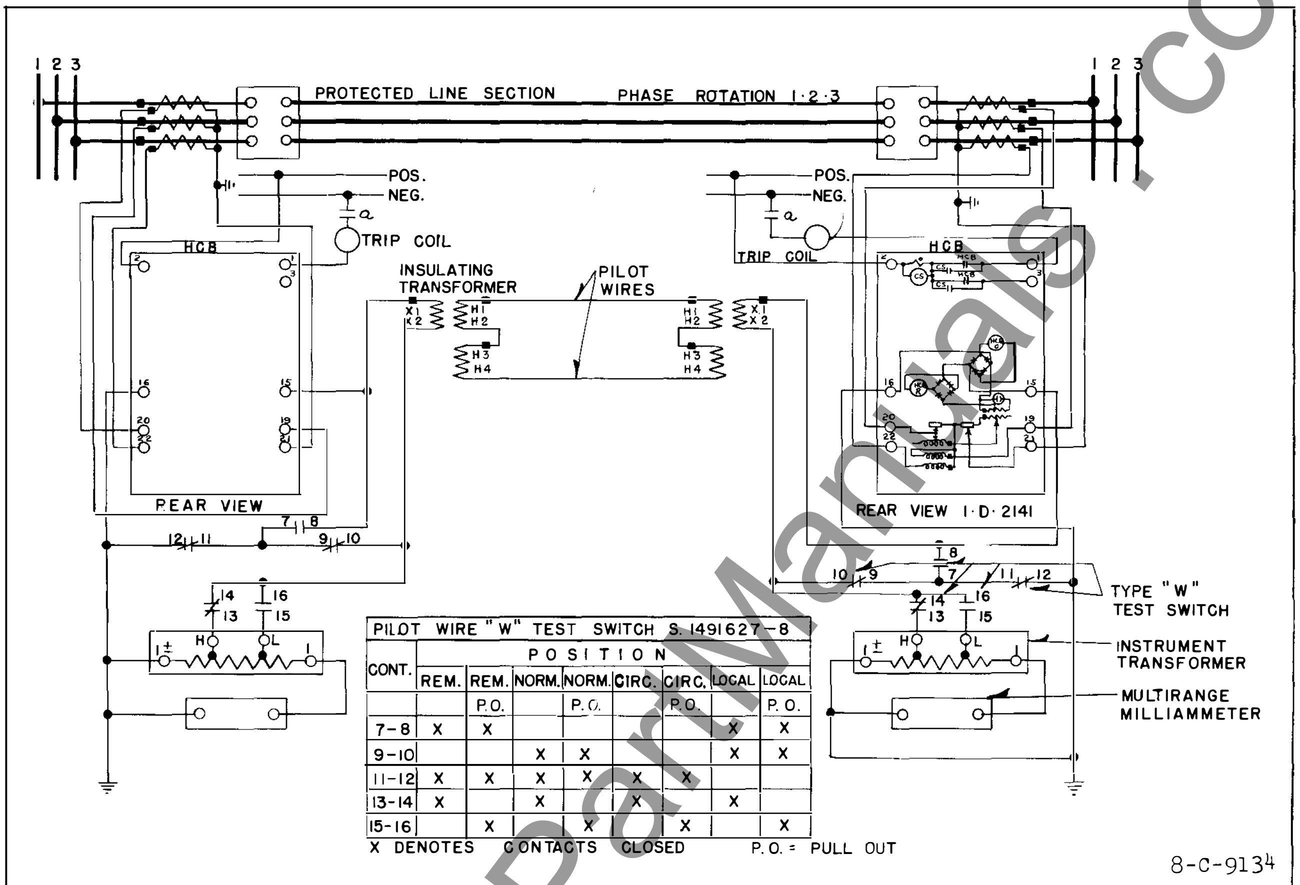


Fig. 7— Typical Operating Characteristics On Phase A to Ground Faults With Currents in Phase and 2000 Ohm Pilot Wire.



PILOT WIRE "W" TEST SWITCH S. 1491627-8

CONT.	POSITION REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 8—External Connections of the Type HCB Relay in the Standard Case For Phase and Ground Protection of A Two Terminal Line.

Figure 6 shows typical values for relay output current vs. positive sequence input current. For this test, the insulating transformer is short circuited on the low voltage side so that the milliammeter is connected directly across the relay output terminals.

CHARACTERISTICS

Typical overall operating characteristics of the relay are illustrated in Figures 7 and 8. The general shape of these curves is similar for other types of faults, relay settings, and pilot wire lengths. The ampere abscissa and ordinate scales may be interpolated to show the operating characteristics for other conditions and tap settings by the use of the following equation:

$$I_{an} = \frac{2.35}{T}\left\{2\dot{I}_{a1}R_1 + \dot{I}_{ao}\,(R_1 + 3R_o)\right\} \quad (1)$$

where I_{an} is the value to read on the curve (Figures 7 and 8).

For example, assume relay tap settings of $T = 6$, $R_1 = .1$, $R_o = .68$, and also assume that a phase b to ground fault occurs, for which the "near" relay components are as follows:

$$\dot{I}_{a1} = 10 + jo \quad (2)$$

$$\dot{I}_{ao} = .9a^2(I_{a1}) \quad (3)$$

In equation (3), the factor .9 was arbitrarily used as a reminder that the distribution factors for positive and zero sequence components are not necessarily equal for any given system. Also, the operator a^2 signifies that I_{ao} is 240° leading I_{a1} for a phase b to ground fault, neglecting dissimilarities in the sequence networks. First substituting the particular condition of equation (3) in equation (1) gives

$$I_{an} = \frac{2.35}{T} I_{a1}\left\{2R_1 + .9a^2(R_1 + 3R_o)\right\} \quad (4)$$

Substituting values for the several taps in (4) gives

$$I_{an} = \frac{2.35}{6} I_{a1} \left\{ \begin{matrix} 2 \times .1 + .9 \, (-.5-j.866) \\ (.1 + 3 \times .68) \end{matrix} \right\} \quad (5)$$

$$I_{an} = .392 \, I_{a1} \left\{ -.763-j1.67 \right\} \quad (6)$$

$$I_{an} = \mathring{I}_{a1} \, .718 \, \underline{|245.4°} \quad (7)$$

Substituting the numberical value for I_{a1} given by equation (2) results in a numerical value for I_{an} of

I an= .718 x 10 = 7.18 amperes.

This is the value to read on the curve for the typical values chosen for the taps R_1, R_o, and T at the particular phase b to ground fault values indicated by equations (2) and (3). It should be noted that the total phase b current to the "near" relay is $I_b = I_{b1} + I_{b2} + I_{bo} = 29$ amperes, assuming $I_{b2} = I_{b1}$.

For a phase to phase fault, there is no zero sequence current, and the phase current, I_{LL}, is equal in magnitude to $\sqrt{3}\, I_{a1}$. Hence, for phase to phase faults, equation (1) reduces to:

$$I_{an} = \frac{2.35}{T} \left\{ 2 \frac{I_{LL}}{\sqrt{3}} R_1 \right\} \quad (8)$$

SETTINGS

The HCB relay has three different taps which are provided to obtain flexibility for a wide range of application. The taps to provide correct operation for any given application are easily selected and have a wide latitude. That is, correct operation can be obtained for different combinations of tap values. The following discussion establishes limits for the various tap settings under different operating conditions. It should be kept in mind that settings to obtain operation on minimum internal fault conditions are based on the total current that flows into the section from all terminals.

Positive Sequence Filter Tap

The lower left tap (R_1) has three available taps .075, .10, and .15 (the .075 tap is actually marked .07 because of space limitations). These taps permit compensation for current transformers of different ratios at the various terminals. Where the current transformers have the same ratios, the values of R_1 should be the same on all relays. A value of $R_1 = .10$ is usually recommended except where a more sensitive setting of "T" (described below) is desired than is obtainable with $R_1 = .10$. Where the current transformers are different at the different terminals, select the value of R_1 which is proportional to the current transformer ratios. For example, assume a ratio of 300/5 at one terminal and 600/5 at another terminal. Set $R_1 = .075$ at the 300/5 terminal and $R_1 = .15$ at the 600/5 terminal. The ratios obtainable are 1/1, 2/1, 3/2, and 4/3. In the event that the ratio of the R_1 taps is not 1/1 it will be necessary to compensate for the unbalance by increasing the minimum trip calibration 25% above its normal value or by neutralizing the distributed capacitance of the pilot wire. The same procedure applies to three terminal lines.

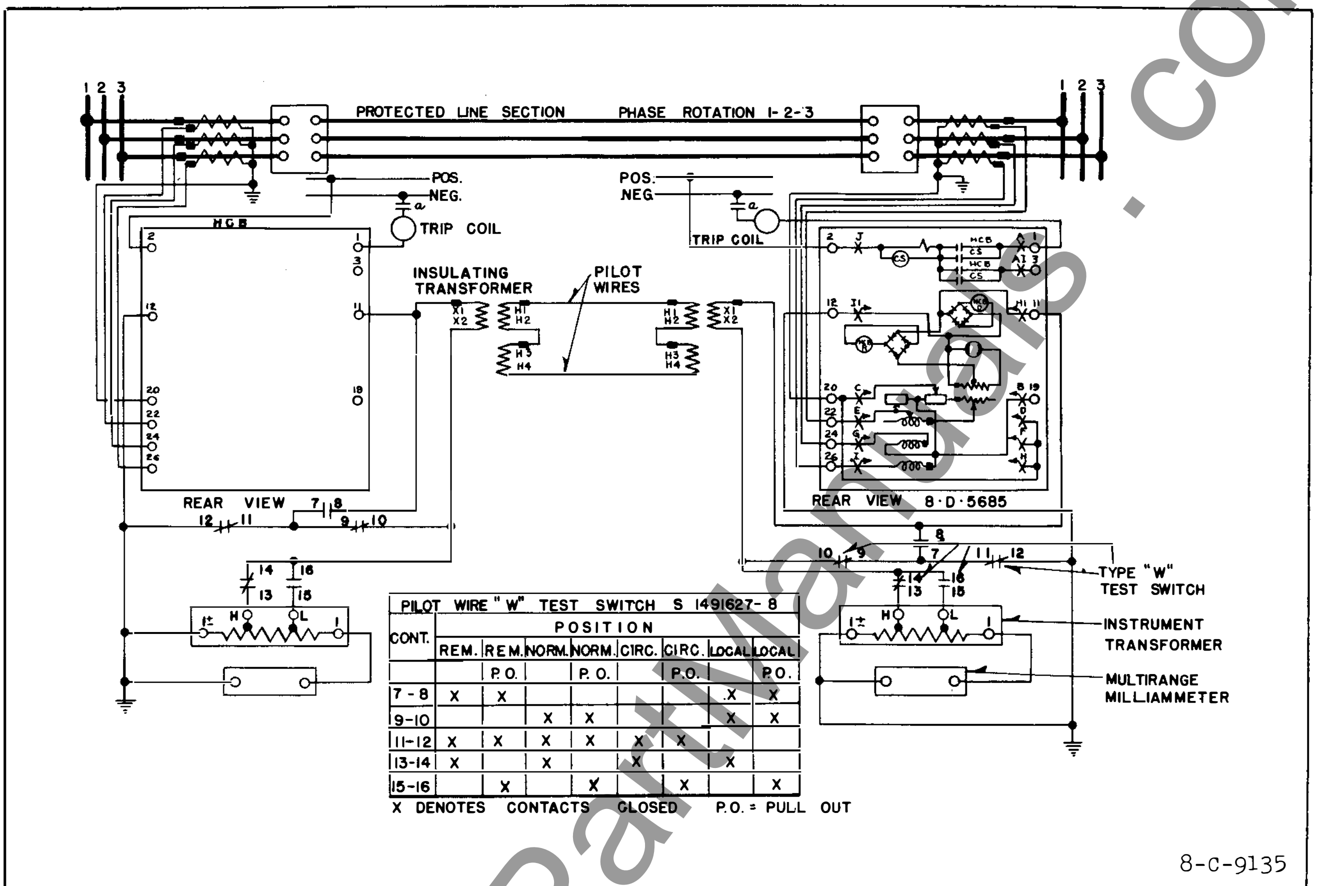
Positive Sequence Current Tap

The upper tap (T) has values of 4, 5, 6, 8, 10, 12 and 15. This tap should be selected to assure operation on minimum internal line-to-line faults, and where possible, to prevent tripping on load current if the pilot wire becomes accidentally open circuited. The highest setting of "T" that will cause operation on internal line-to-line faults is given by the equation :

$$T = 5.7 \, I_{LL} \, R_1 \quad (9)$$

where I_{LL} is the total minimum internal line-to-line secondary fault current fed from all terminals, divided by the number of terminals.

The factor "5.7" is used as the operation of the positive sequence filter is such that the relay requires 1.73 times as much current for operation on a line-to-line fault as on a three phase fault. This means that the three-phase trip setting should be 57% of the desired line-to-line current setting. Also, the

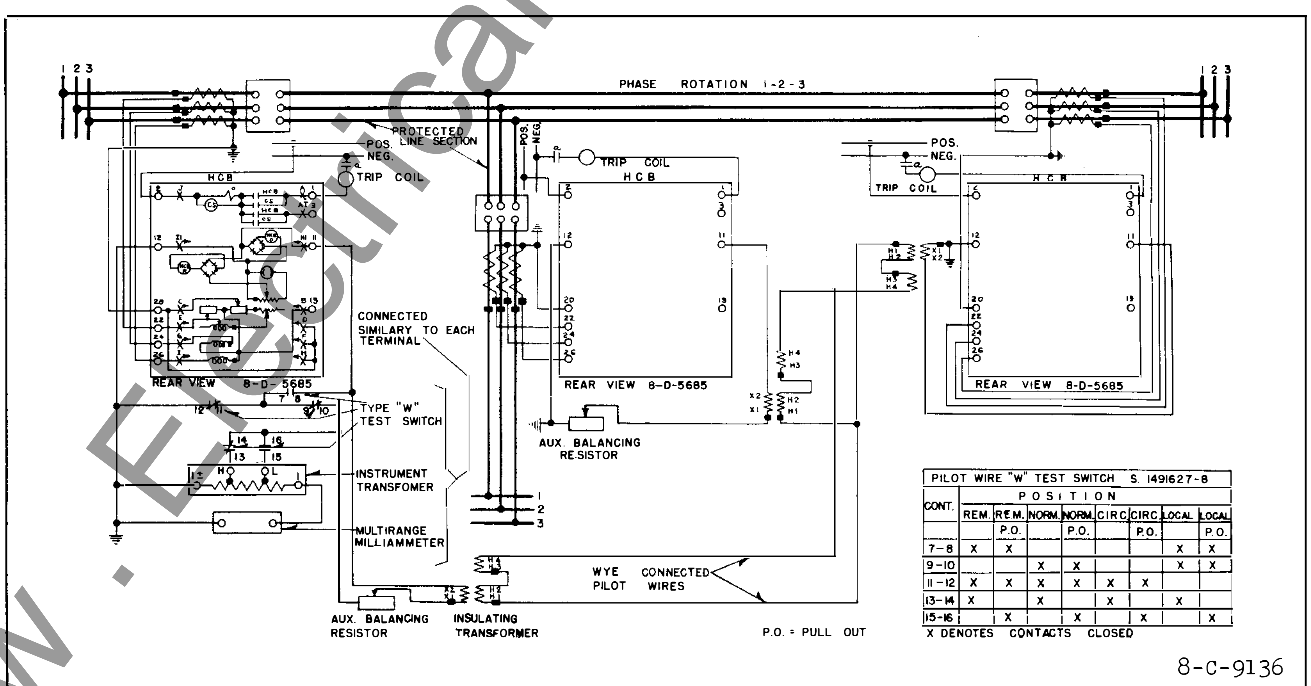


PILOT WIRE "W" TEST SWITCH S 1491627-8

CONT.	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 9– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line.

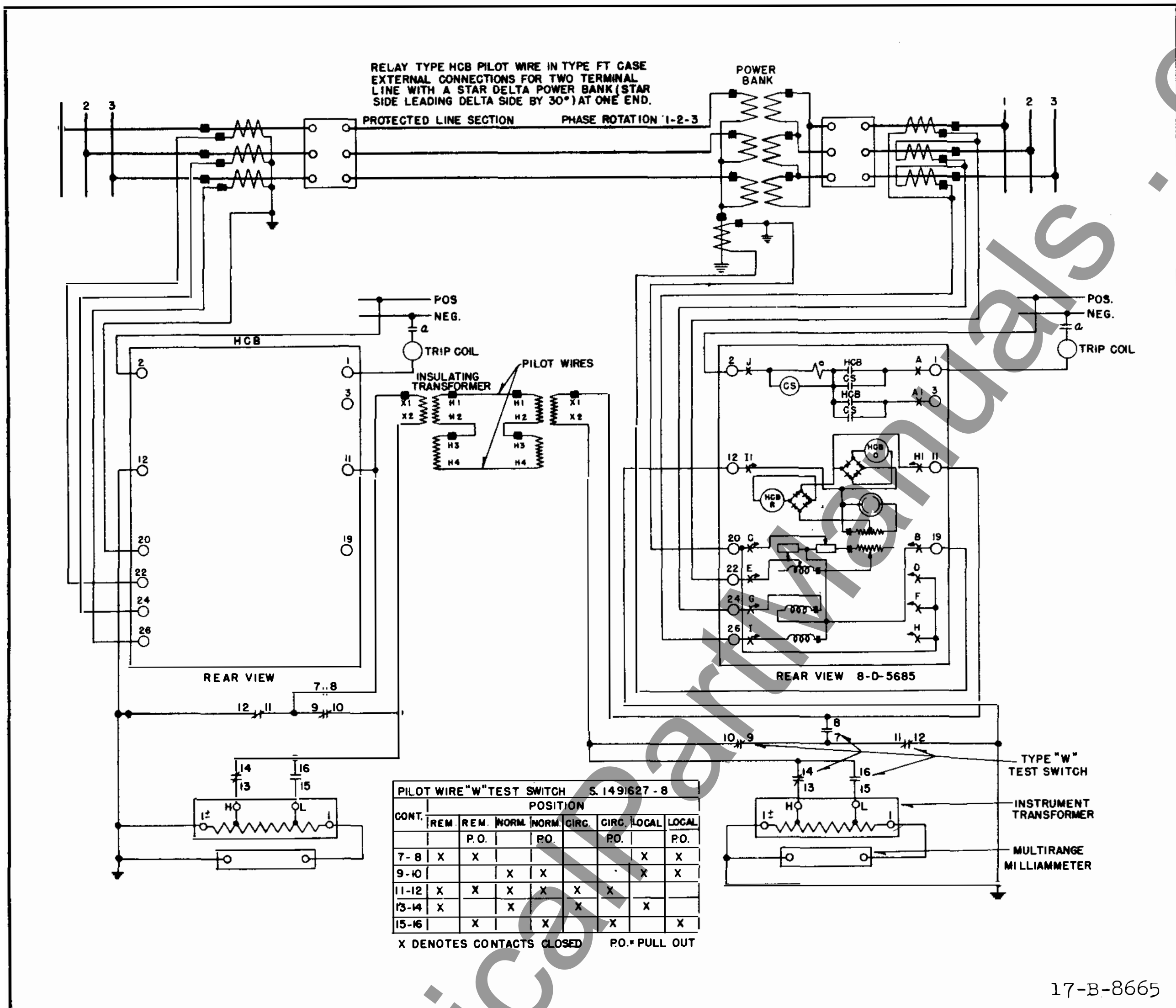


PILOT WIRE "W" TEST SWITCH S. 1491627-8

CONT.	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED

Fig. 10– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of A Three Terminal Line.



PILOT WIRE "W" TEST SWITCH S. 1491627-8								
CONT.	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X DENOTES CONTACTS CLOSED P.O. = PULL OUT

Fig. 11– External Connections of the Type HCB Relay in the Type FT Case For Phase and Ground Protection of a Two Terminal Line With a Transformer Bank.

numerical values of T are the positive sequence currents required to operate the relay when R_1 is set on .10. Therefore, to compensate for the value of R_1 used in the formula, T, must be divided by 0.1 thereby obtaining the factor "5.7".

Where line-to-line currents are not known, an alternate equation can be used.

The alternate equation is:

$$T = (5.7)\ (.86)\ (I_{3\phi})\ R_1 \qquad (10)$$

where $I_{3\phi}$ is the total minimum internal three phase secondary fault current fed from all terminals divided by the number of terminals. The factor ".86" is used as line-to-line fault current is 86% of the three phase fault current when the negative sequence impedance of the system equals the positive sequence impedance of the system.

Equation (9) and (10) give the upper limit of "T" which must not be exceeded to obtain operation on the line-to-line faults. The actual setting should always be below the values obtained from equation (9) or (10). The minimum limits for this setting are discussed below.

The setting of "T" which will cause operation on load current if the pilot wires become accidentally open circuited is given by the equation:

$$T = 10\ R_1\ I_{Load} \quad (11)$$

where "I_{Load}" is the maximum secondary full load balanced current flowing through the terminal.

It is generally desirable to select a value of "T" which will not cause operation if the pilot wires are accidentally open circuited. A safety factor of at least 25% is generally recommended to prevent such operations. That is, "T", should be set 25% above the value obtained from equation (11) if the relay is not to operate on load current with the pilot wires open circuited.

This consideration may be neglected if it is realized that relay operation will be obtained if pilot wires are opened during heavy load currents,

Note: "T" must be set the same at all terminals (even where different transformer ratios are used.)

Zero Sequence Tap

The lower tap (R_0) has taps .025, .033, .05, .39, .51, .68, .90, 1.2 and 1.6. (The first two taps are actually marked .02 and .03 because of space limitations). The three lowest taps are not used in applications where high sensitivity to ground faults is required. They are used on special applications where response to positive sequence current only is required. Where such response is required, R_0 is set to equal to 1/3 R_1

Maximum sensitivity to ground faults is obtained with R_0 = 1.6. This setting is generally recommended where current transformers with the same ratio are installed at all terminals. Where current transformers of different ratios are installed at the various terminals, values of R_0 should be selected which are most nearly proprotional to the transformer ratios. When the ratio of the R_0 taps can not be made to exactly match the ratio of the R_1 taps, pick the ratio to match as closely as possible, and use maximum restraint tap.

The minimum tap to obtain operation on minimum ground faults is expressed by the equation:

$$R_0 = \frac{0.2T}{I_g} \quad (12)$$

where I_g is the total minimum secondary ground fault current fed into the section from all terminals (taking into account possible ground fault resistance), divided by the number of terminals, and where "T" is the actual tap selected (not the value calculated from equation (9) or (10).

It is recommended that "R_0" be set as high above the value obtained from equation (12) as possible keeping the value of R_0 approximately proportional to the current transformer ratios.

Restraint Tap

The restraint coil has a tap which permits the entire coil or part of it to be used. The relay is normally shipped with the restraint tap link connected in the maximum restraint position. This link is in the upper left hand corner of the panel carrying the polar element. The link is connected to the left for minimum restraint, and to the right for maximum restraint. Maximum restraint should be used with pilot wires of 1500 to 2000 ohms.

Example of Relay Settings

Assume a two terminal line with current transformers rated 400/5 at station 1 and 300/5 at station 2. Also assume that full load current is 300 amperes, and on **minimum**

internal phase-to-phase faults 2000 amperes feed into the fault from station 1 and 1000 amperes from station 2. Further assume that on minimum internal ground faults, 400 amperes feed into the fault from station 1 and none from station 2.

Positive Sequence Filter Tap

Set R_1 proportional to the transformer ratio. R_1 at station 1 = 0.10, R_1 at station 2 = 0.075.

Positive Sequence Current Tap

From equation (9)

$$T = \frac{5.7 \times 3000 \times 5 \times .1}{400 \times 2} = 10.7$$

or

$$T = \frac{5.7 \times 3000 \times 5 \times .075}{300 \times 2} = 10.7$$

This represents the highest permissable setting. The setting which will cause tripping on load current if the pilot wire becomes accidentally open circuited is given by equation (11).

$$T = \frac{10 \times .1 \times 300 \times 5}{400} = 3.75$$

or

* $$T = \frac{10 \times 0.075 \times 300 \times 5}{300} = 3.75$$

Select T at both stations = 6.

Zero Sequence Tap

The minimum tap which will cause tripping to minimum internal ground faults is given by equation (12).

$$R_o = \frac{0.2 \times 6 \times 400}{200 \times 5} = .48 \text{ at station 1}$$

$$R_o = \frac{0.2 \times 6 \times 300}{200 \times 5} = .36 \text{ at station 2}$$

Select R_o at station 1 = 1.6
And R_o at station 2 = 1.2

RELAYS IN TYPE FT CASE

The type FT cases are dust-proof enclosures combining relay elements and knife-blade test switches in the same case. This combination provides a compact flexible assembly easy to maintain, inspect, test and adjust. There are three main units of the type FT case: the case, cover and chassis. The case is an all welded steel housing containing the hinge half of the knife-blade test switches and the terminals for external connections. The cover is a drawn steel frame with a clear window which fits over the front of the case with the switches closed. The chassis is a frame that supports the relay elements and the contact jaw half of the test switches. This slides in and out of the case. The electrical connections between the base and chassis are completed through the closed knife-blades.

Removing Chassis

To remove the chassis, first remove the cover by unscrewing the captive nuts at the corners. This exposes the relay elements and all the test switches for inspection and testing. The next step is to open the test switches. Always open the elongated red handle switches first before any of the black handle switches or the cam action latches. This opens the trip circuit to prevent accidental trip out. Then open all the remaining switches. The order of opening the remaining switches is not important. In opening the test switches they should be moved all the way back against the stops. With all the switches fully opened, grasp the two cam action latch arms and pull outward. This releases the chassis from the case. Using the latch arms as handles, pull the chassis out of the case. The chassis can be set on a test bench in a normal upright position as well as on its top, back or sides for easy inspection, maintenance and test.

After removing the chassis a duplicate chassis may be inserted in the case or the blade portion of the switches can be closed and the cover put in place without the chassis. The chassis operated shorting switch located behind the short circuiting

test switch prevents open circuiting that circuit when the short circuiting type test switches are closed.

When the chassis is to be put back in the case, the above procedure is to be followed in the reversed order. The elongated red handle switch should not be closed until after the chassis has been latched in place and all of the black handle switches closed.

Electrical Circuits

Each terminal in the base connects thru a test switch to the relay elements in the chassis as shown on the internal schematic diagrams. The relay terminal is identified by numbers marked on both the inside and outside of the base. The test switch positions are identified by letters marked on the top and bottom surface of the moulded blocks. These letters can be seen when the chassis or removed from the case.

The potential and control circuits thru the relay are disconnected from the external circuit by opening the associated test switches. Opening the short circuiting test switch short-circuits that circuit and disconnects one side of the relay coil but leaves the other side of the coil connected to the external circuit thru the current test jack jaws. This circuit can be isolated by inserting the current test plug (without external connections) by inserting the ten circuit test plug, or by inserting a piece of insulating material approximately 1/32" thick into the current test jack jaws. Both switches of the current test switch pair must be open when using the current test plug or insulating material in this manner to short-circuit the current transformer secondary.

A cover operated switch can be supplied with its contacts wired in series with the trip circuit. This switch opens the trip circuit when the cover is removed. This switch can be added to the existing type FT cases at any time.

Testing

The relays can be tested in service, in the case but with the external circuits isolated or out of the case as follows:

Testing In Service

The ammeter test plug can be inserted in the current test jaws after opening the knife-blade switch to check the current thru the relay. This plug consists of two conducting strips separated by an insulating strip. The ammeter is connected to these strips by terminal screws and the leads are carried out thru holes in the back of the insulated handle.

Voltages between the potential circuits can be measured conveniently by clamping #2 clip leads on the projecting clip lead lug on the contact jaw.

Testing In Case

With all blades in the full open position, the ten circuit test plug can be inserted in the contact jaws. This connects the relay elements to a set of binding posts and completely isolates the relay circuits from the external connections by means of an insulating barrier on the plug. The external test circuits are connected to these binding posts. The plug is inserted in the bottom test jaws with the binding posts up and in the top test switch jaws with the binding posts down.

The external test circuits may be made to the relay elements by #2 test clip leads instead of the test plug. When connecting an external test circuit to the current elements using clip leads, care should be taken to see that the current test jack jaws are open so that the relay is completely isolated from the external circuits. Suggested means for isolating this circuit are outlined above, under "Electrical Circuits."

Testing Out of Case

With the chassis, removed from the base,

relay elements may be tested by using the ten circuit test plug or by #2 test clip leads as described above. The factory calibration is made with the chassis in the case and removing the chassis from the case will change the calibration values by a small percentage. It is recommended that the relay be checked in position as a final check on calibration.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay vertically by means of the two mounting studs for the standard cases 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.

The relay is shipped with the operation indicator and the contactor switch connected in parallel. This circuit has a resistance of approximately 0.25 ohm and is suitable for all trip currents above 2.25 amperes d-c. If the trip current is less than 2.25 amperes, there is no need for the contactor switch and it should be disconnected. To disconnect the coil, remove the short lead to the coil on the front stationary contact of the contactor switch. This lead should be fastened (dead ended) under the small fillister-head screw located in the Micarta base of the contactor switch. The operation indicator will operate for trip currents above 0.2 amperes d-c. The resistance of its coil is approximately 2.8 ohms.

ADJUSTMENTS AND MAINTENANCE

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if 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.

CAUTION 1. Make sure that the neon lamp is in place, whenever relay operation is being checked. This is required to limit distortion in pilot wire voltage wave.

2. When changing taps under load the spare tap screw should be inserted before removing the other tap screw.

Sequence Filter

There are no adjustments to be made in the zero sequence resistor. The taps on the R_1 resistor are adjustable, however, but this is a factory calibration which should not ordinarily be disturbed. To check the positive sequence current filter, pass a current $I = 6.94$ amperes through a pair of phase terminals, for example, in at phase B, out of phase C (see Figure 2) and measure the open circuit filter voltage with a high resistance voltmeter. This may be done by removing the positive sequence current tap screw, T, and connecting the voltmeter across the open circuit thus formed. The voltage should be $8R_1$ plus or minus 5% for each of the three phase-to-phase combinations, AB, BC, or CA. For example, at $I = 6.94$ amperes and $R_1 = .1$, the voltage should be 0.8 volts.

Polar-Type Element

Contact Adjustment: Adjust the left-hand (front view) contacts until they just make a light circuit, when the armature rivet touches the left-hand pole face. Give both the left-hand contact screws four to five additional turns, and lock in position with the lock nuts provided. This moves the armature rivet away from the left-hand pole face and provides

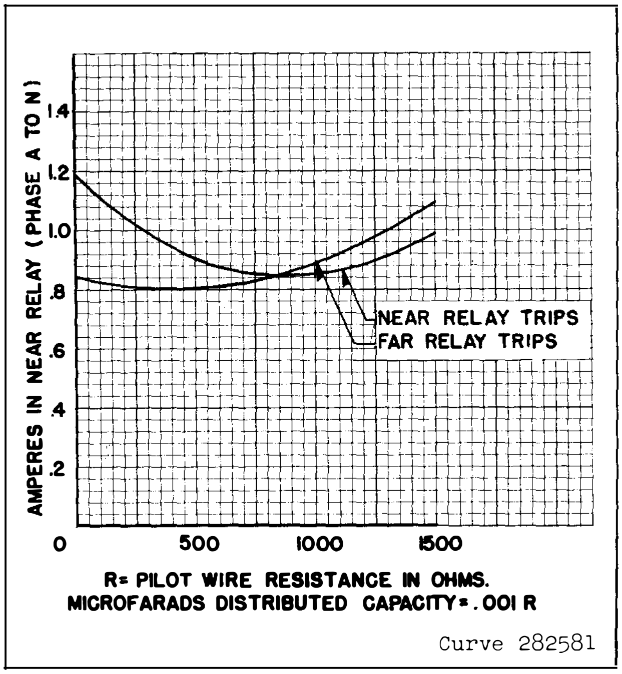


Fig. 12—Typical Curves Showing the Effect of Pilot Wires Resistance and Capacitance on Minimum Trip Current With Minimum Restraint.

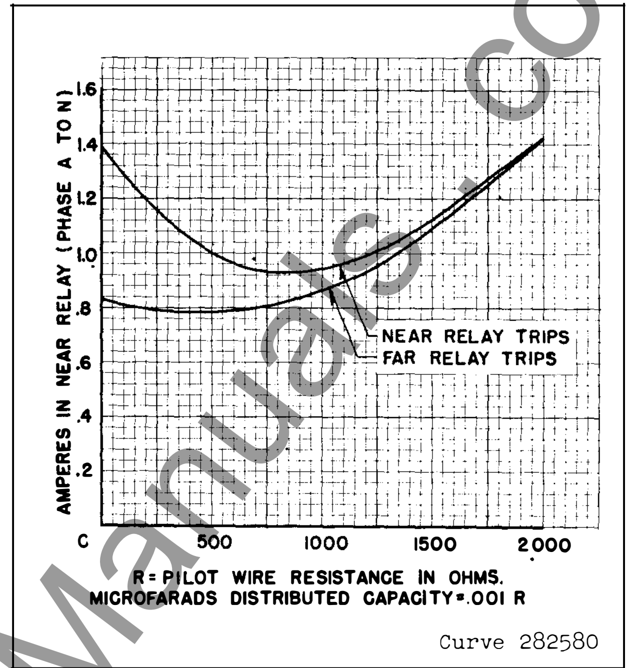


Fig. 13—Typical Curves Showing the Effect of Pilot Wire Resistance and Capacitance on Minimum Trip Current With Maximum Restraint.

contact follow. Now adjust the right-hand backstop screws until they just touch the moving contacts when the moving contacts are in the contact closing position as above. Back off each backstop screw two turns and lock in position.

Calibration: Connect the restraint tap link in the position in which it will be used. Connect the low voltage terminals of the insulating transformer across the pilot wire terminals of the relay. Connect the relay taps on T = 4, R_1 = .1, R_o = 1.6.

Adjust the right-hand magnetic shunt in or out as required, until the relay just closes contacts at 6.9 to 7.0 amperes phase B to phase C current. When this adjustment has been made, change the input current connections to phase A to neutral. The relay should trip for phase A to neutral current between .45 and .55 ampers.

The above is given as a laboratory calibration on an individual relay with its insulating transformer. This does not take into consideration the characteristics of the pilot wire circuit between the relays.

Figures 13 and 14 show typical variations of minimum trip current for various lengths of pilot wire circuits up to the limiting values of 1500 ohms for relays operating on minimum restraint (Fig. 13) and 2000 ohms for relays operating on maximum restraint (Fig. 14).

For these curves, both relays are set on taps T = 4, R_1 = 0.1, R_o = 1.6. Each relay is originally calibrated to trip on a current of .47 amperes, phase A to neutral, with the high side of the insulating transformer open-circuited. This value of current is equivalent in the relay filter to 4 amperes positive sequence only, with the taps as specified above.

Restraining Coil: The effectiveness of the restraining coil of the relay element, and the performance of the Rectox units, may be checked as follows, if desired. Connect a variable non-inductive resistor across the high voltage terminals of the insulating transformer, and connect d-c milliammeters in series with the operating and restraining coils of the element, by opening these circuits at the test links provided for this purpose. These milliammeters should have low resistance, and should be capable of reading in the order of 20 to 25 ma. in the operating coil and 100 to 150 ma. in the restraining circuit. Using T = 4, R_1 = .1, R_o = 1.6, pass 10 amperes 60 cycles from phase A to Neutral in the relay, and increase the variable resistance across the insulating transformer high voltage terminals until the relay just trips. This should be in the order of 1400 to 2000 ohms when maximum restraint is used. Read the d-c current (milliamperes) in the operating and restraining coils at this point. The values obtained should conform substantially to the following equations.

For Minimum Restraint

$$I_O = .12\ I_R + 8$$

For Maximum Restraint

$$I_O = .16\ I_R + 8$$

where I_O and I_R are operating and restraining coil currents, respectively, in milliamperes. The results are subject to slight variations between individual relays.

The polarity of the connections to the pilot wires, and the correct "Phasing out" of A, B, C phases at the two stations may be checked by the six tests outlined on Page 17.

Pilot Wire Current

The pilot wire current which should flow under normal load conditions is given in Figures 4 and 5. If the relay taps in use differ from those indicated in these figures, suitable conversion factors must be used. The pilot wire current will vary inversely with T and directly with R_1.

Contactor Switch

Adjust the stationary core of the switch for a clearance between the stationary core and the moving core of 1/64" when the switch is picked up. This can be done by turning the relay up-side-down or by disconnecting the switch and turning it up-side-down. Then screw up the core screw until the moving core starts rotating. Now, back off the core screw until the moving core stops rotating. This indicates the points where the play in the assembly is taken up, and where the moving core just separates from the stationary core screw. 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" by means of the two small nuts on either side of the Micarta disc. The switch should pick up at 2 amperes d-c. Test for sticking after 30 amperes d-c have been passed through the coil.

Operation Indicator

Adjust the indicator to operate at 0.2 ampere d-c gradually applied by loosening the two screws on the under side of the assembly, and moving the bracket forward or backward. If the two helical springs which reset the armature are replaced by new springs, they should be weakened slightly by stretching to obtain the 0.2 ampere calibration. The coil resistance is approximately 2.8 ohms.

ENERGY REQUIREMENTS

The volt-ampere burden of the type HCB relay is practically independent of the pilot wire resistance and of the current tap used. The following burdens were measured at a balanced three - phase current of 5 amperes:

For tap 4 R_1 = .075 and R_o = .39

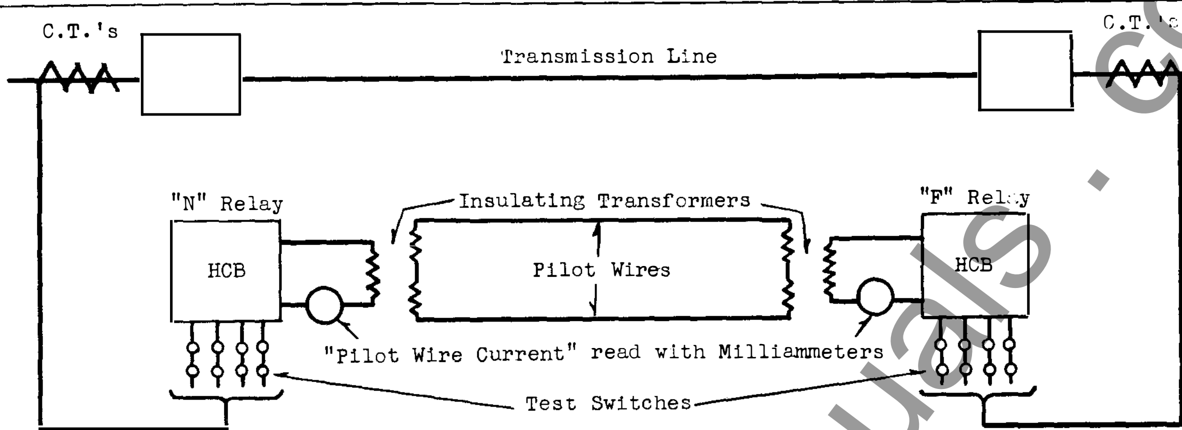
Phase A	1.25 volt-amperes	0°
Phase B	.30 volt-amperes	285°
Phase C	.90 volt-amperes	45°

For tap 4 R_1 = .15 and R_o = 1.6

Phase A	2.3 volt-amperes	120°
Phase B	4.6 volt-amperes	285°
Phase C	5.3 volt-amperes	45°

The angles above are the degrees by which the current lags its respective voltage.

The two second overload ratings of the relay are 150 amperes phase and 125 amperes ground currents.



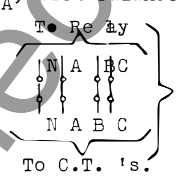
Note: The line should be carrying through load current amounting to at least 1.5 amperes as measured in the secondary of the Current Transformers. This test is based on the ratio of the C.T.'s being the same at each end of the line, in which case set the taps of both relays to $R_1 = .1$; $R_0 = 1.6$; $T = 4$ for this test.

Test No.	RELAY "N"					RELAY "F"				
	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay F	Test Switch	Relay Current	Relay Trip	"Pilot Wire Current" Circulating	"Pilot Wire Current" Relay N
1		A,B,C,N	No	(1)	(1)		A,B,C,N	No	(1)	(1)
2		A,C,B,N	No	(2)	(2)		A,C,B,N	No	(2)	(2)
3		A,N	Yes	(3)	(0)		0	Yes	(3)	(3) (4)
4		0	Yes	(3)	(3) (4)		A,N	Yes	(3)	(0)
5		A,N	No	(3)	(3)		A,N	No	(3)	(3)
6		A,N	Yes	(6)			B,C,N	Yes	(6)	

REMARKS

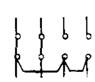
Tests 1 and 2 are to check normal positive sequence rotation of phases. The test switch connections of test #2 may be made readily with relays in the Flexitest case by using clip leads and insulating barriers in the ammeter test jacks. However, care should be used to avoid accidentally open-circuiting the current transformer circuits.
Tests 3 and 4 simulate internal Phase A to Ground fault with single end feed.
Test 5 simulates an external Phase A to Ground fault. (5)
Test 6 simulates an internal Phase A to Ground fault, with equal feed from the two ends, since $I_B + I_C = - I_A$, with balanced load.

LEGEND OF TEST SWITCH SYMBOLS:



Normal Connection. All Currents to Relay.

EXAMPLE



Phase A current from C.T.'s to Relay. Phase B and C C.T.'s shorted to neutral.

(1) The "pilot wire current" will vary depending upon the magnitude of the through load current and the characteristics of the pilot wire. See Figures 4 and 5.
(2) Since the relay is temporarily connected for negative sequence, it should have practically zero output in this test.
(3) These readings may be "off scale" depending upon the magnitude of the load current.
(4) The relay at this station should reset when the "far" current is being read because the local relay will be receiving no current from either the pilot wire or the current transformers.
(5) Test 4 and 5 can be repeated using phase B to neutral current, and again with phase C to neutral current, but this is not strictly necessary on the basis that, having proved the phase sequence with tests 1 and 2, and having proved the correspondence of phase A at the two ends of the line with test 5, then phases B and C must be correct.
(6) Some pilot wire current will be read, depending upon the magnitude of the distributed capacity of the pilot wire in combination with the magnetizing impedance of the insulating transformer.

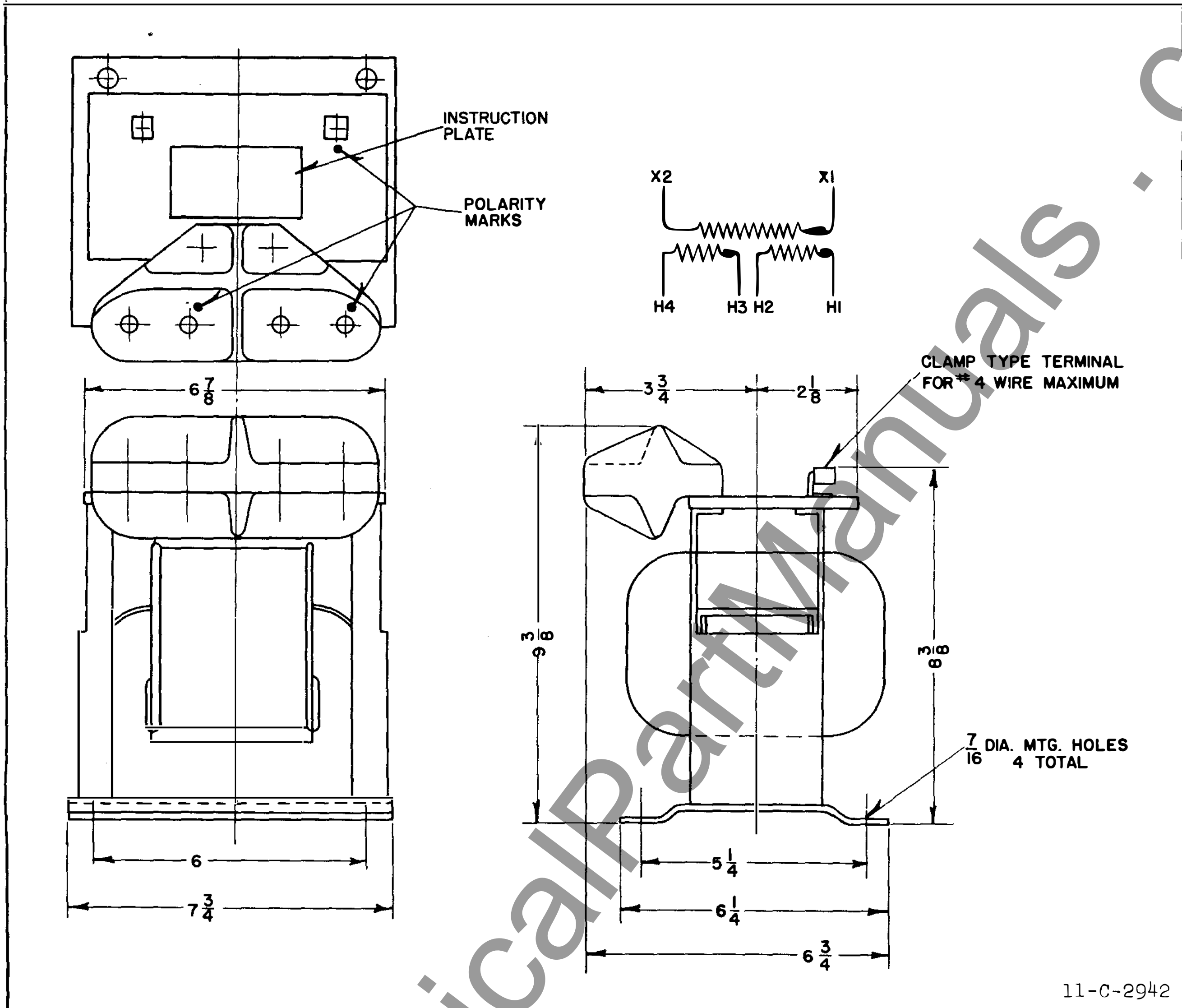


Fig. 14—Outline and Drilling Plan of the Insulating Transformer. For Reference Only.

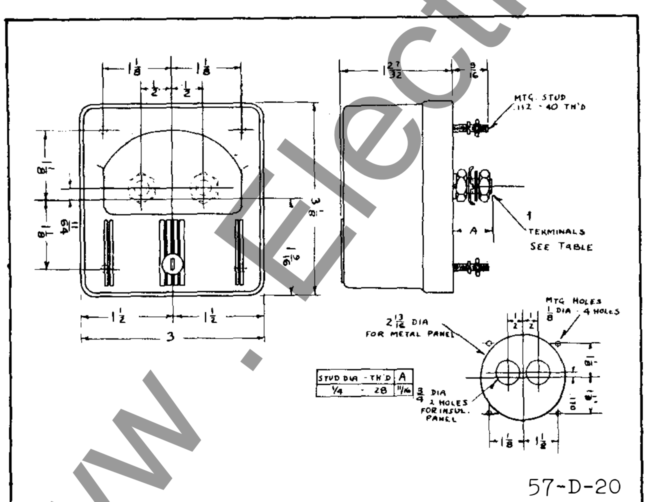


Fig. 15—Outline and Drilling Plan of the Projection Type Test Milliammeter. For Reference Only.

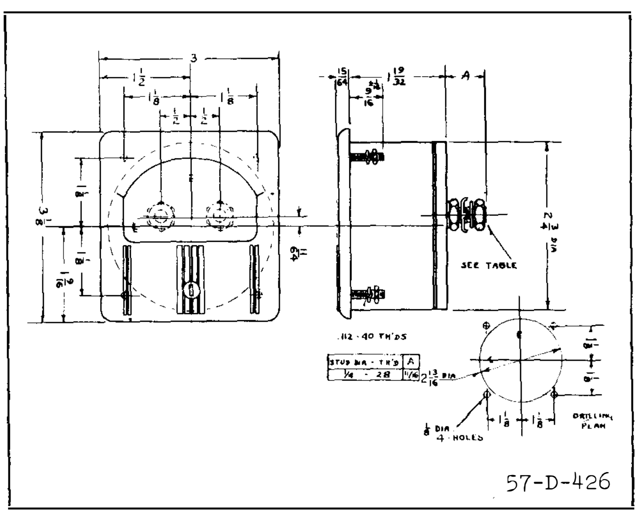


Fig. 16—Outline and Drilling Plan of the Semi-flush Type Test Milliammeter. For Reference Only.

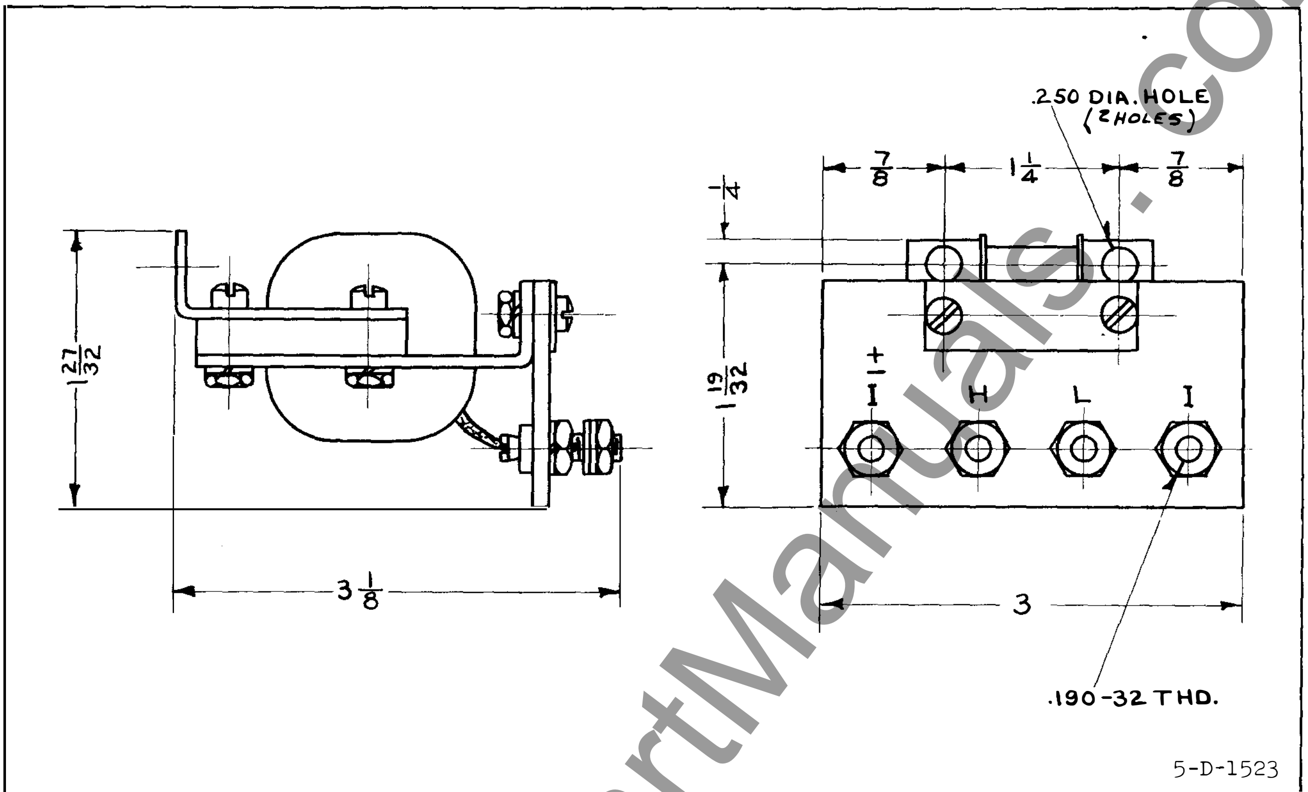
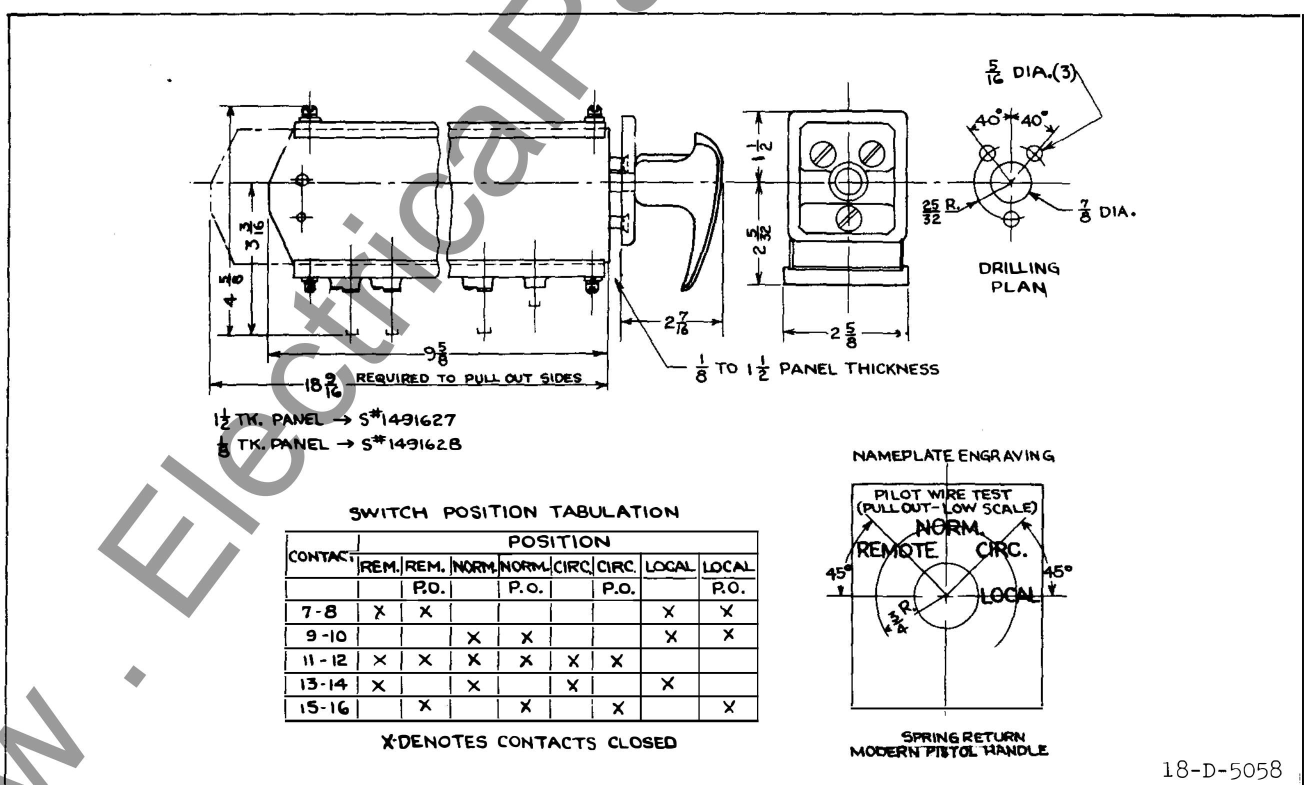


Fig. 17—Outline of the Test Milliammeter Auxiliary Transformer. For Reference Only.



SWITCH POSITION TABULATION

CONTACT	POSITION							
	REM.	REM. P.O.	NORM.	NORM. P.O.	CIRC.	CIRC. P.O.	LOCAL	LOCAL P.O.
7-8	X	X					X	X
9-10			X	X			X	X
11-12	X	X	X	X	X	X		
13-14	X		X		X		X	
15-16		X		X		X		X

X-DENOTES CONTACTS CLOSED

Fig. 18—Outline and Drilling Plan of the Type W Test Switch. For Reference Only.

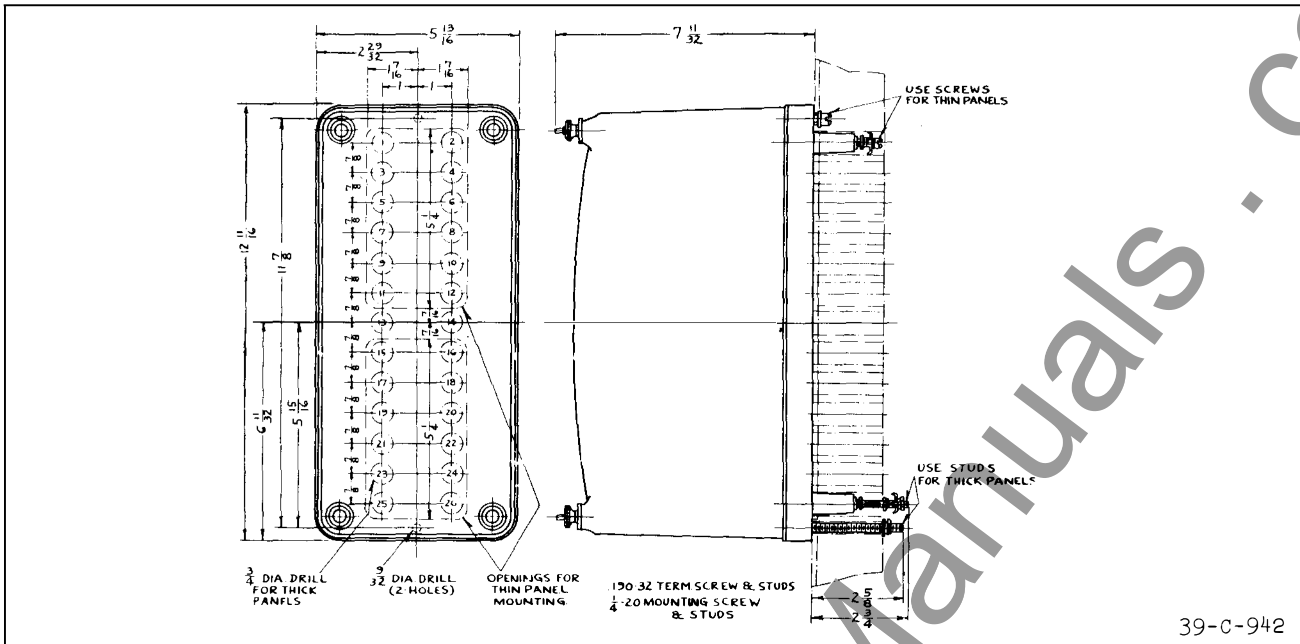


Fig. 19—Outline and Drilling Plan For the Projection Type Standard Case. See the Internal Schematics For The Terminals Supplied. For Reference Only.

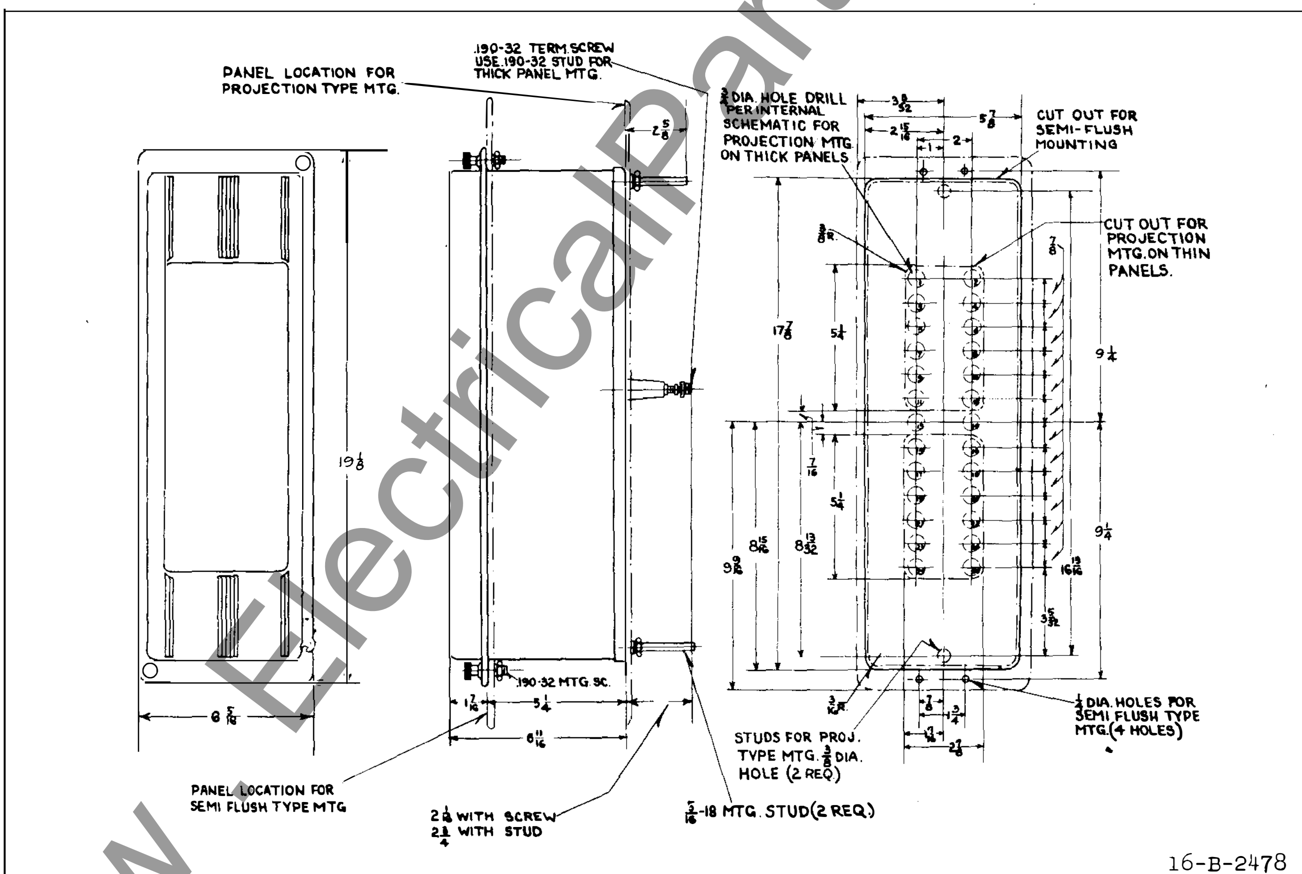


Fig. 20—Outline and Drilling Plan for the M-20 Projection or Semi-Flush Type FT Case. See the Internal Schematic for the Terminals Supplied. For Reference Only.