INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11B
*Denotes changes from superseded issue.

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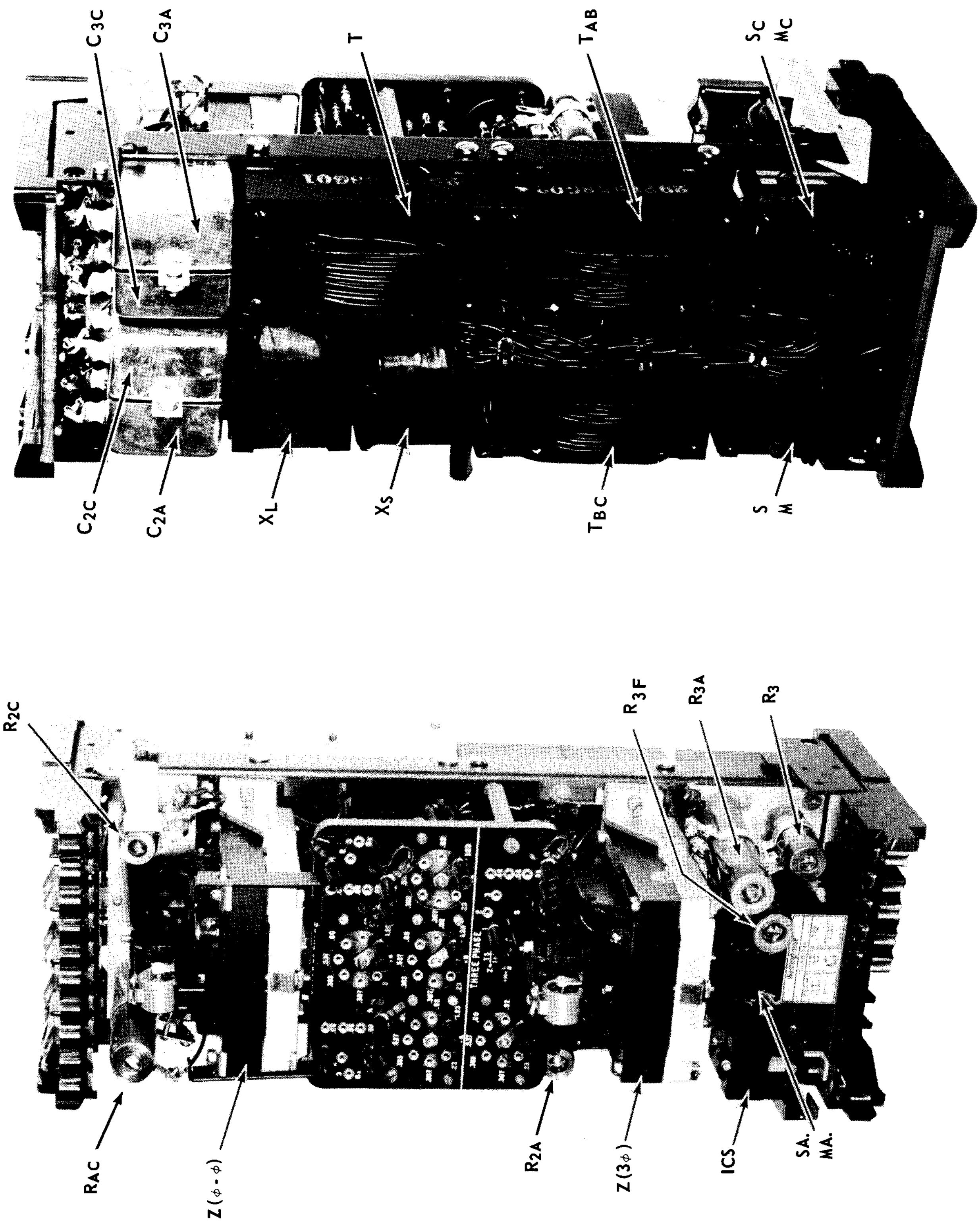


(Rear View)

(Front View)

Fig. 1 Type KD-4 Relay Without case

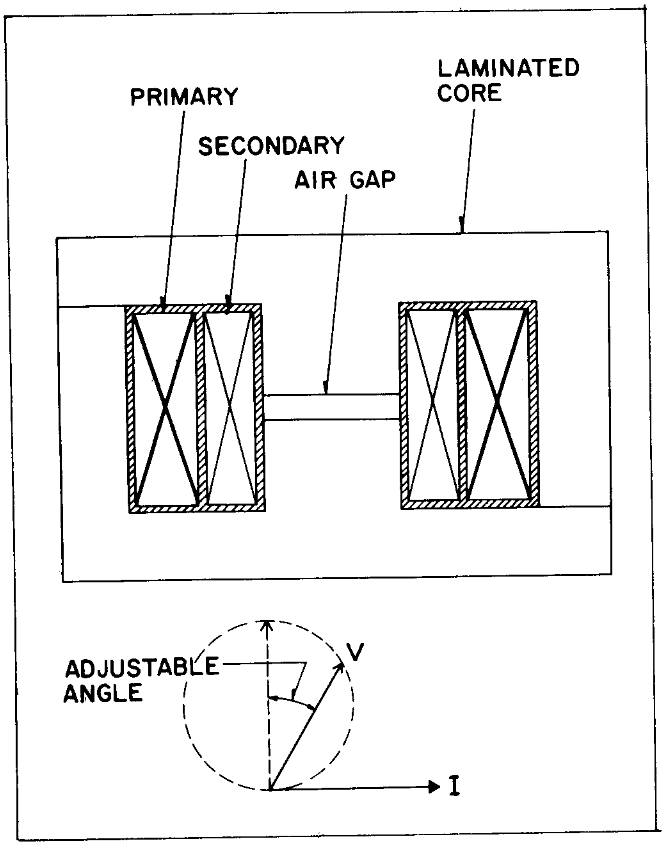


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

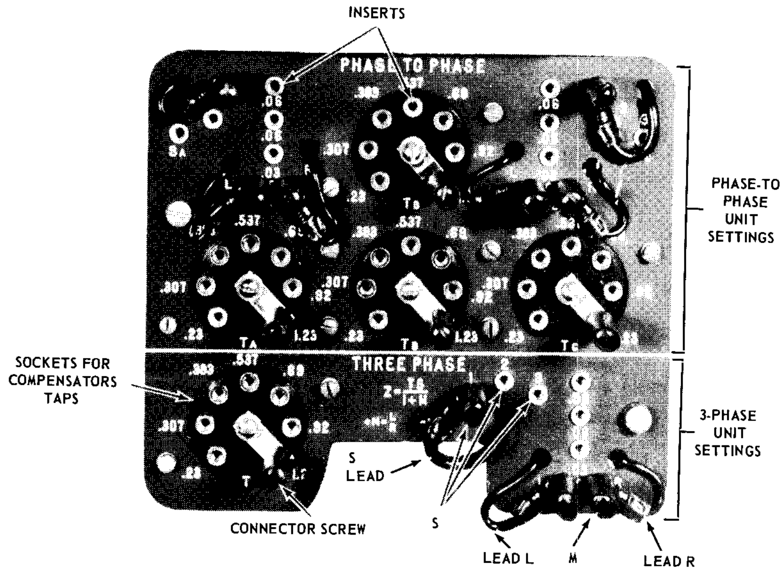


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

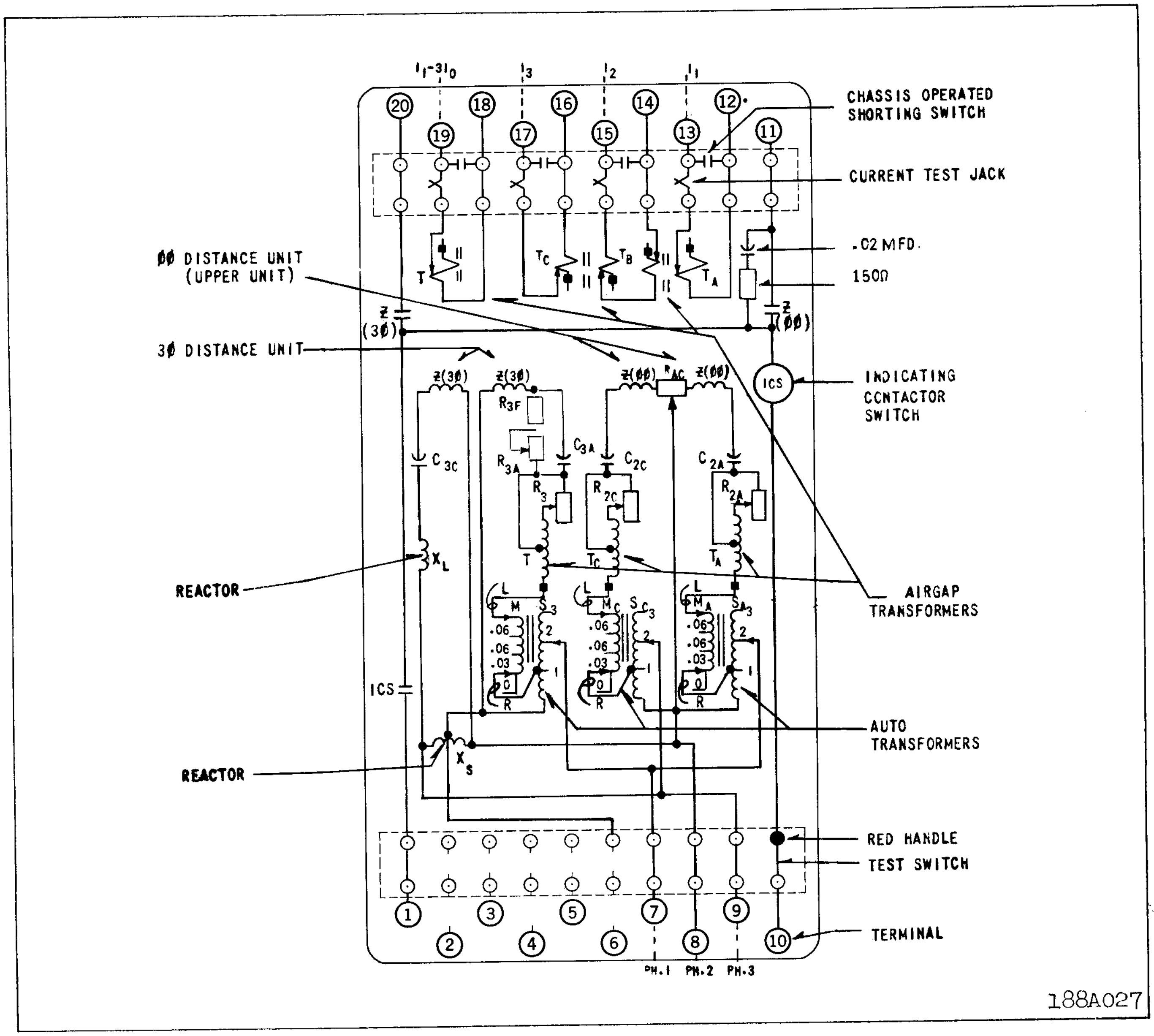


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

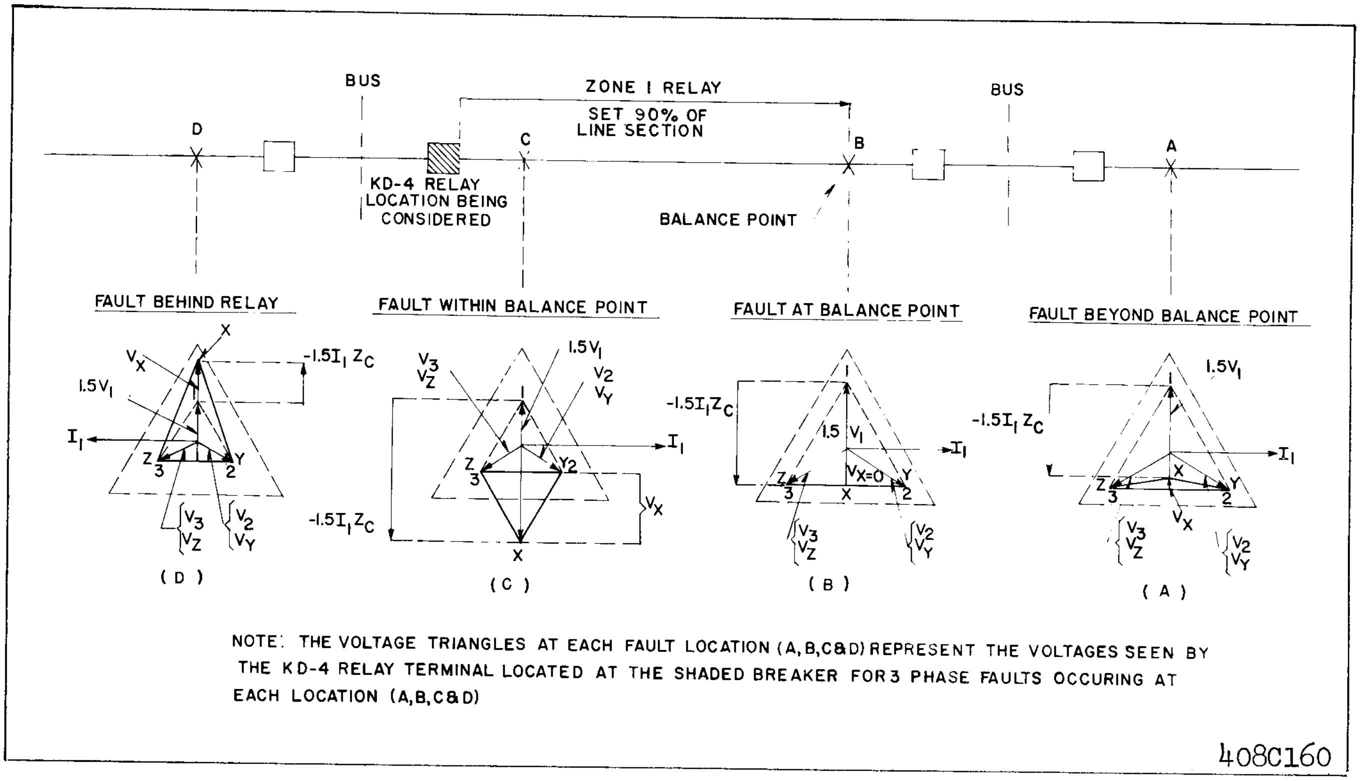


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

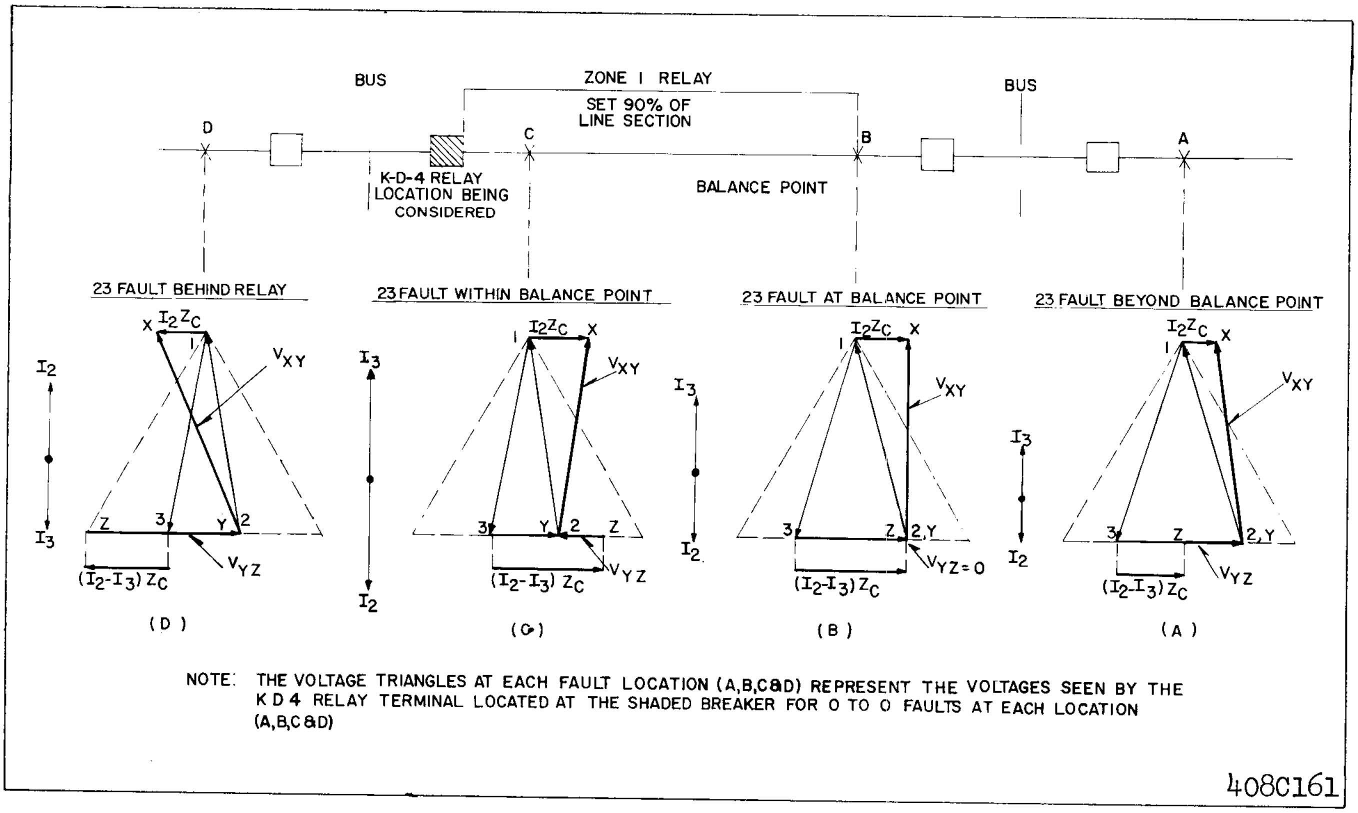


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

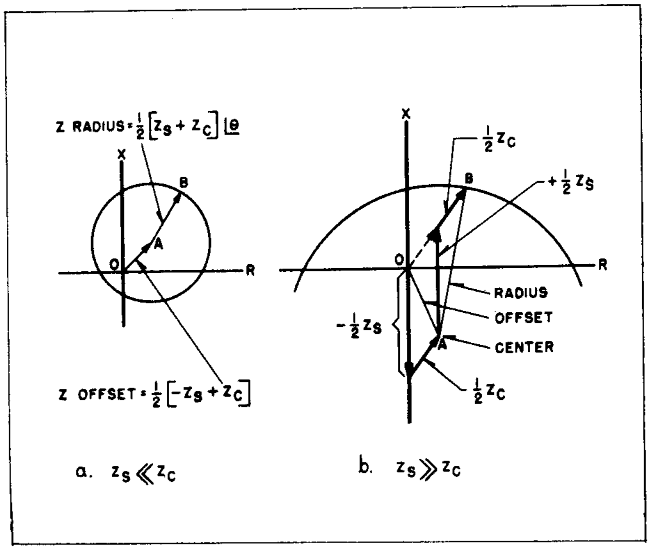


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

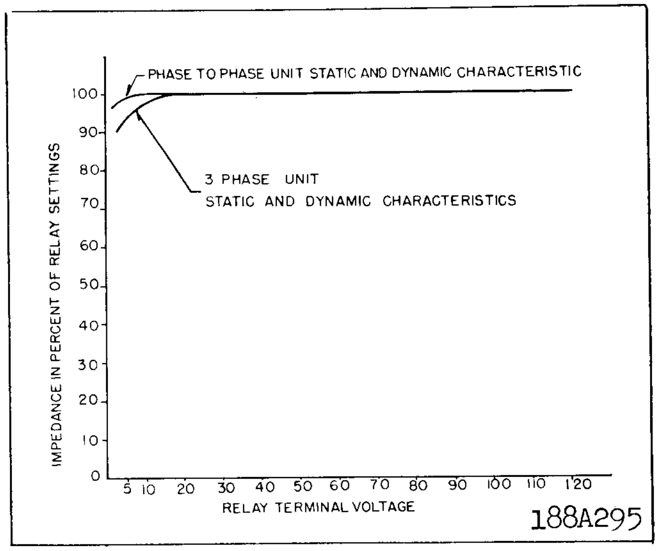


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

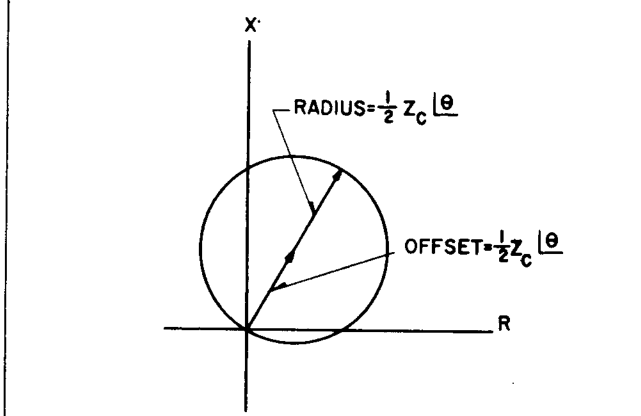


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Y-Z sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

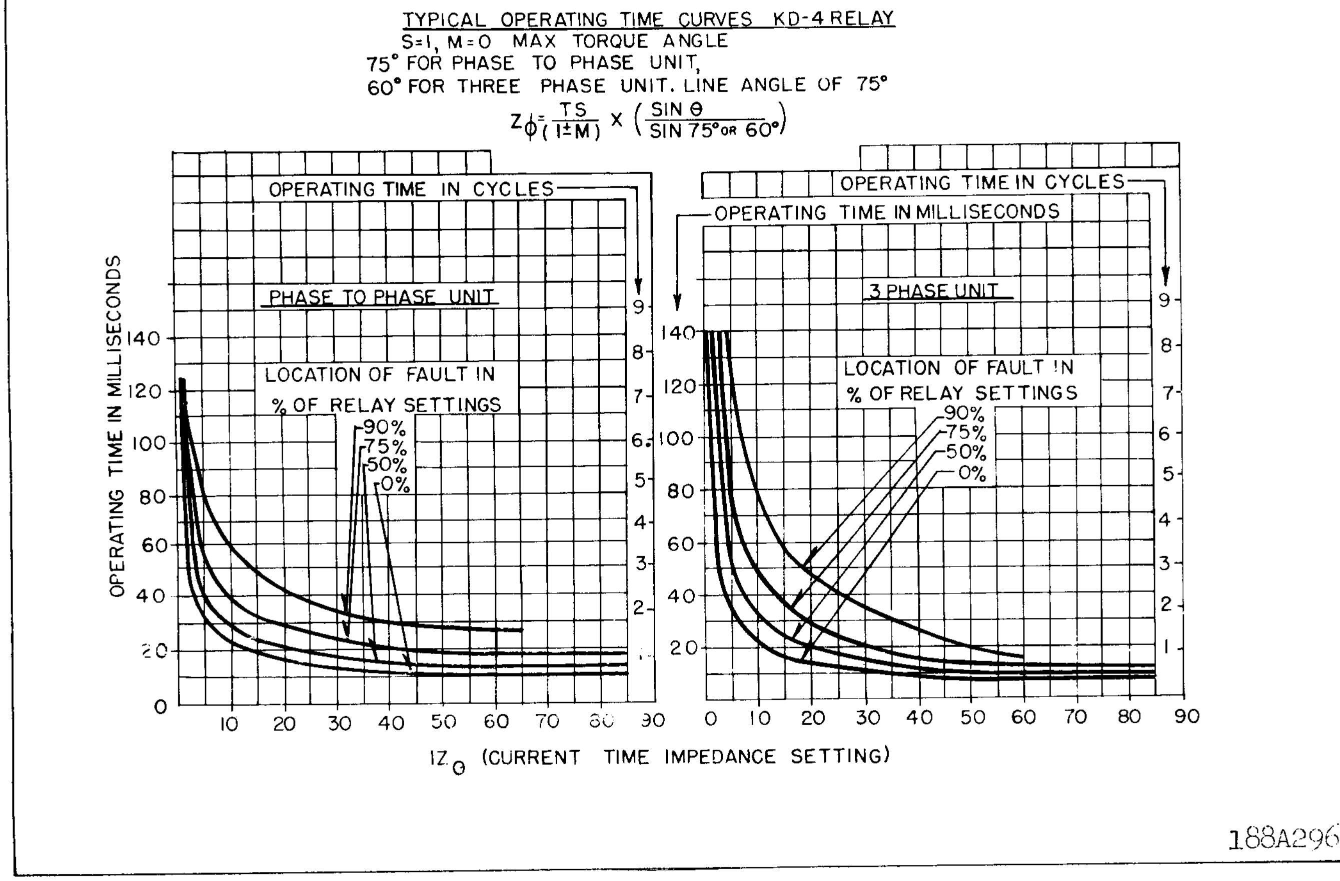


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

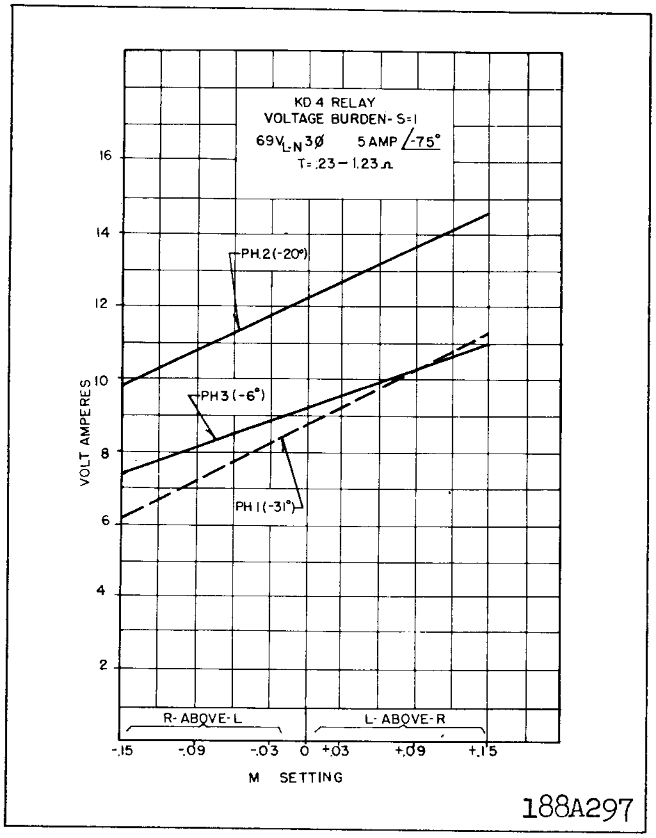
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

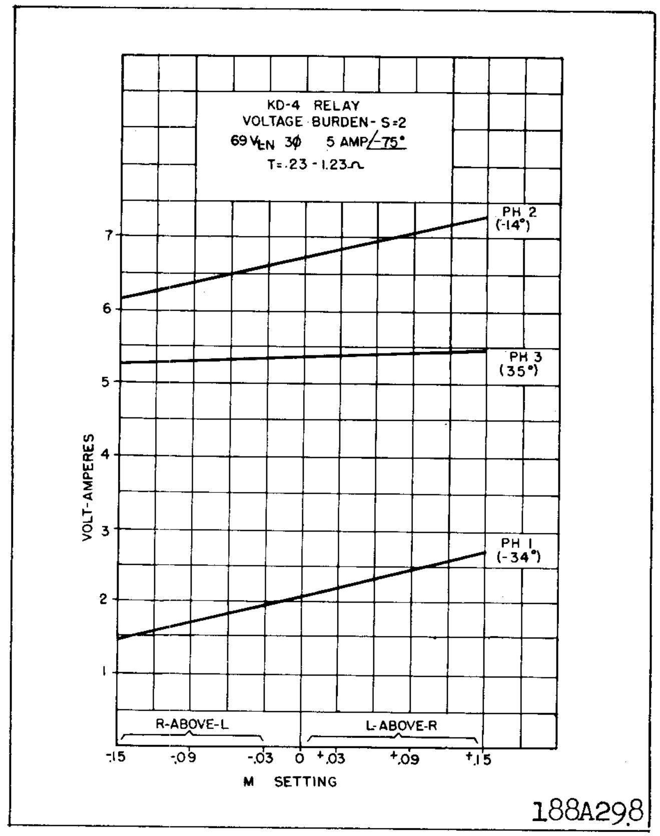
Distance Characteristic - 3 Phase Unit

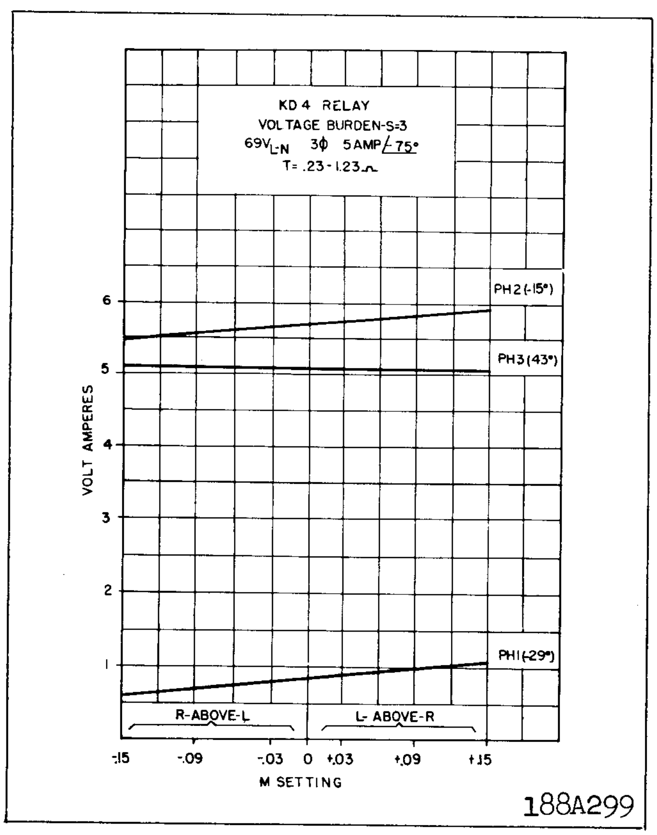
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT 69V_{L-N}, S=1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1 VA	PHASE 1 VARS	PHASE 1 WATTS	PHASE 2 VA	PHASE 2 VARS	PHASE 2 WATTS	PHASE 3 VA	PHASE 3 VARS	PHASE 3 WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z_θ varies with the maximum torque angle θ, as follows:

$$Z_\theta = \frac{TS \sin\theta}{(1 \pm M) \sin\alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, TA, T_B, and T_C)
.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)		
1	2	3

	(M, M_A, M_C)		
±Values between taps	.03	.06	.06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C

.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C

1 2 3

M, M_A, M_C

.03 .06 .06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°)

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

* θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_V = potential transformer ratio

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ

   * b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ should be different from the factory setting multiply the Z_θ – value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.

2. Now refer to the Table I.

   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.

   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).

   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.

   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ is 1.7 ohms at 60°. Making correction for maximum torque angle of the line (60°) that is different from factory setting of 75° the relay setting, Z should be Z = 1.7 x 1.11 = 1.89 ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

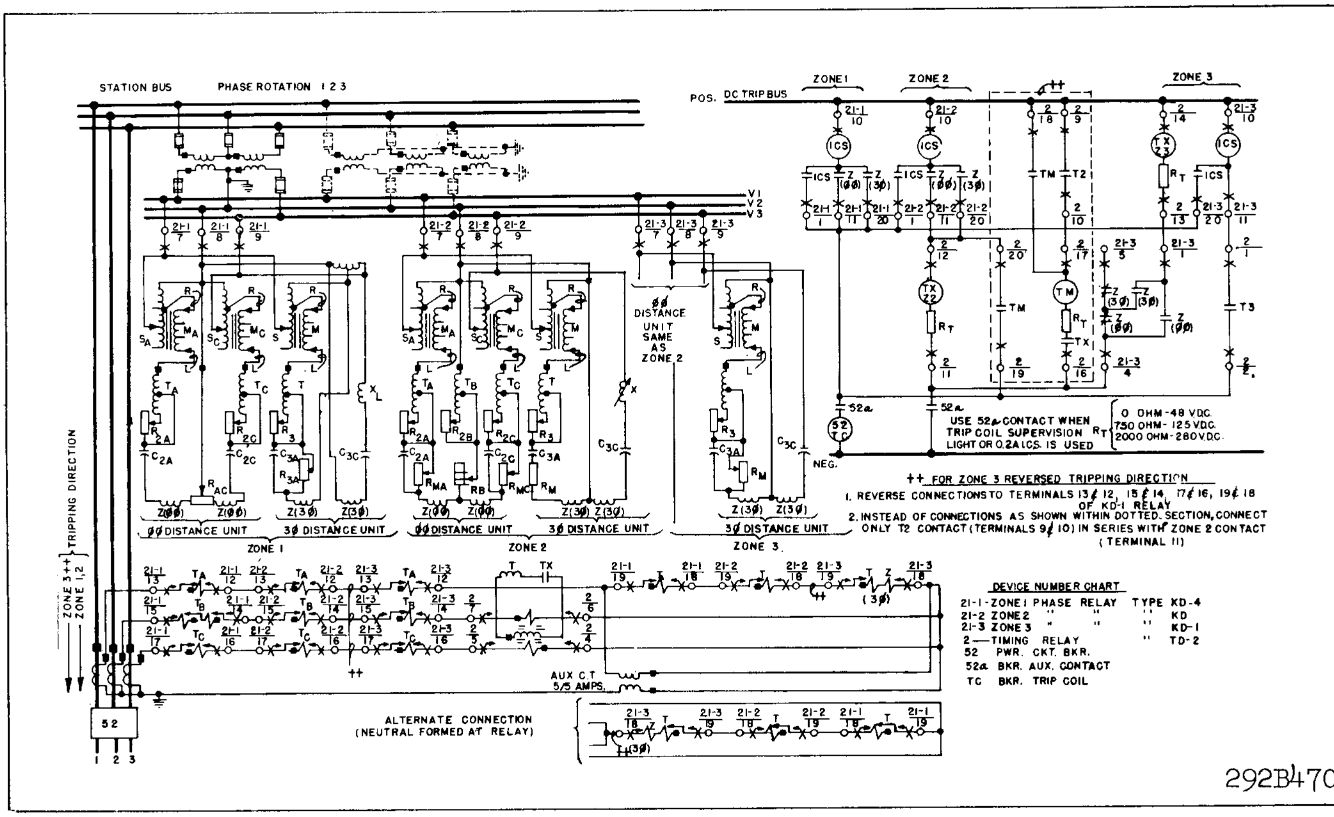
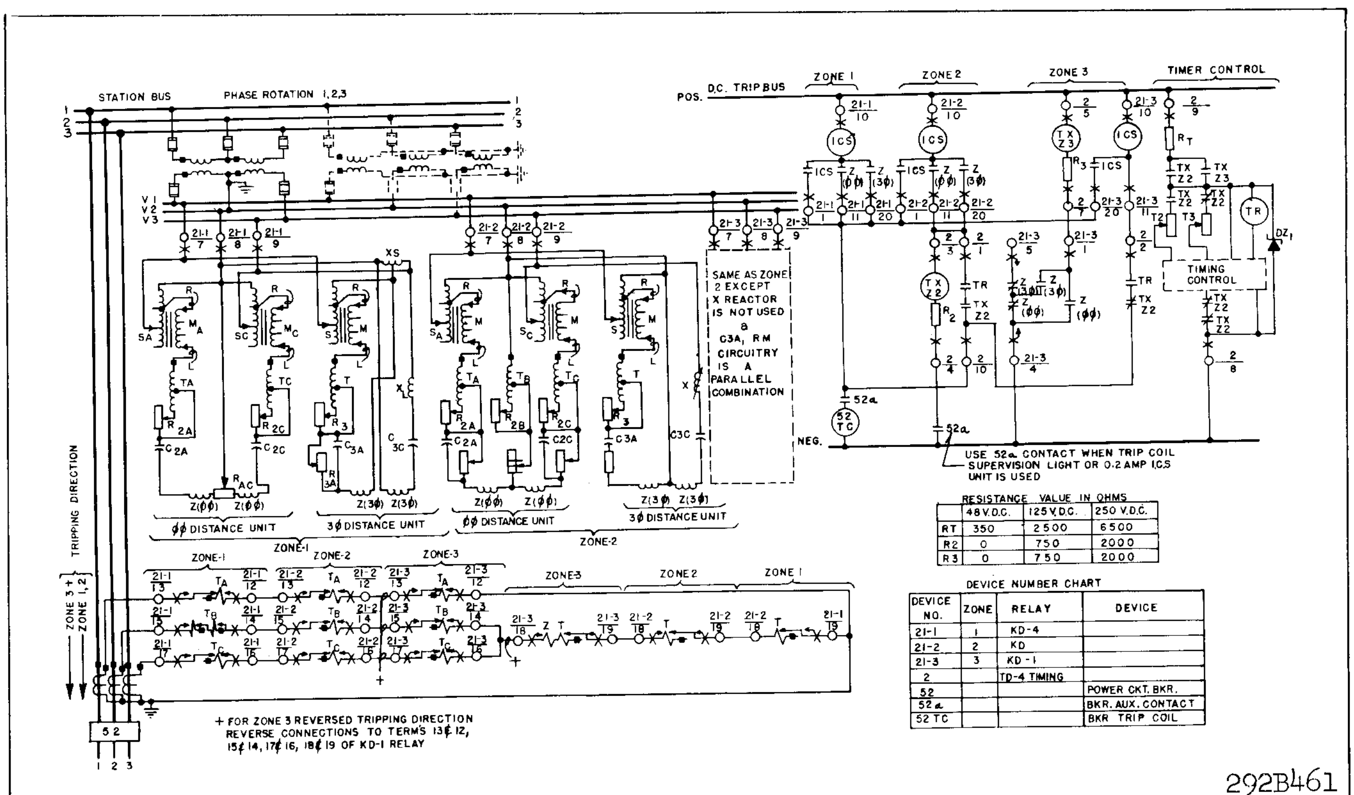


Fig. 12 External Schematic of Type KD-4, KD and KD-1 Relays with Type TD-2 Timing Relay.



RESISTANCE VALUE IN OHMS

	48 V.D.C.	125 V.D.C.	250 V.D.C.
RT	350	2500	6500
R2	0	750	2000
R3	0	750	2000

DEVICE NUMBER CHART

DEVICE NO.	ZONE	RELAY	DEVICE
21-1	1	KD-4	
21-2	2	KD	
21-3	3	KD-1	
2		TD-4 TIMING	
52			POWER CKT. BKR.
52a			BKR. AUX. CONTACT
52 TC			BKR TRIP COIL

Fig. 13 External Schematic of Type KD-4, KD and KD-1 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2
T = .920
M = –.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or
$$Z_{60^\circ} = Z \frac{\sin 60^\circ}{\sin 75^\circ} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line impedance angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. Then the relay setting Z should be $= Z = Z_\theta \cdot \frac{\sin 60^\circ}{\sin \theta} = 1.7 \times 1.225 = 2.08$

a) The nearest table value is 2.09

b) From the Table I read off
S = 2
T = .920
M = – .12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or
$$Z_{45^\circ} = Z \frac{\sin 45}{\sin 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from –.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (–) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	
	.205	.274	.341	.479	.615	.822	1.100	—	1.64	2.20	—	3.29	+.12		Upper .06	.03	
	.211	.282	.350	.493	.632	.843	1.120	—	1.69	2.24	—	3.38	+.09		Lower .06	0	"L" over "R"
	.217	.290	.361	.506	.650	.869	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower .06	
	.224	.298	.371	.521	.670	.892	1.191	—	1.78	2.38	—	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	
	.237	.317	.395	.552	.713	.948	1.270	—	1.90	2.54	—	3.80		-.03	0	.03	
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	—	3.93		-.06	Lower .06	Upper .06	
	.253	—	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower .06	"R" over "L"
	.261	—	.435	—	.785	1.048	1.395	1. -	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	—	.450	—	—	—	1.45	—	—	2.90	—	4.35		-.15	0	Upper .06	

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting, or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

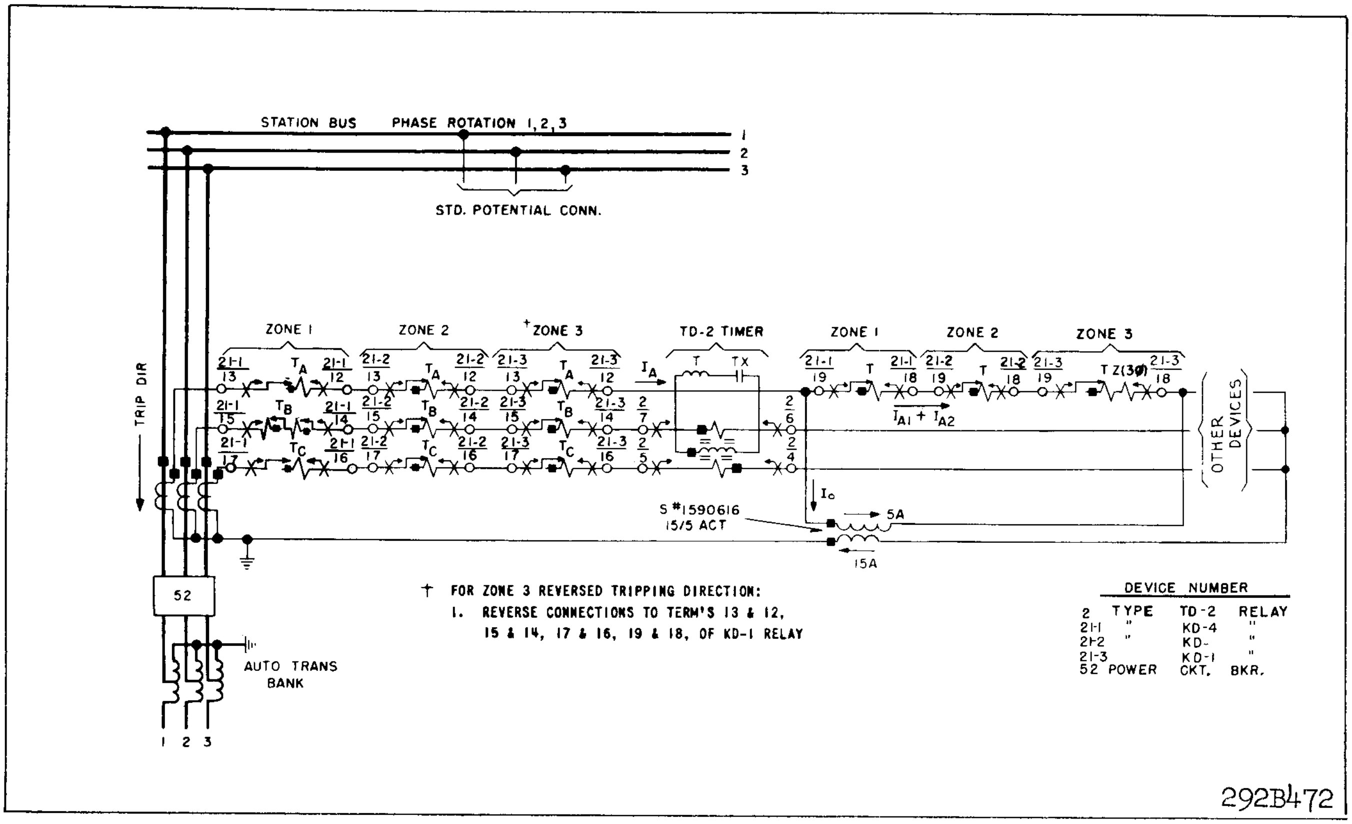


Fig. 14 A.C. External Schematic of Type KD-4, KD and KD-1 Relays with Type TD-2 Timing Relay-Auto-transformer Termination.

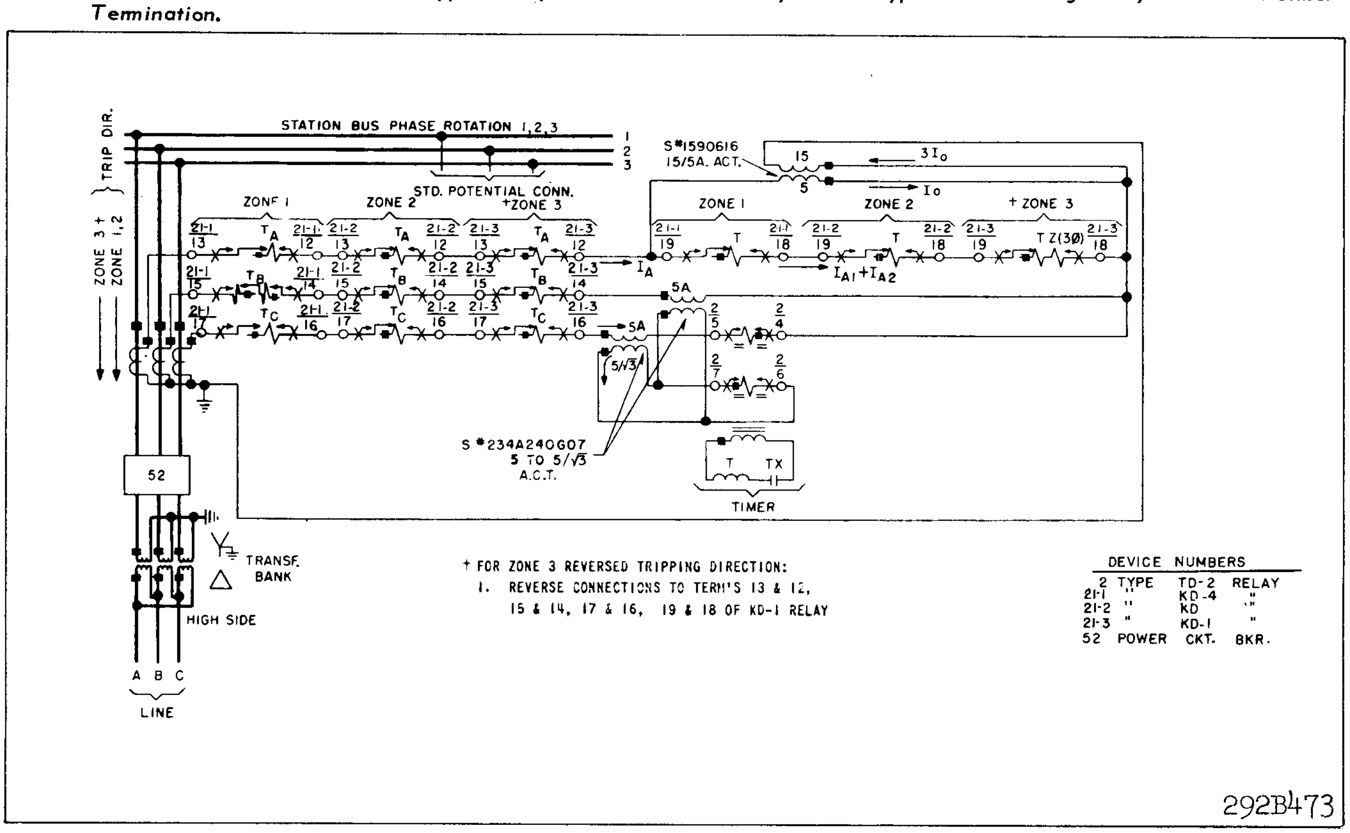


Fig. 15 A.C. External Schematic of Type KD-4, KD and KD-1 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

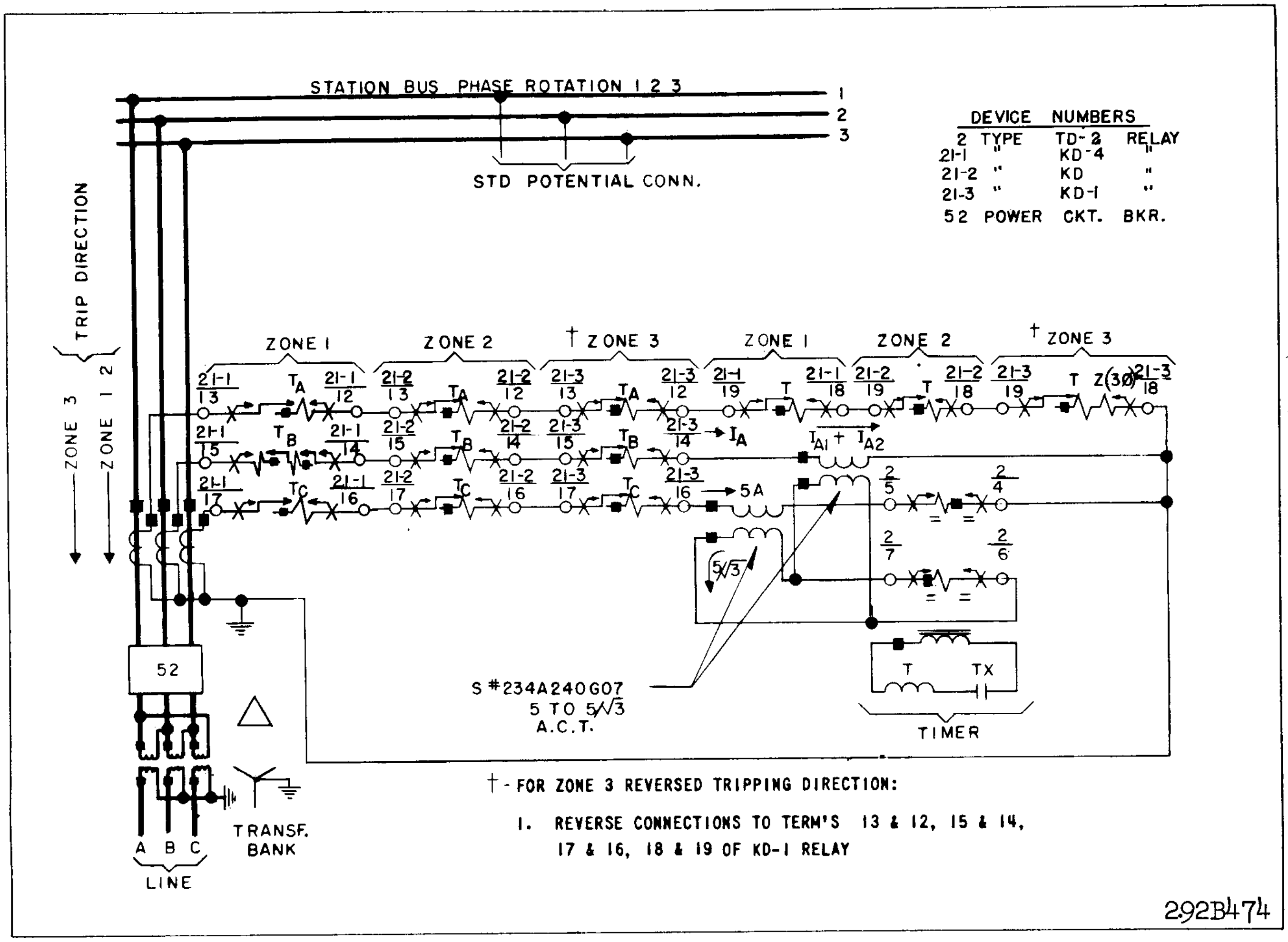


Fig. 16 A.C. External Schematic of Type KD-4, KD and KD-1 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

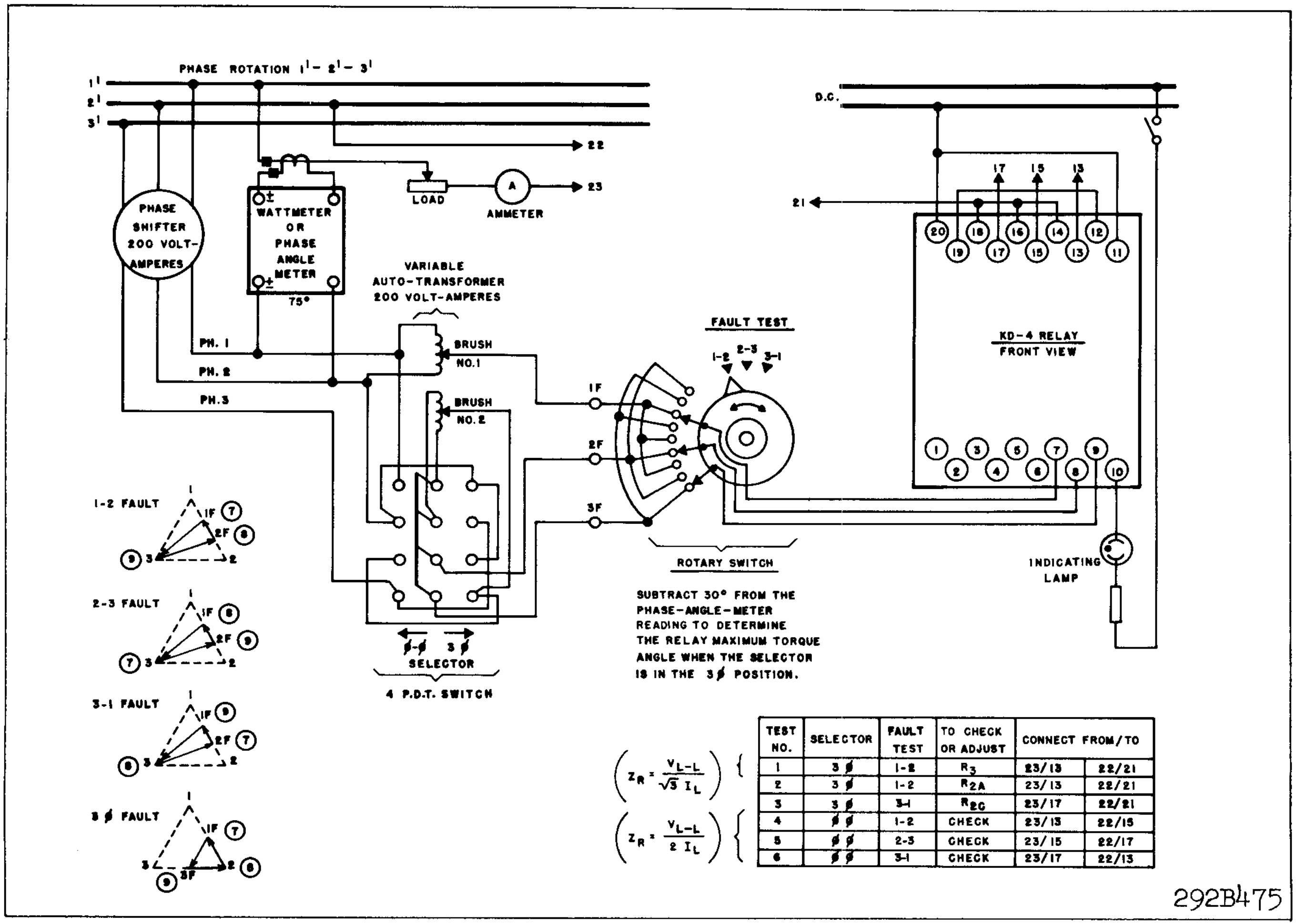
A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.

SWITCHBOARD TESTING WIDTH KD-4 RELAY

Immediately prior to placing the relays in service, the external wiring can be checked by manipulating the current and voltage applied to the relay.



$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right)$ (Tests 1–3)

$\left(Z_R = \frac{V_{L-L}}{2\, I_L}\right)$ (Tests 4–6)

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3ϕ	1-2	R_3	23/13	22/21
2	3ϕ	1-2	R_{2A}	23/13	22/21
3	3ϕ	3-1	R_{2C}	23/17	22/21
4	ϕϕ	1-2	CHECK	23/13	22/15
5	ϕϕ	2-3	CHECK	23/15	22/17
6	ϕϕ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & * M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should * be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should * be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\sin 60^\circ}{\sin \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.
2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.
3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees.

   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.
5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 $V_{L\text{-}L}$ to 120 $V_{L\text{-}L}$. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$
"L" of M_C	R_{2C}	= 50.9 volts ($\theta = 90^\circ$)

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{\sqrt{3}I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) † † & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{2\ I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08 *
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3φ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3φ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	2 of 3-½ inch Resistors, Total Resistance 2000 ohms (One Resistor is fixed, one adjustable)
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (φ-φ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

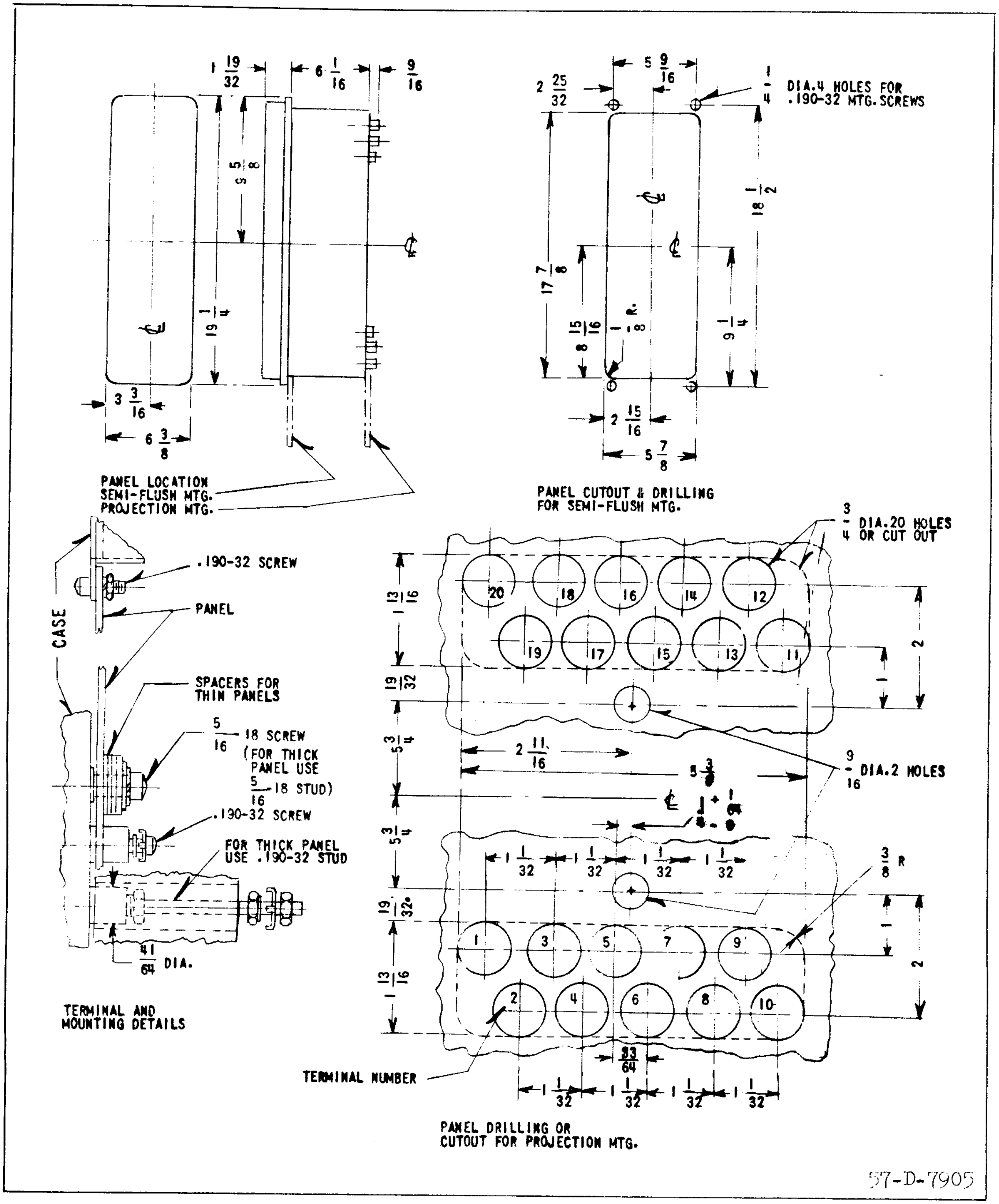


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11C
*Denotes changes from superseded issue.

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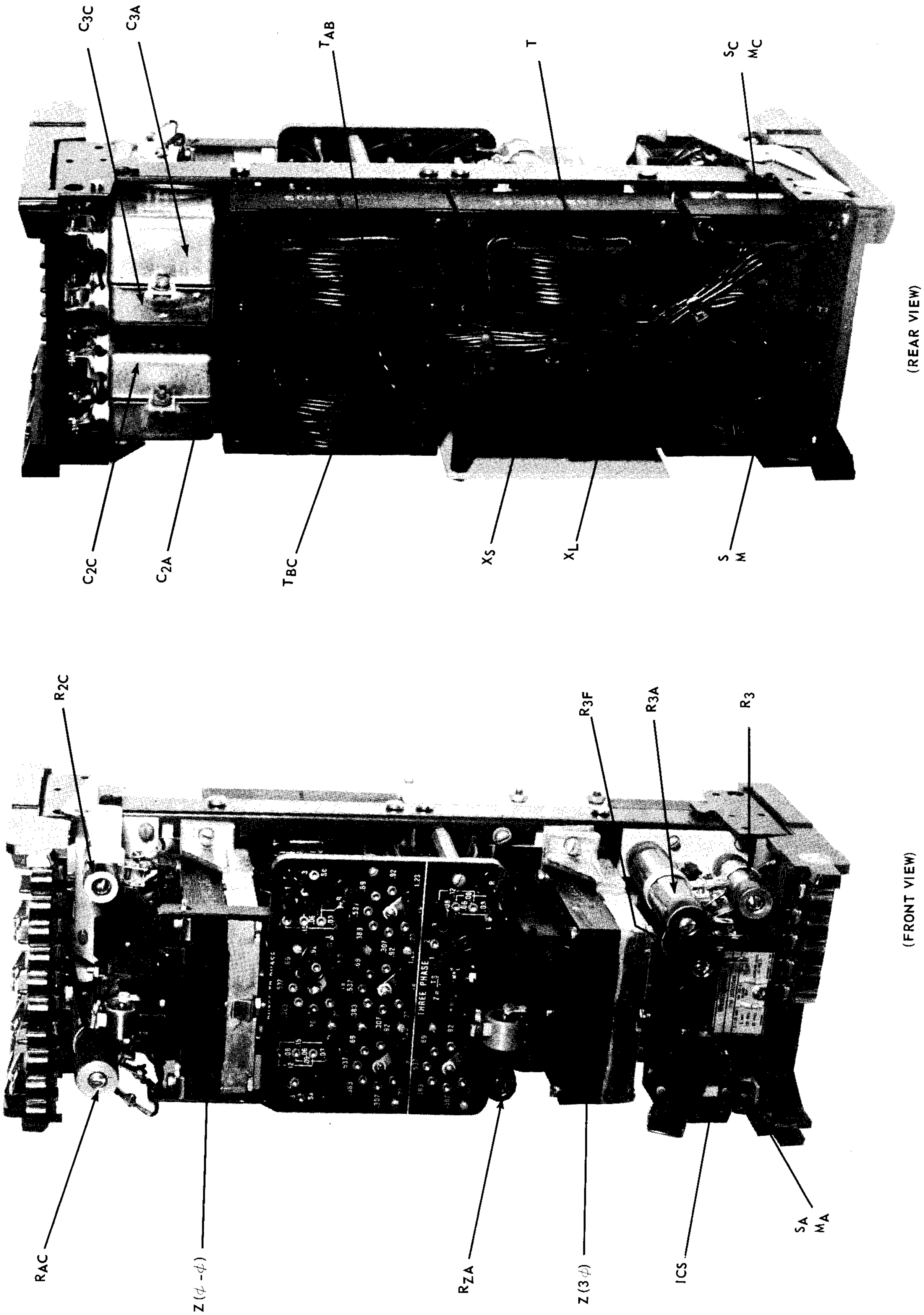


Fig. 1 Type KD-4 Relay Without case

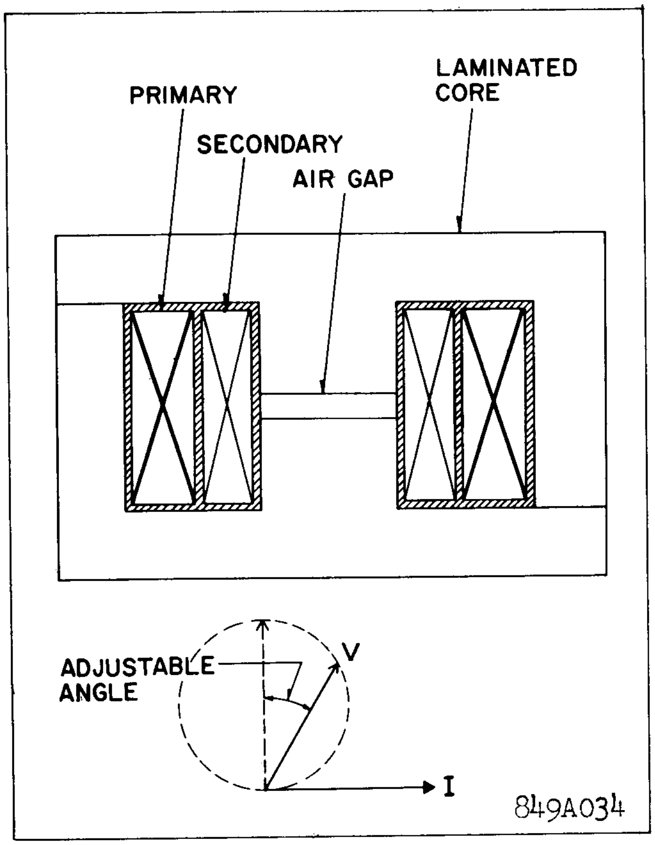


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

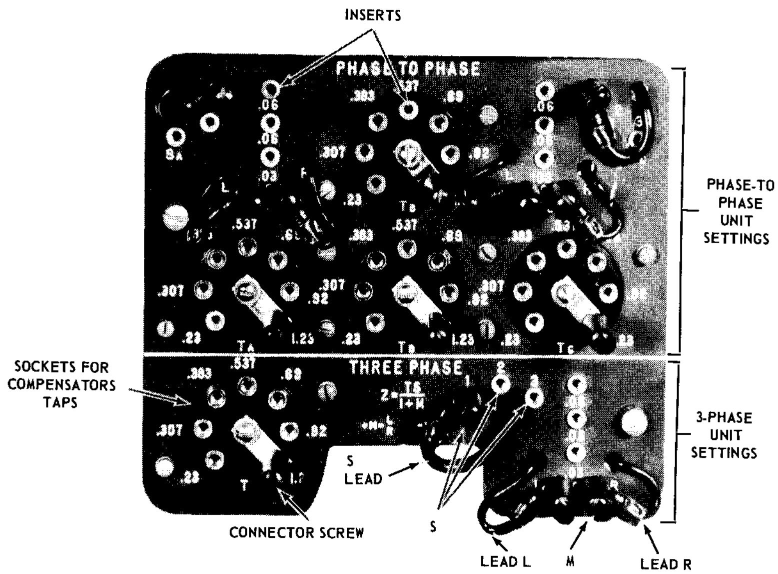


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

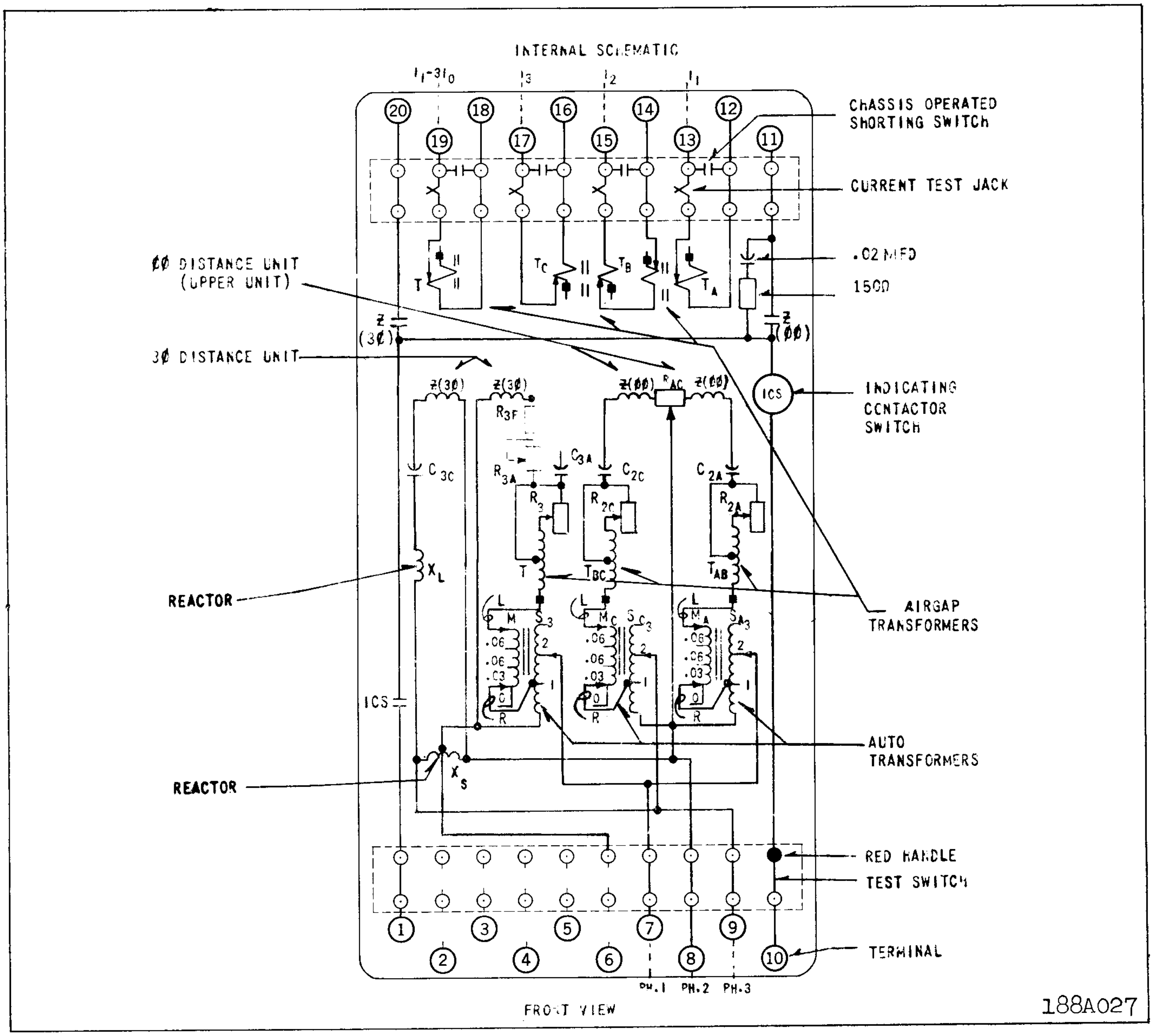
Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3ø) & Z (øø). The phase-to-phase unit Z (øø) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered



* *Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).*

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

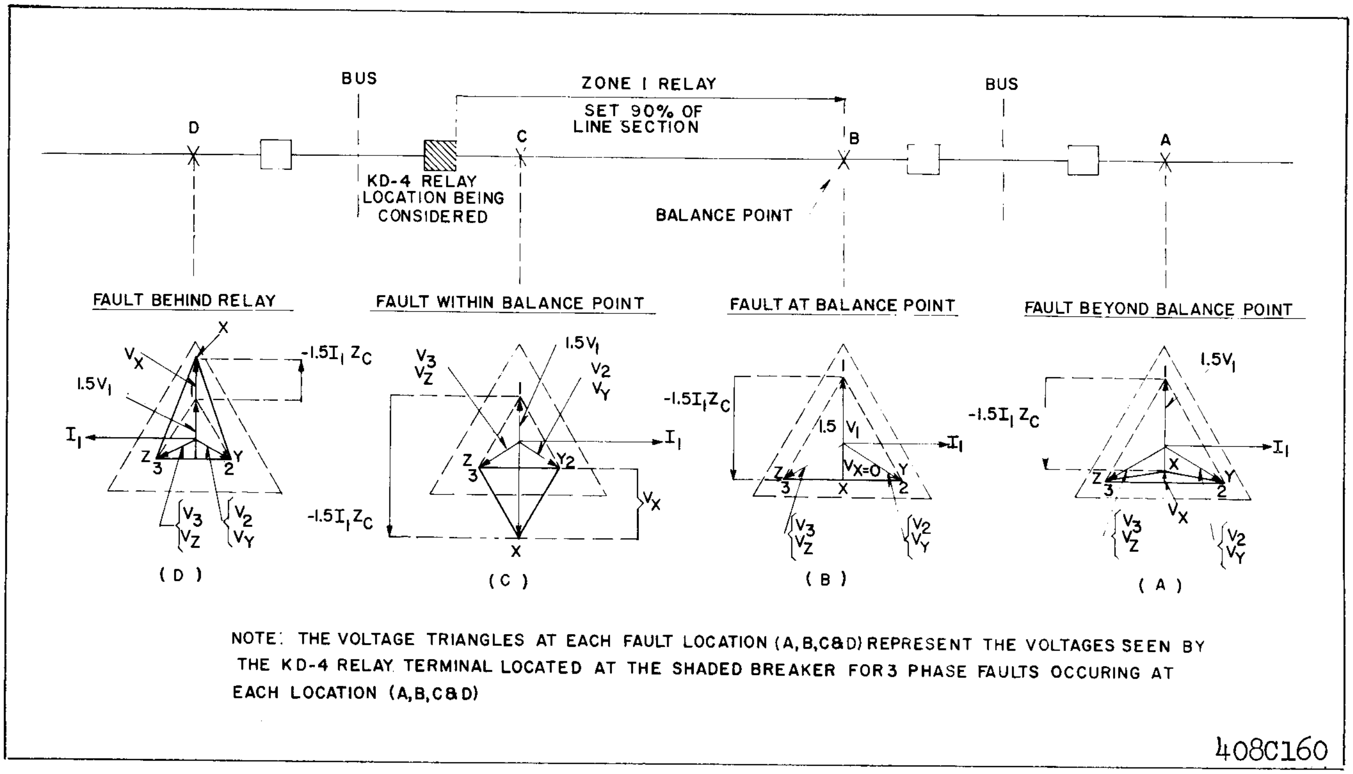


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

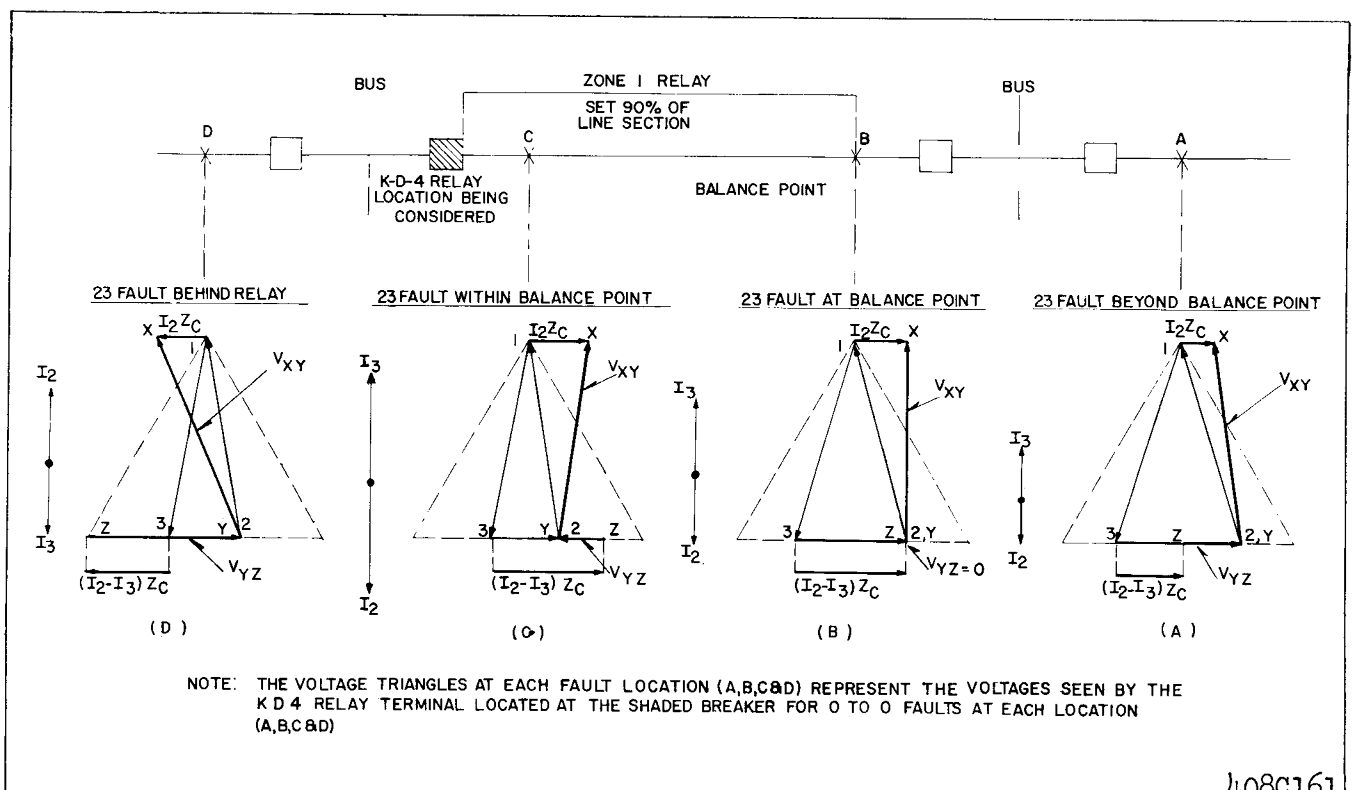


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

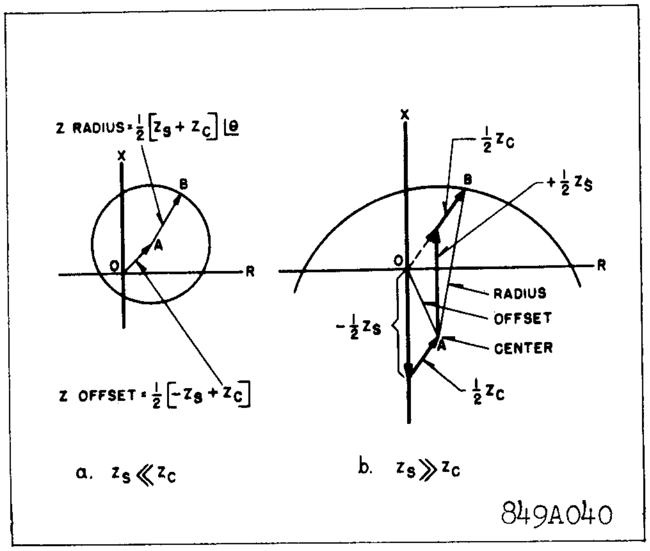


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

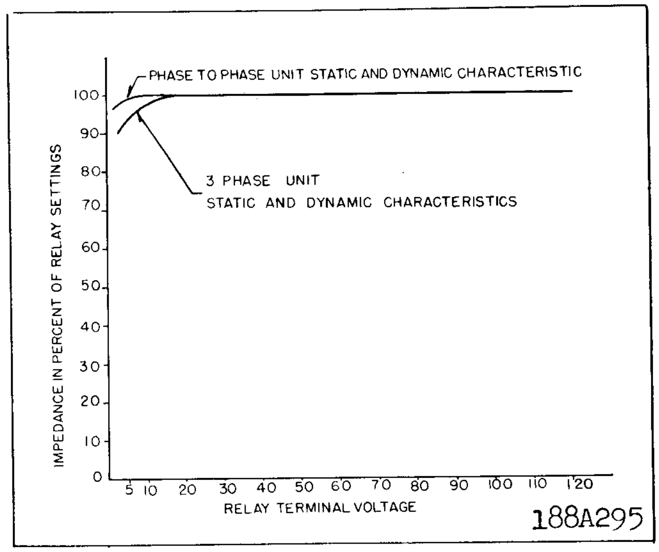


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-\ 1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

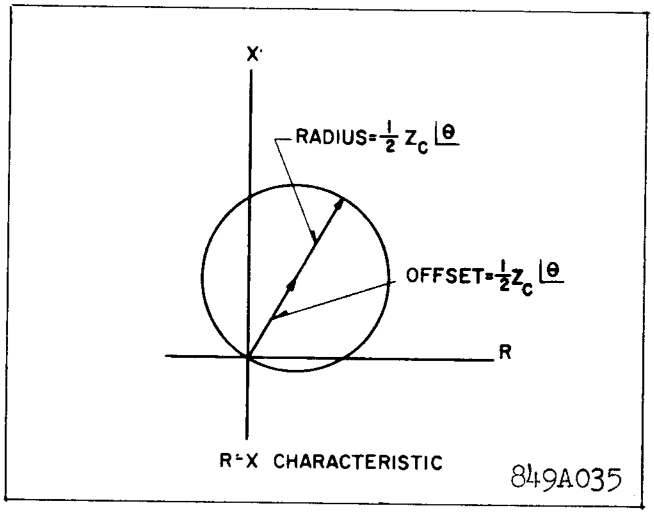


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2)\, Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3)\, Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Y-Z sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

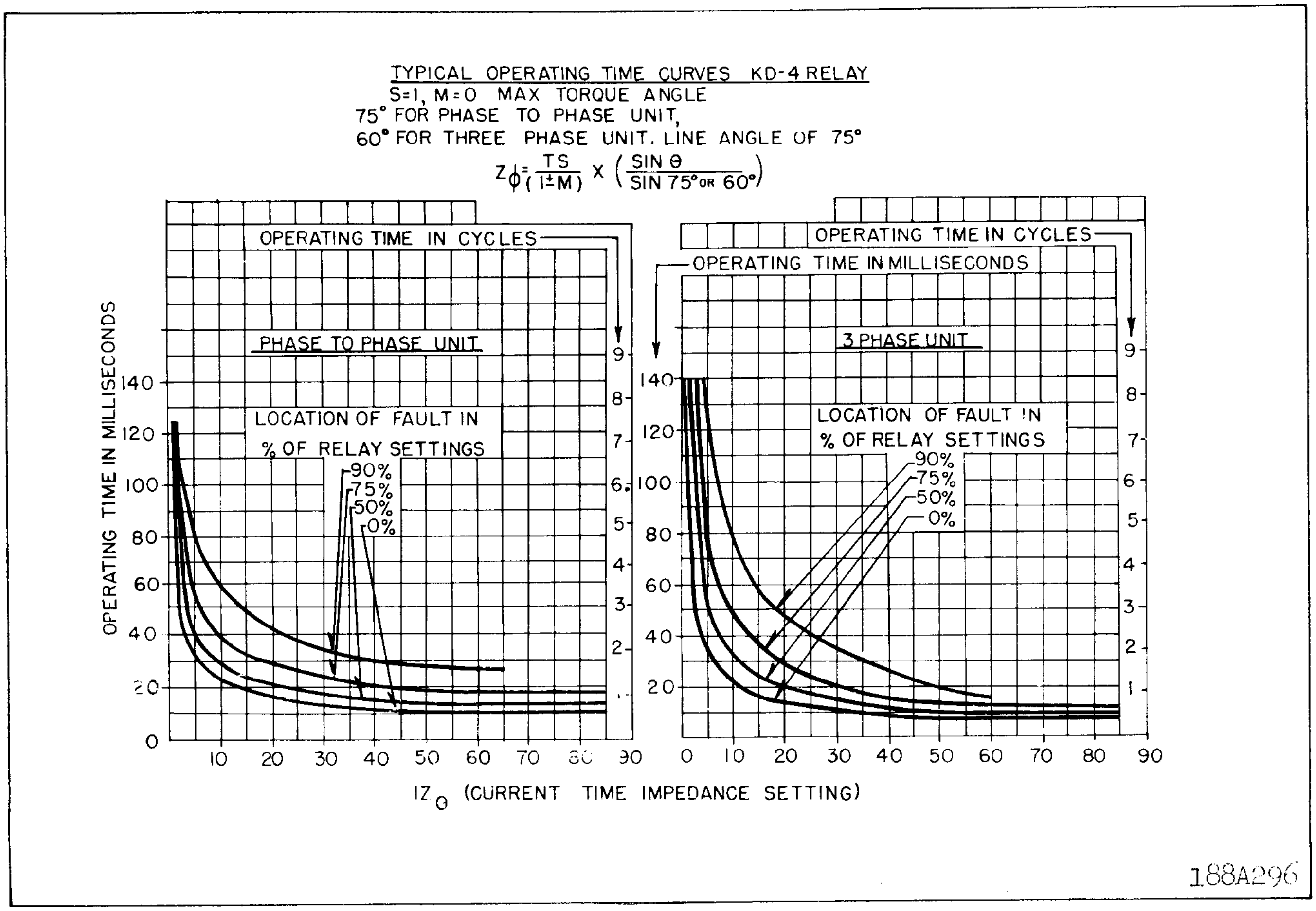


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

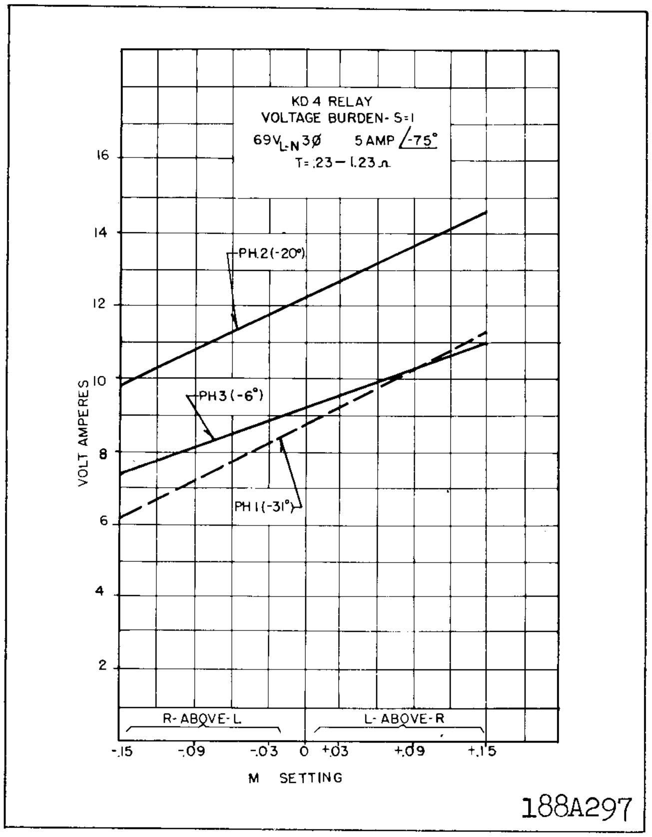
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

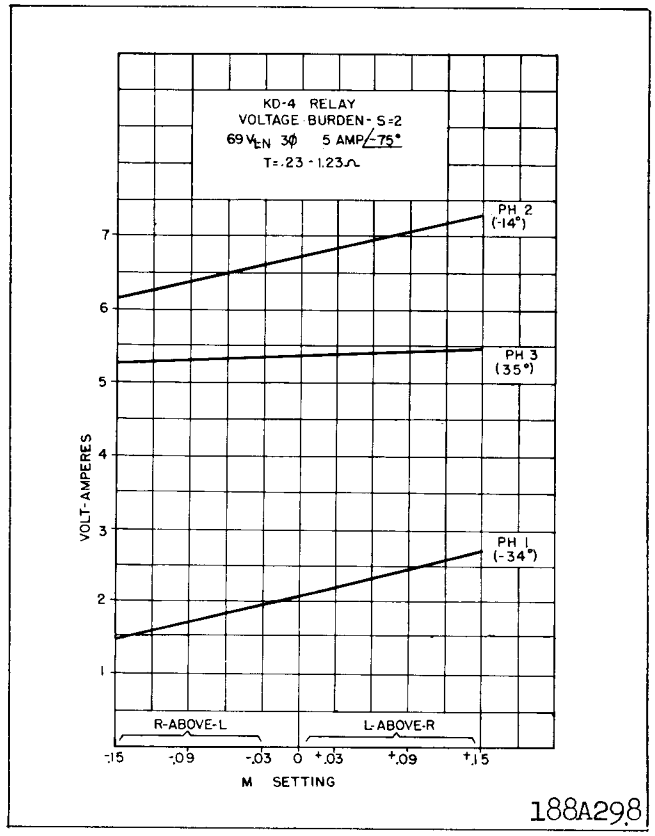
Distance Characteristic - 3 Phase Unit

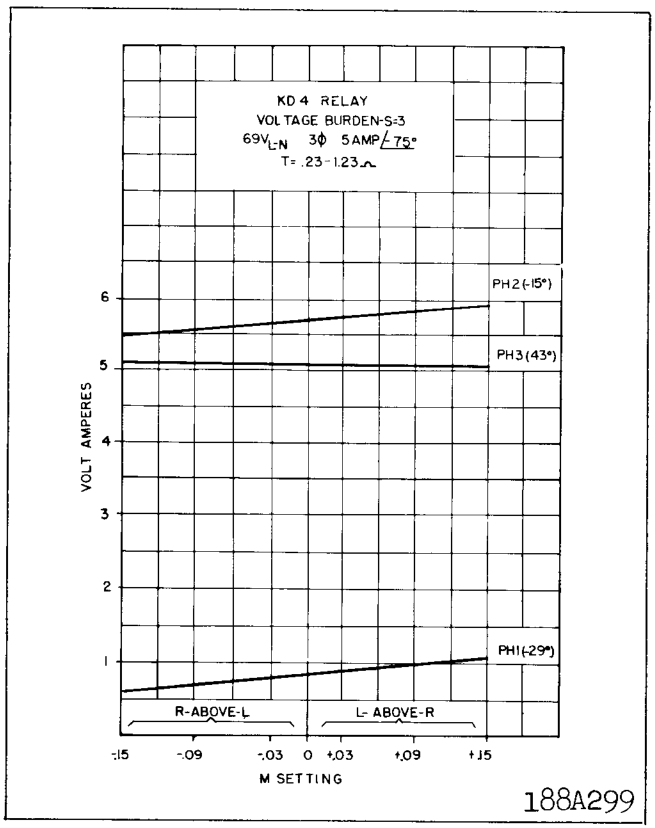
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$ S = 1
THREE PHASE CURRENT = 5 /-75° AMPS.

TAP SETTING	PHASE 1			PHASE 2			PHASE 3		
	VA	VARS	WATTS	VA	VARS	WATTS	VA	VARS	WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z_θ varies with the maximum torque angle θ, as follows:

$$Z_\theta = \frac{TS \sin \theta}{(1 \pm M) \sin \alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)
.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)
1 2 3

	(M, M_A, M_C)
±Values between taps	.03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°)

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9\ R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_v = potential transformer ratio

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

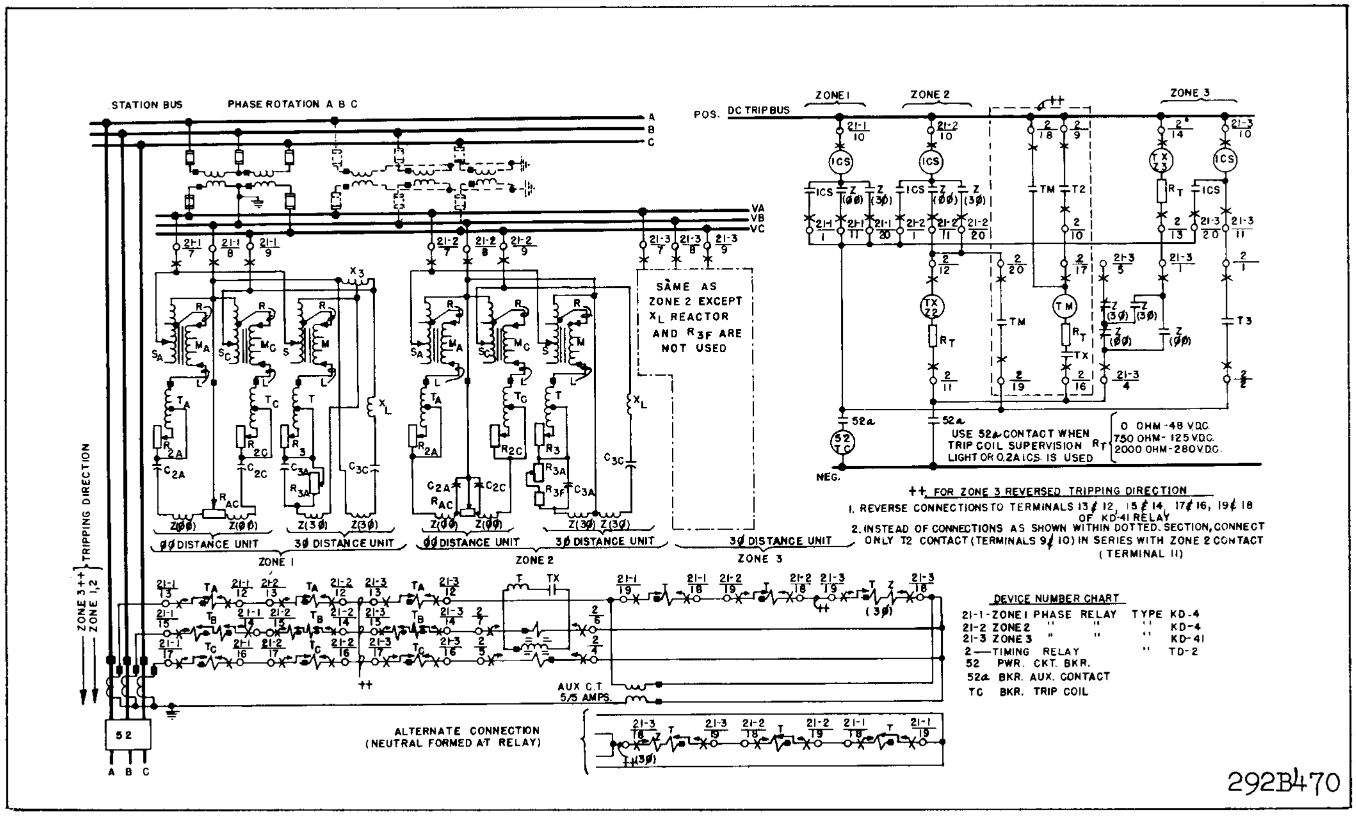
1. a) Establish $Z\ \theta$
   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ should be different from the factory setting multiply the Z_θ – value by factor $\frac{\text{Sin } 75°}{\text{Sin } \theta°}$ for phase to phase unit, and by factor $\frac{\text{Sin } 60°}{\text{Sin } \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

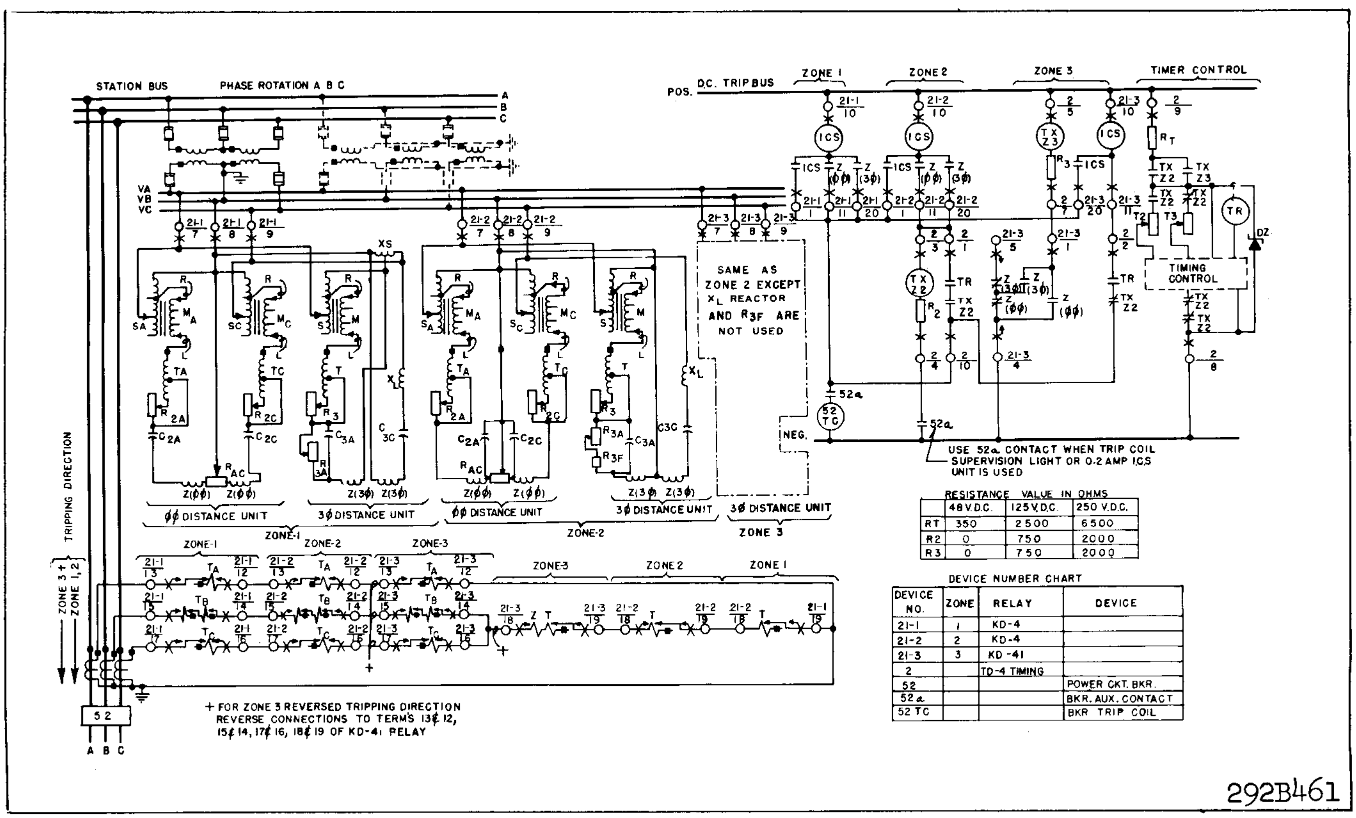
For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. Making correction for maximum torque angle of the line (60°) that is different from factory setting of 75° the relay setting, Z should be Z = 1.7 x 1.11 = 1.89 ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89}$ x 100 = 100.5% of the desired reach.



* *Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.*



* *Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.*

b) From the Table I read off S = 2
T = .920
M = −.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line impedance angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. Then the relay setting Z should be $= Z = Z_\theta \cdot \frac{\text{Sin } 60°}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$

a) The nearest table value is 2.09

b) From the Table I read off
S = 2
T = .920
M = −.12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from −.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	“L”-Lead	“R” Lead	
	.200	.272	.333	.466	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	
	.205	.274	.341	.479	.615	.822	1.100	—	1.64	2.20	—	3.29	+.12		Upper .06	.03	
	.211	.282	.350	.493	.632	.843	1.120	—	1.69	2.24	—	3.38	+.09		Lower .06	0	“L” over “R”
	.217	.290	.361	.506	.650	.869	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower .06	
	.224	.298	.371	.521	.670	.892	1.191	—	1.78	2.38	—	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	
	.237	.317	.395	.552	.713	.948	1.270	—	1.90	2.54	—	3.80		-.03	0	.03	
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	—	3.93		-.06	Lower .06	Upper .06	
	.253	—	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower .06	“R” over “L”
	.261	—	.435	—	.785	1.048	1.395	1. -	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	—	.450	—	—	—	1.45	—	—	2.90	—	4.35		-.15	0	Upper .06	

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

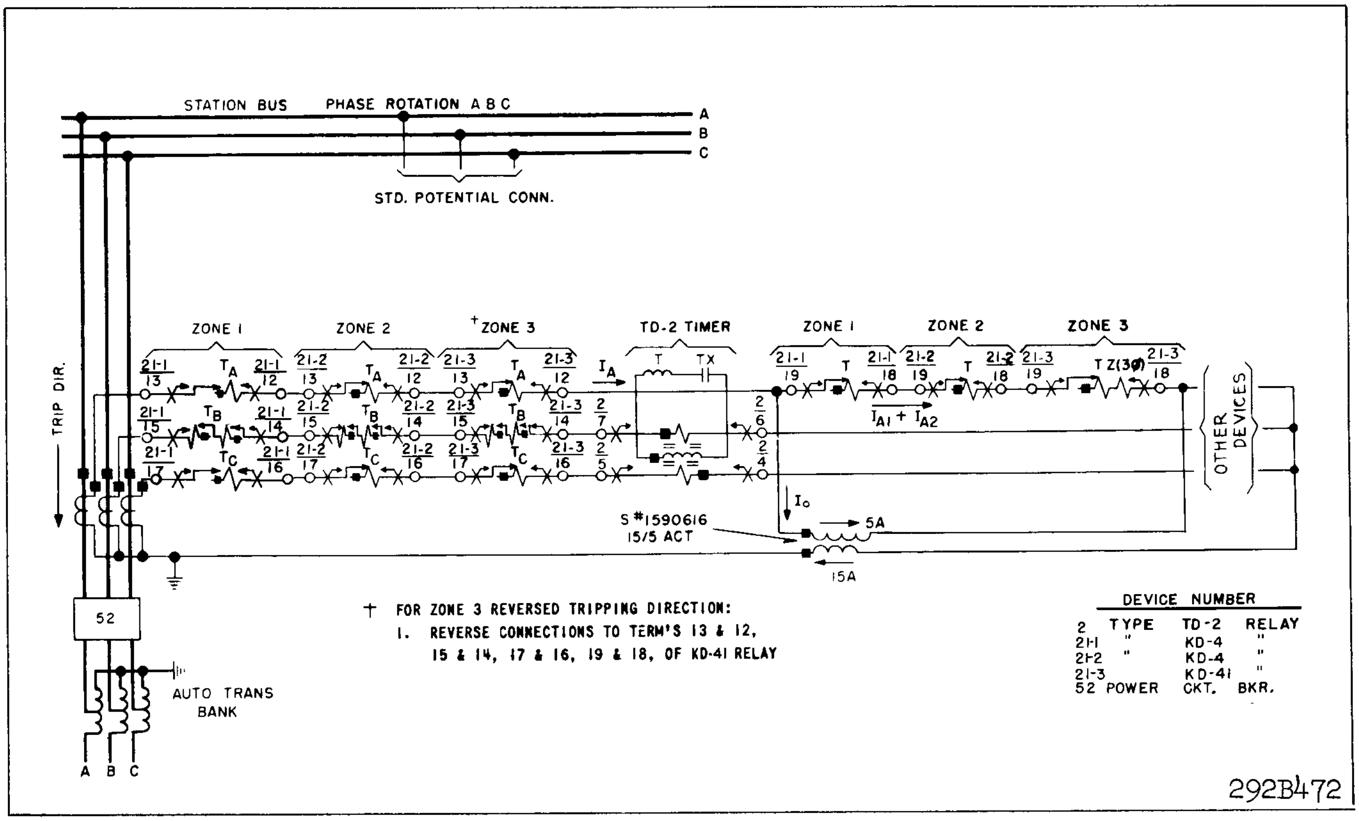
Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

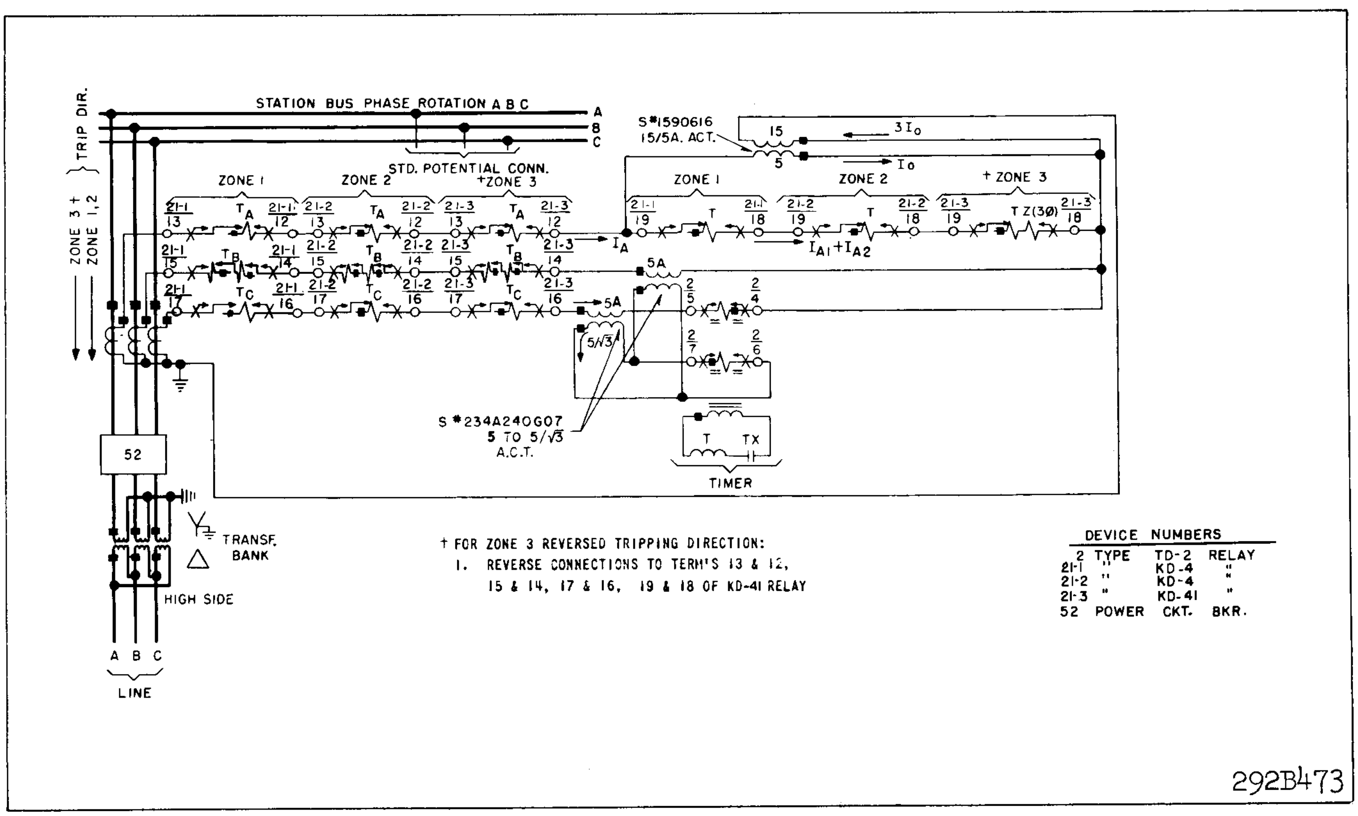
INSTALLATION

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting, or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

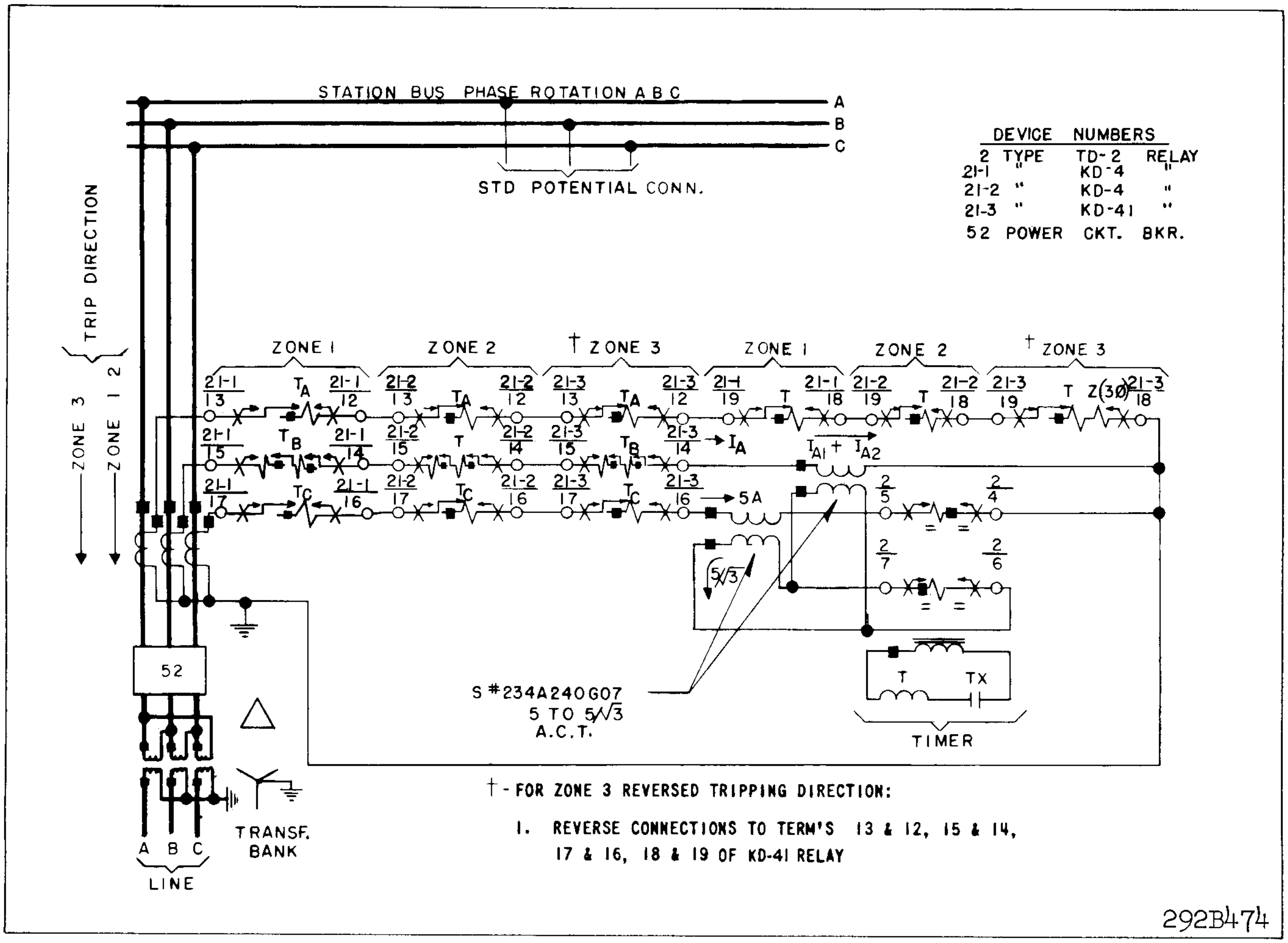
For detail information on the FT case refer to IL 41-076.



* *Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.*



* *Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.*



* *Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.*

EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

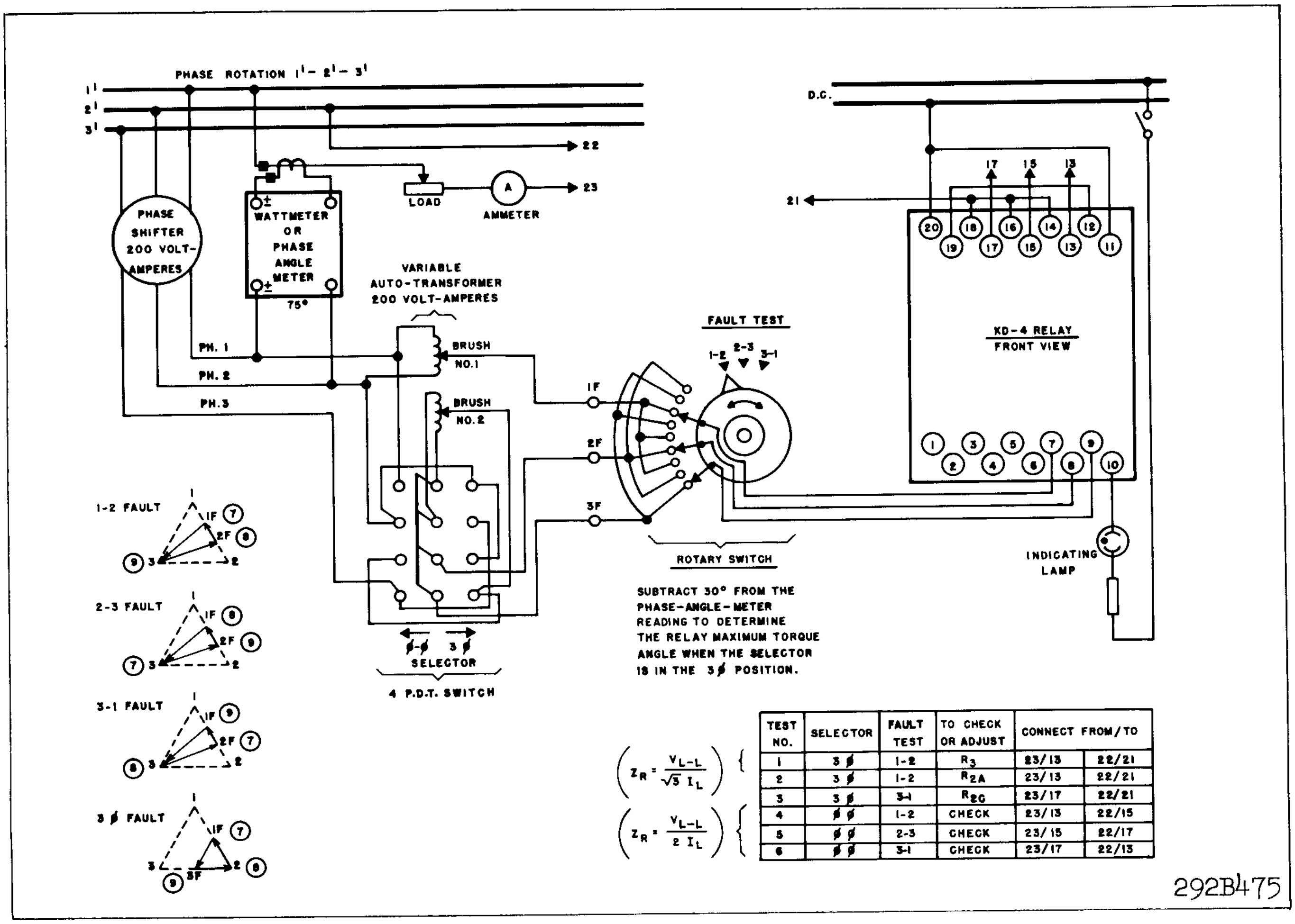
A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.

SWITCHBOARD TESTING WITH KD-4 RELAY

Immediately prior to placing the relays in service, the external wiring can be checked by manipulating the current and voltage applied to the relay.



$$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right) \text{ Tests 1–3}$$

$$\left(Z_R = \frac{V_{L-L}}{2\, I_L}\right) \text{ Tests 4–6}$$

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3ϕ	1-2	R_3	23/13	22/21
2	3ϕ	1-2	R_{2A}	23/13	22/21
3	3ϕ	3-1	R_{2C}	23/17	22/21
4	ϕϕ	1-2	CHECK	23/13	22/15
5	ϕϕ	2-3	CHECK	23/15	22/17
6	ϕϕ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should
* be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\sin 60^\circ}{\sin \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 amperes and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \quad (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

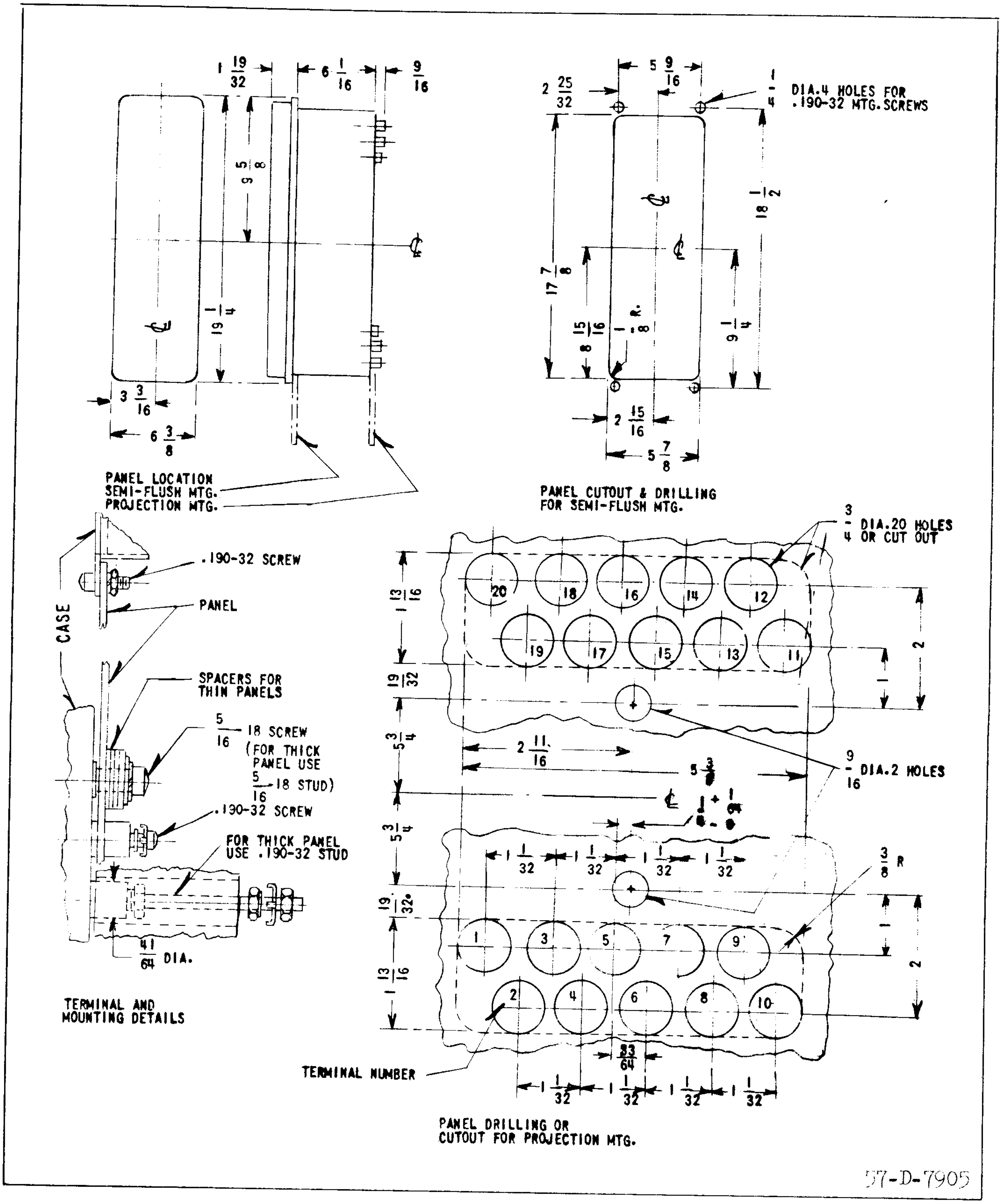


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11D
*Denotes changes from superseded issue.

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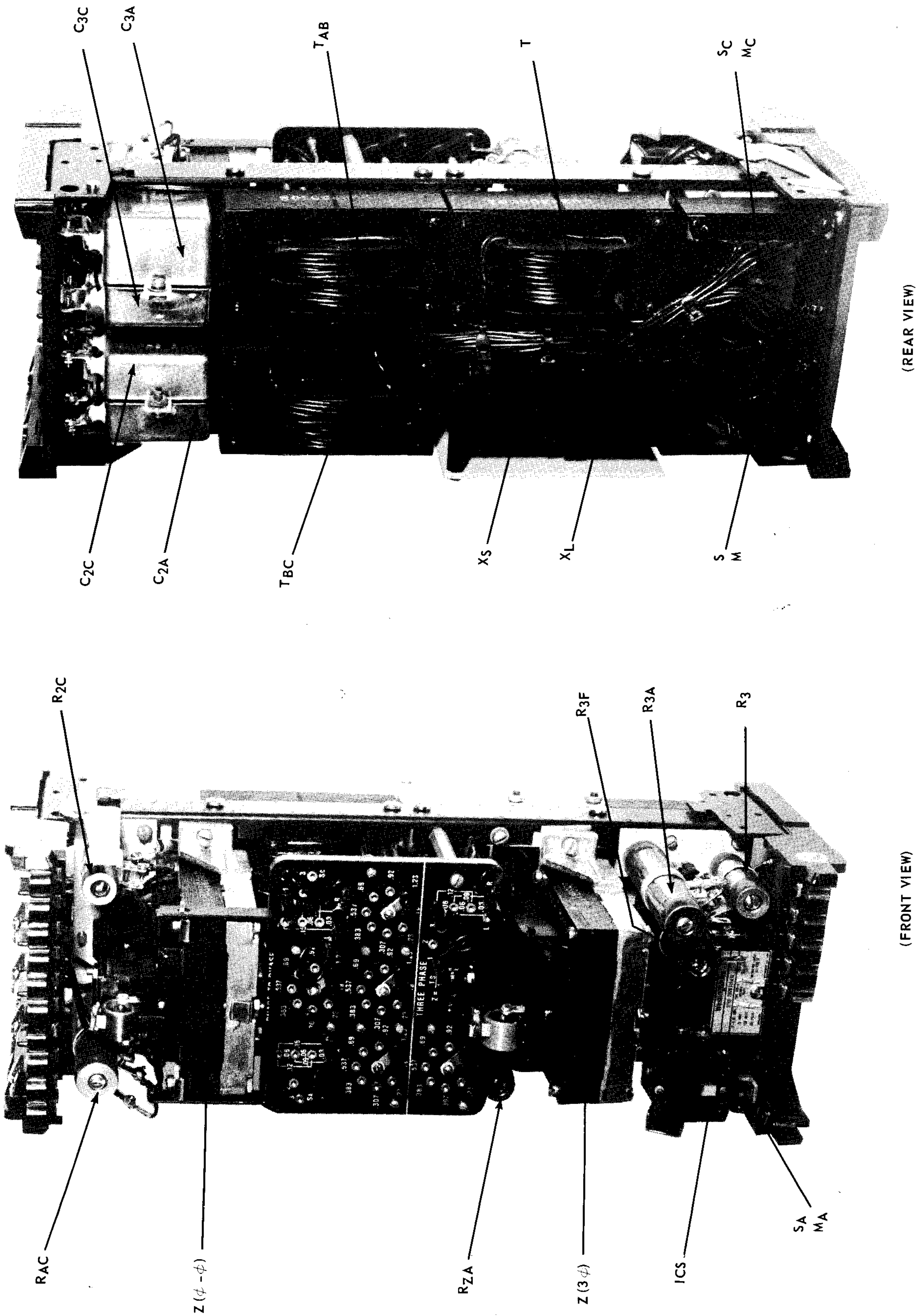


Fig. 1 Type KD-4 Relay Without case

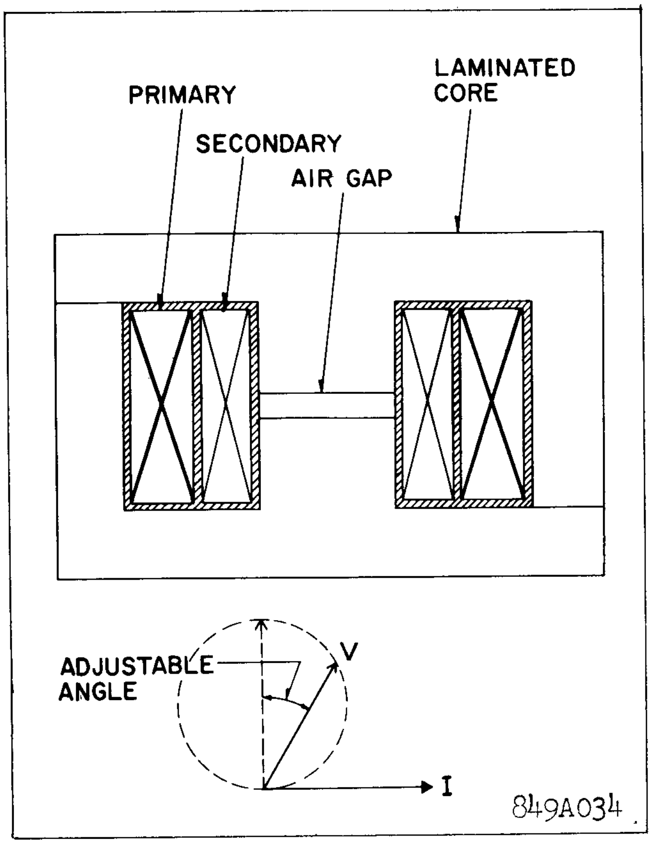


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

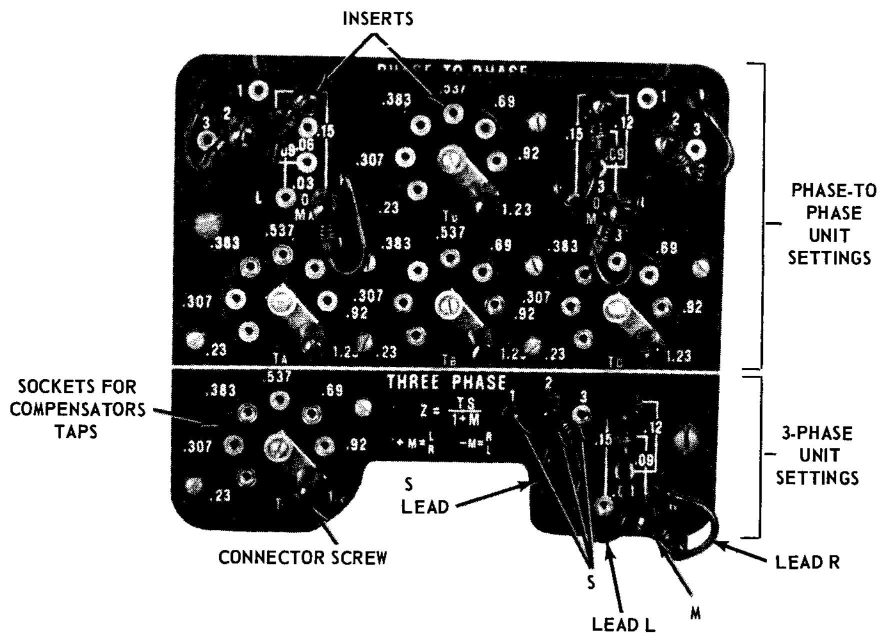


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3ϕ) & Z ($\phi\phi$). The phase-to-phase unit Z ($\phi\phi$) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3ϕ) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

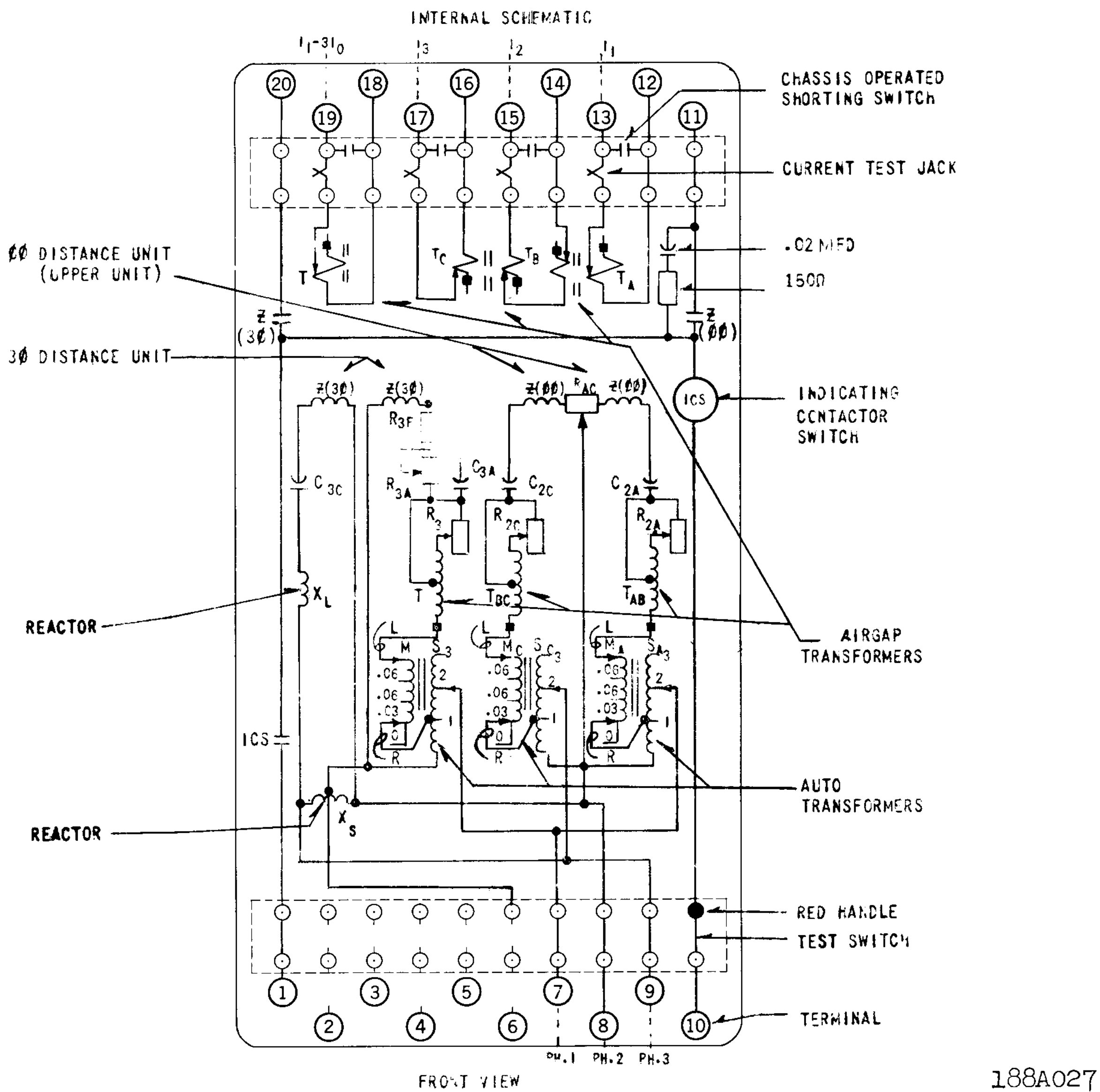


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown — one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

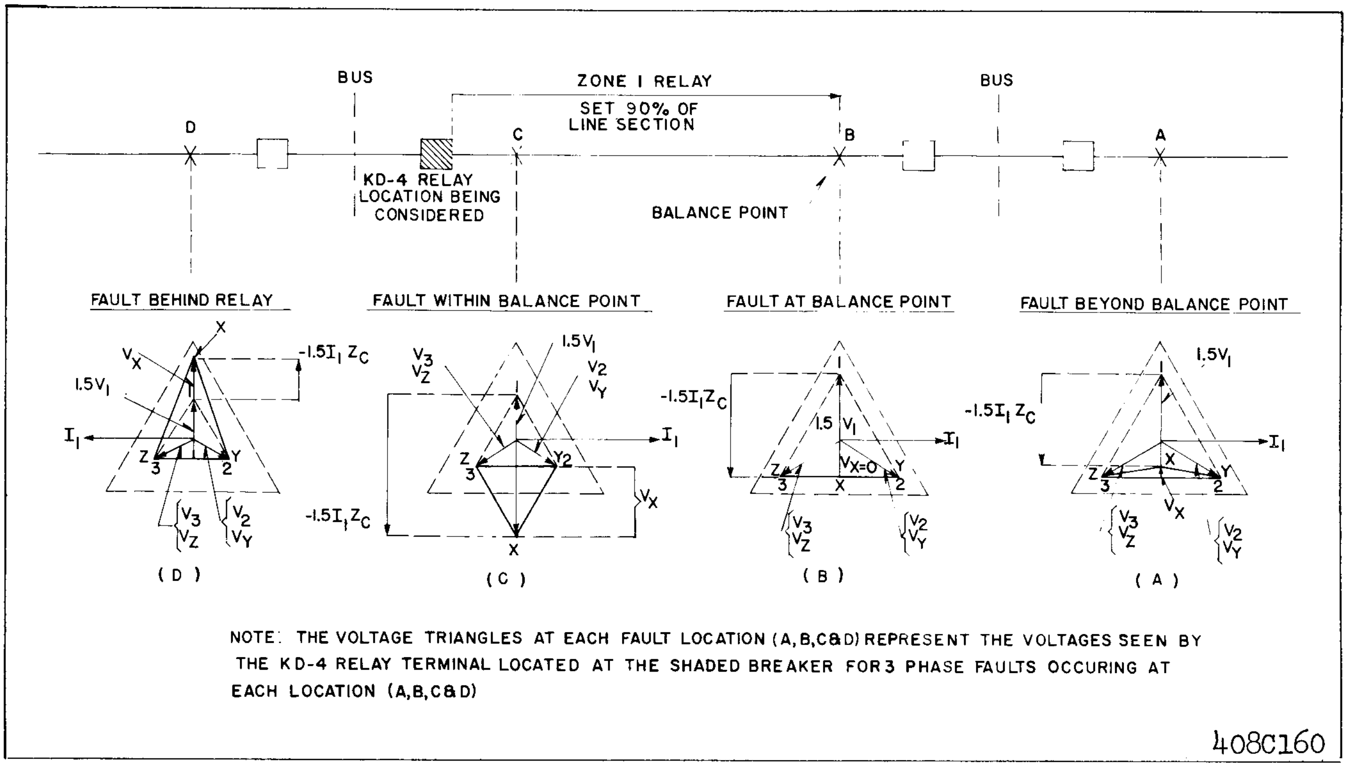


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

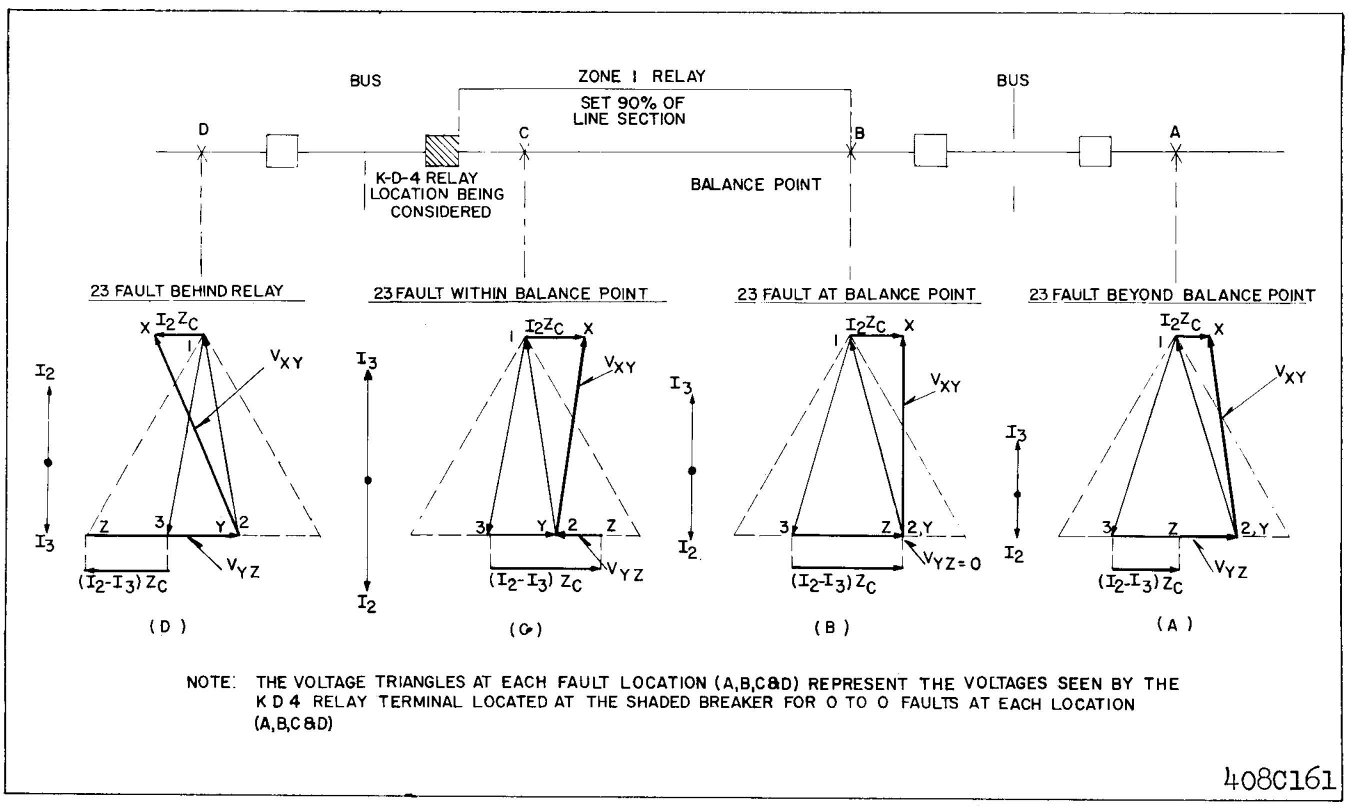


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

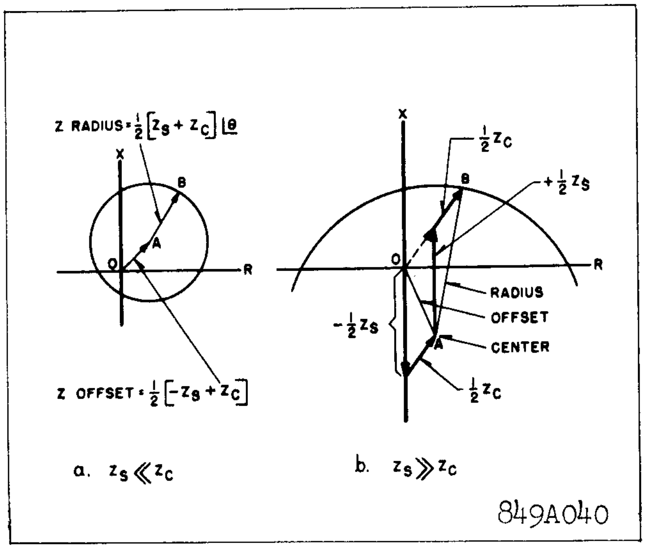


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

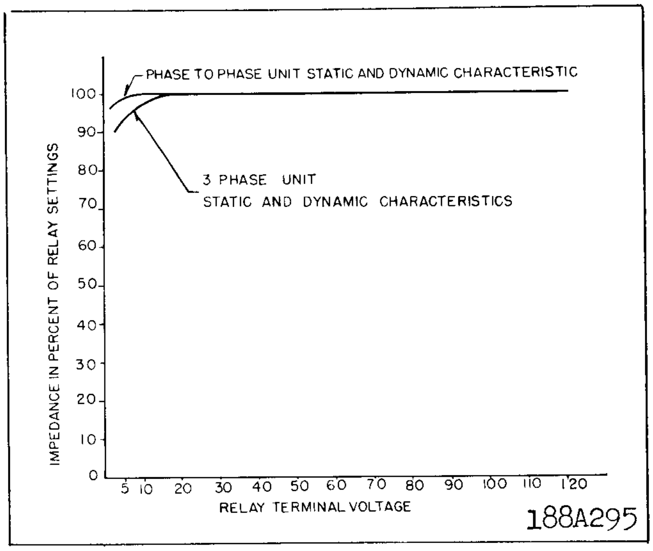


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3∅) and the voltage across the right hand coils of Z (3∅), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

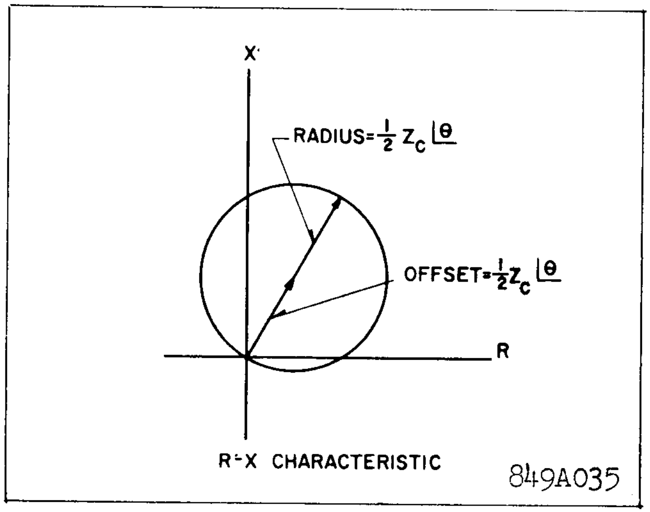


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2)\, Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3)\, Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Y-Z sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

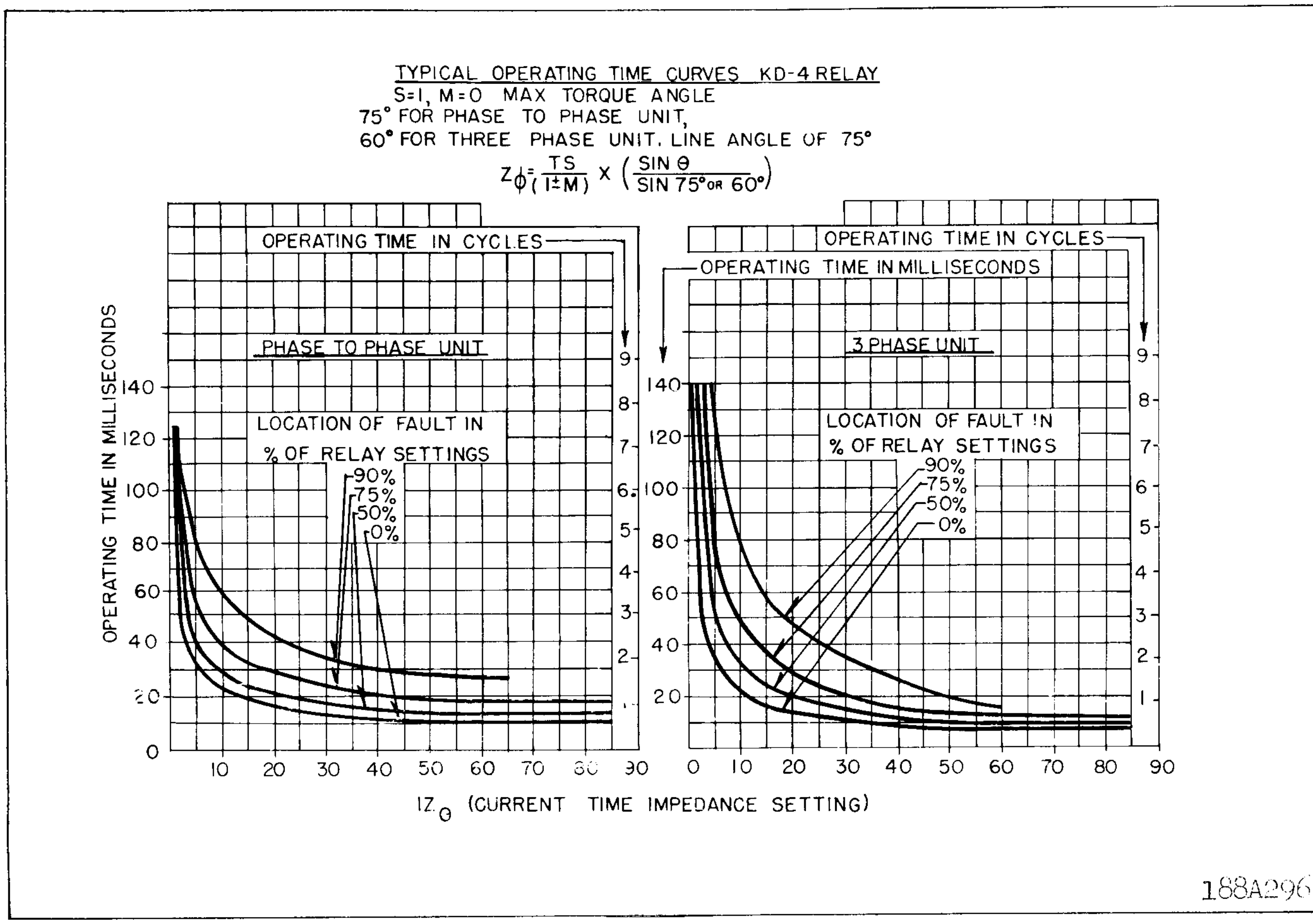


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

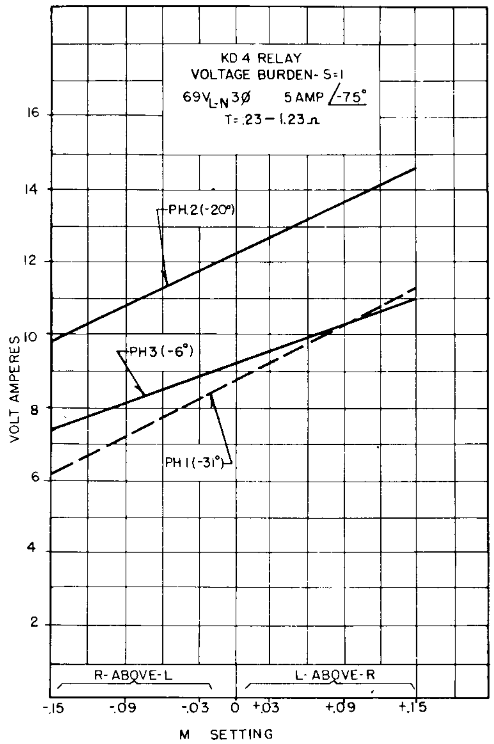
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

Distance Characteristic - 3 Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-



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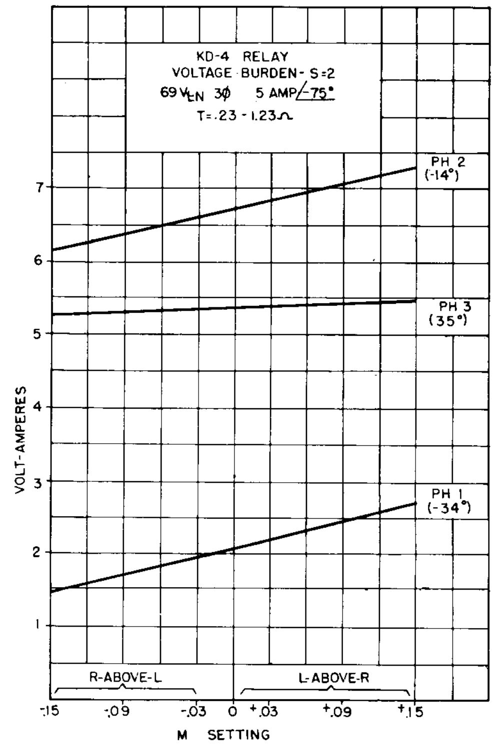

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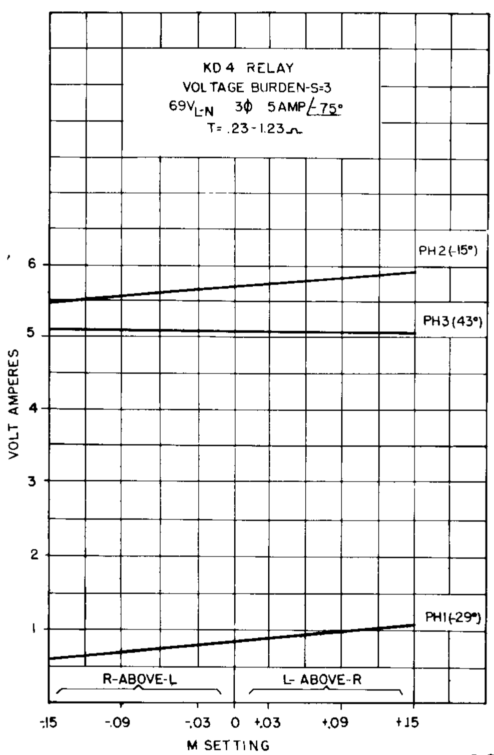

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KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$, S= 1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1 VA	PHASE 1 VARS	PHASE 1 WATTS	PHASE 2 VA	PHASE 2 VARS	PHASE 2 WATTS	PHASE 3 VA	PHASE 3 VARS	PHASE 3 WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin \theta}{(1 \pm M) \sin \alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)
.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)
1 2 3

±Values between taps (M, M_A, M_C)
.03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of
* less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9\, R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_C = current transformer ratio

R_V = potential transformer ratio

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ *

   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ should be different from the factory setting multiply the Z_θ – value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.

2. Now refer to the Table I.

   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.

   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).

   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.

   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is
* 1.7 ohms at 60°. Making correction for characteristic angle of the Line (60°) that is different from factory setting of 75° the relay setting, Z should be Z = 1.7 x 1.11 = 1.89 ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

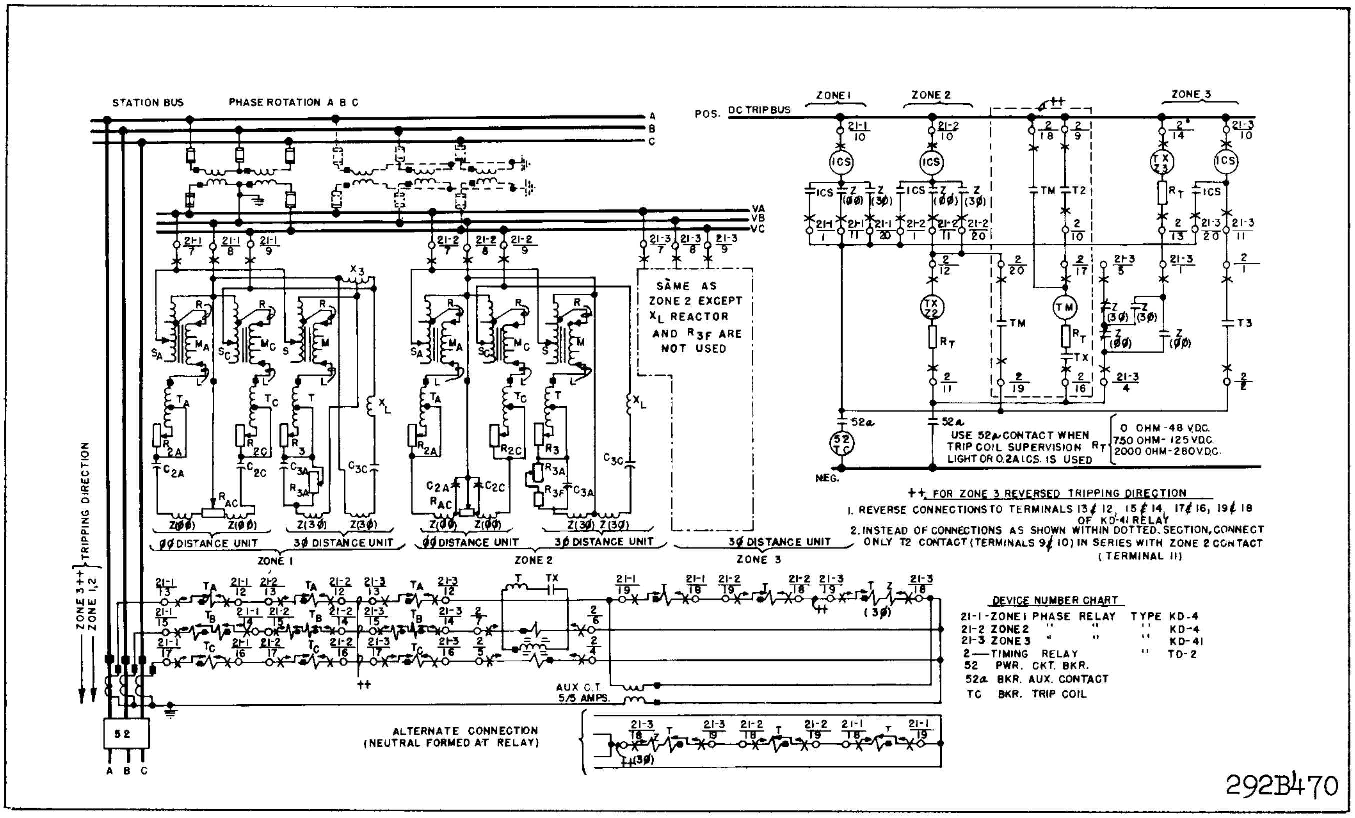


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.

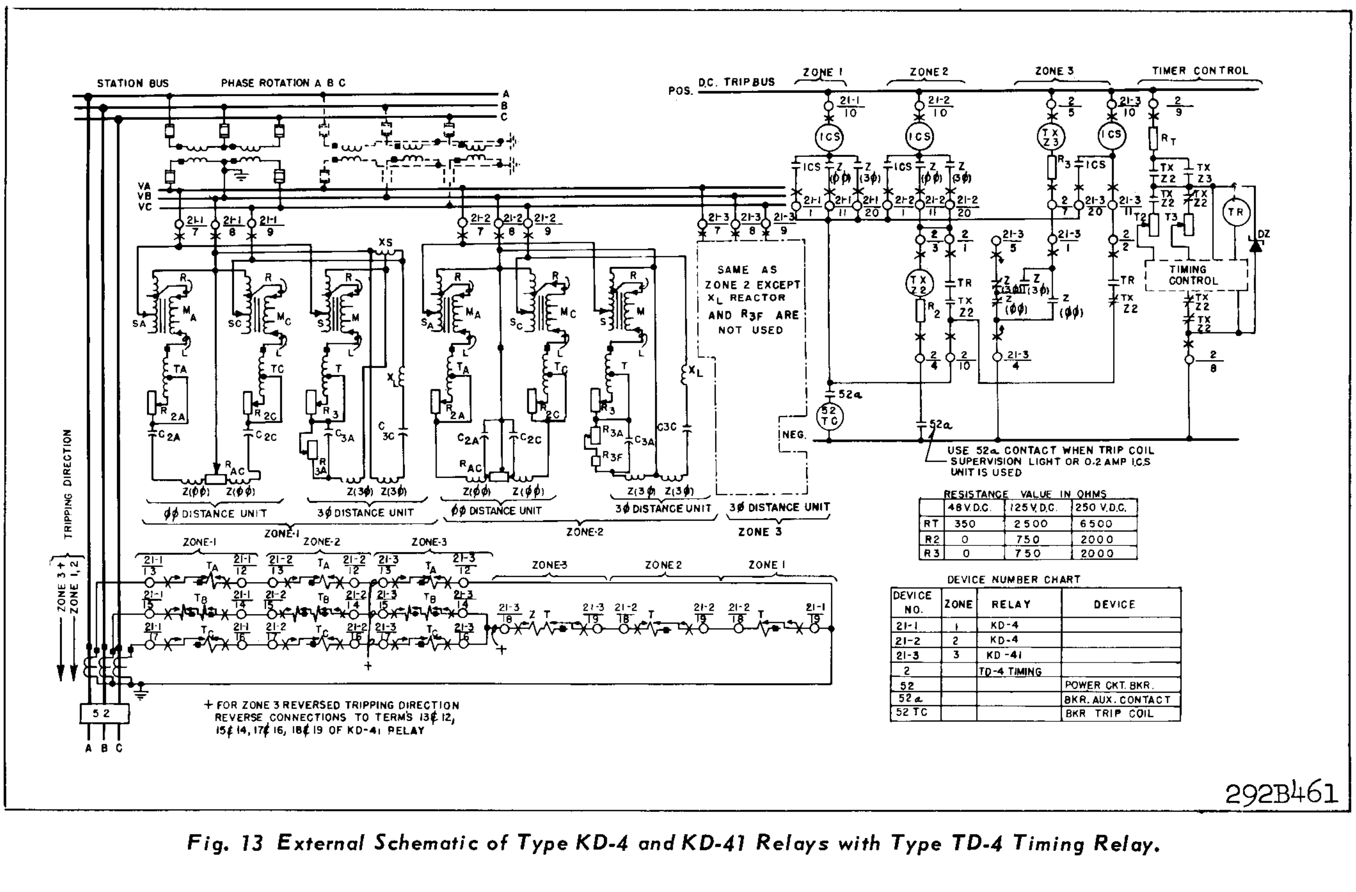


Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2

T = .920

M = –.03

and "R" lead should be connected over "L"–lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60^\circ} = Z \frac{\sin 60^\circ}{\sin 75^\circ} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

* Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. Then the relay setting Z should be

$$= Z = Z_\theta \cdot \frac{\sin 60^\circ}{\sin \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off

S = 2

T = .920

M = –.12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45^\circ} = Z \frac{\sin 45}{\sin 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from –.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (–) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	"L" over "R"
	.205	.274	.341	.479	.615	.822	1.100	—	1.64	2.20	—	3.29	+.12		Upper .06	.03	
	.211	.282	.350	.493	.632	.843	1.120	—	1.69	2.24	—	3.38	+.09		Lower .06	0	
	.217	.290	.361	.506	.650	.869	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower .06	
	.224	.298	.371	.521	.670	.892	1.191	—	1.78	2.38	—	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	
	.237	.317	.395	.552	.713	.948	1.270	—	1.90	2.54	—	3.80		-.03	0	.03	"R" over "L"
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	—	3.93		-.06	Lower .06	Upper .06	
	.253	—	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower .06	
	.261	—	.435	—	.785	1.048	1.395	1. -	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	—	.450	—	—	—	1.45	—	—	2.90	—	4.35		-.15	0	Upper .06	

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting, or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

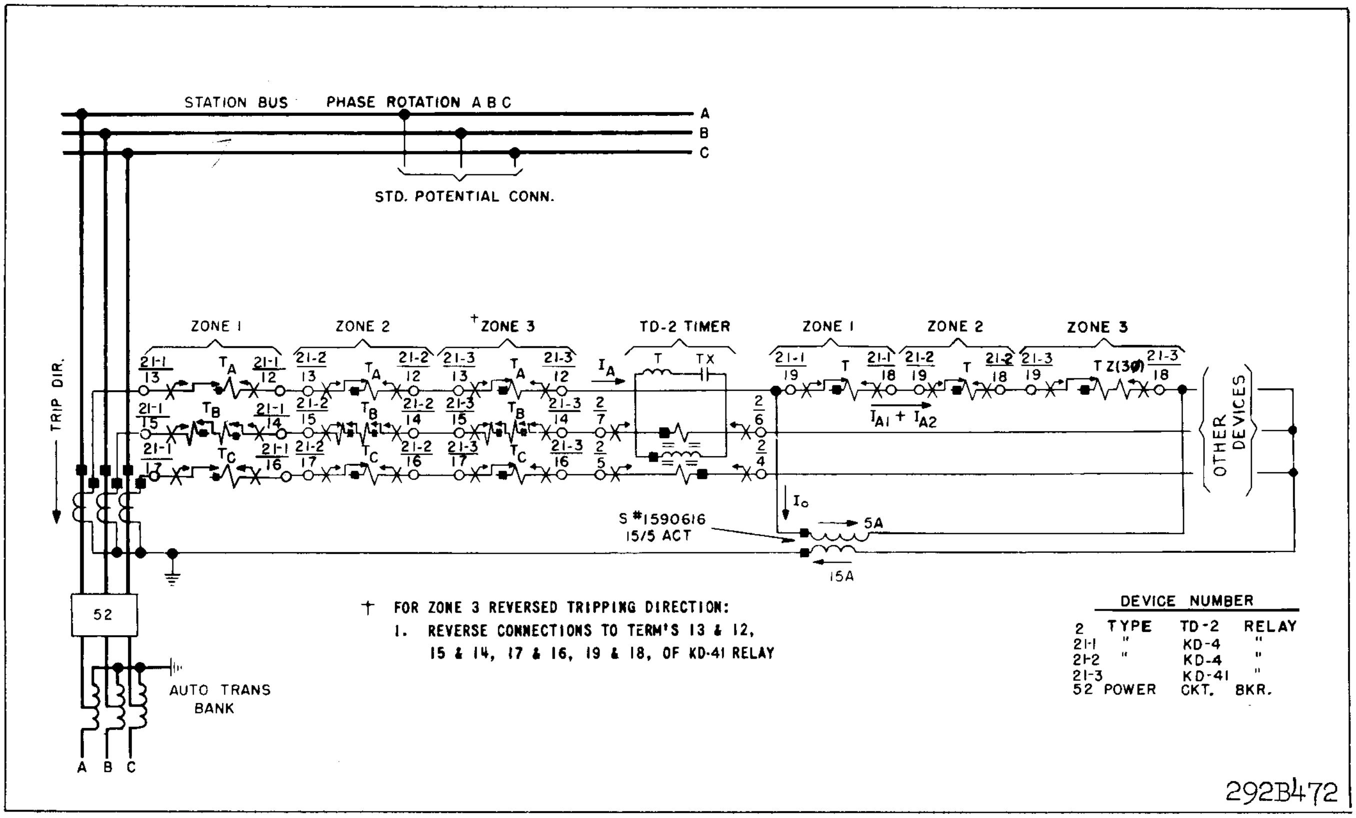


Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.

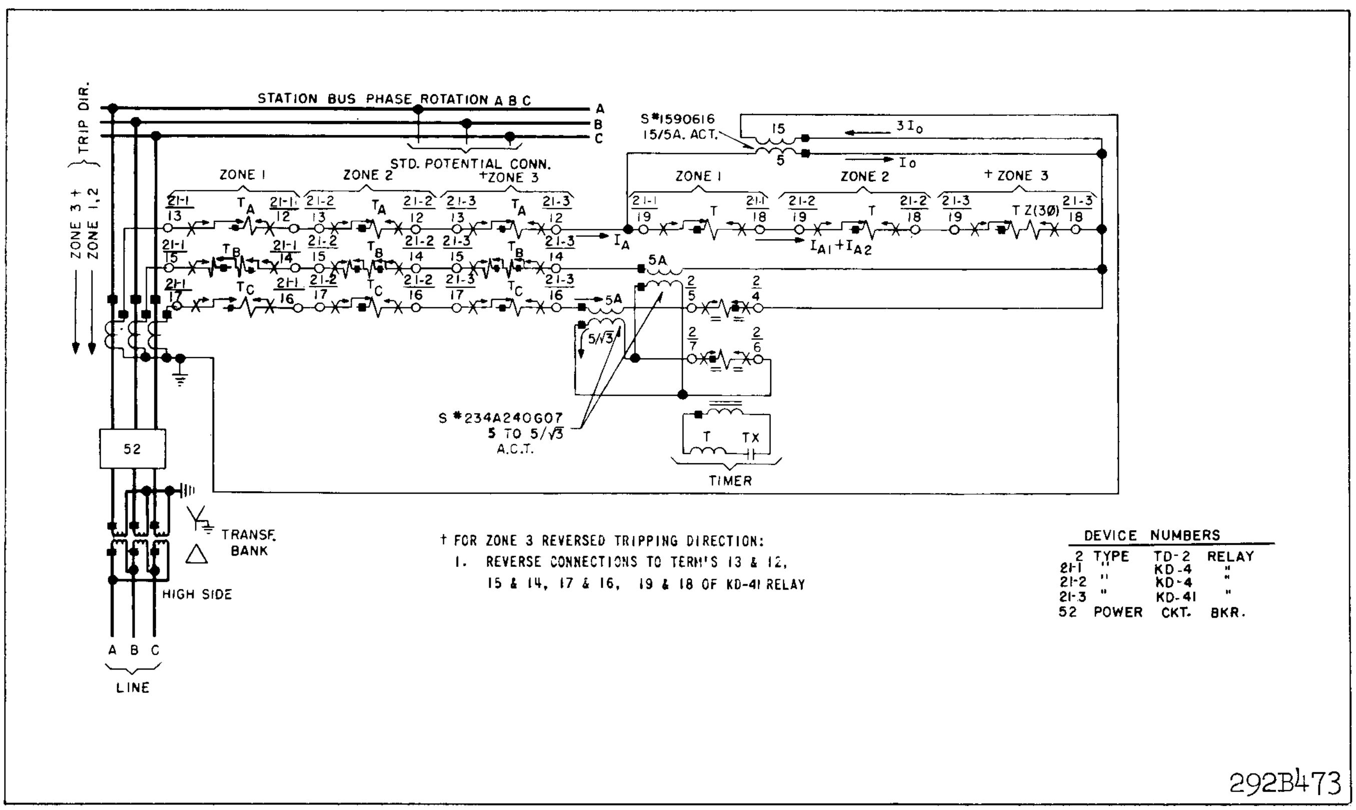


Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

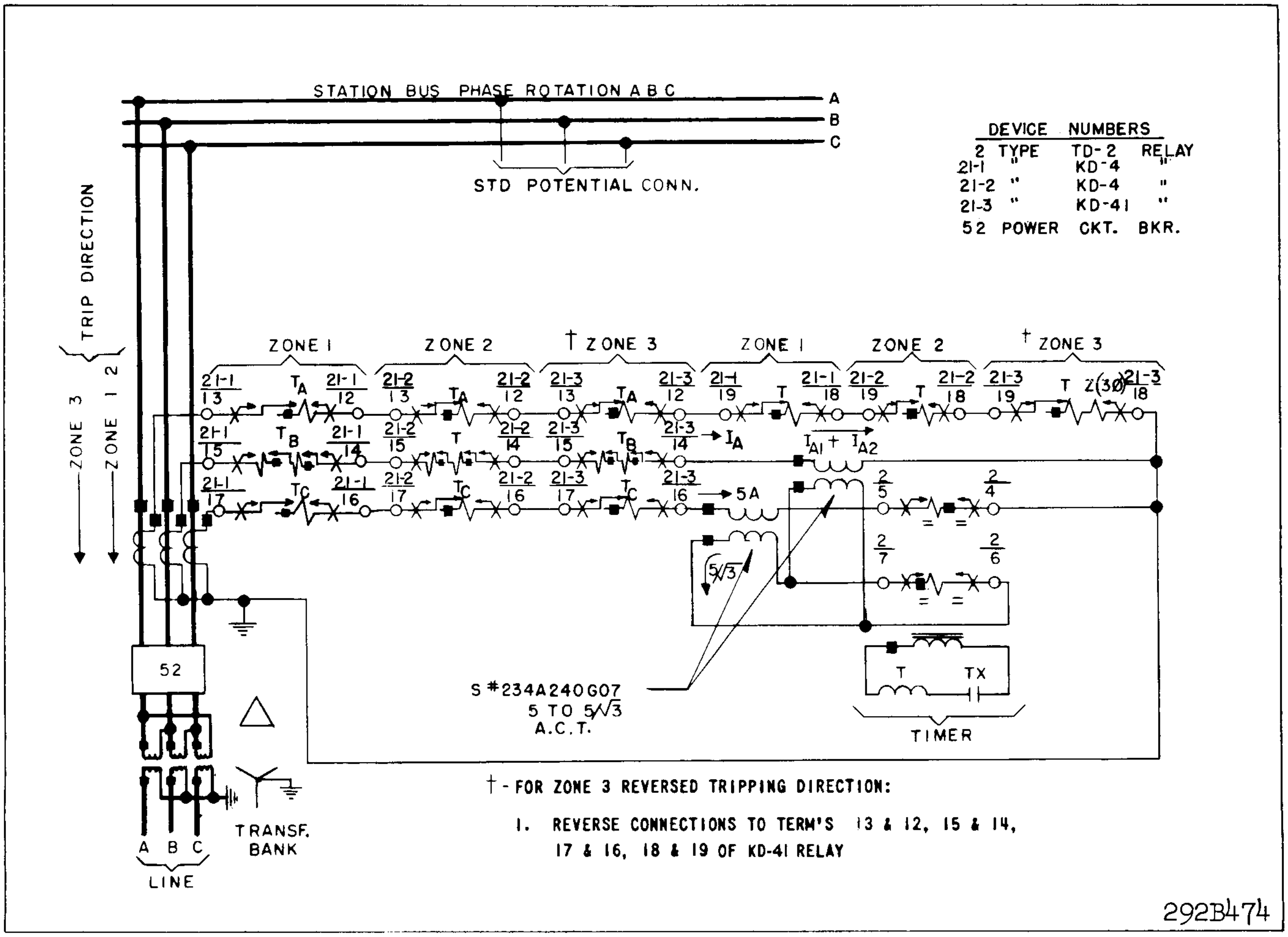


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

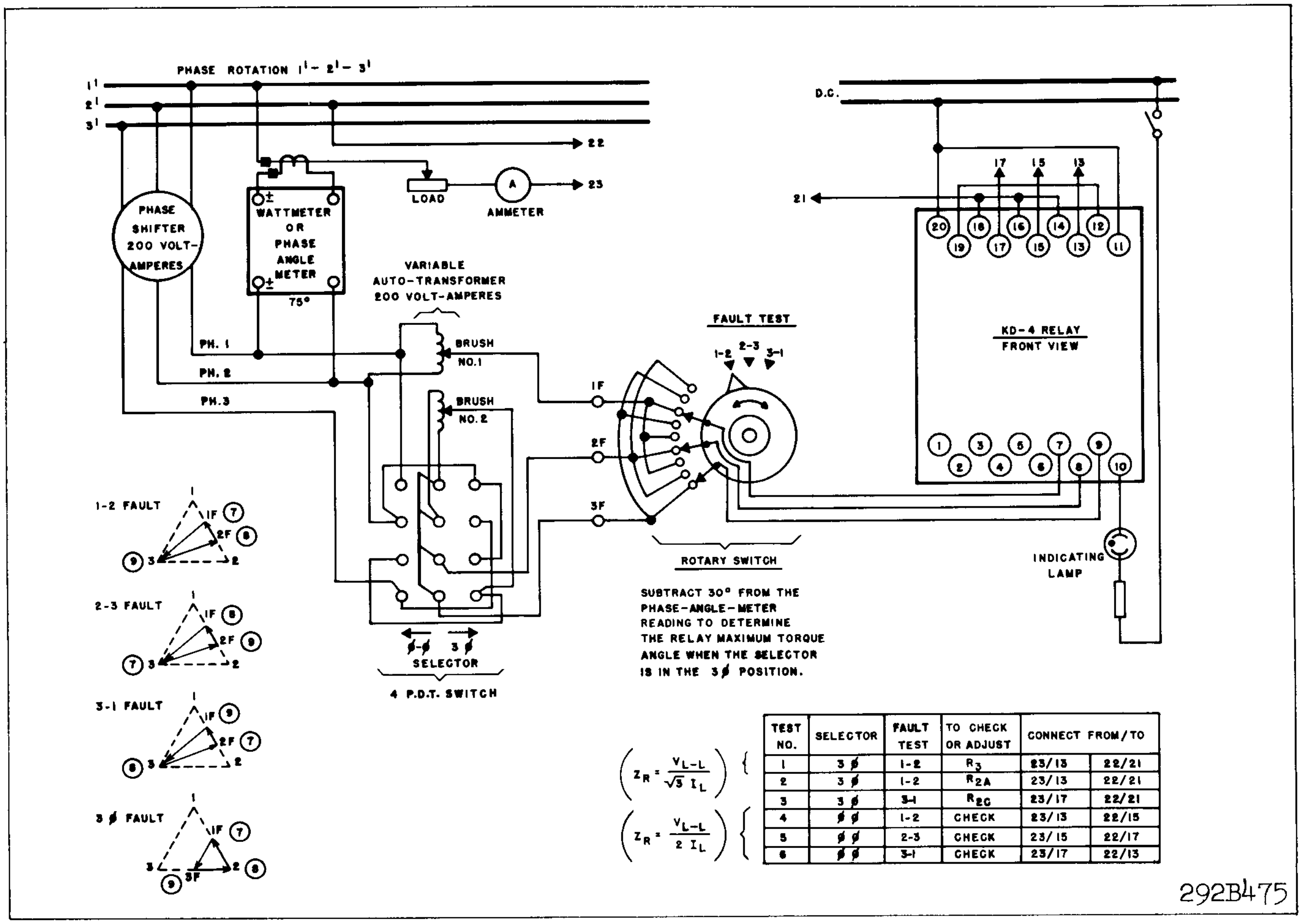
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L} \right)$ (Tests 1–3)

$\left(Z_R = \frac{V_{L-L}}{2\, I_L} \right)$ (Tests 4–6)

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3Ø	1-2	R_3	23/13	22/21
2	3Ø	1-2	R_{2A}	23/13	22/21
3	3Ø	3-1	R_{2C}	23/17	22/21
4	ØØ	1-2	CHECK	23/13	22/15
5	ØØ	2-3	CHECK	23/15	22/17
6	ØØ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of $\frac{\sin 60°}{\sin \theta}$.

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60°}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \sin \theta}{(1 \pm M)(\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed θ = 90°).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{\sqrt{3}I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{2I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass-sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	2 of 3-½ inch Resistors, Total Resistance 2000 ohms (One Resistor is fixed, one adjustable)
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

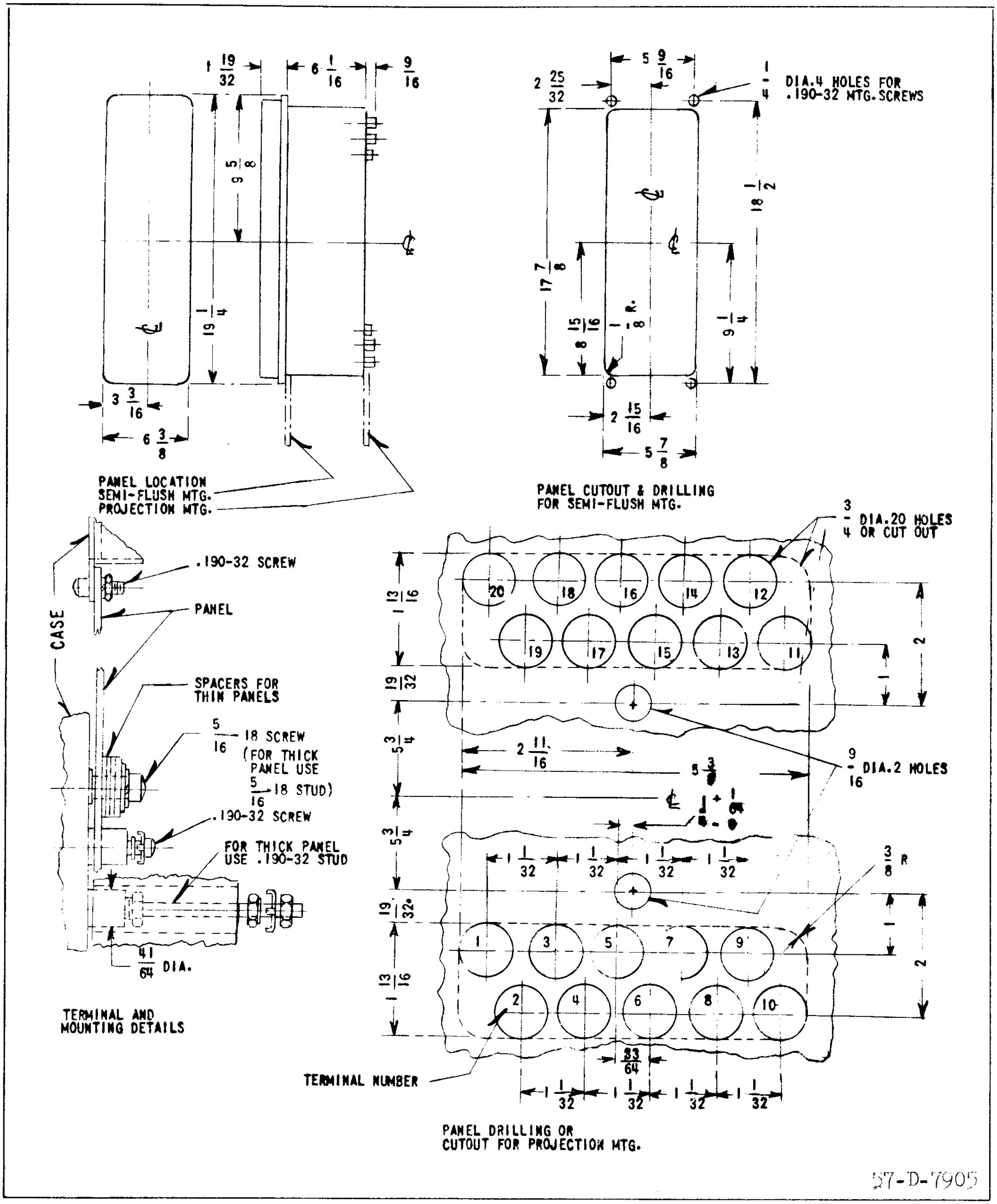


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 - 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11E
*Denotes change from superseded issue.

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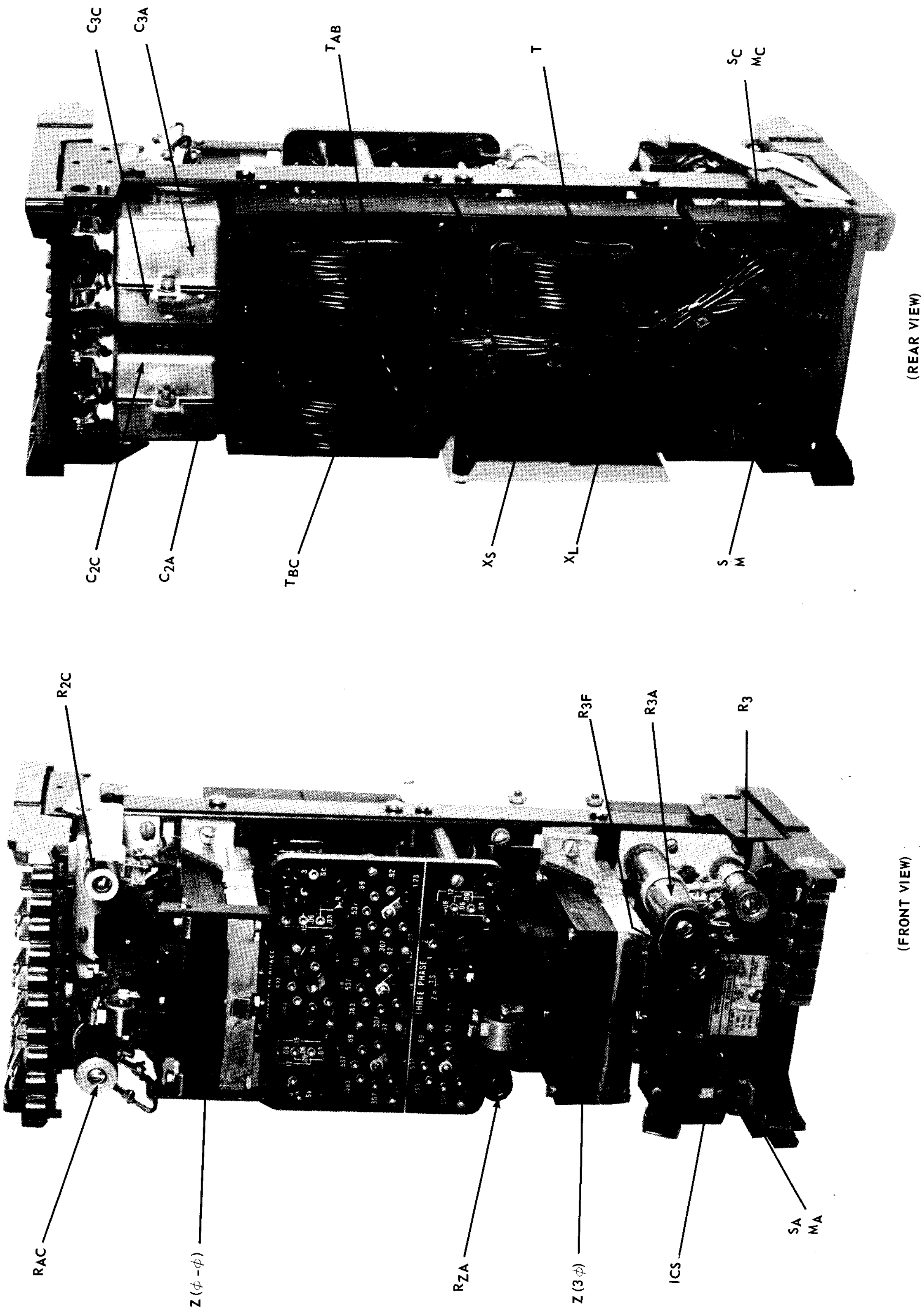


Fig. 1 Type KD-4 Relay Without case

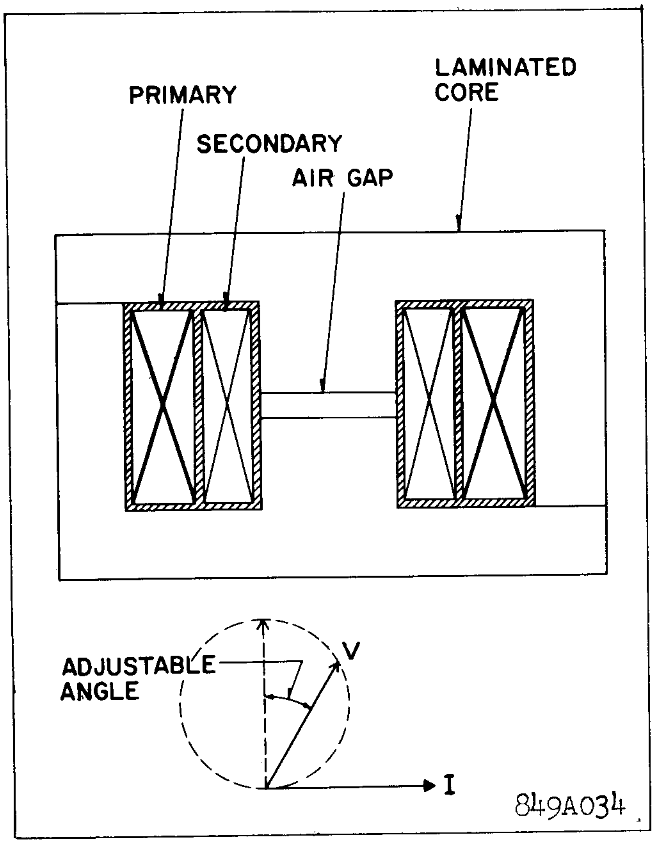


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

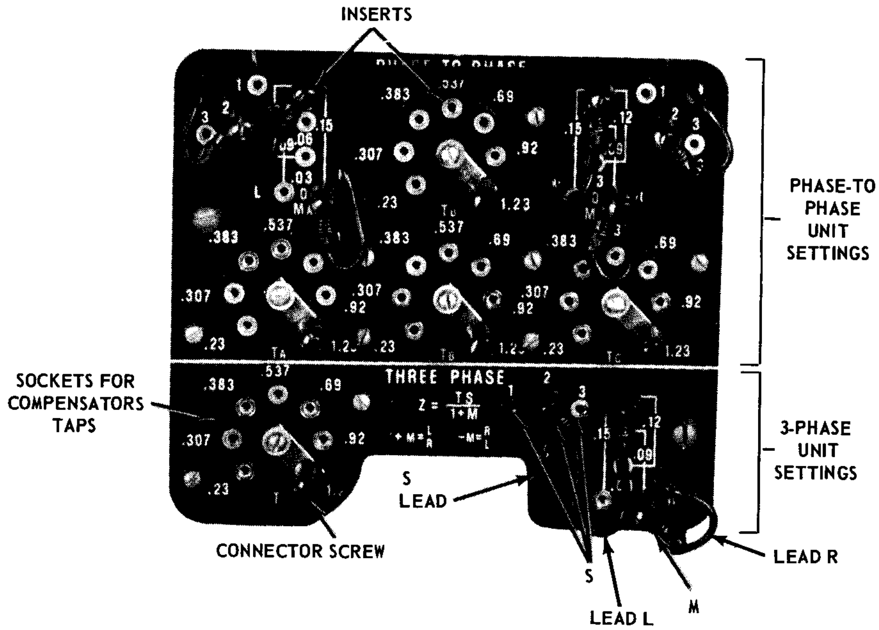


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

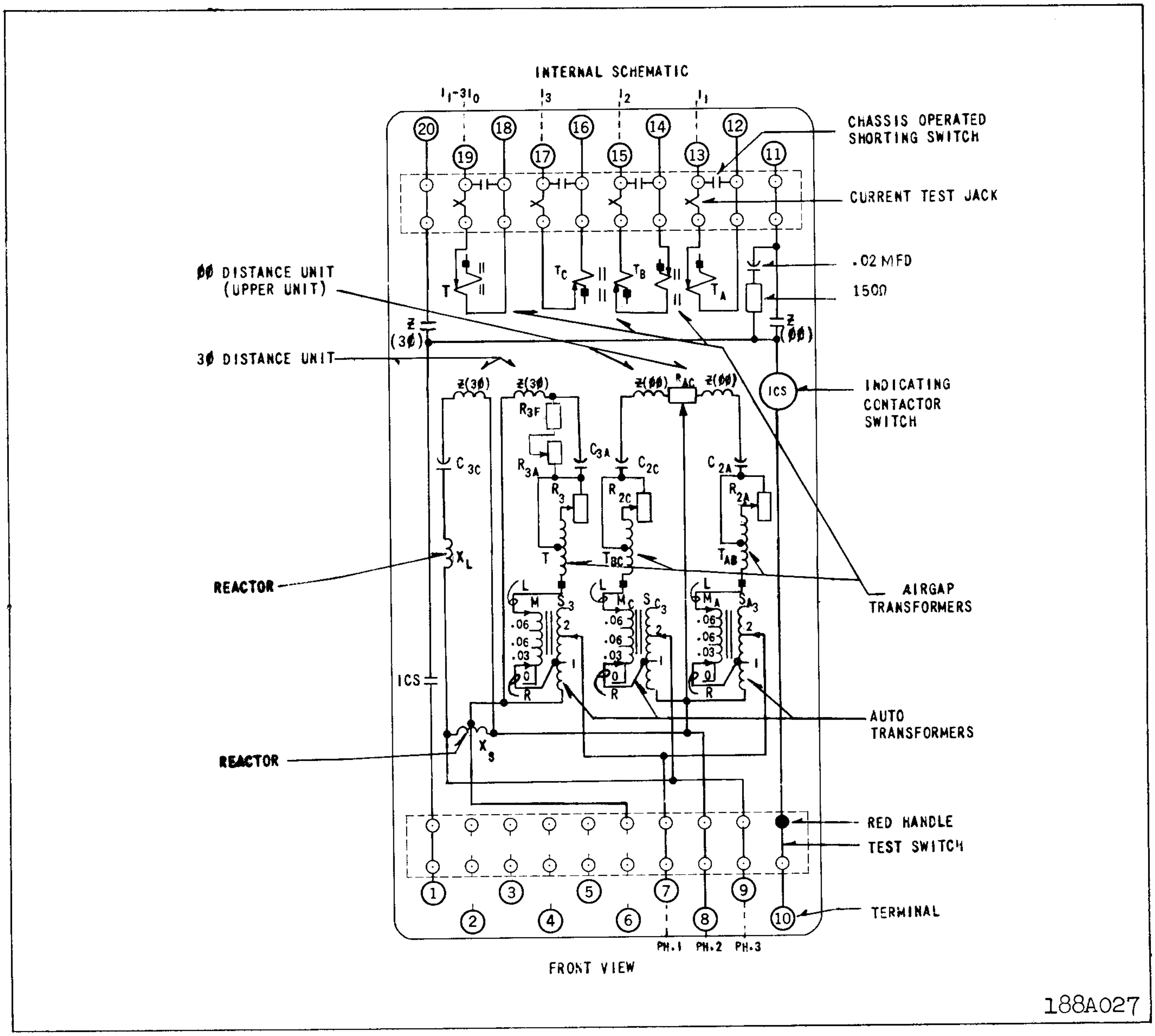
Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered



* *Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).*

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

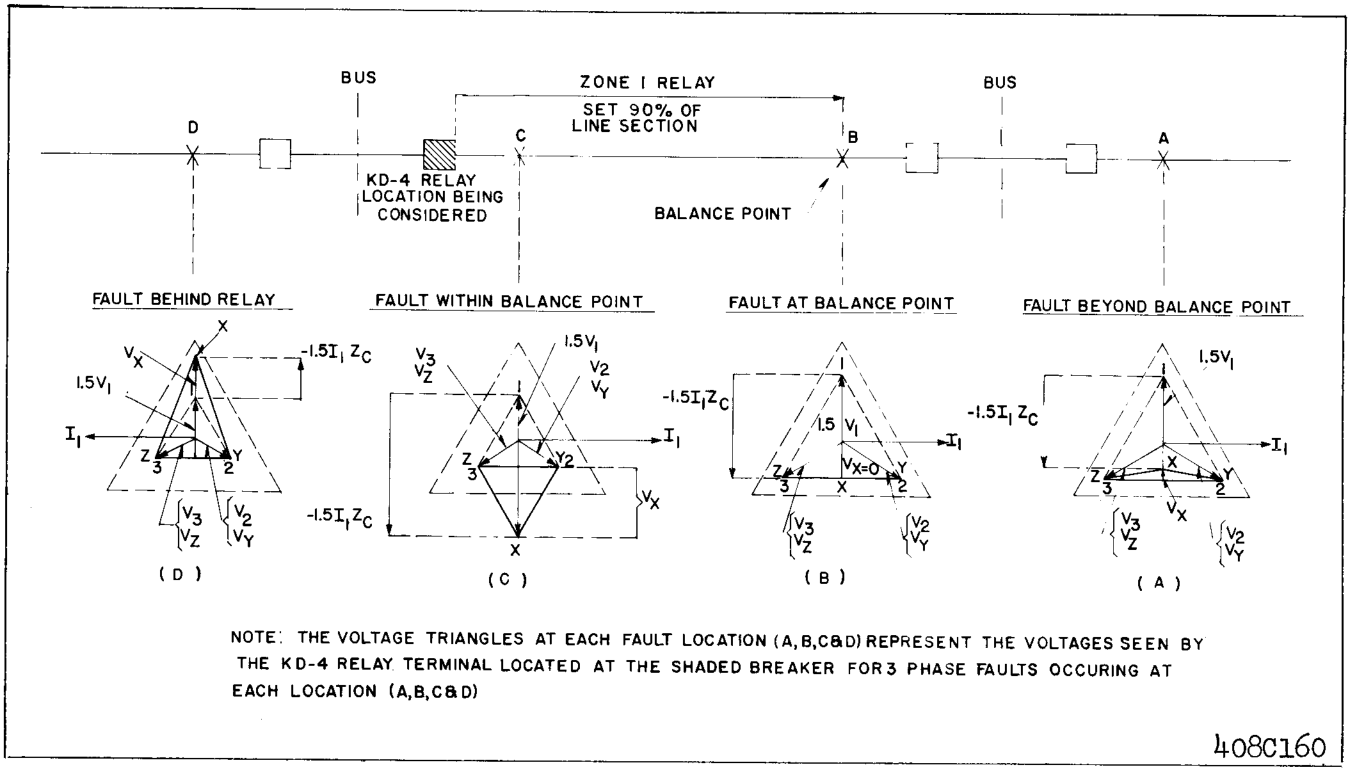


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

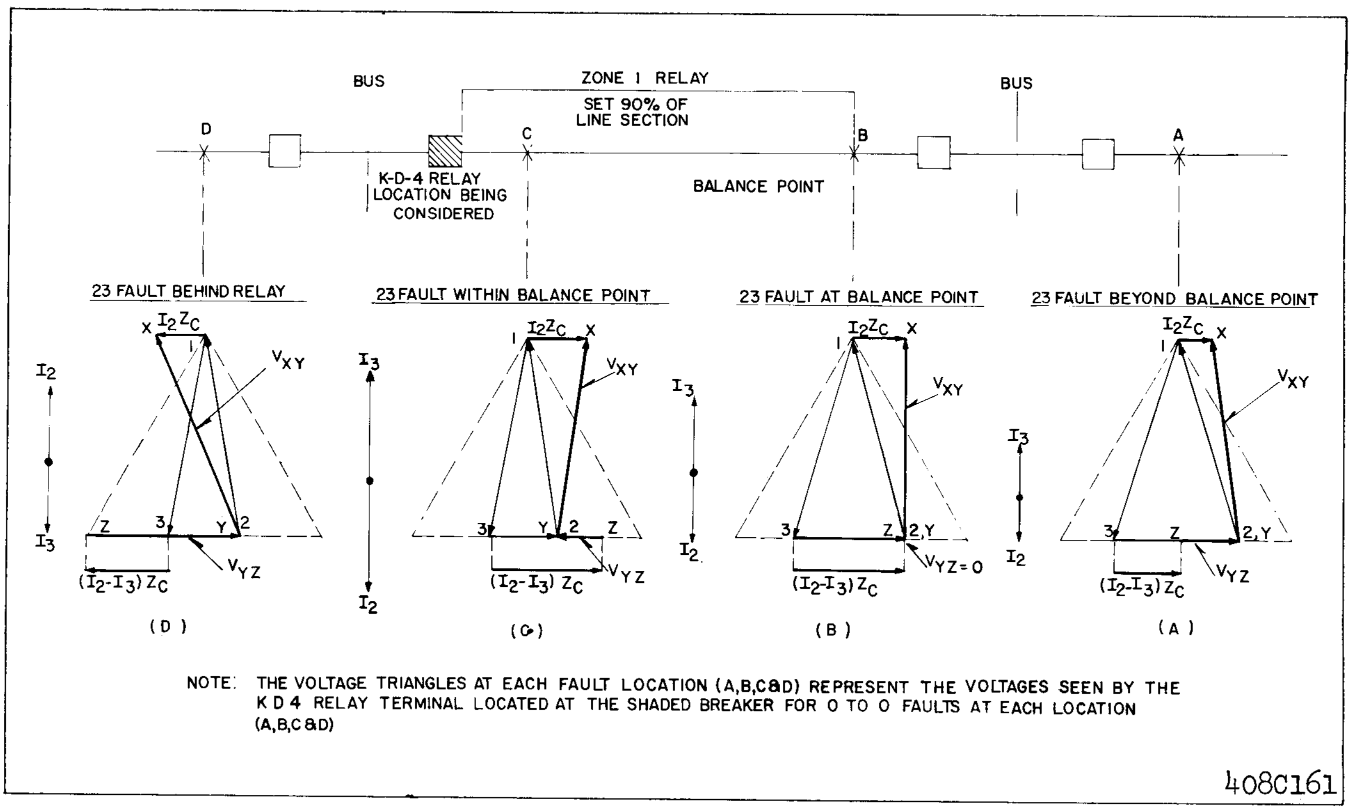


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

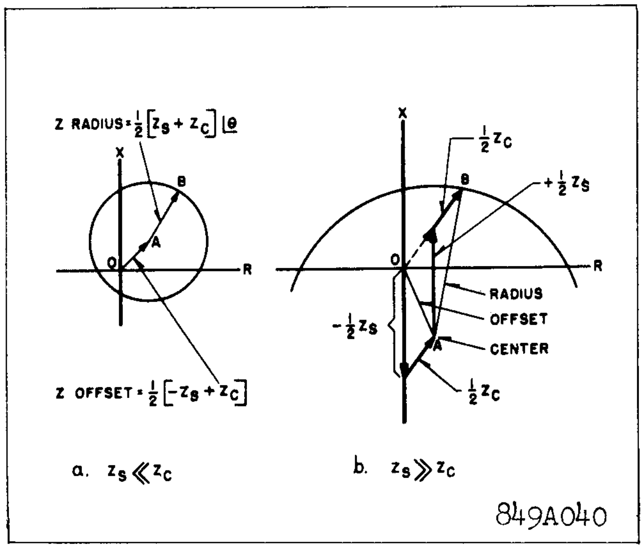


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

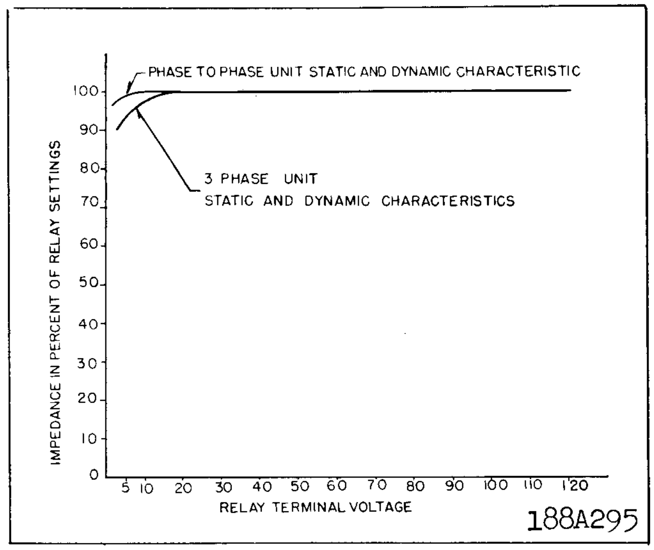


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

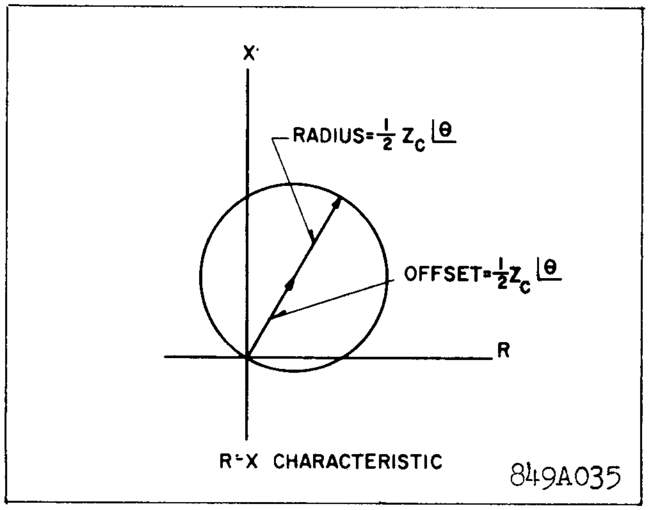


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of
* tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

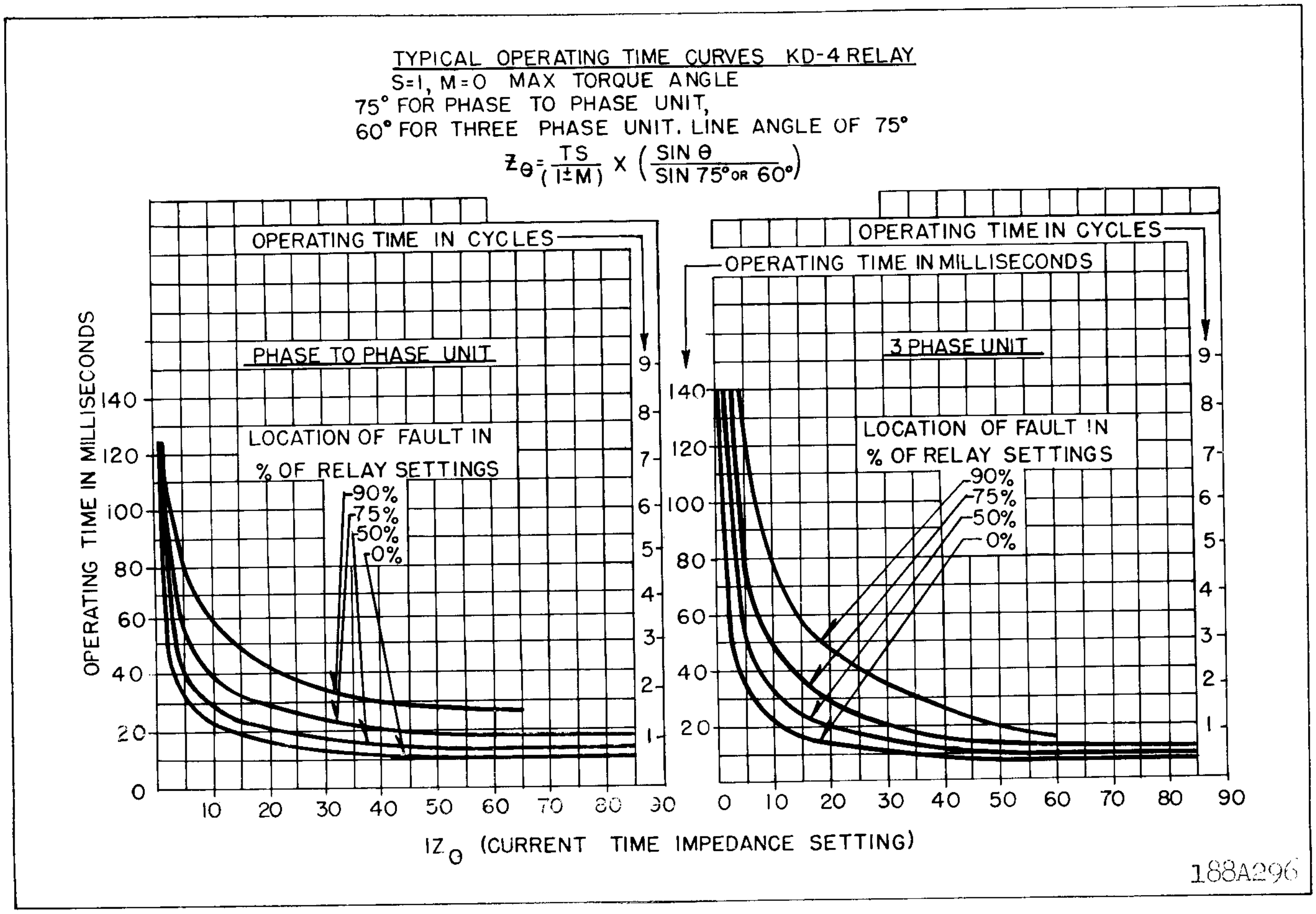
Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct



* *Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.*

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

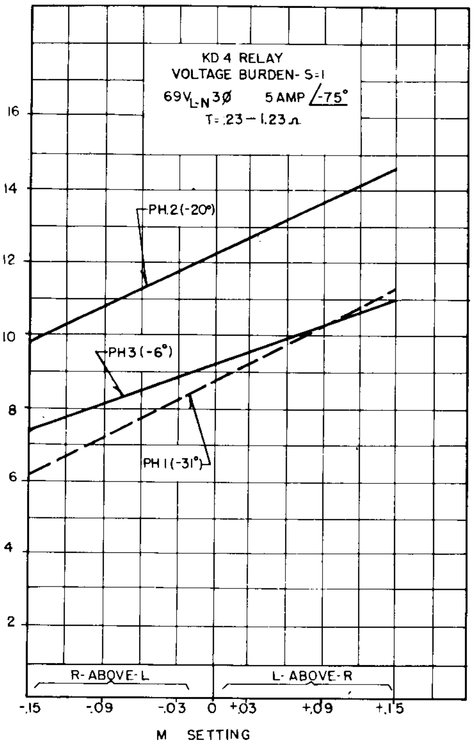
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

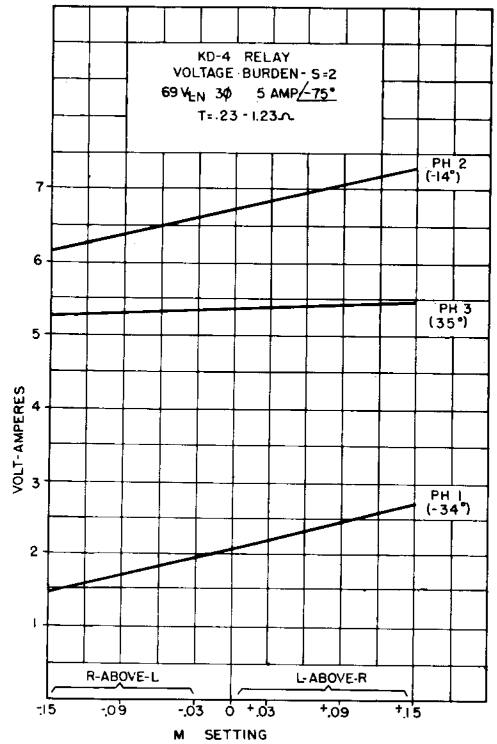
Distance Characteristic - 3 Phase Unit

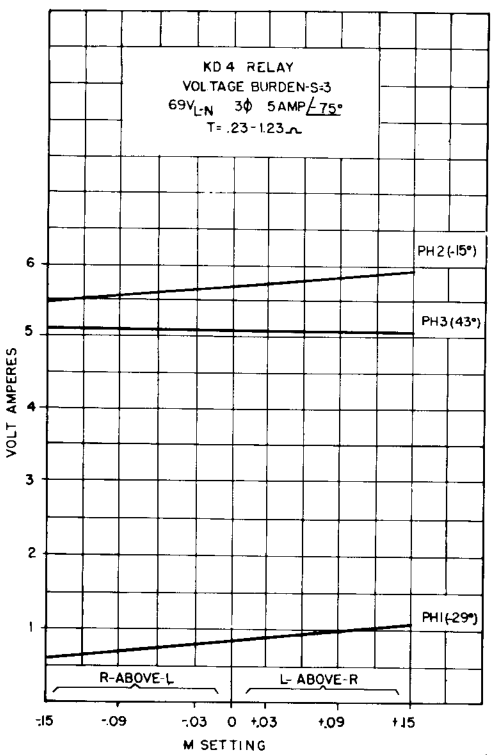
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$ S=1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1			PHASE 2			PHASE 3		
	VA	VARS	WATTS	VA	VARS	WATTS	VA	VARS	WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin\theta}{(1 \pm M)\sin\alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

	(T, TA, T_B, and T_C)
	.23, .307, .383, .537, .690, .920, 1.23
	(S, S_A, S_C)
	1 2 3
	(M, M_A, M_C)
±Values between taps	.03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating:	0.1 ohms d-c. resistance
0.2/2.0 ampere rating:	0.2 tap – 6.5 ohms
	2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_c}{R_v}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9R_C}{R_v}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_v = potential transformer ratio

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ
   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ should be different from the factory setting multiply the Z_θ – value by factor $\frac{\text{Sin } 75°}{\text{Sin } \theta°}$ for phase to phase unit, and by factor $\frac{\text{Sin } 60°}{\text{Sin } \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. Making correction for characteristic angle of the Line (60°) that is different from factory setting of 75° the relay setting, Z should be Z = 1.7 x 1.11 = 1.89 ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89}$ x 100 = 100.5% of the desired reach.

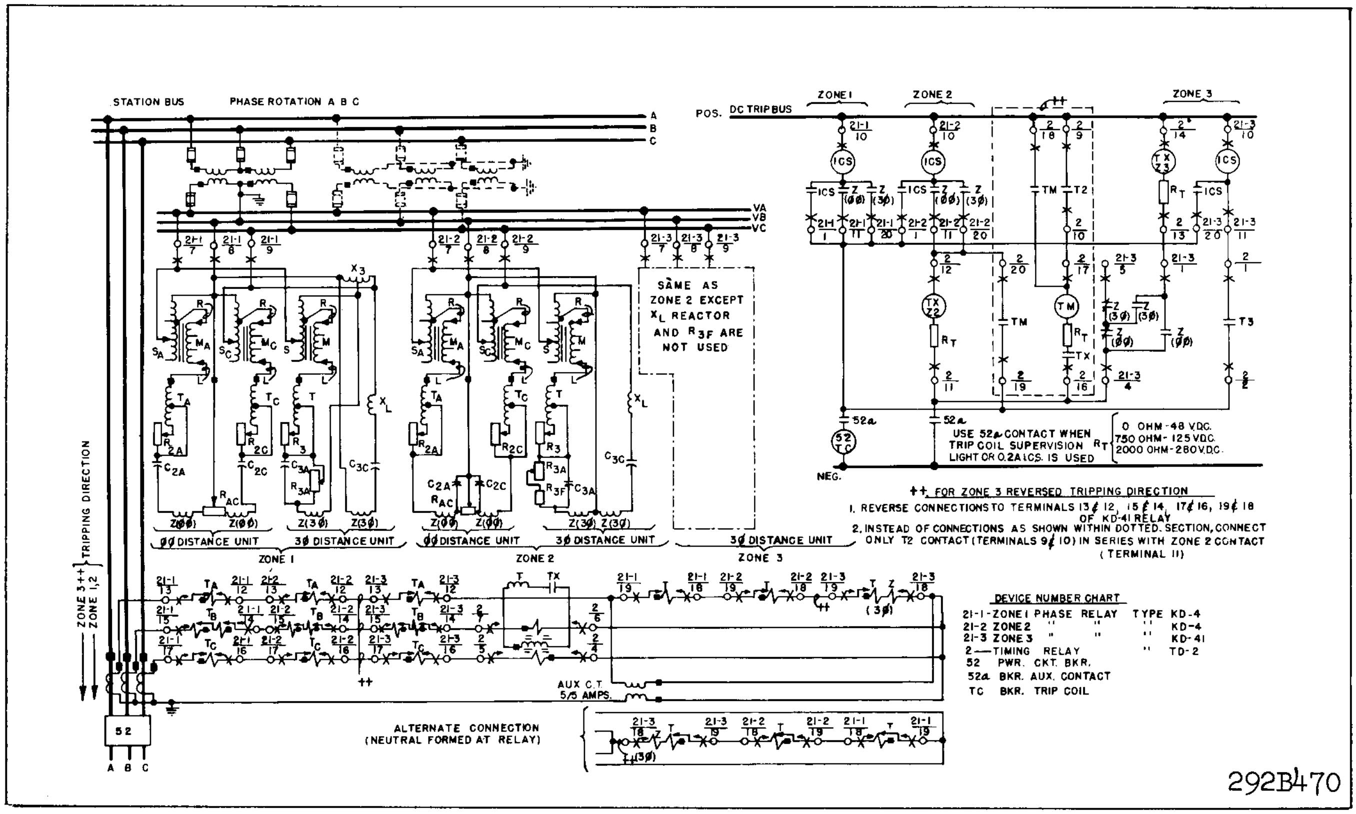


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.

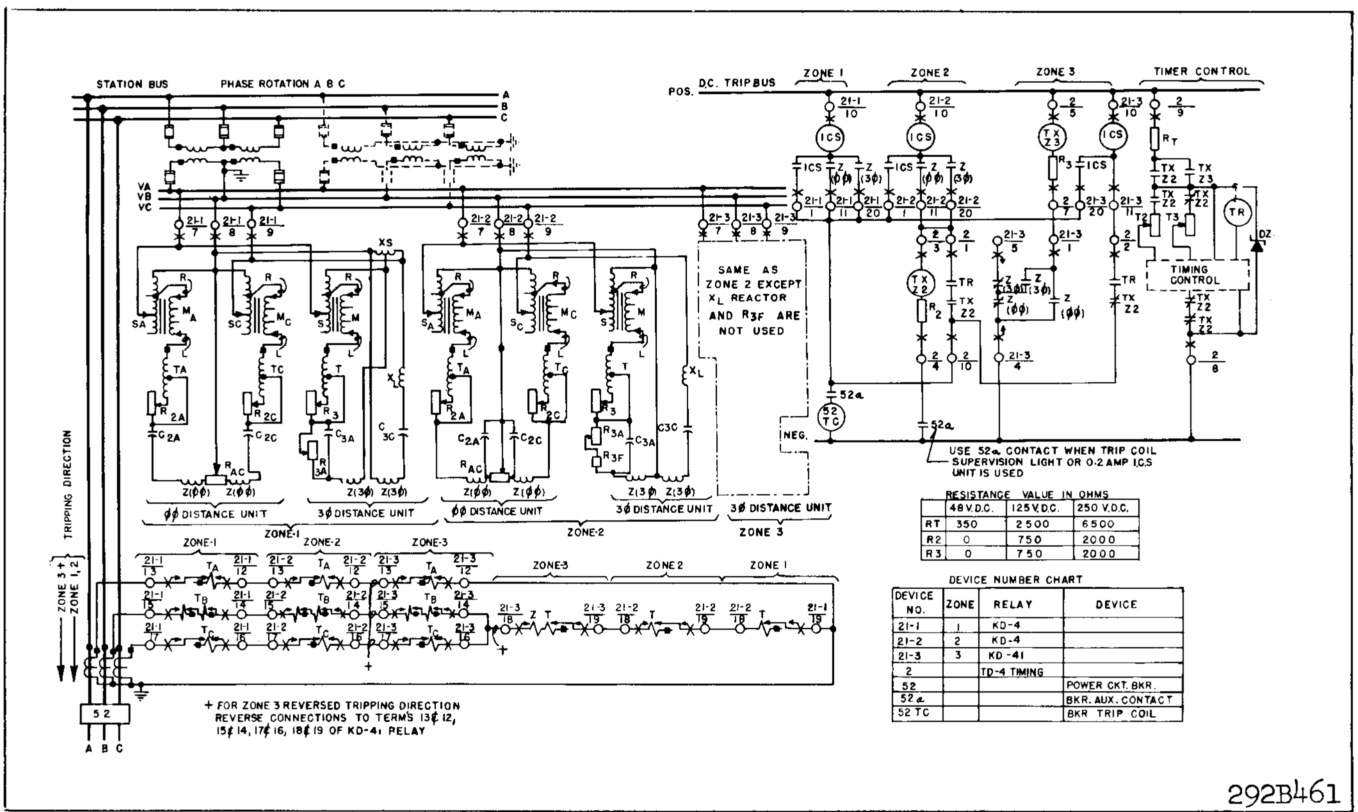


Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2
T = .920
M = −.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. Then the relay setting Z should be $= Z = Z_\theta \cdot \frac{\text{Sin } 60°}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$

a) The nearest table value is 2.09

b) From the Table I read off
S = 2
T = .920
M = − .12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from −.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	"L" over "R"
	.205	.274	.341	.479	.615	.822	1.100	—	1.64	2.20	—	3.29	+.12		Upper .06	.03	
	.211	.282	.350	.493	.632	.843	1.120	—	1.69	2.24	—	3.38	+.09		Lower .06	0	
	.217	.290	.361	.506	.650	.869	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower.06	
	.224	.298	.371	.521	.670	.892	1.191	—	1.78	2.38	—	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	
	.237	.317	.395	.552	.713	.948	1.270	—	1.90	2.54	—	3.80		-.03	0	.03	"R" over "L"
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	—	3.93		-.06	Lower.06	Upper .06	
	.253	—	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower.06	
	.261	—	.435	—	.785	1.048	1.395	1. -	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	—	.450	—	—	—	1.45	—	—	2.90	—	4.35		-.15	0	Upper .06	

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting, or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

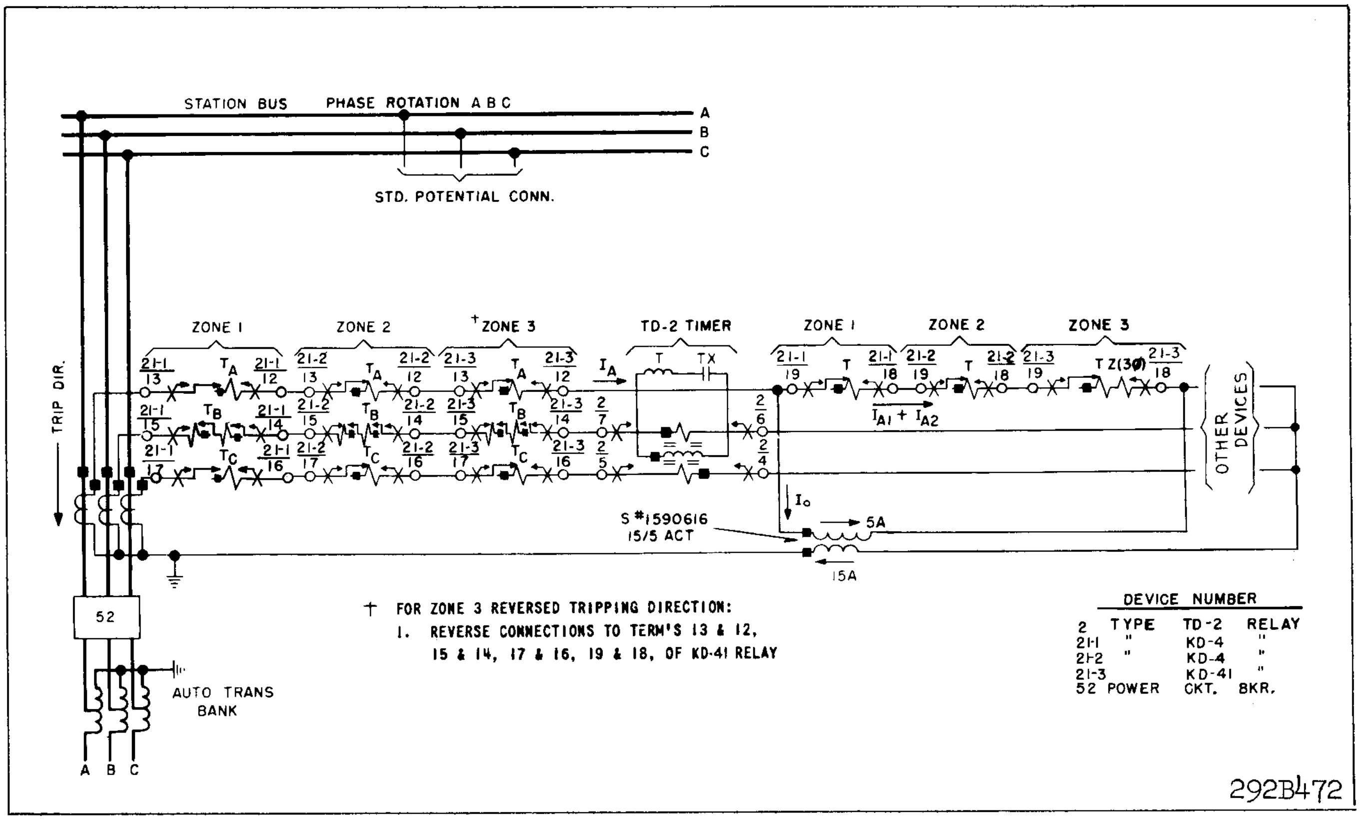


Fig. 14 ***A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.***

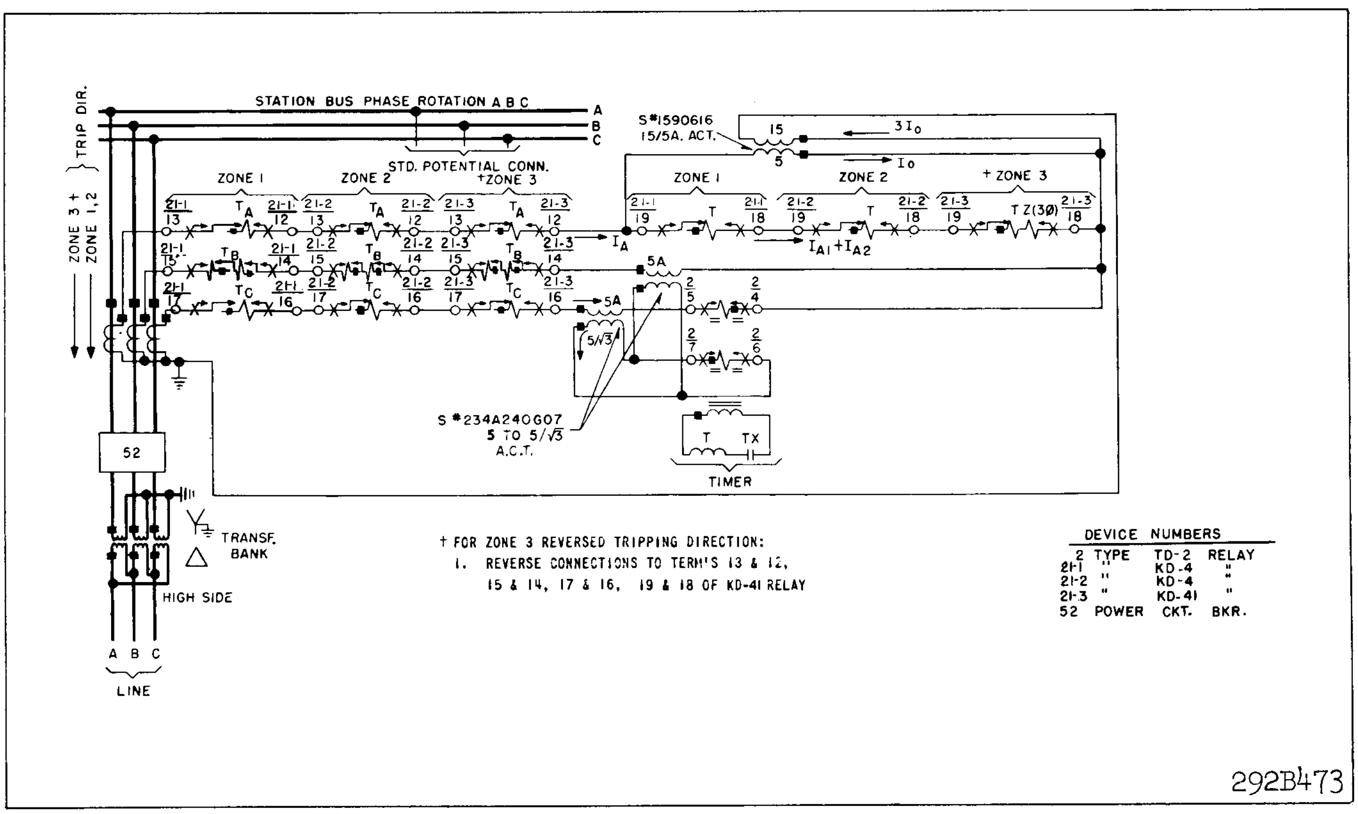


Fig. 15 ***A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.***

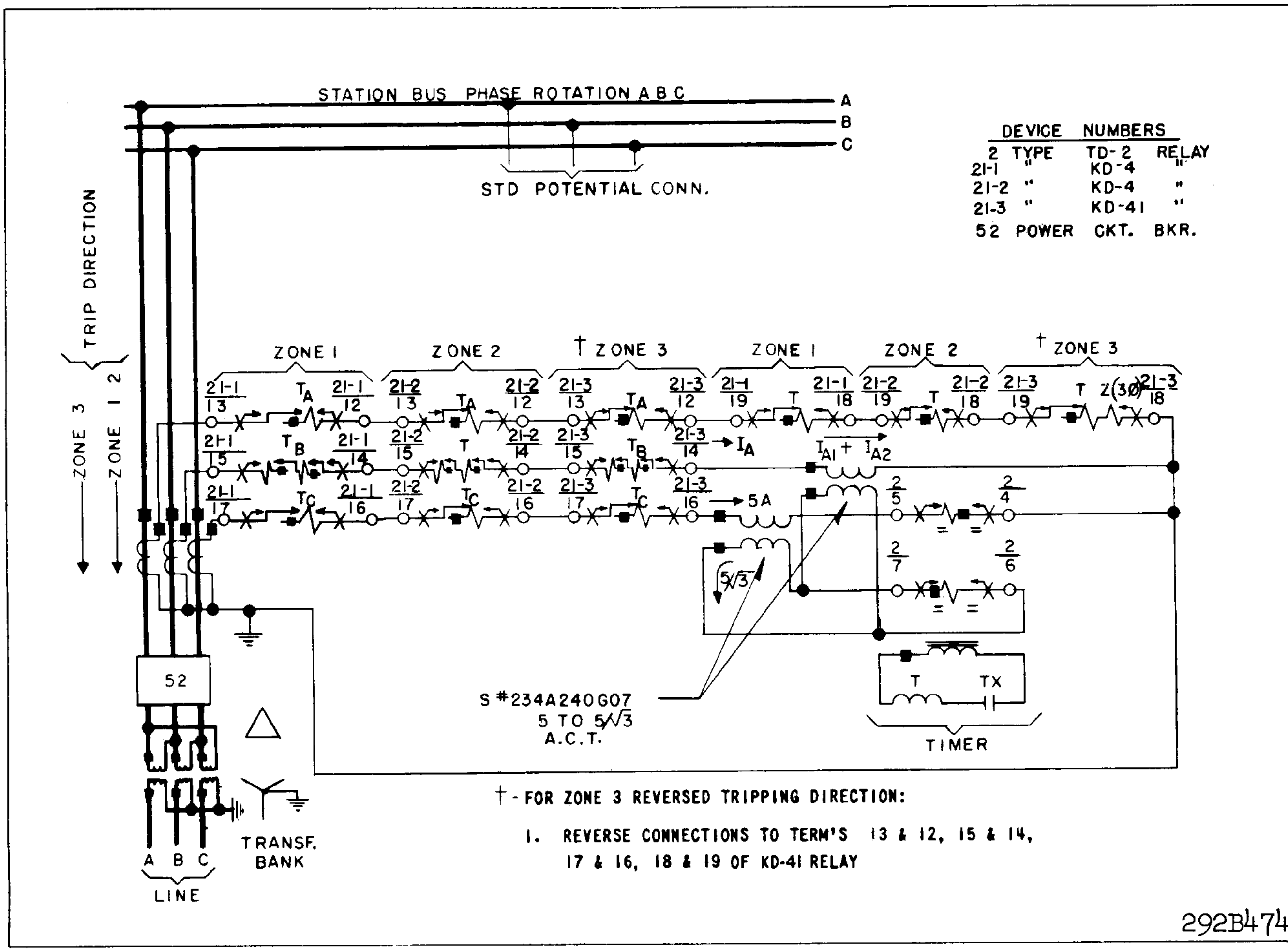


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

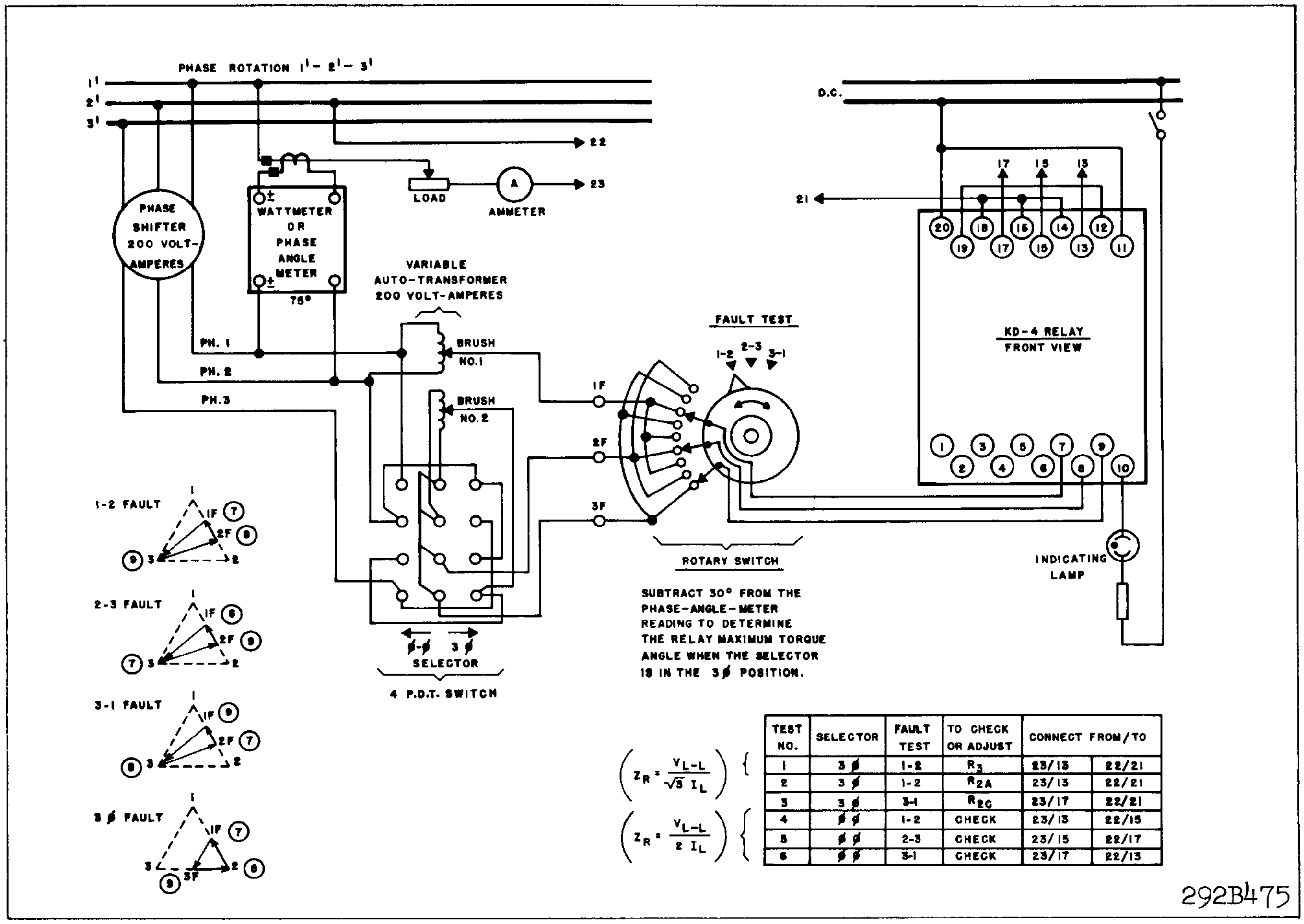
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right)$ Tests 1–3; $\left(Z_R = \frac{V_{L-L}}{2\, I_L}\right)$ Tests 4–6

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3ϕ	1-2	R_3	23/13	22/21
2	3ϕ	1-2	R_{2A}	23/13	22/21
3	3ϕ	3-1	R_{2C}	23/17	22/21
4	ϕϕ	1-2	CHECK	23/13	22/15
5	ϕϕ	2-3	CHECK	23/15	22/17
6	ϕϕ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L\text{-}L}}{\sqrt{3}\, I_L}$ where $V_{L\text{-}L}$ is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures $Z_R = \frac{V_{L\text{-}L}}{2 I_L}$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of $\frac{\sin 60^\circ}{\sin \theta}$.

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

* Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.

* 3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3}I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2\ I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass-sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3φ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3φ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	2 of 3-½ inch Resistors, Total Resistance 2000 ohms (One Resistor is fixed, one adjustable)
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (φ-φ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

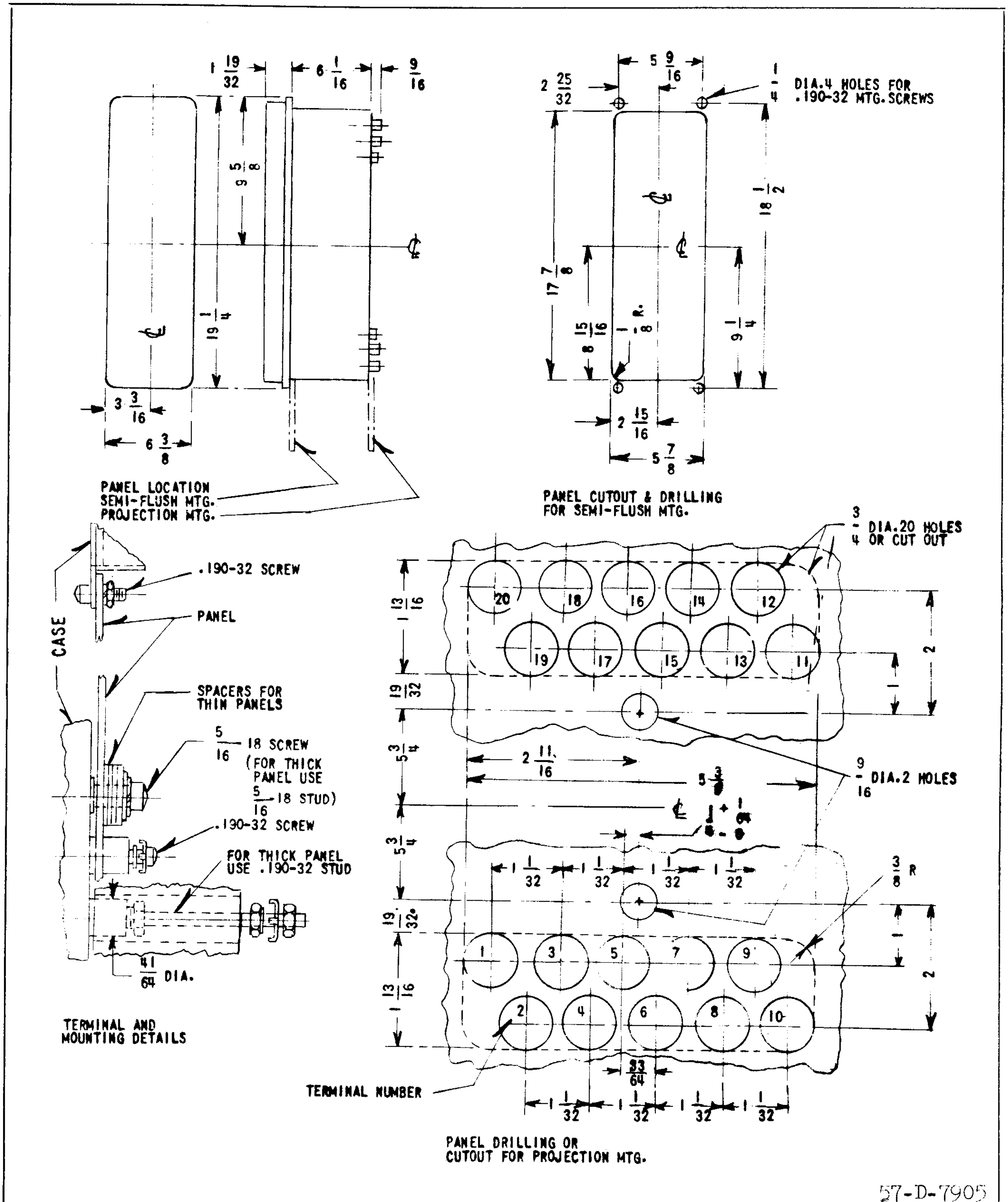


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11F
*Denotes change from superseded issue.

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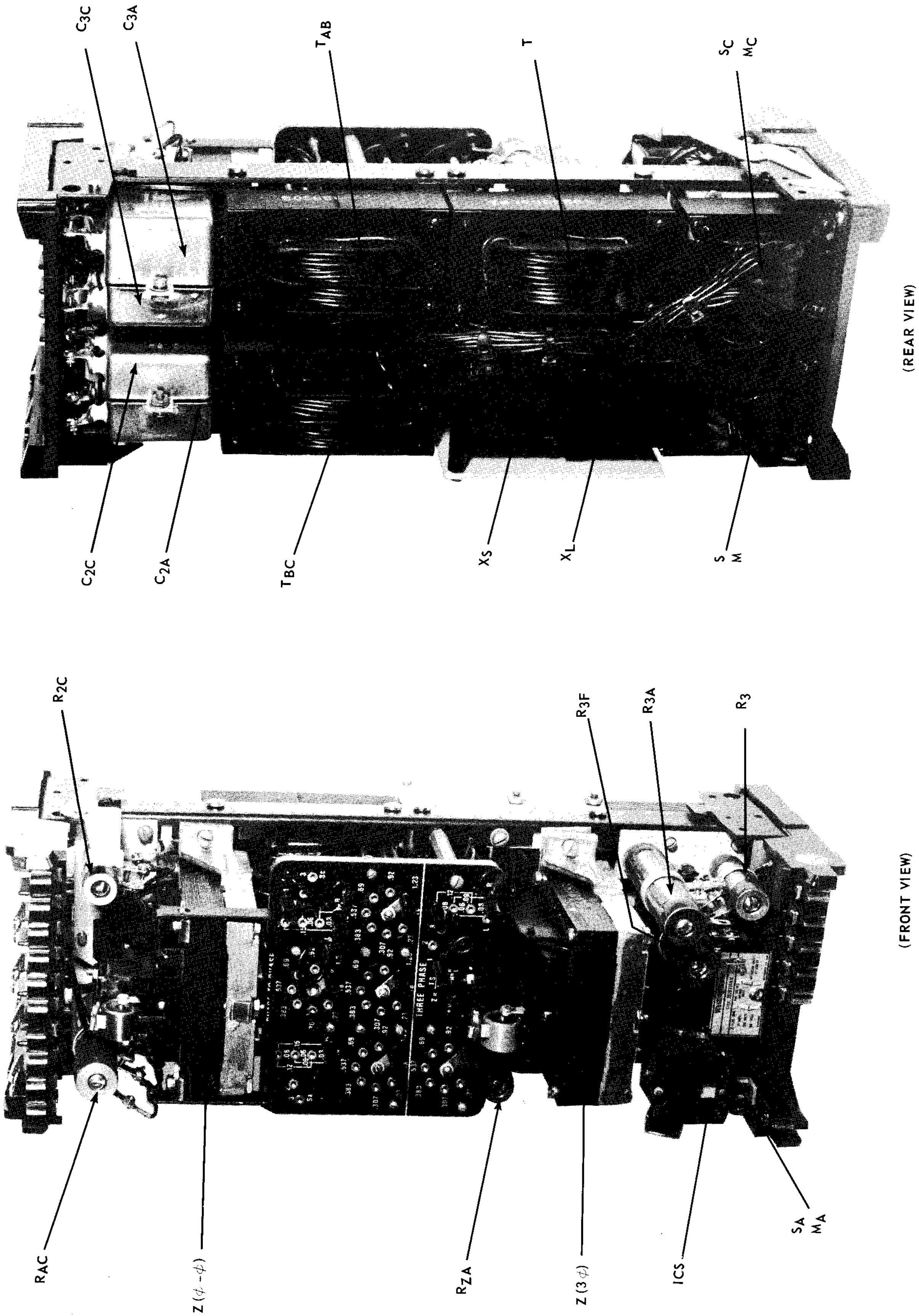


Fig. 1 Type KD-4 Relay Without case

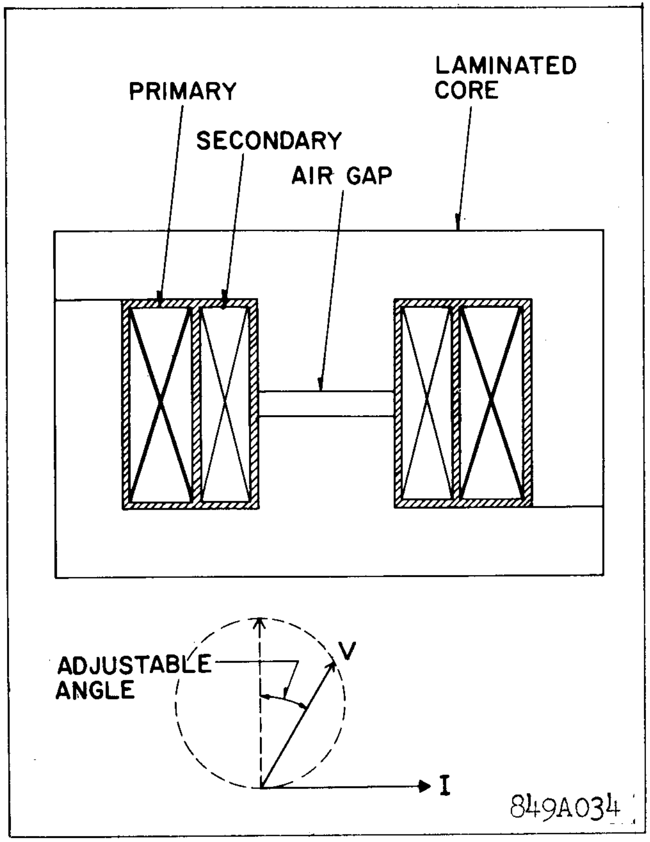


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

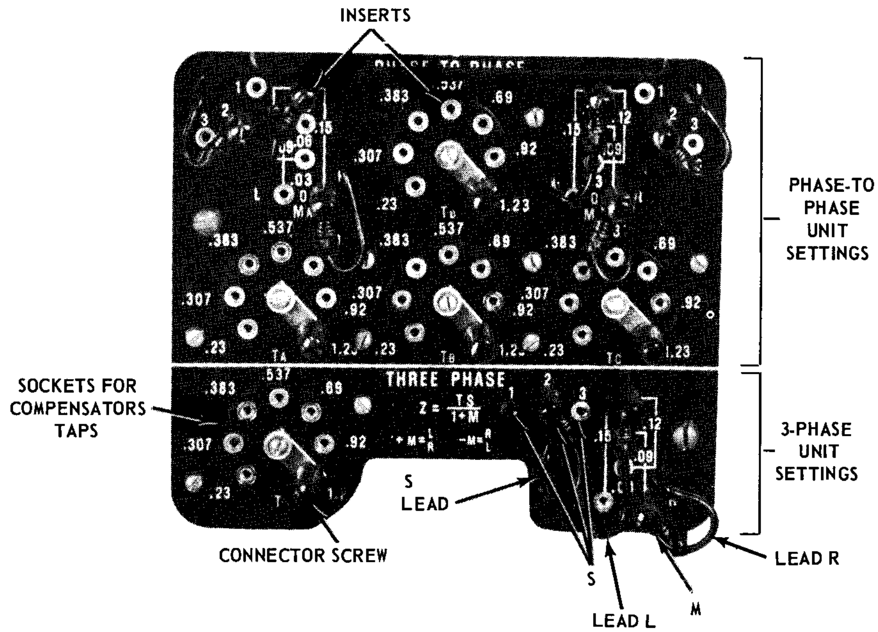


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

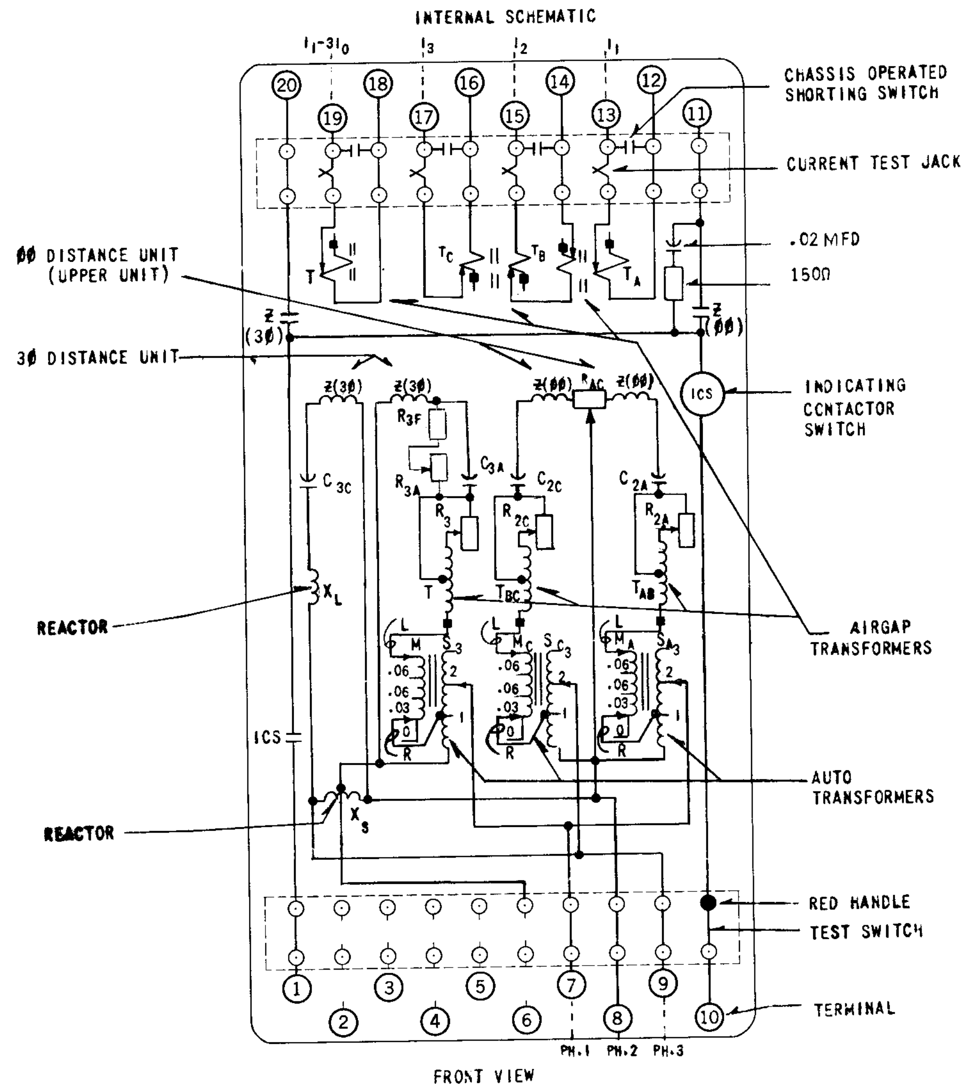


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

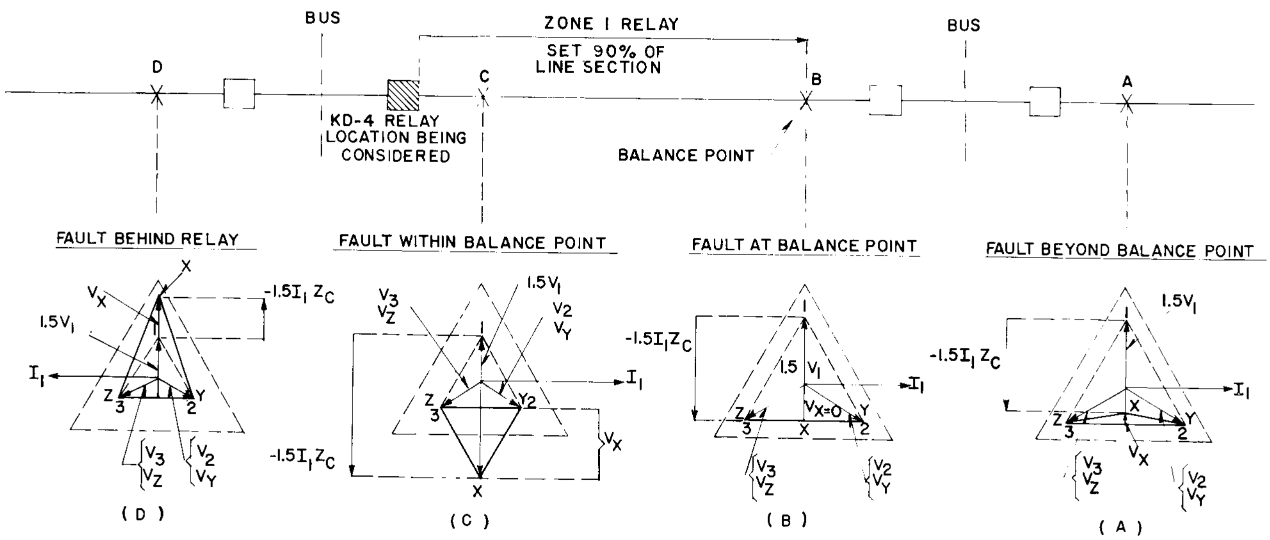
successively.

Three Phase Unit

A single compensator T has its primary energized with $(I_1 - 3I_0)$current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with $(-I_2 - I_3)$. Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault



NOTE: THE VOLTAGE TRIANGLES AT EACH FAULT LOCATION (A,B,C&D) REPRESENT THE VOLTAGES SEEN BY THE KD-4 RELAY TERMINAL LOCATED AT THE SHADED BREAKER FOR 3 PHASE FAULTS OCCURING AT EACH LOCATION (A,B,C&D)

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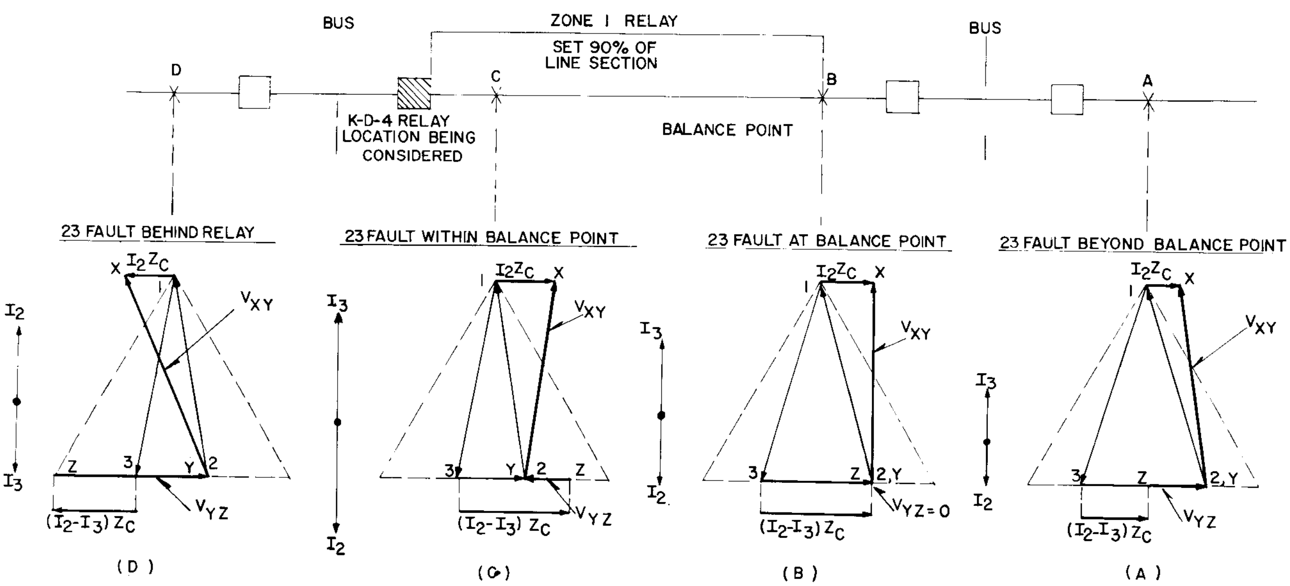
Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.



NOTE: THE VOLTAGE TRIANGLES AT EACH FAULT LOCATION (A,B,C&D) REPRESENT THE VOLTAGES SEEN BY THE KD 4 RELAY TERMINAL LOCATED AT THE SHADED BREAKER FOR O TO O FAULTS AT EACH LOCATION (A,B,C&D)

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Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

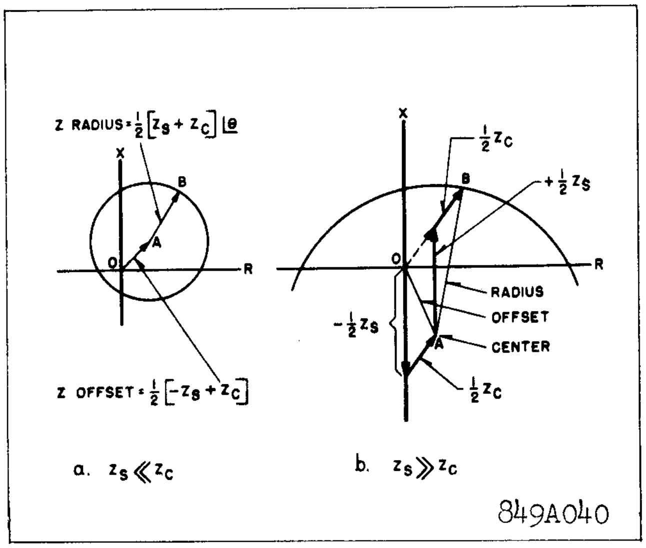


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

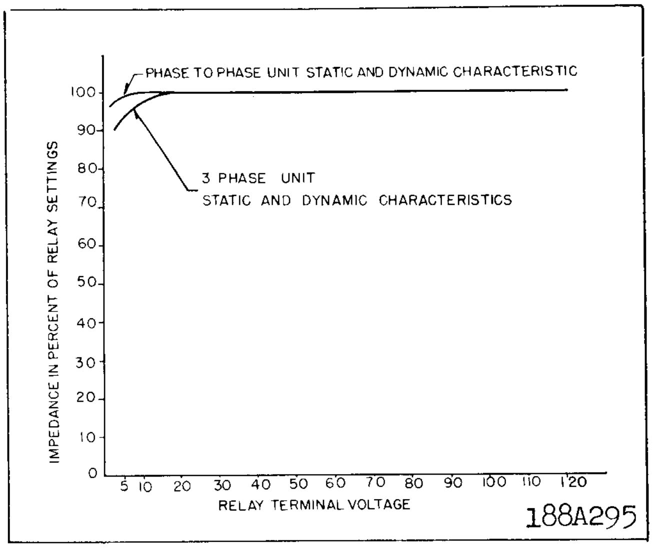


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, -1.5 I_1Z_C, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage -1.5I_1Z_C, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that -1.5IZ_C is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage - 1.5 IZ_C, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages (I_1 - I_2) Z_C and (I_2 - I_3) Z_C where Z_C is the compensator mutual impedance. In this case I_1 = 0. The terminals of the trip-

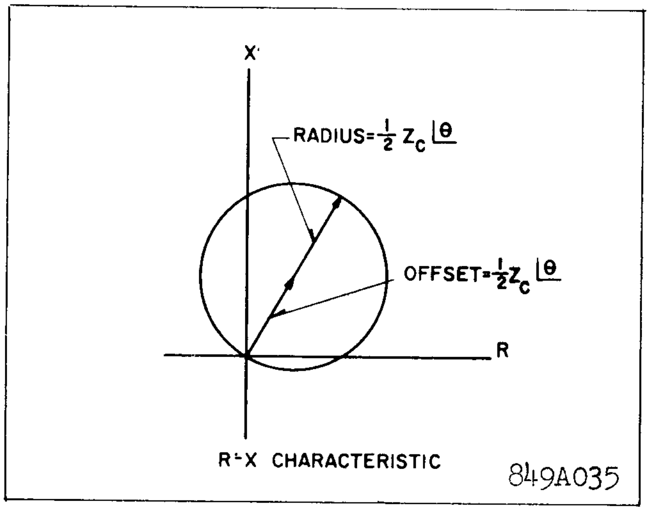


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

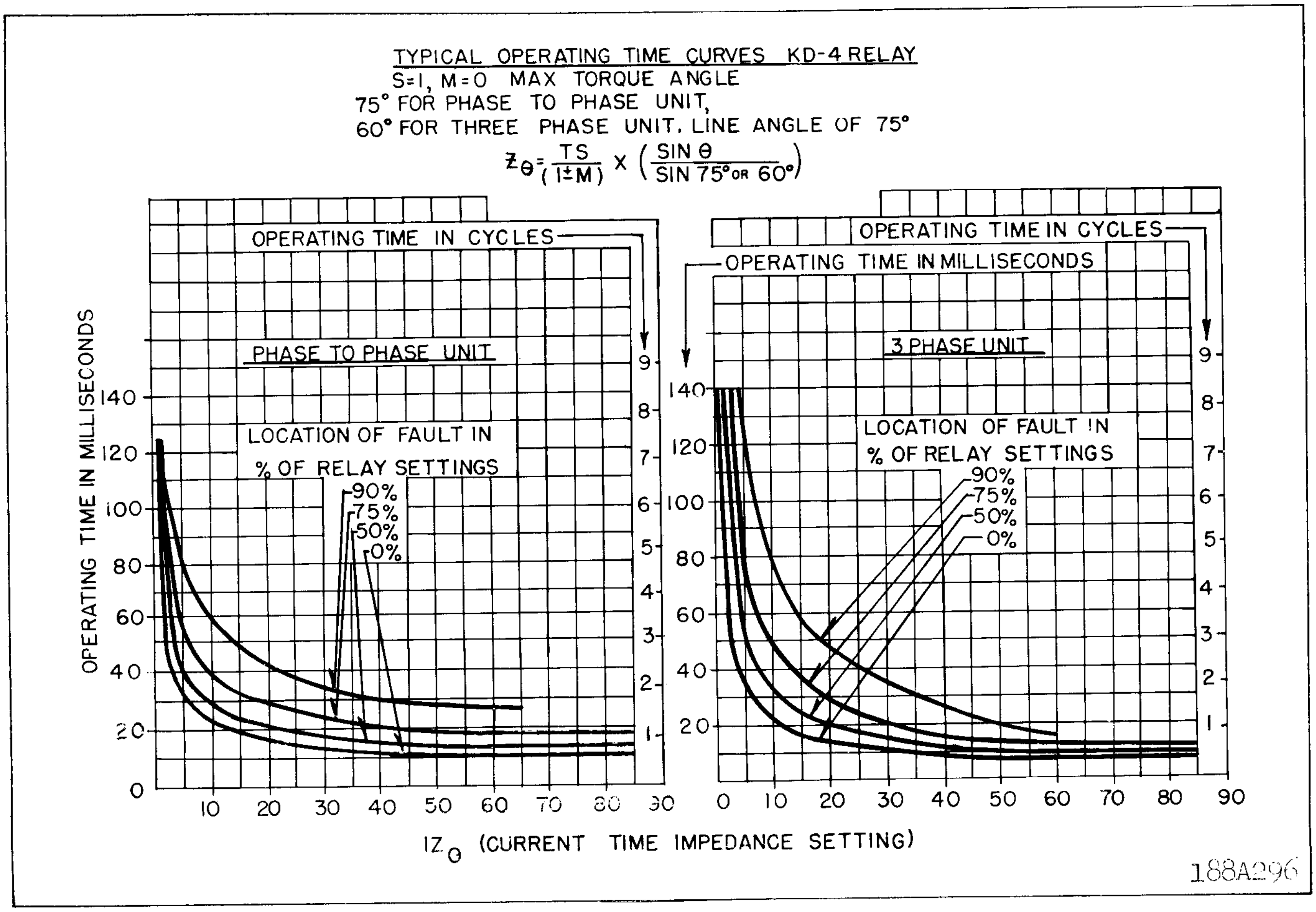


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

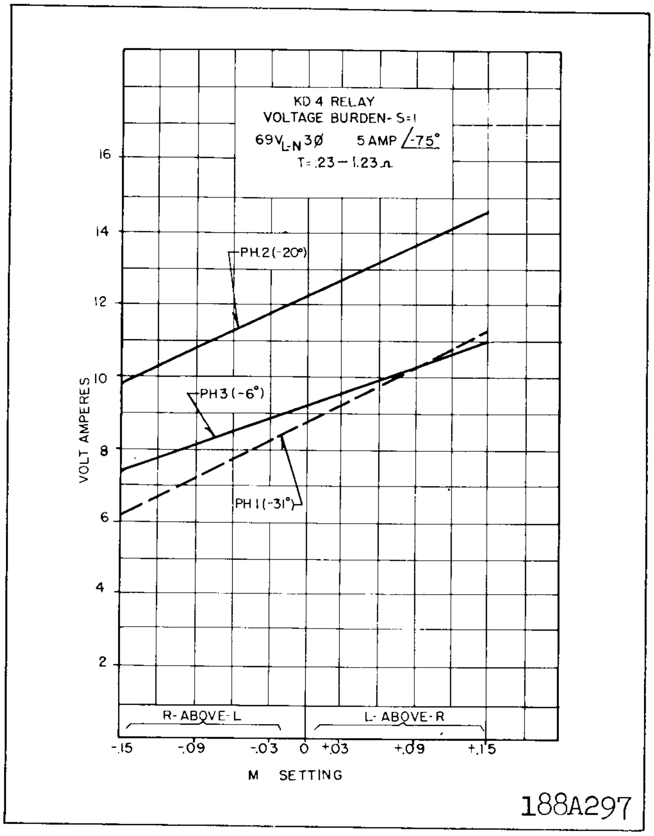
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

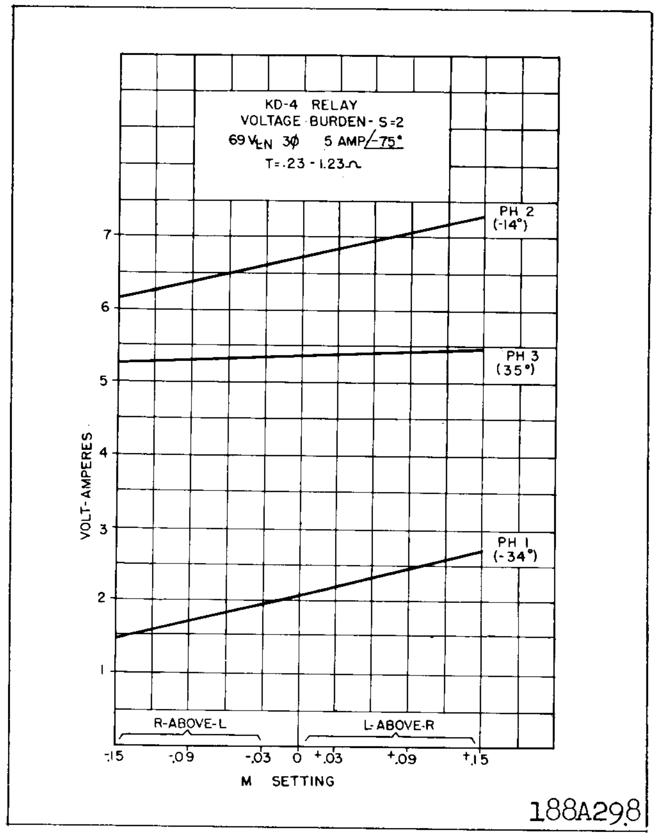
Distance Characteristic - 3 Phase Unit

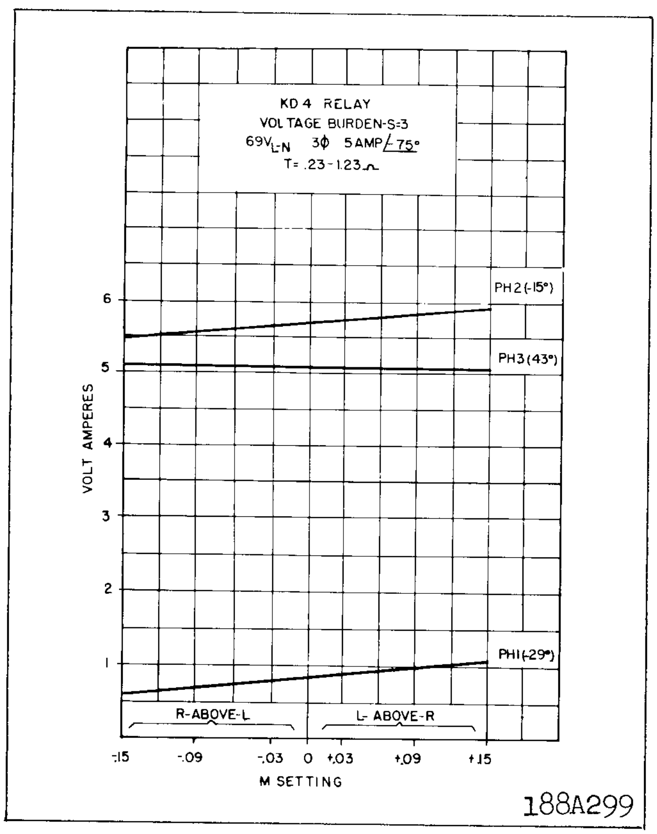
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$ S = 1
THREE PHASE CURRENT = 5 /-75° AMPS.

TAP SETTING	PHASE 1 VA	PHASE 1 VARS	PHASE 1 WATTS	PHASE 2 VA	PHASE 2 VARS	PHASE 2 WATTS	PHASE 3 VA	PHASE 3 VARS	PHASE 3 WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin\theta}{(1 \pm M)\sin\alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)

.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)

1 2 3

	(M, M_A, M_C)		
±Values between taps	.03	.06	.06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_V = potential transformer ratio

* T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z. Setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

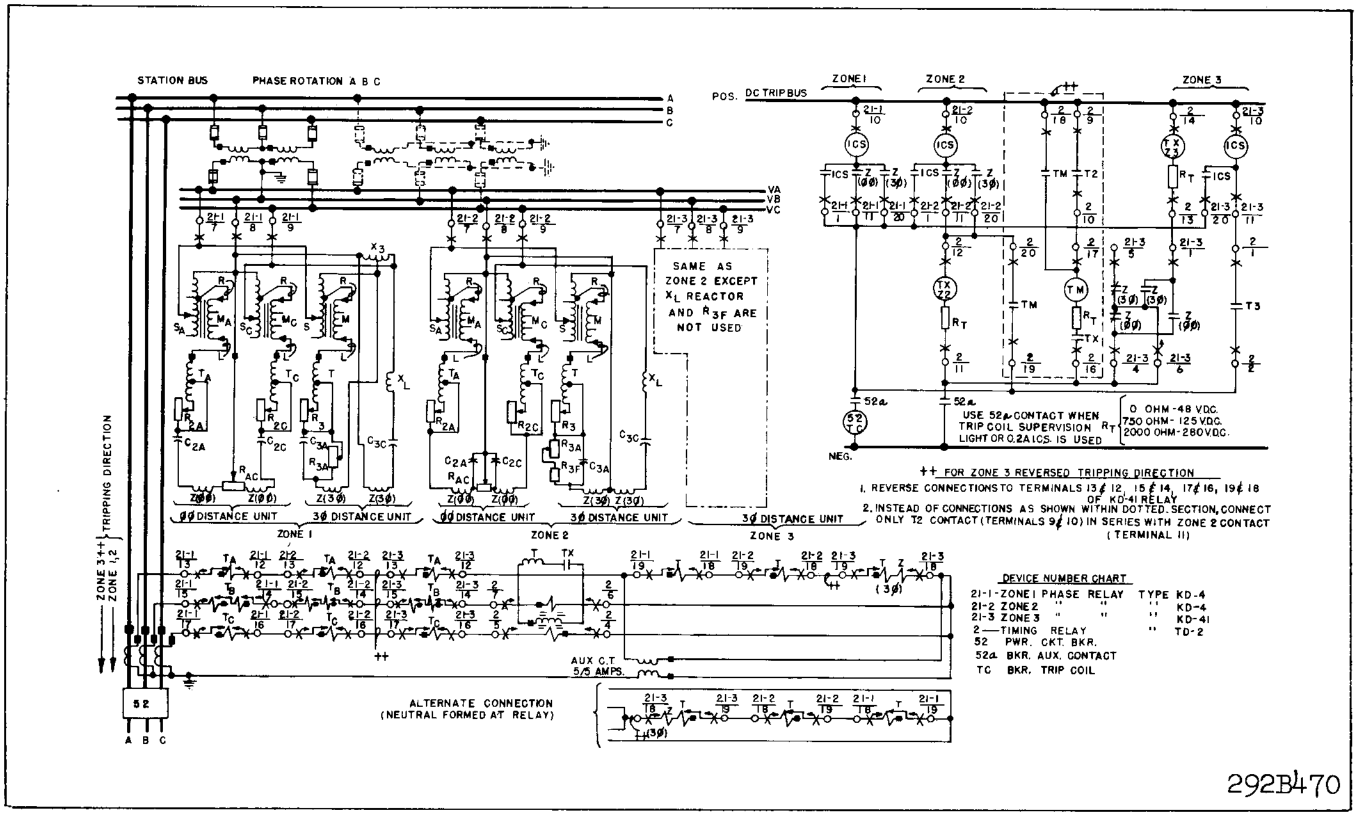
1. a) Establish Z_θ
   b) Establish Z — Relay tap plate settings. If the relay maximum torque angle θ should be different from the factory setting multiply the Z_θ — value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. Making correction for characteristic angle of the Line (60°) that is different from factory setting of 75° the relay setting, Z should be Z = 1.7 x 1.11 = 1.89 ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89}$ x 100 = 100.5% of the desired reach.



* *Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.*

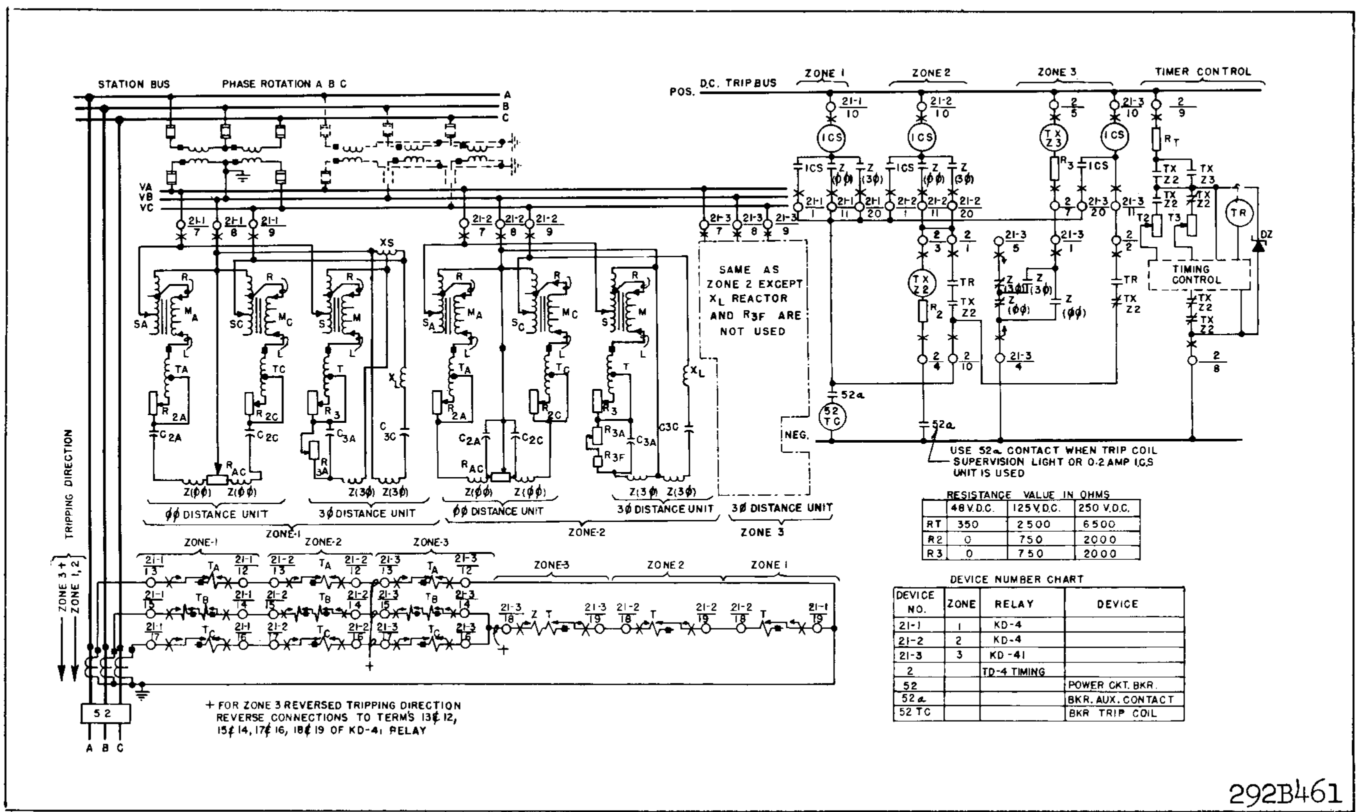


Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off $S = 2$
$T = .920$
$M = -.03$

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\sin 60°}{\sin 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. Then the relay setting Z should be $= Z = Z_\theta \cdot \frac{\sin 60°}{\sin \theta} = 1.7 \times 1.225 = 2.08$

a) The nearest table value is 2.09

b) From the Table I read off
$S = 2$
$T = .920$
$M = -.12$

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\sin 45}{\sin 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from -.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (-) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	–	1.60	2.14	–	3.21	+.15		Upper .06	0	"L" over "R"
	.205	.274	.341	.479	.615	.822	1.100	–	1.64	2.20	–	3.29	+.12		Upper .06	.03	
	.211	.282	.350	.493	.632	.843	1.120	–	1.69	2.24	–	3.38	+.09		Lower .06	0	
	.217	.290	.361	.506	.650	.869	1.160	–	1.74	2.32	–	3.48	+.06		Upper .06	Lower.06	
	.224	.298	.371	.521	.670	.892	1.191	–	1.78	2.38	–	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	–	1.84	2.46	–	3.69	0	- 0	0	0	
	.237	.317	.395	.552	.713	.948	1.270	–	1.90	2.54	–	3.80		-.03	0	.03	"R" over "L"
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	–	3.93		-.06	Lower.06	Upper .06	
	.253	–	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower.06	
	.261	–	.435	–	.785	1.048	1.395	1. -	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	–	.450	–	–	–	1.45	–	–	2.90	–	4.35		-.15	0	Upper .06	

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting, or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

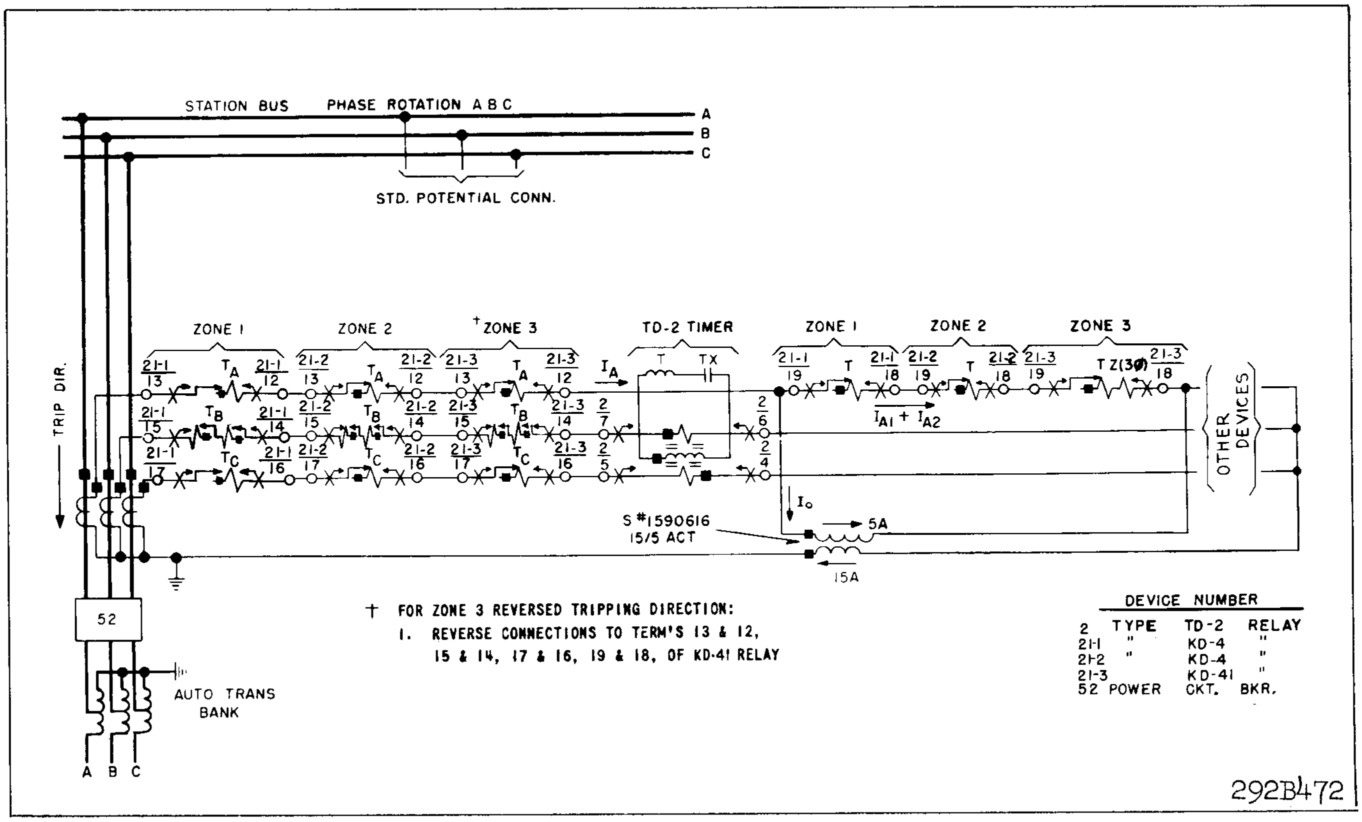


Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.

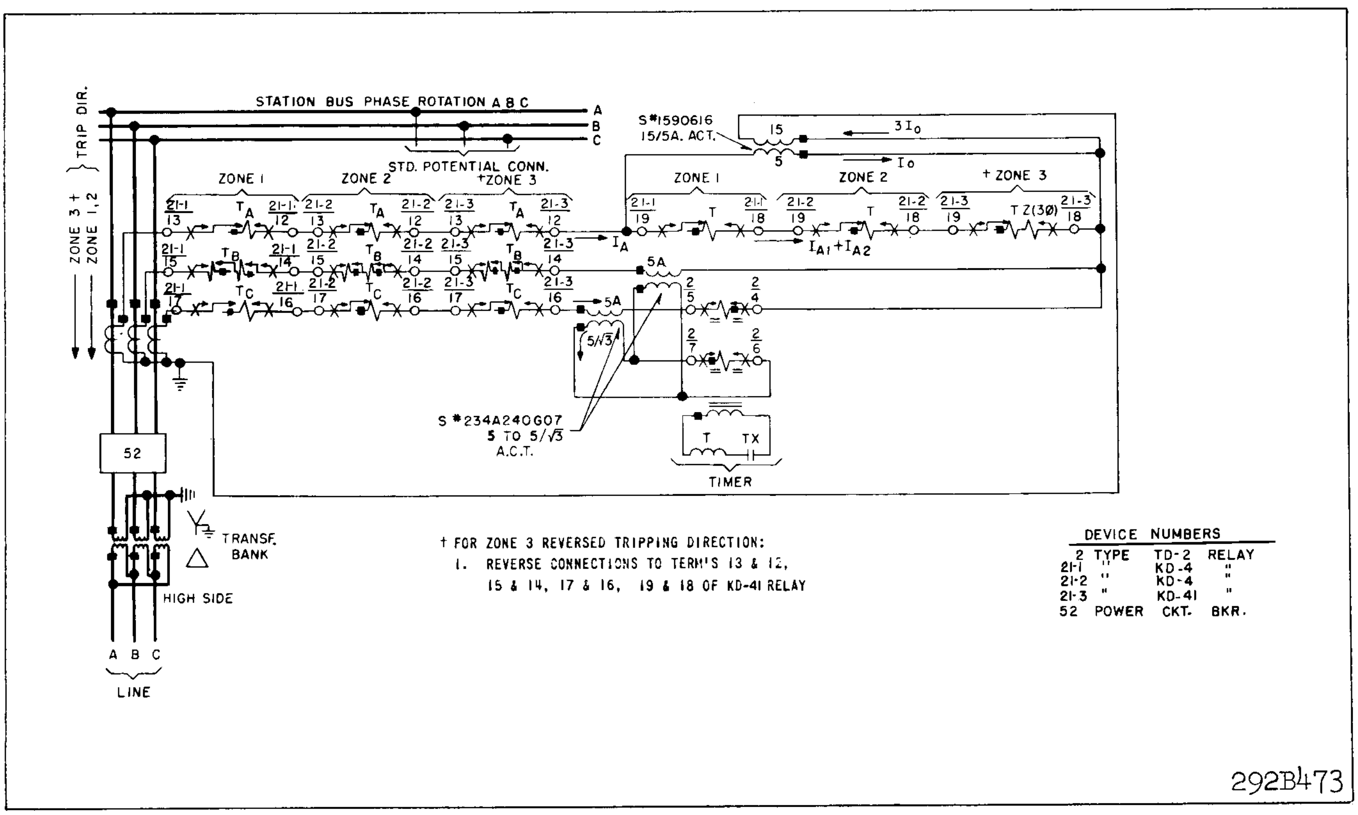


Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

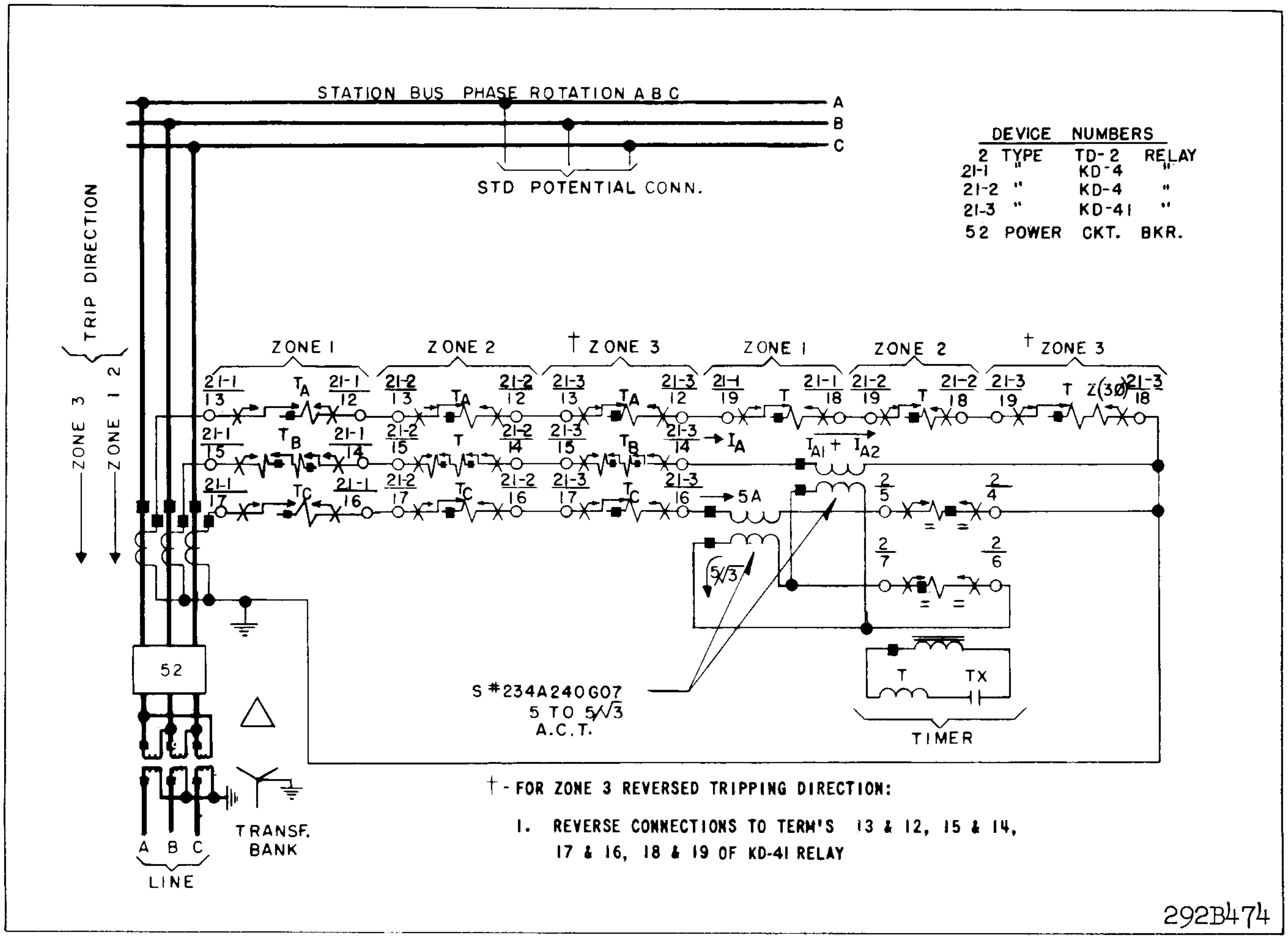


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

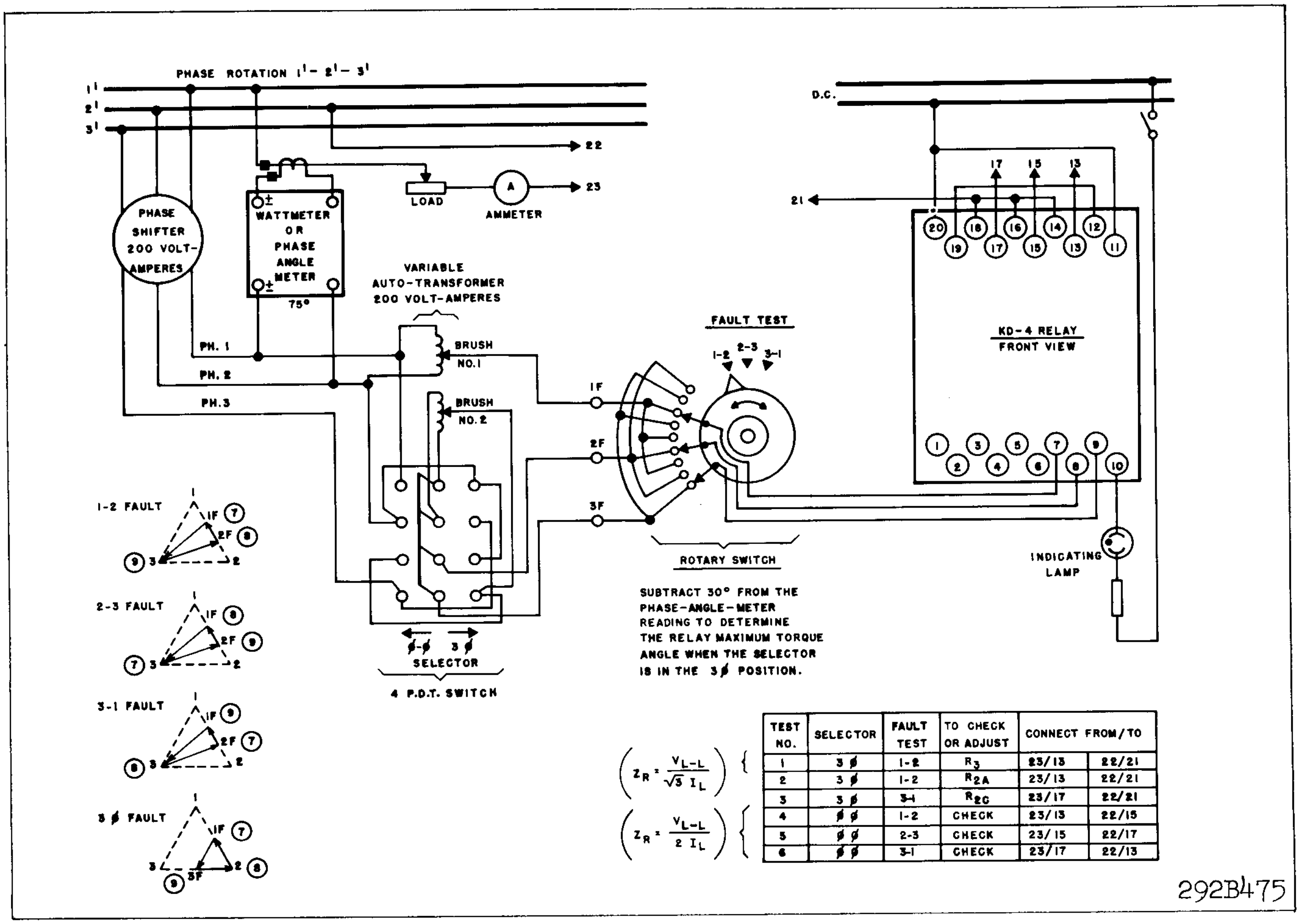
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 ∅	1-2	R_3	23/13	22/21
2	3 ∅	1-2	R_{2A}	23/13	22/21
3	3 ∅	3-1	R_{2C}	23/17	22/21
4	∅ ∅	1-2	CHECK	23/13	22/15
5	∅ ∅	2-3	CHECK	23/15	22/17
6	∅ ∅	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° - for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 - .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 - 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\sin 60^\circ}{\sin \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed θ = 90°).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ $= 42.6$ volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$
"L" of M_C	R_{2C}	$= 50.9$ volts ($\theta = 90^\circ$)

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3}I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes ($\theta = 60^\circ$) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2\ I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes ($\theta = 75^\circ$) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	2 of 3-½ inch Resistors, Total Resistance 2000 ohms (One Resistor is fixed, one adjustable)
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

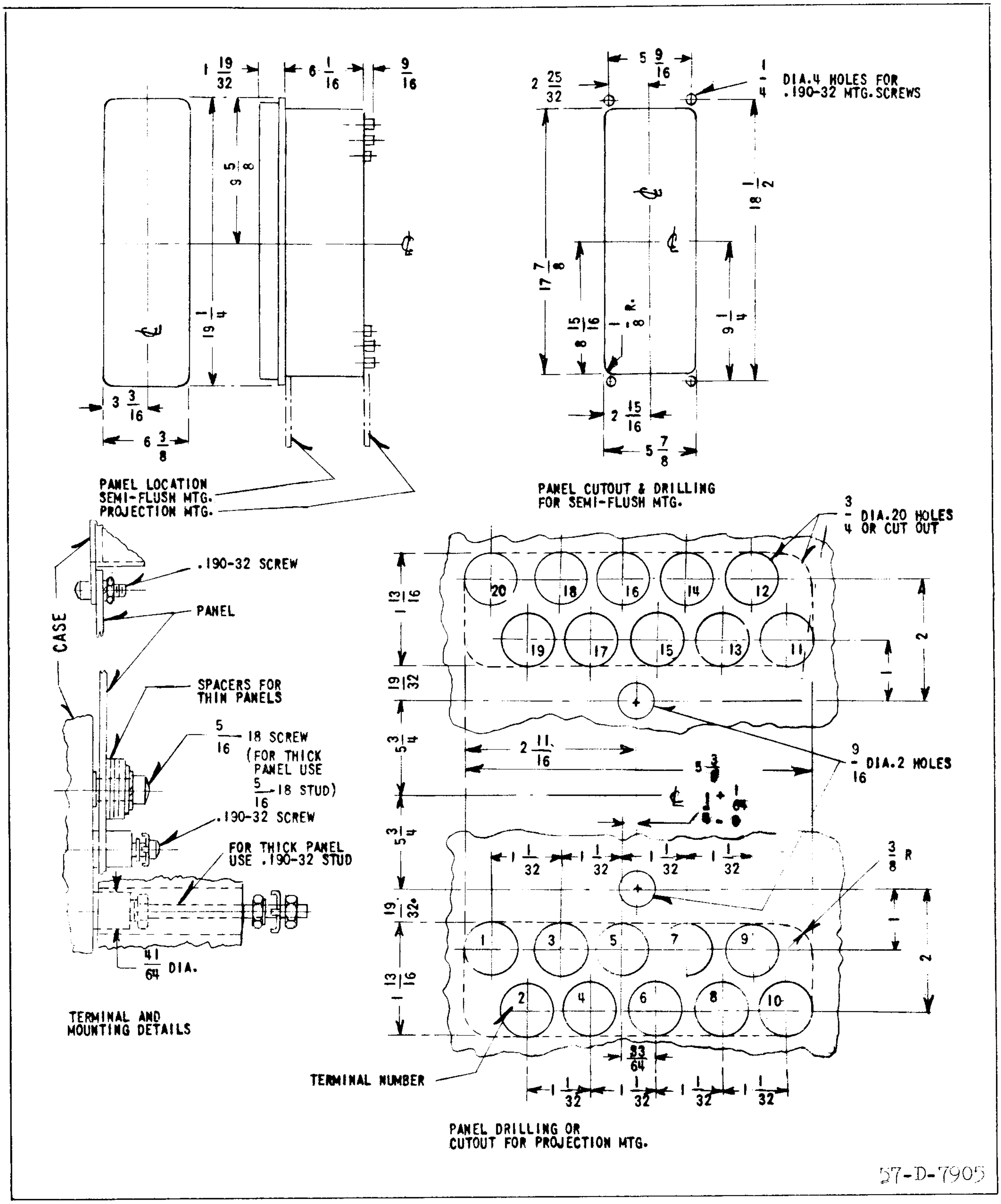


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11G
*Denotes change from superseded issue.

EFFECTIVE JULY 1969

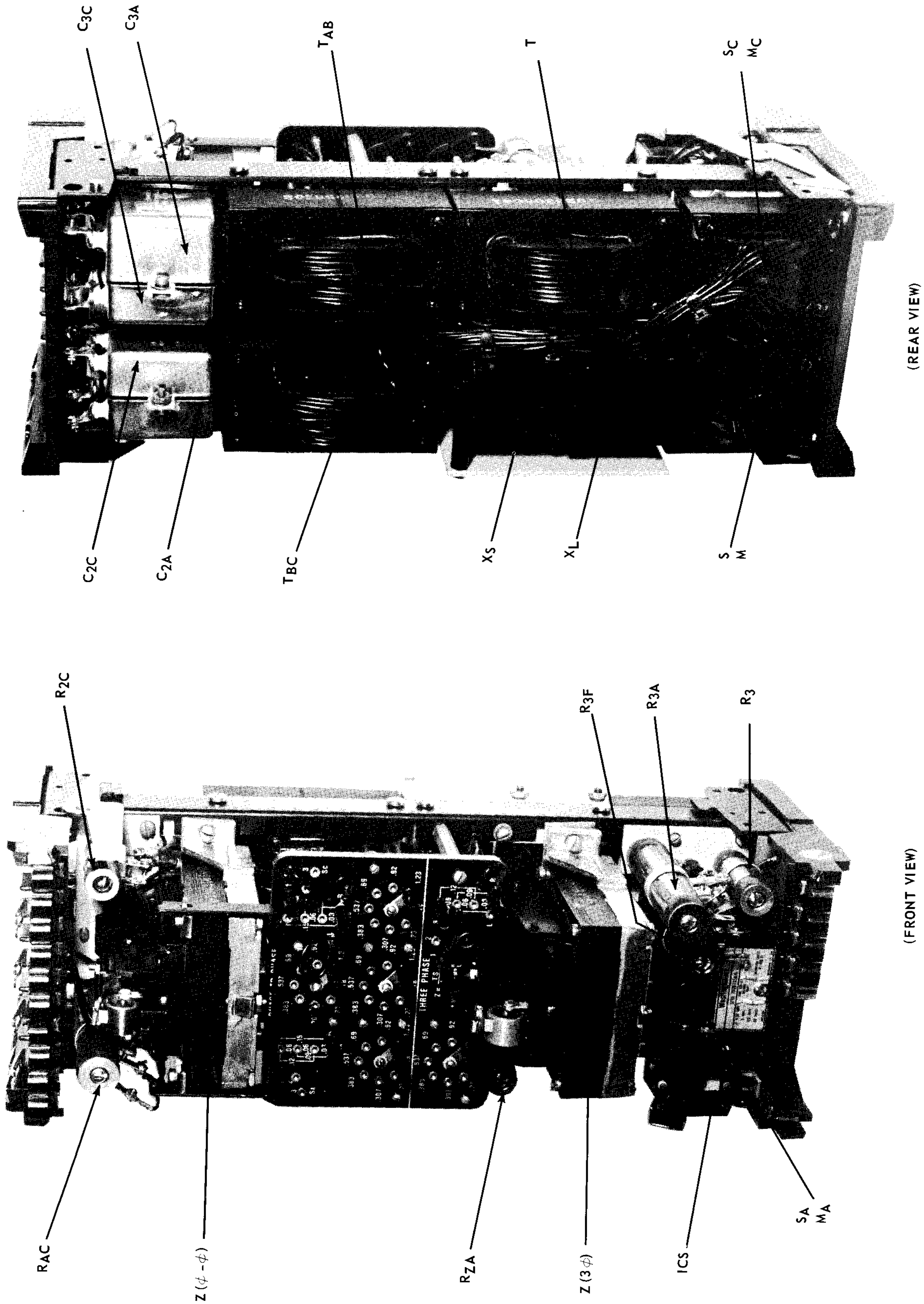


Fig. 1 Type KD-4 Relay Without case

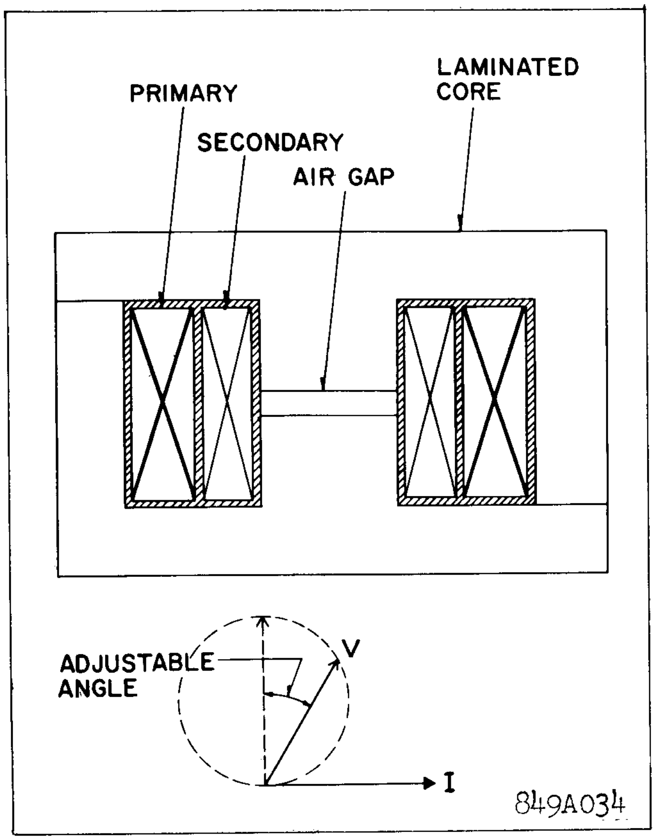


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

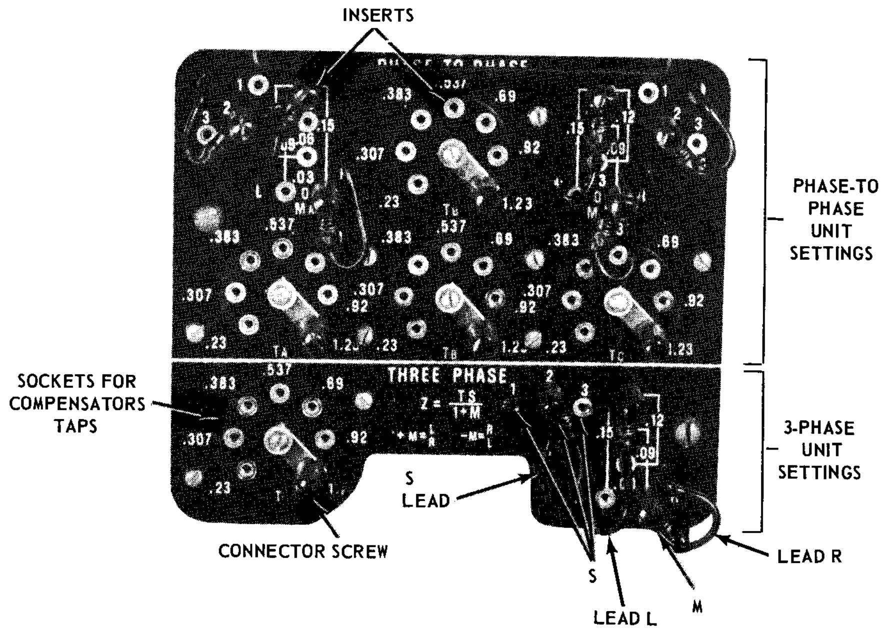


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

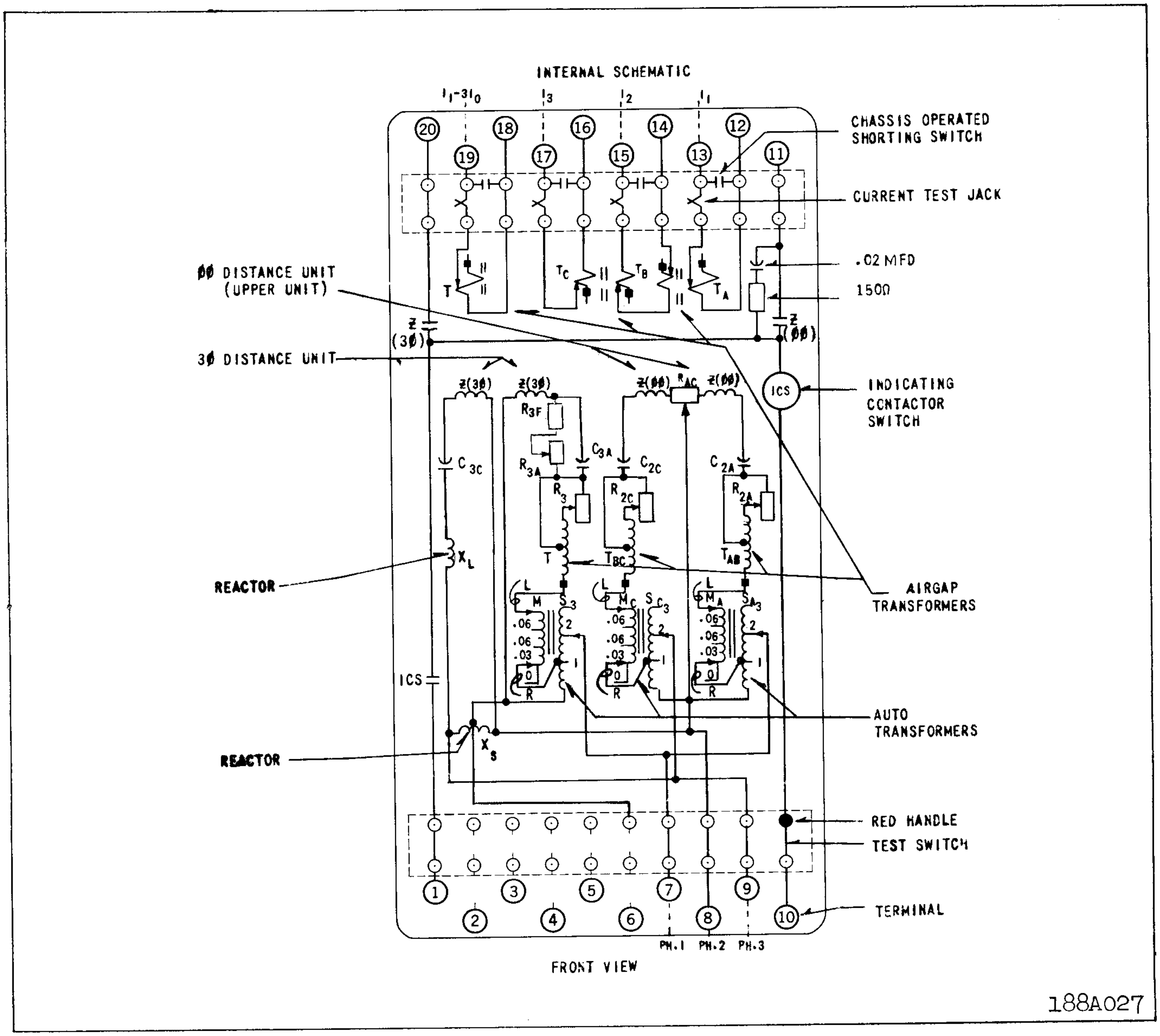


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown — one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, ($I_1 - 3I_0$) = ($-I_2 - I_3$). (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

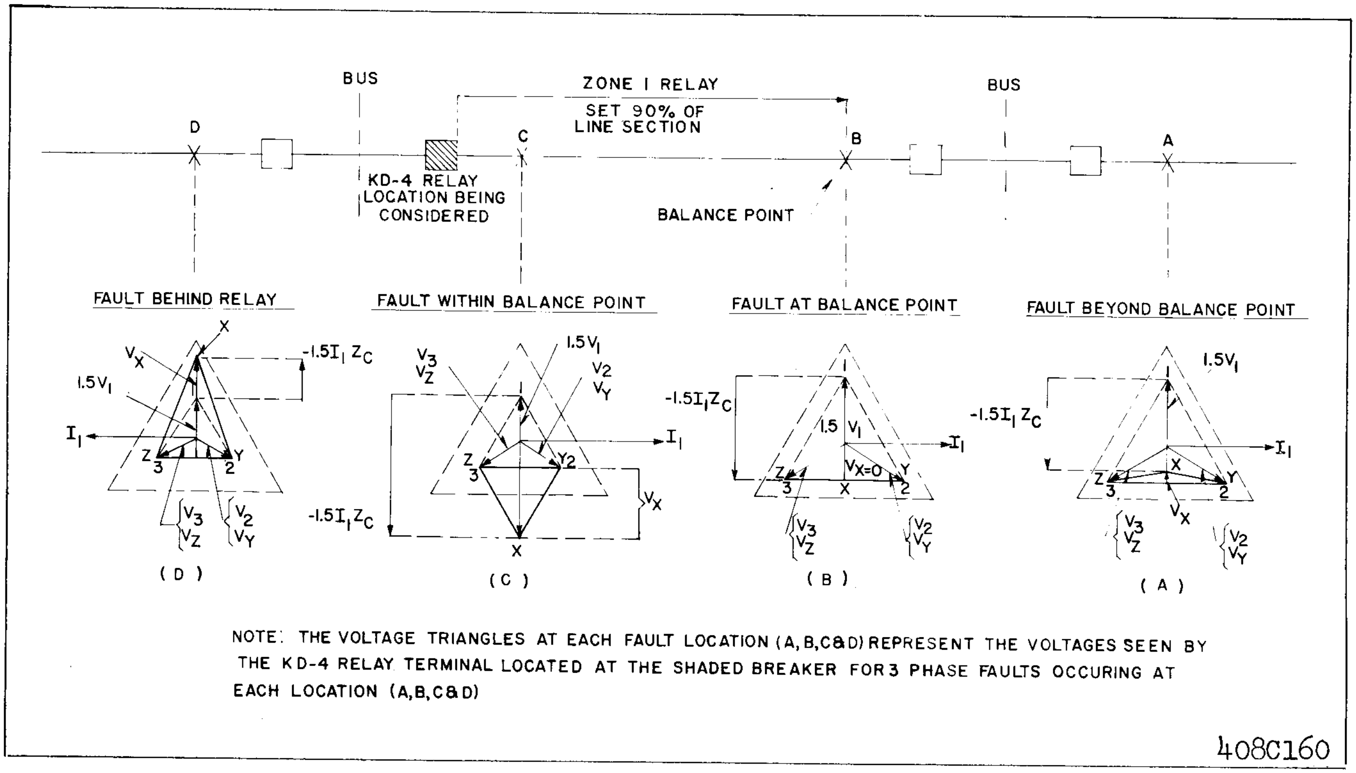


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

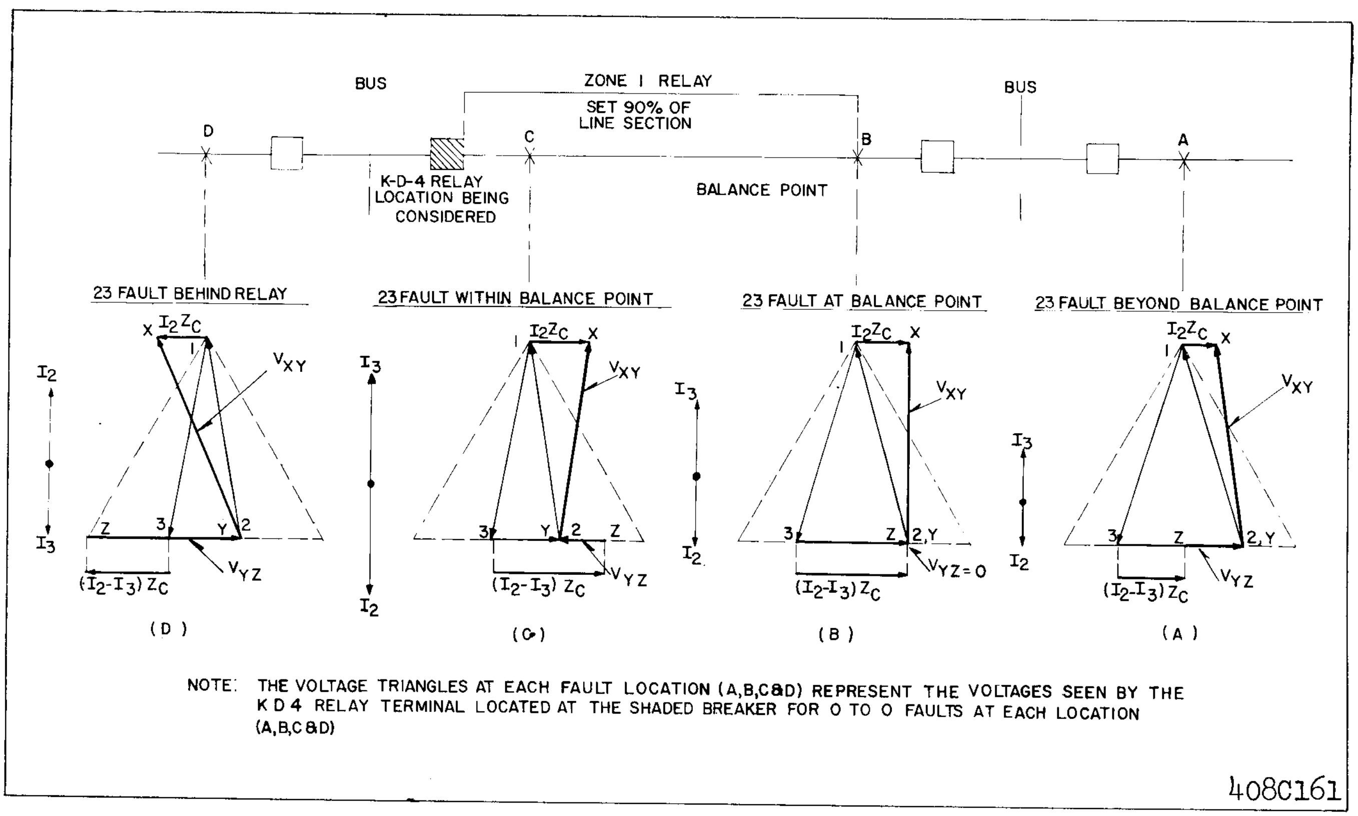


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

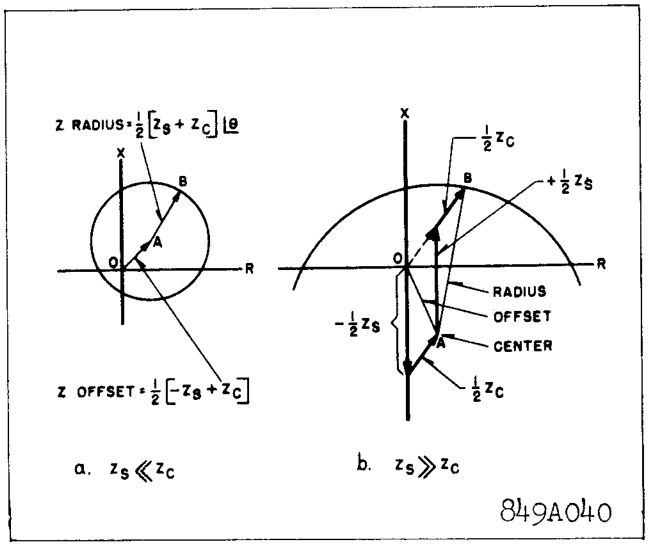


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

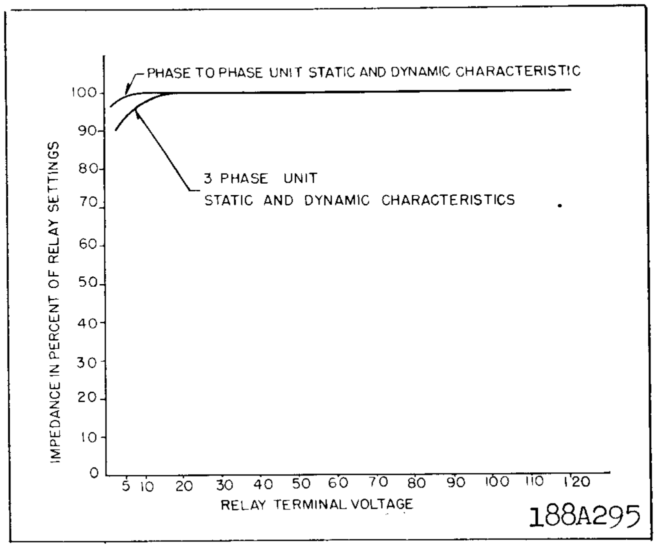


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

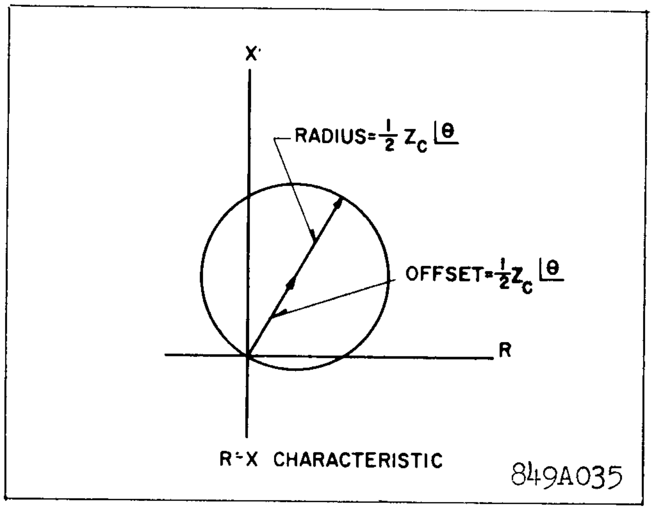


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

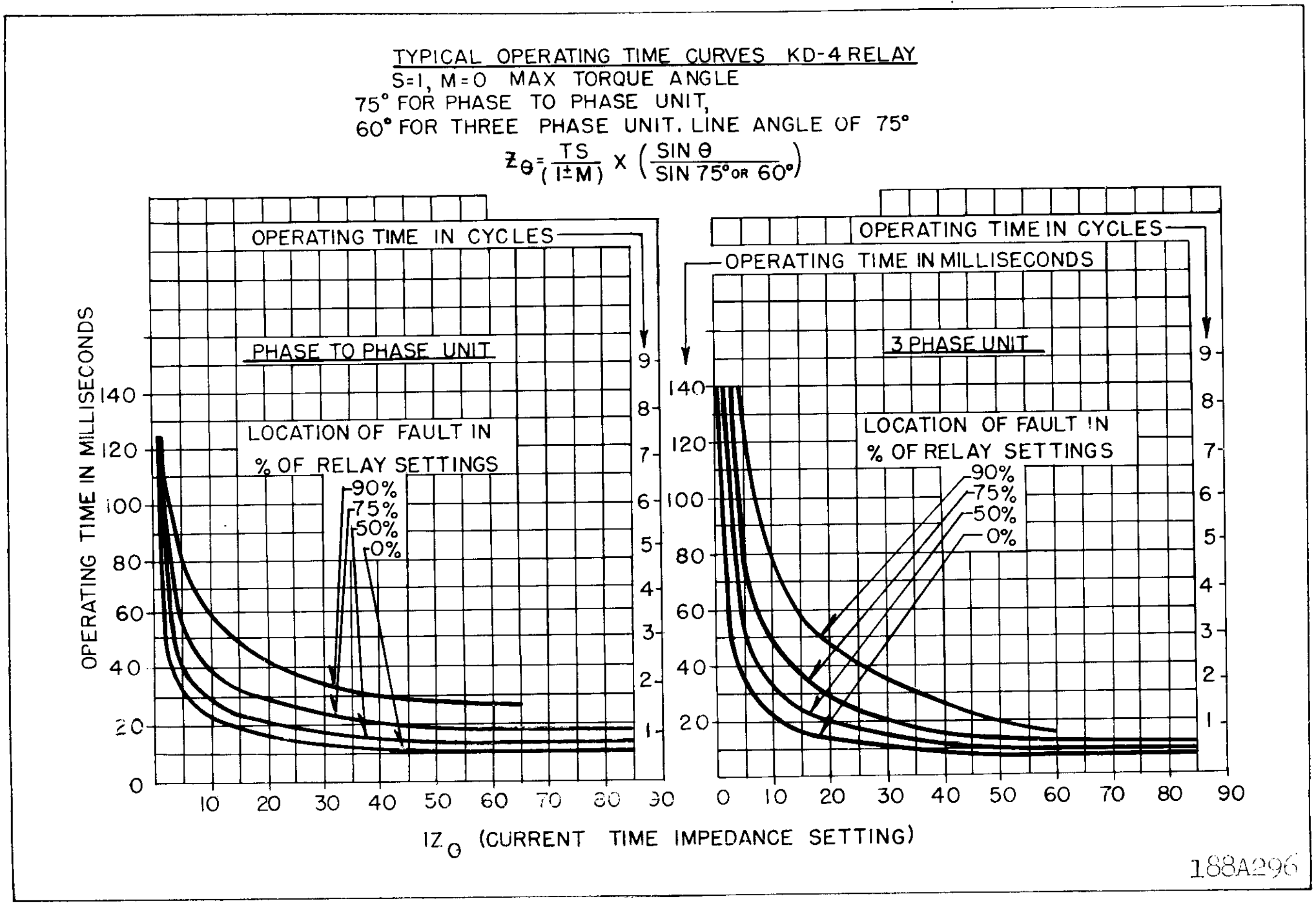


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

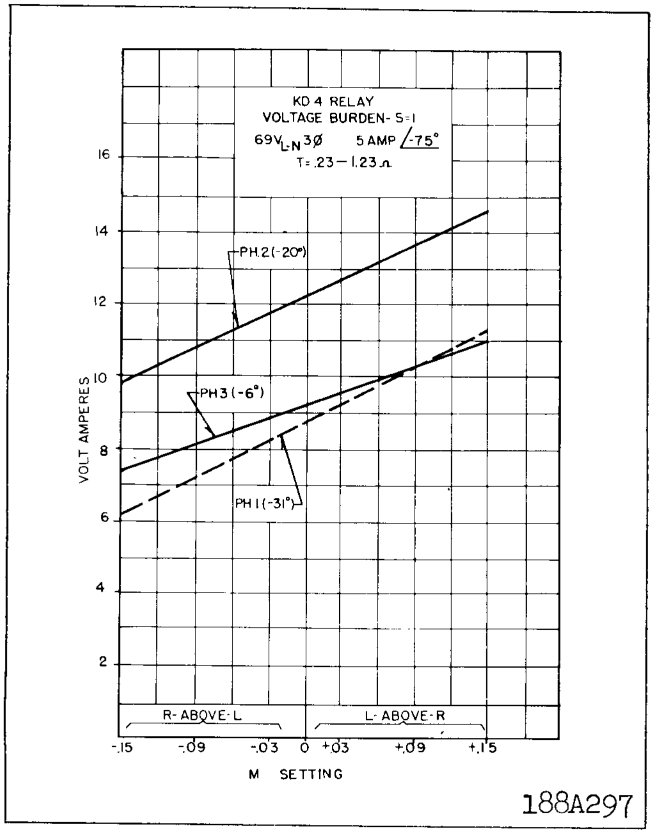
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

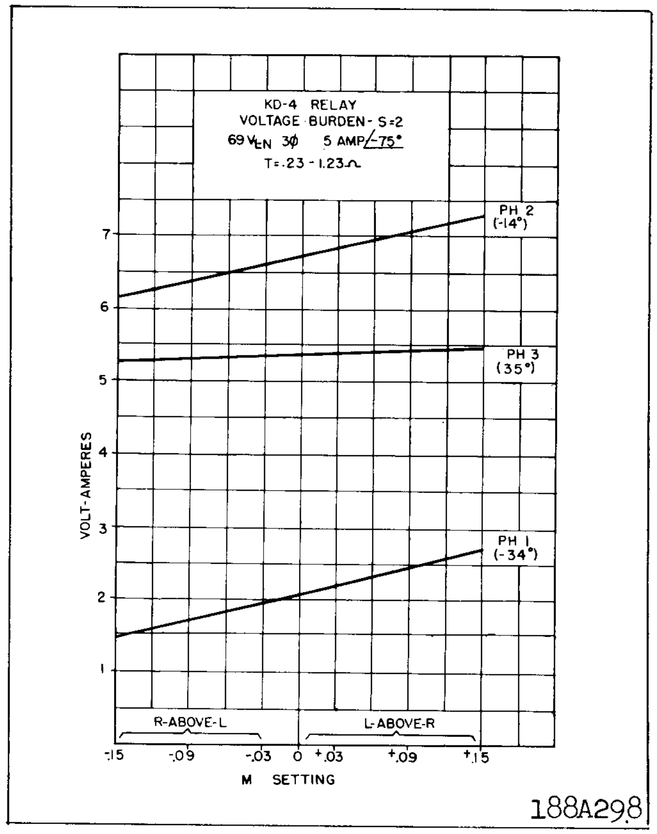
Distance Characteristic - 3 Phase Unit

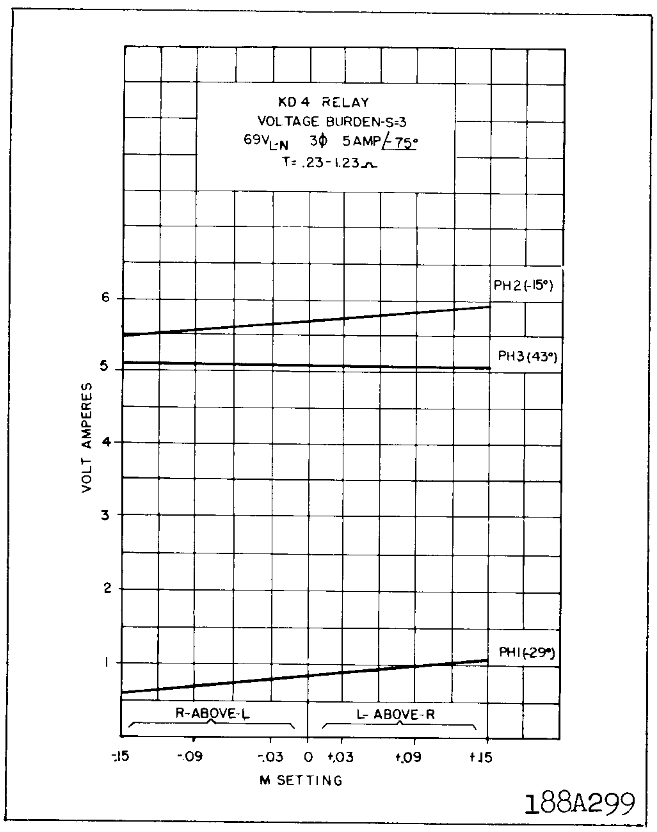
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT 69V_{L-N}, S=1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1			PHASE 2			PHASE 3		
	VA	VARS	WATTS	VA	VARS	WATTS	VA	VARS	WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin\theta}{(1 \pm M)\sin\alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)
.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)
1 2 3

(M, M_A, M_C)
±Values between taps .03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C

.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C

1 2 3

M, M_A, M_C

.03 .06 .06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9\, R_c}{R_v}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_v}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_v = potential transformer ratio

* T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z—setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ

   b) Establish Z — Relay tap plate settings. If * the relay maximum torque angle θ has been recalibrated to an angle different from the factory setting, multiply the $Z\ \theta$ — value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.

2. Now refer to the Table I.

   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.

   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).

   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.

   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is * 1.7 ohms at 60°. If relay has been recalibrated to a maximum torque angle of 60° from factory setting of 75° the relay setting, Z should be:

$$Z = 1.7 \times \frac{\sin 75°}{\sin 60°} \quad 1.89 \text{ ohms.}$$

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

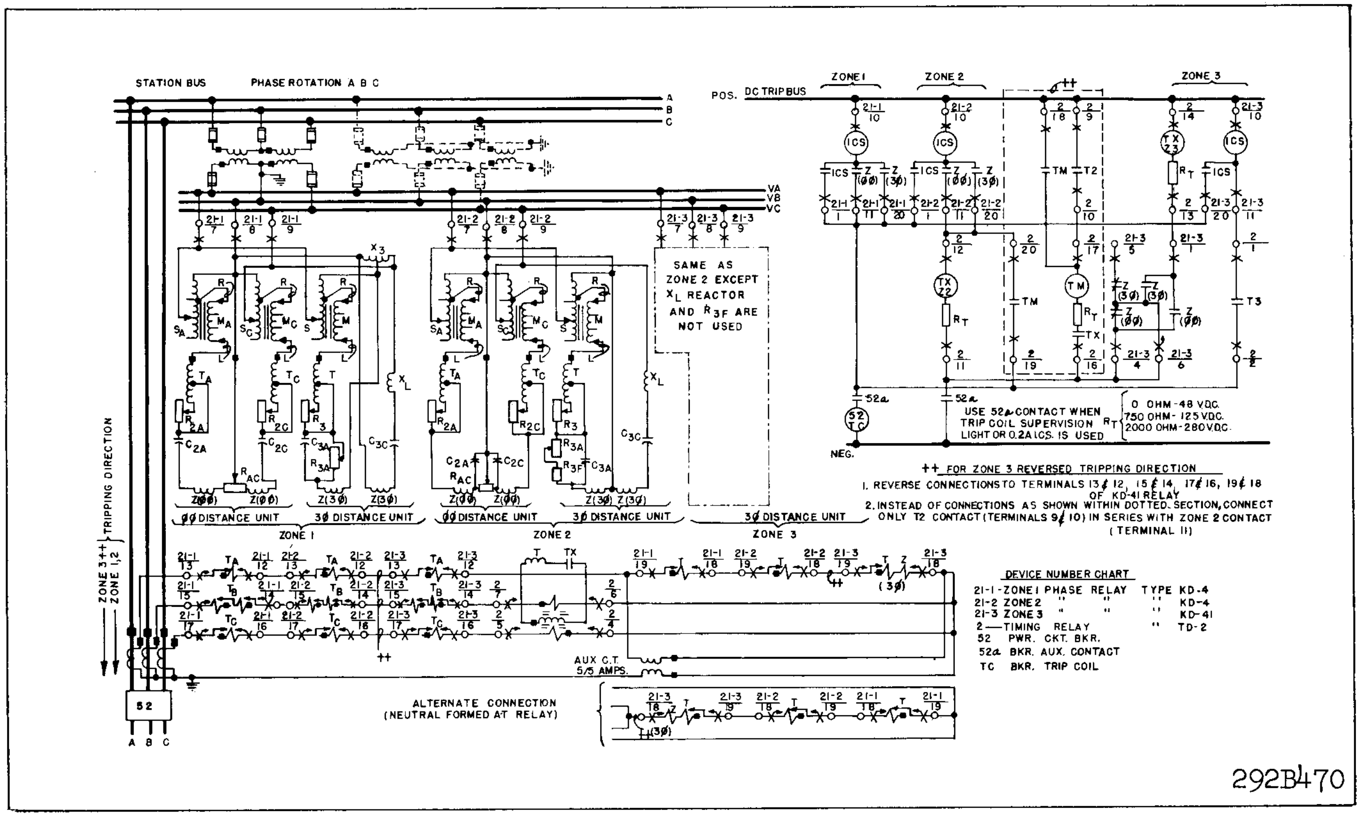


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.

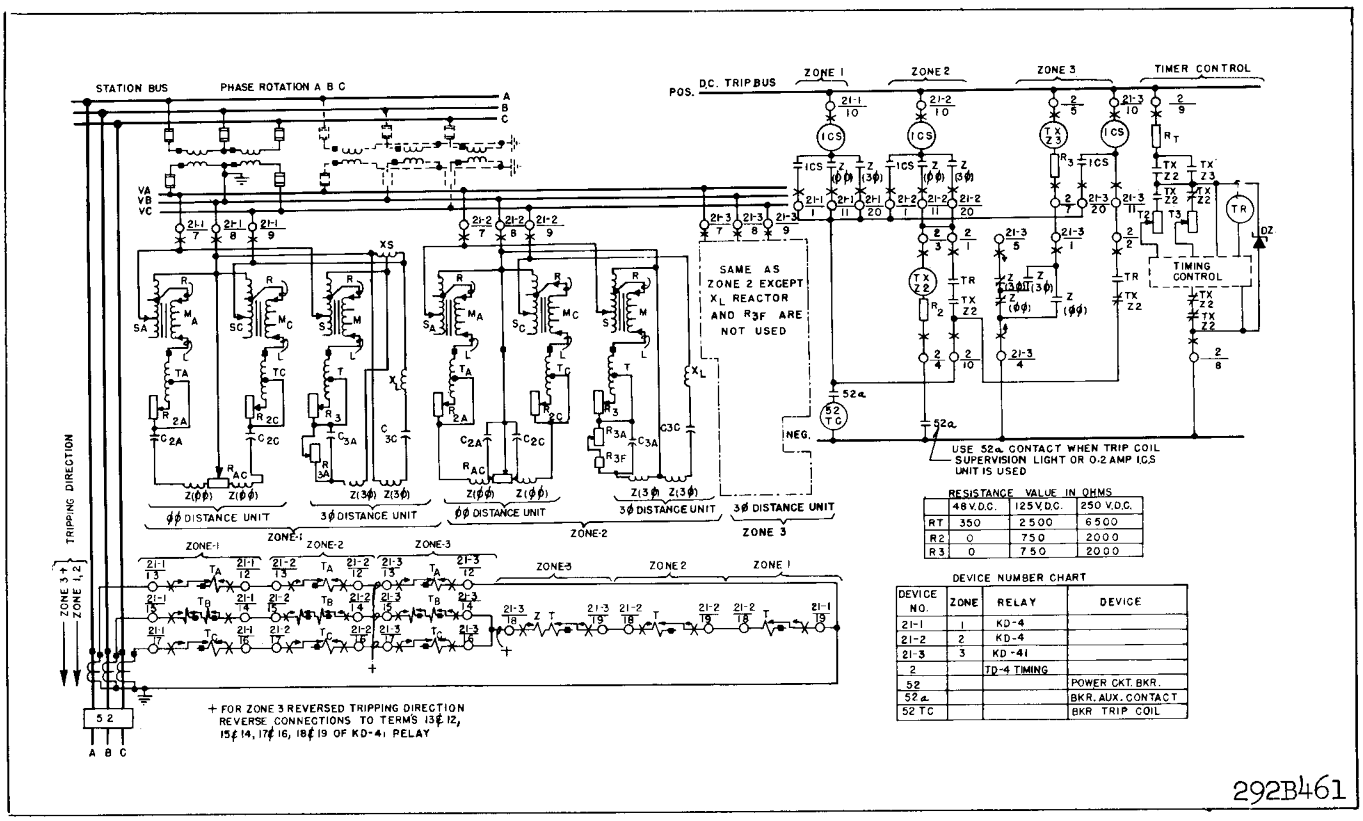


Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2
T = .920
M = –.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or
$$Z_{60^\circ} = Z \frac{\text{Sin } 60^\circ}{\text{Sin } 75^\circ} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. If relay has been recalibrated to 45° from standard factory setting of 60° then the relay setting should be:

$$Z = Z\theta . \frac{\text{Sin } 60^\circ}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off
S = 2
T = .920
M = –.12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or
$$Z_{45^\circ} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from –.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (–) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
* T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	"L" over "R"
	.205	.274	.341	.479	.615	.822	1.100	—	1.64	2.20	—	3.29	+.12		Upper .06	.03	"L" over "R"
	.211	.282	.350	.493	.632	.843	1.120	—	1.69	2.24	—	3.38	+.09		Lower .06	0	"L" over "R"
	.217	.290	.361	.506	.650	.869	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower .06	"L" over "R"
	.224	.298	.371	.521	.670	.892	1.191	—	1.78	2.38	—	3.58	+.03		.03	0	"L" over "R"
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	"L" over "R"
	.237	.317	.395	.552	.713	.948	1.270	—	1.90	2.54	—	3.80		-.03	0	.03	"R" over "L"
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	—	3.93		-.06	Lower .06	Upper .06	"R" over "L"
	.253	—	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		-.09	0	Lower .06	"R" over "L"
	.261	—	.435	—	.785	1.048	1.395	1. –	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	"R" over "L"
	.271	—	.450	—	—	—	1.45	—	—	2.90	—	4.35		-.15	0	Upper .06	"R" over "L"

* The tap plate values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit.

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

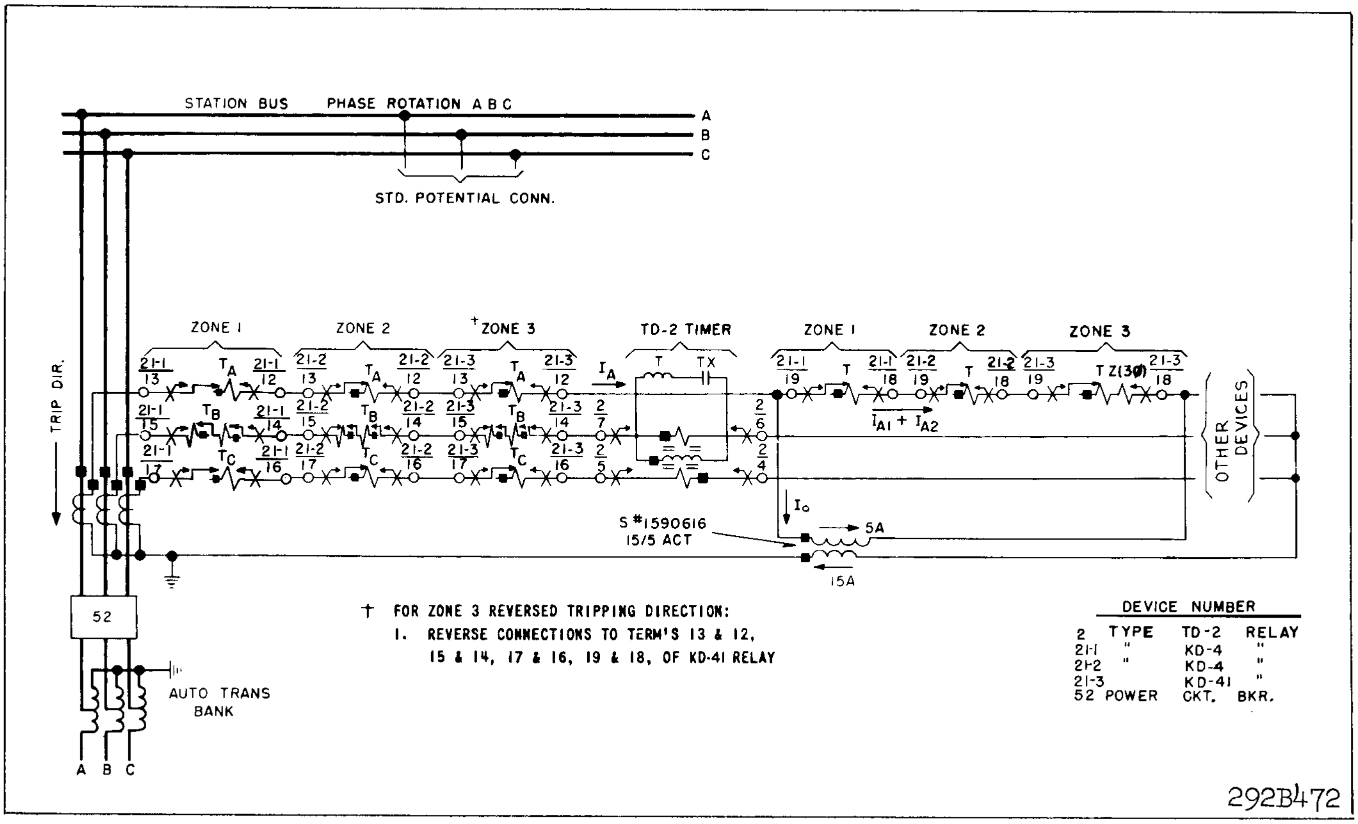


Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.

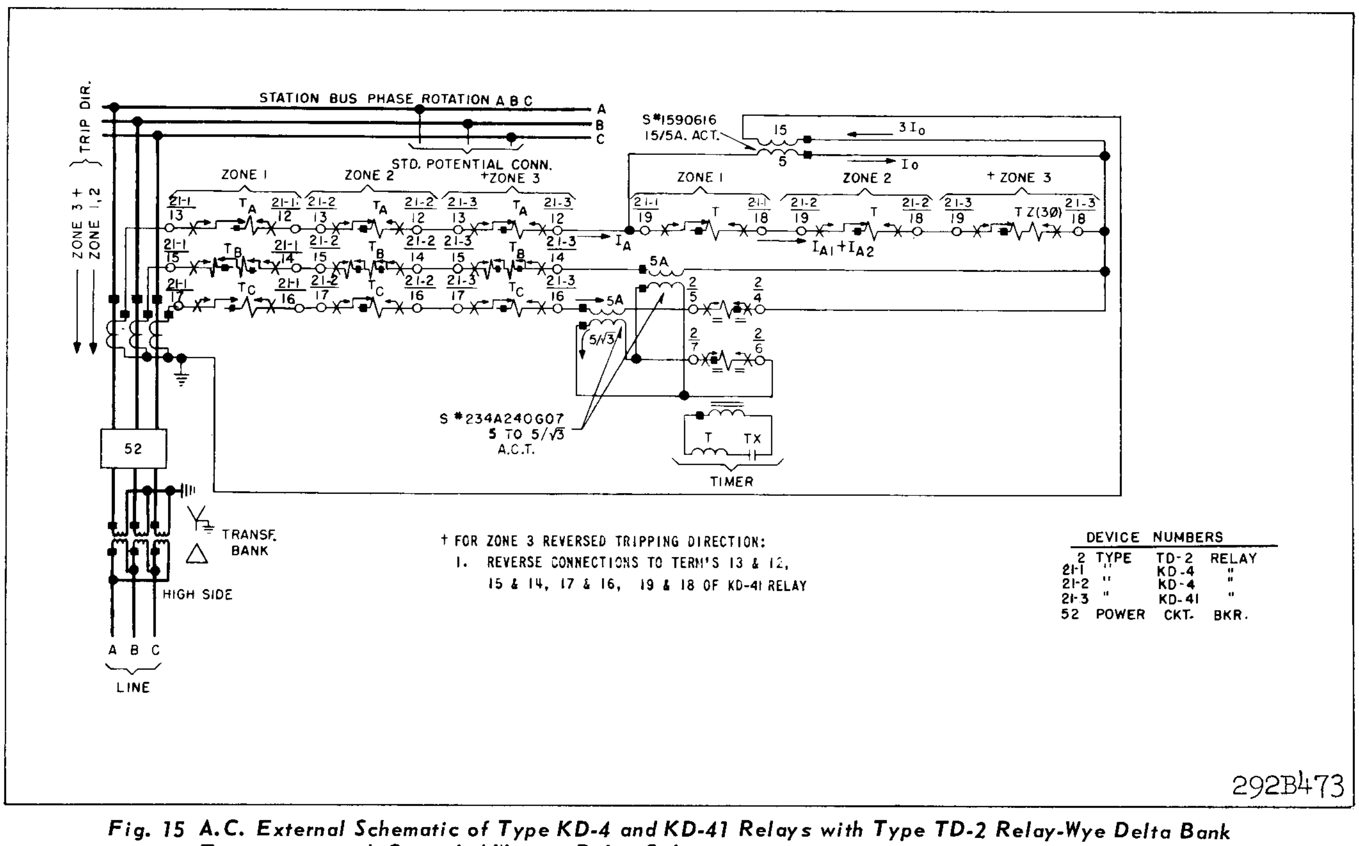


Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

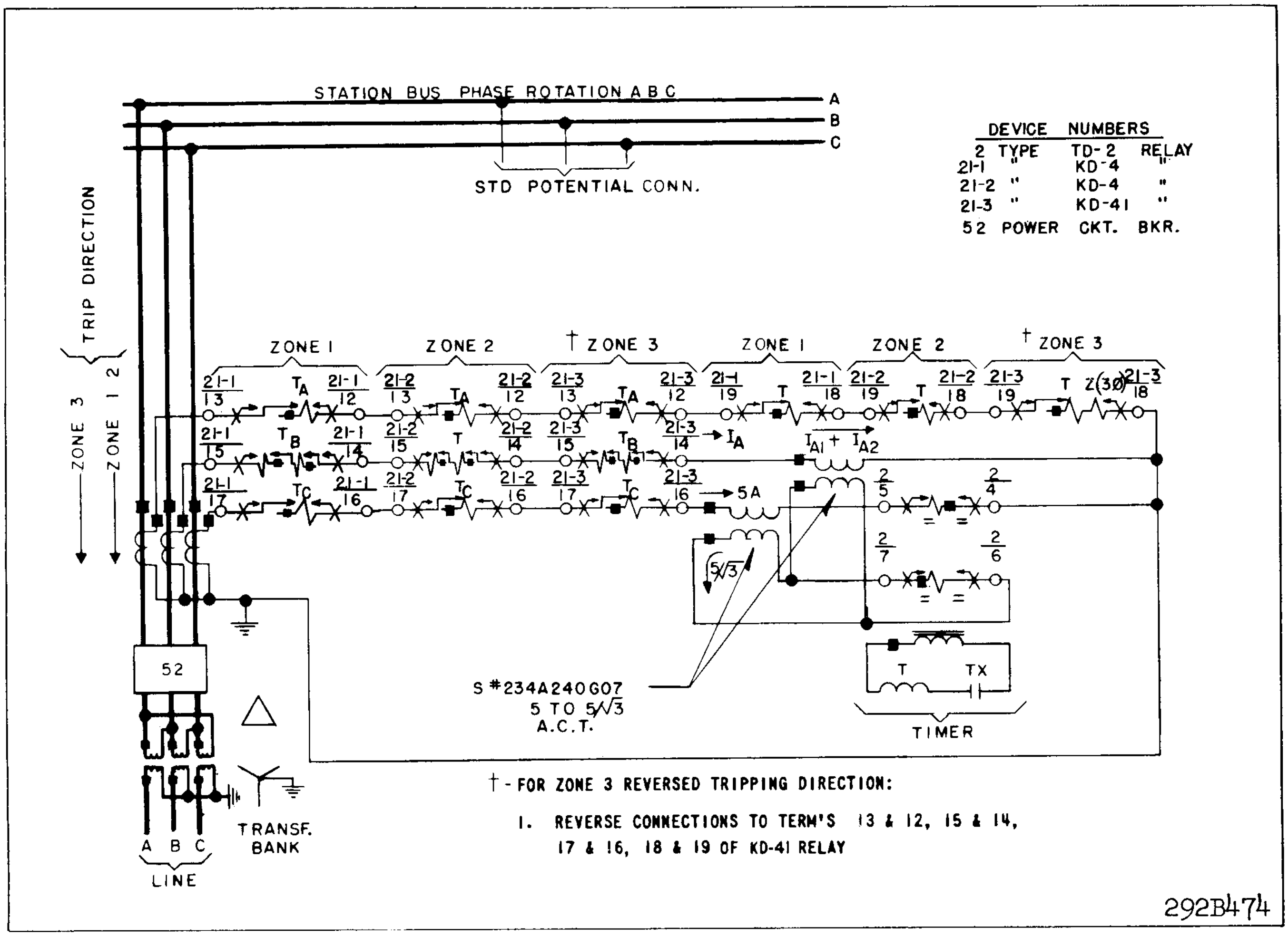


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

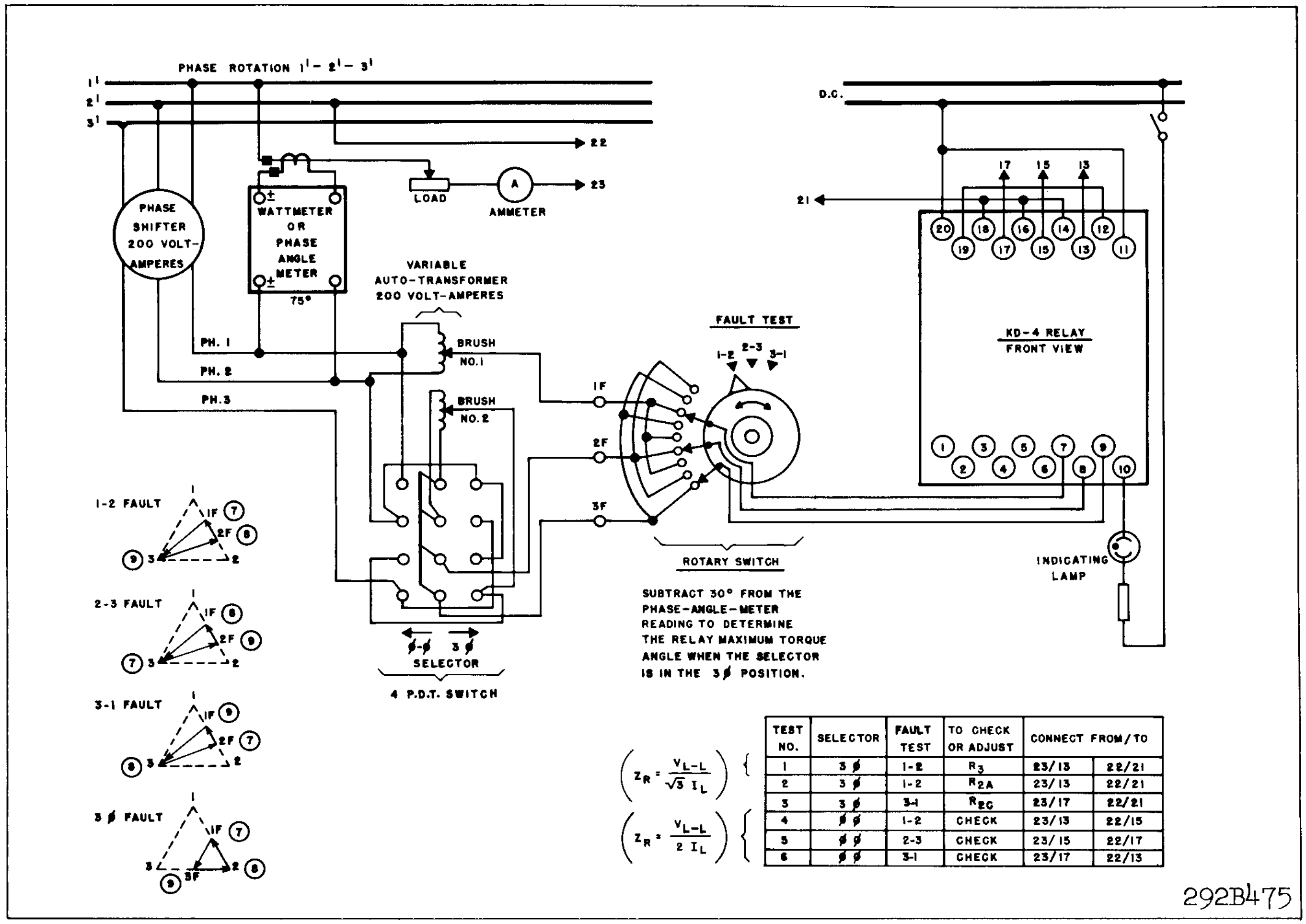
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 φ	1-2	R_3	23/13	22/21
2	3 φ	1-2	R_{2A}	23/13	22/21
3	3 φ	3-1	R_{2C}	23/17	22/21
4	φ φ	1-2	CHECK	23/13	22/15
5	φ φ	2-3	CHECK	23/15	22/17
6	φ φ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures $Z_R = \frac{V_{L-L}}{2I_L}$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

* Tripping Units & Initial Spring Setting

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due
* to self-heating, spring set as above.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° - for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 - .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 - 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\sin 60^\circ}{\sin \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the
* center of the resistor. Spring set as per initial setting.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

* This angle should be 73–77 degrees. This angle θ can be changed by adjusting R_{2A}.

In this case, the test current should be equal to $\frac{15 \sin 75°}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75°)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed θ = 90°).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3}I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2\ I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	* Combination of 2 resistors. Total Resistance 2500 ohms (One Resistor is fixed, one adjustable).
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

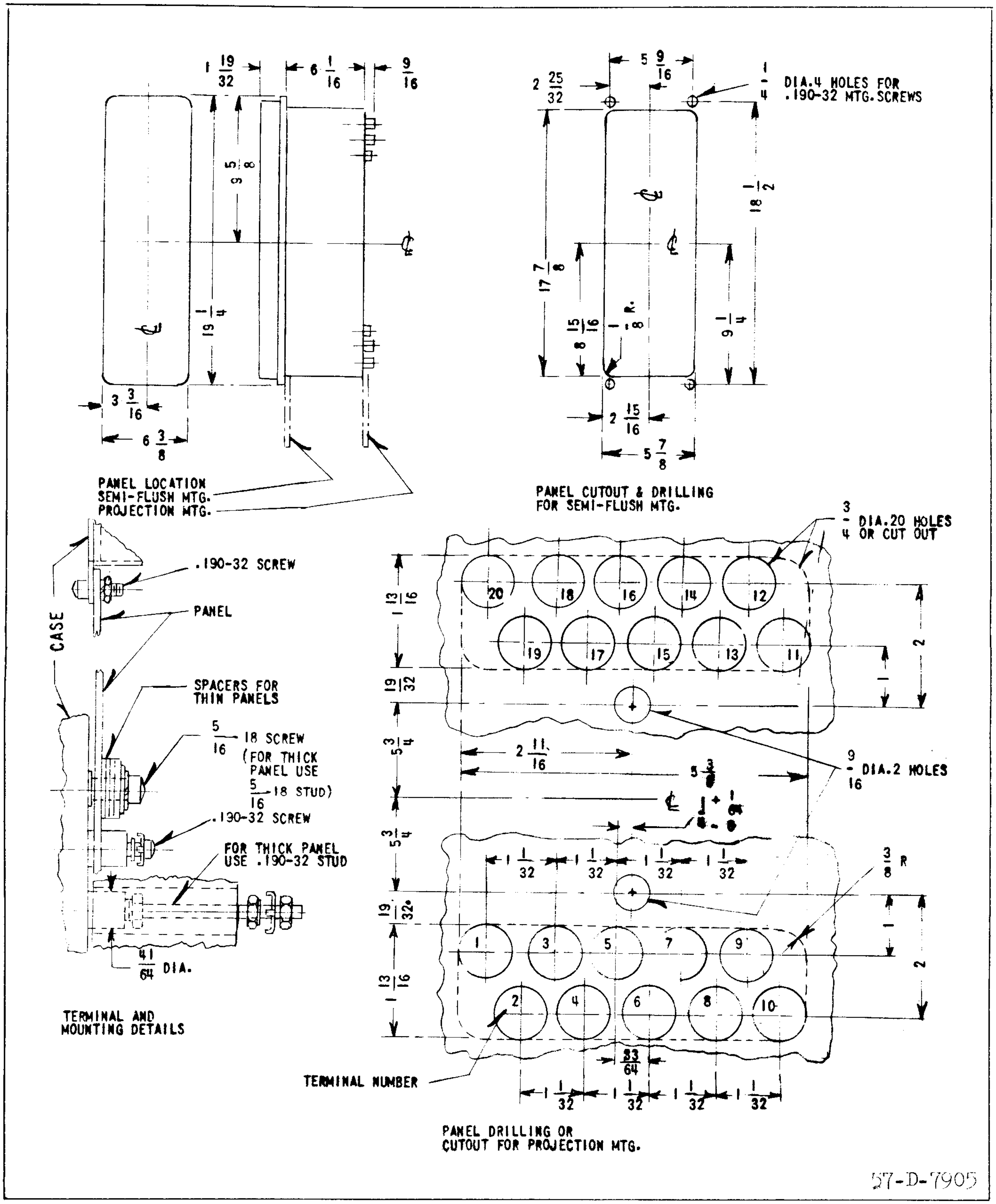


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY (.2 – 4.35 OHMS)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11H
*Denotes change from superseded issue.

EFFECTIVE NOVEMBER 1969

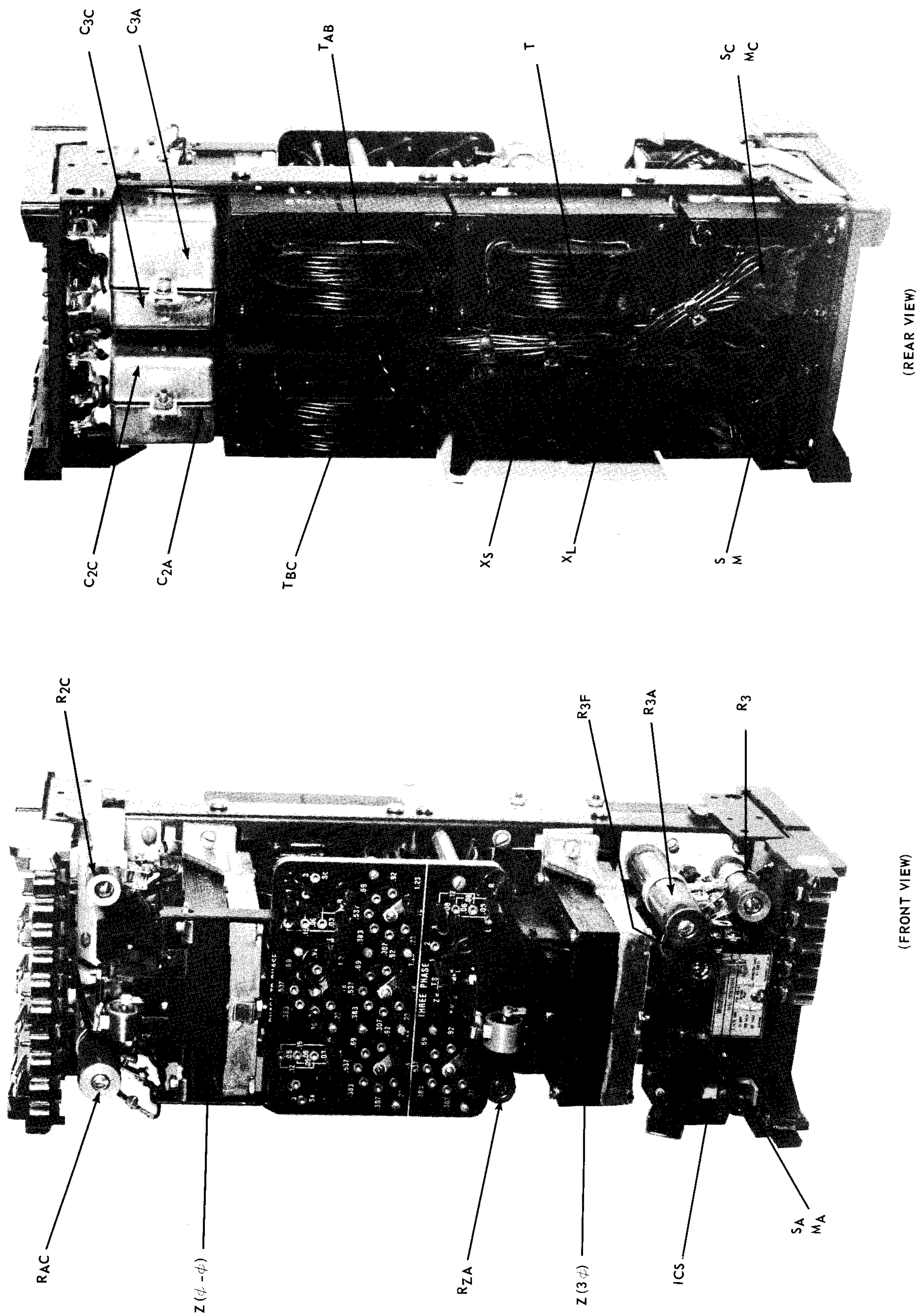


Fig. 1 Type KD-4 Relay Without case

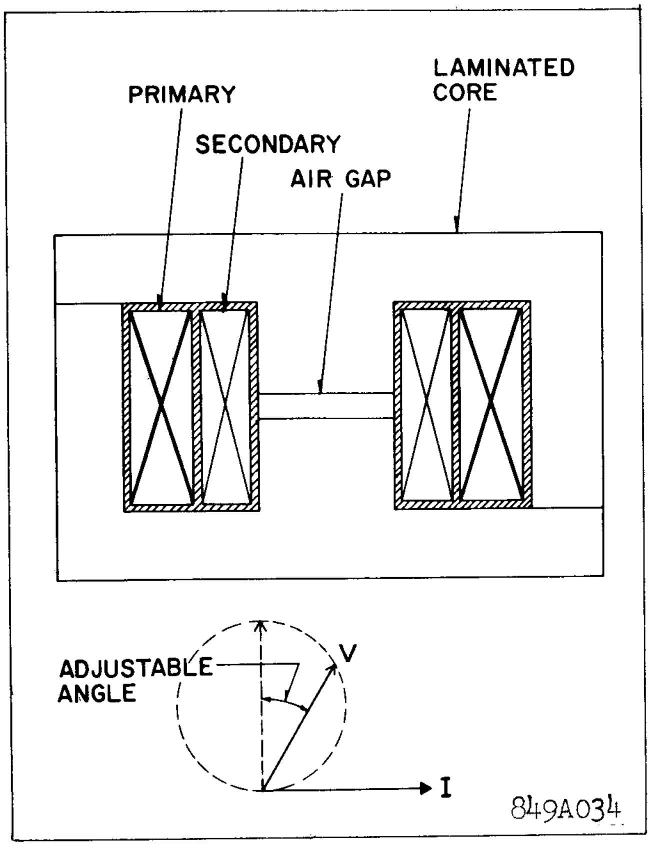


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

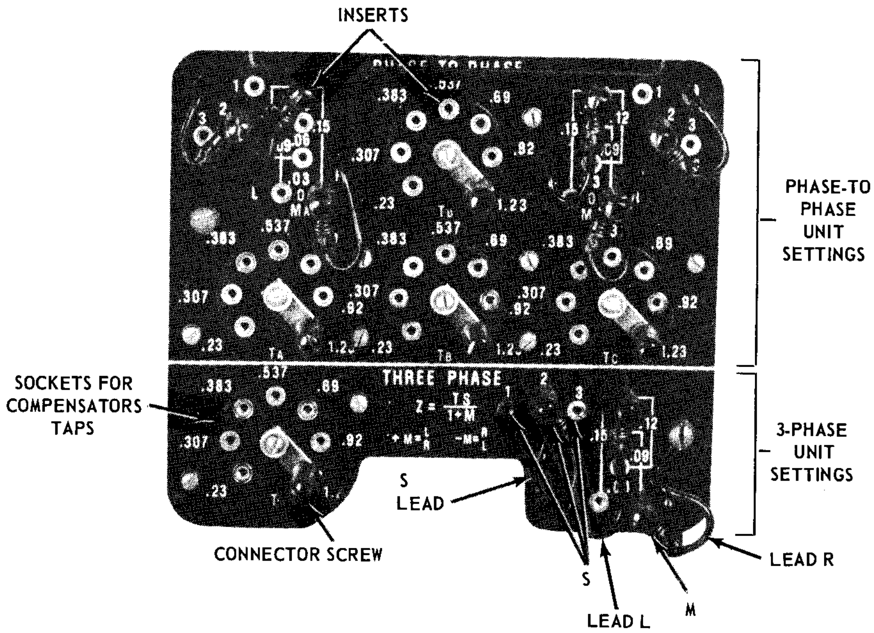


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

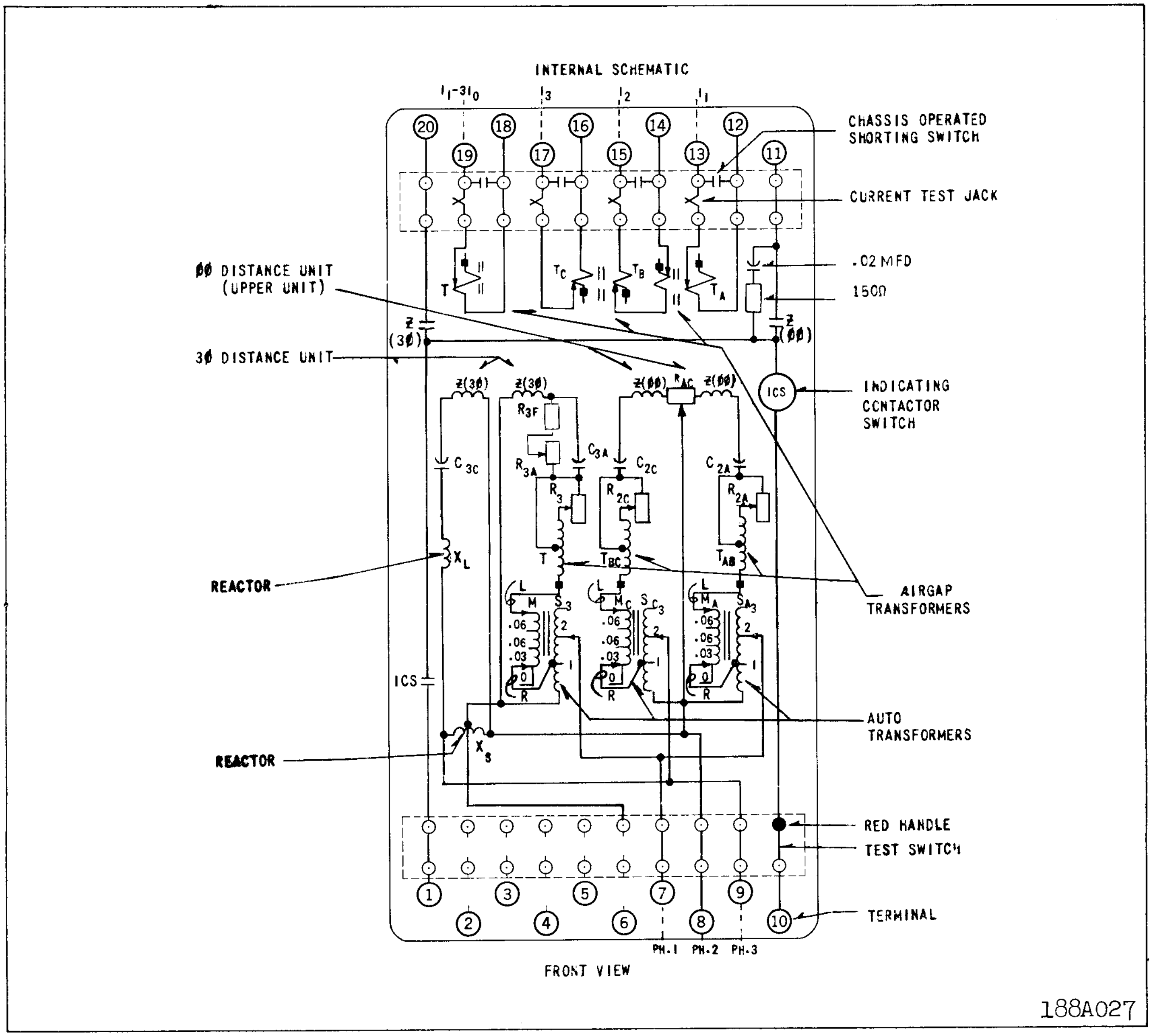


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with $(I_1 - 3I_0)$current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with $(-I_2 - I_3)$. Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

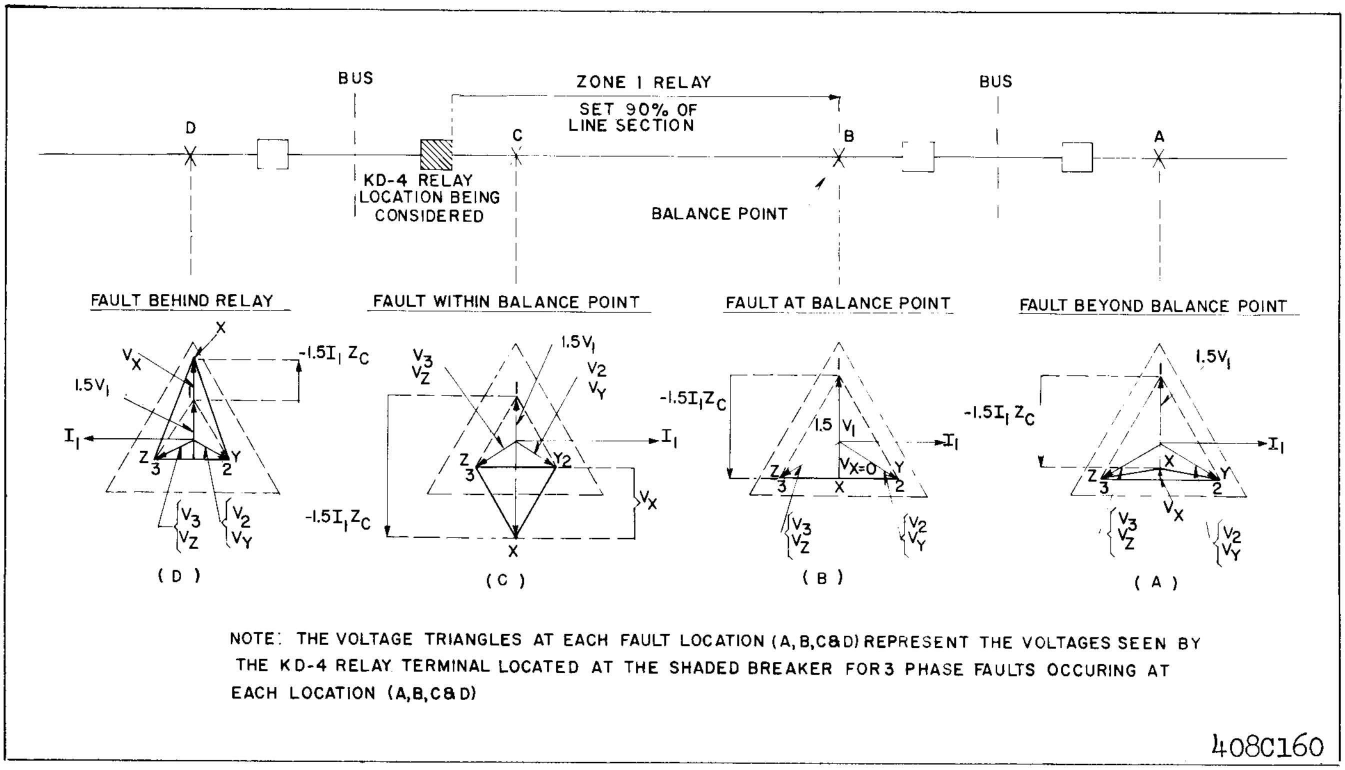


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

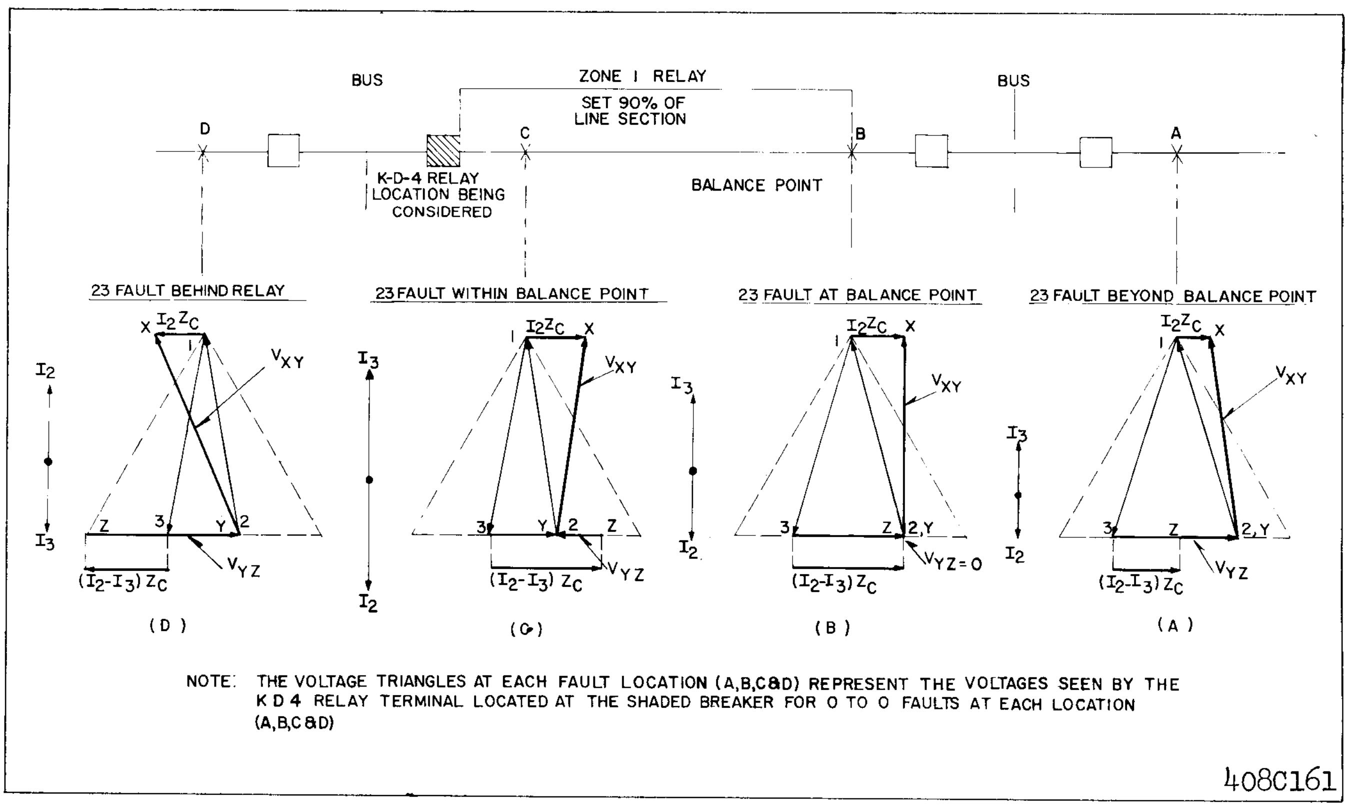


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

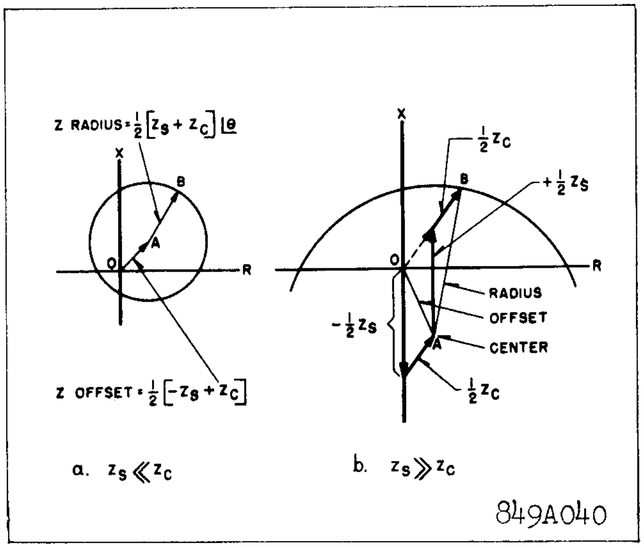


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

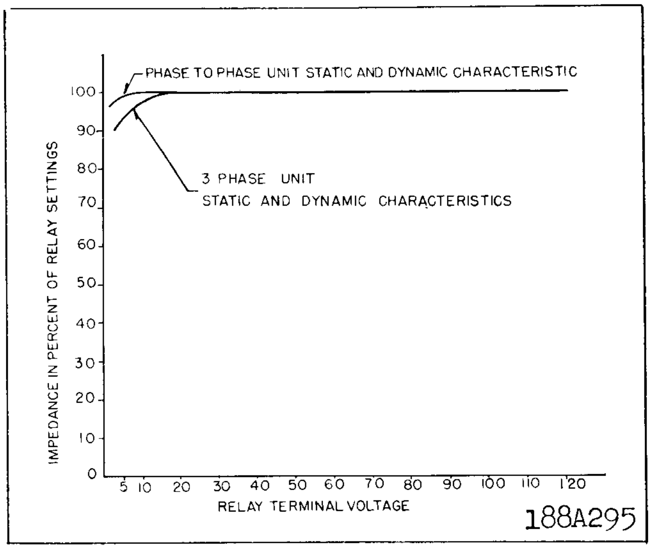


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $- 1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

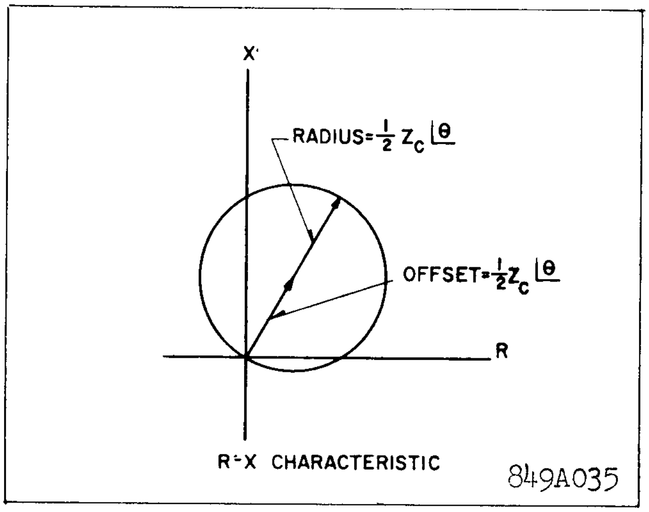


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

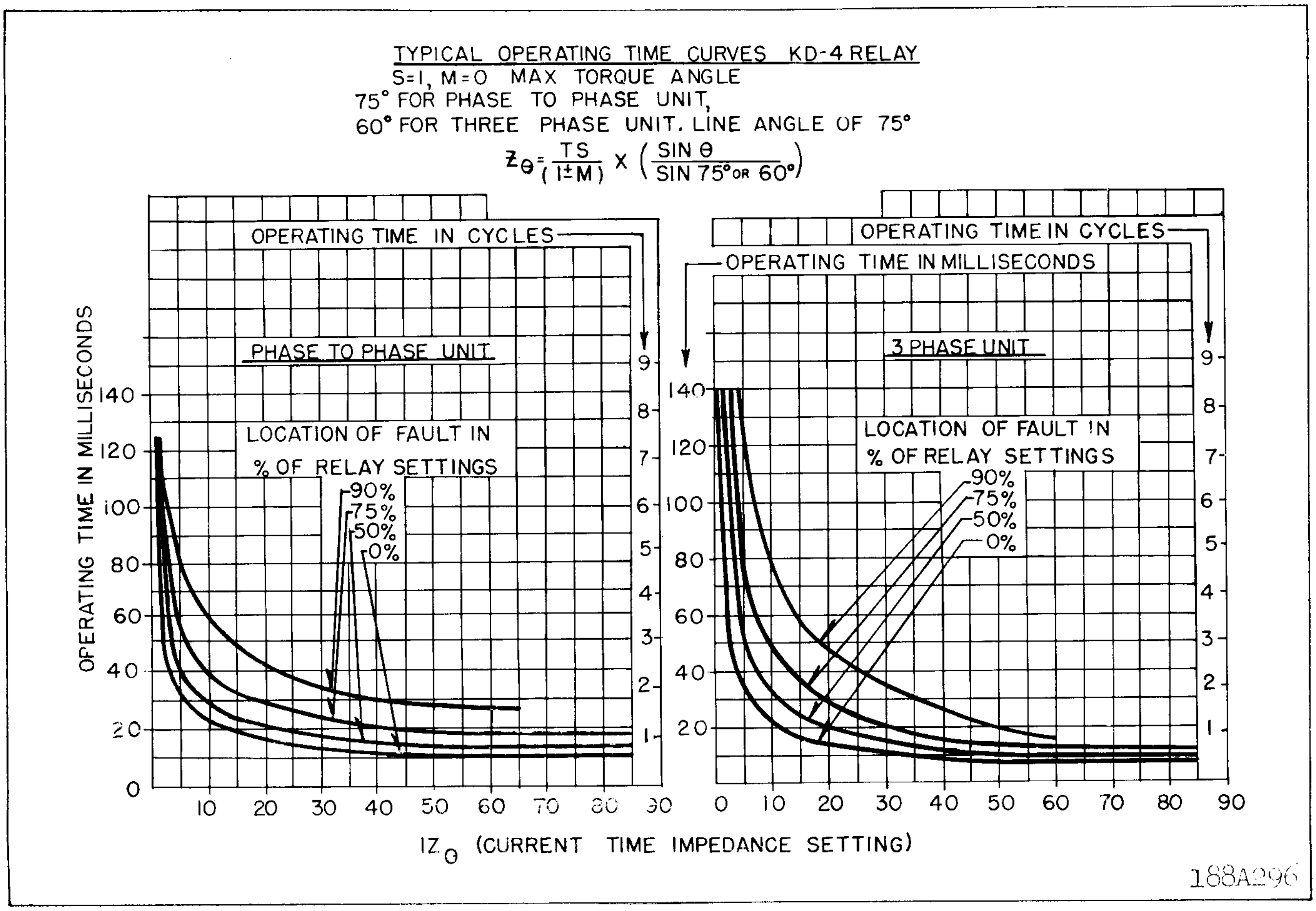


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

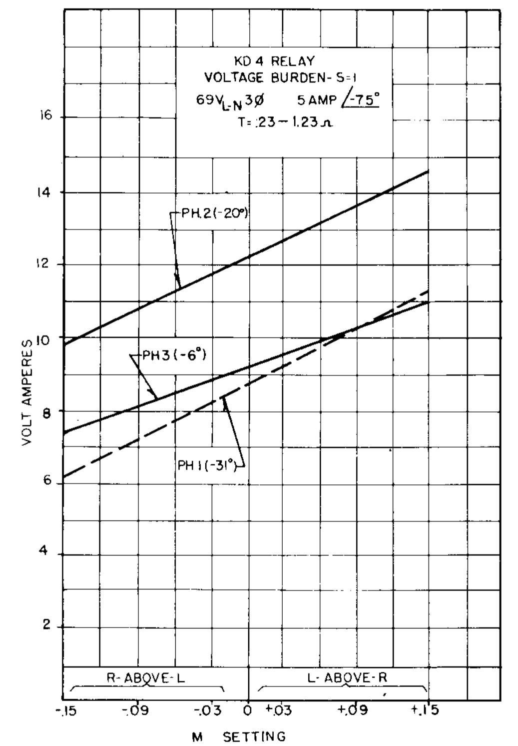
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

Distance Characteristic - 3 Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-



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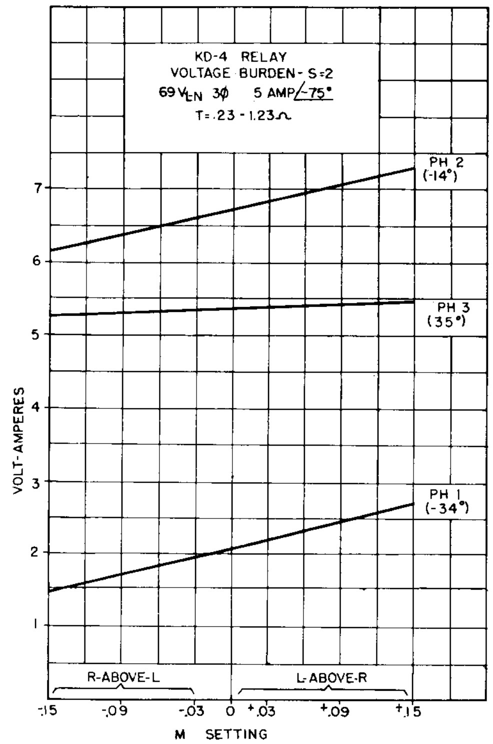

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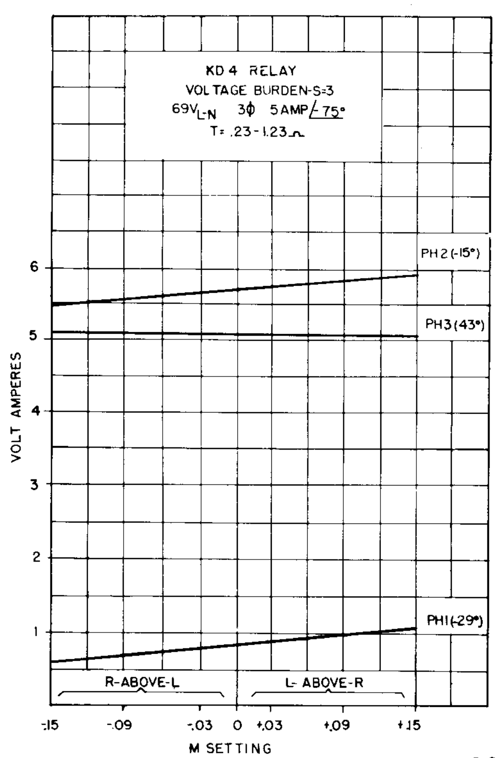

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KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$, S=1
THREE PHASE CURRENT = 5 /-75° AMPS.

	PHASE 1			PHASE 2			PHASE 3		
TAP SETTING	VA	VARS	WATTS	VA	VARS	WATTS	VA	VARS	WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin \theta}{(1 \pm M) \sin \alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)	.23, .307, .383, .537, .690, .920, 1.23
(S, S_A, S_C)	1 2 3
(M, M_A, M_C) ±Values between taps	.03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous S = 1	Continuous S = 2	Continuous S = 3	1 Second
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_C = current transformer ratio

R_V = potential transformer ratio

T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z—setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ
   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ has been recalibrated to an angle different from the factory setting, multiply the $Z\ \theta$ – value by factor $\frac{\text{Sin } 75°}{\text{Sin } \theta°}$ for phase to phase unit, and by factor $\frac{\text{Sin } 60°}{\text{Sin } \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. If relay has been recalibrated to a maximum torque angle of 60° from factory setting of 75° the relay setting, Z should be:

$$Z = 1.7 \times \frac{\text{Sin } 75°}{\text{Sin } 60°} \quad 1.89 \text{ ohms.}$$

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

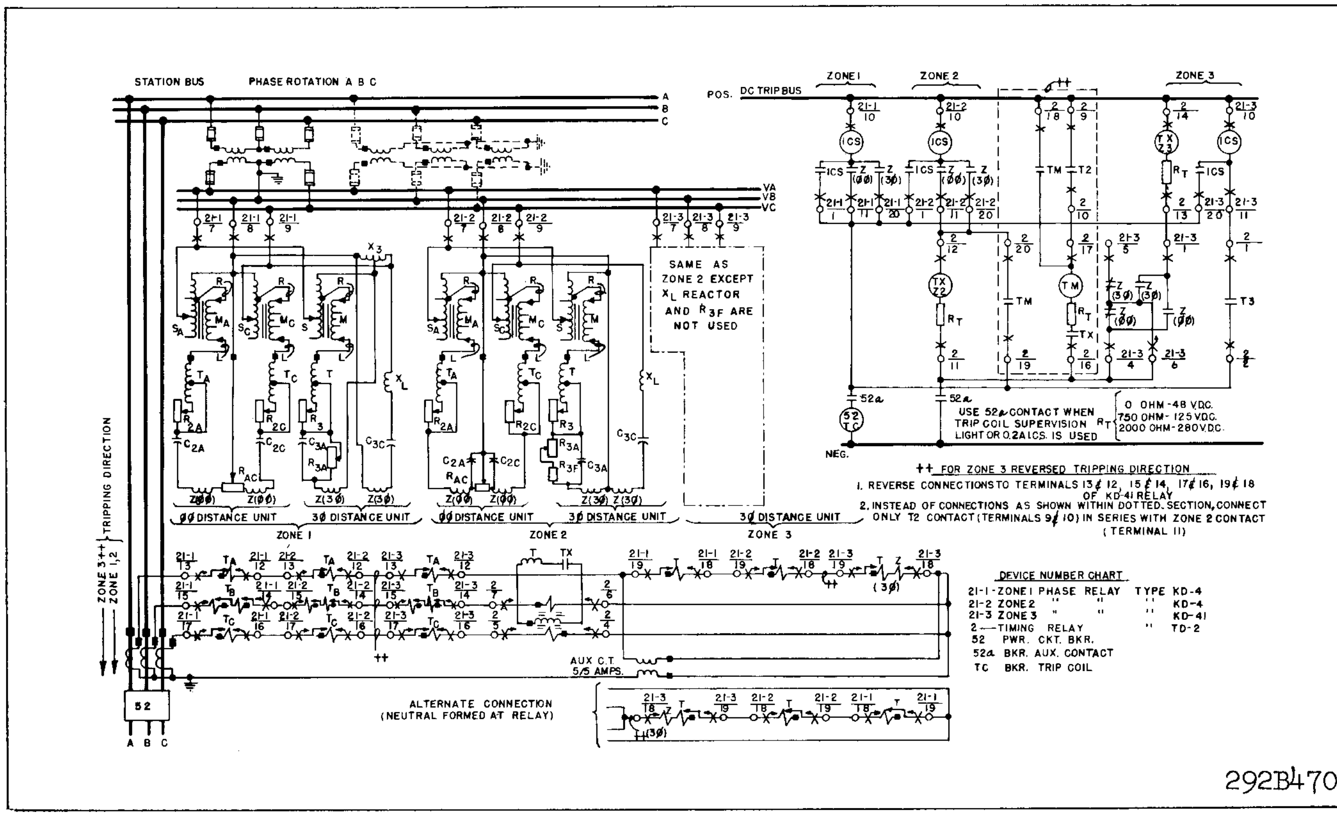
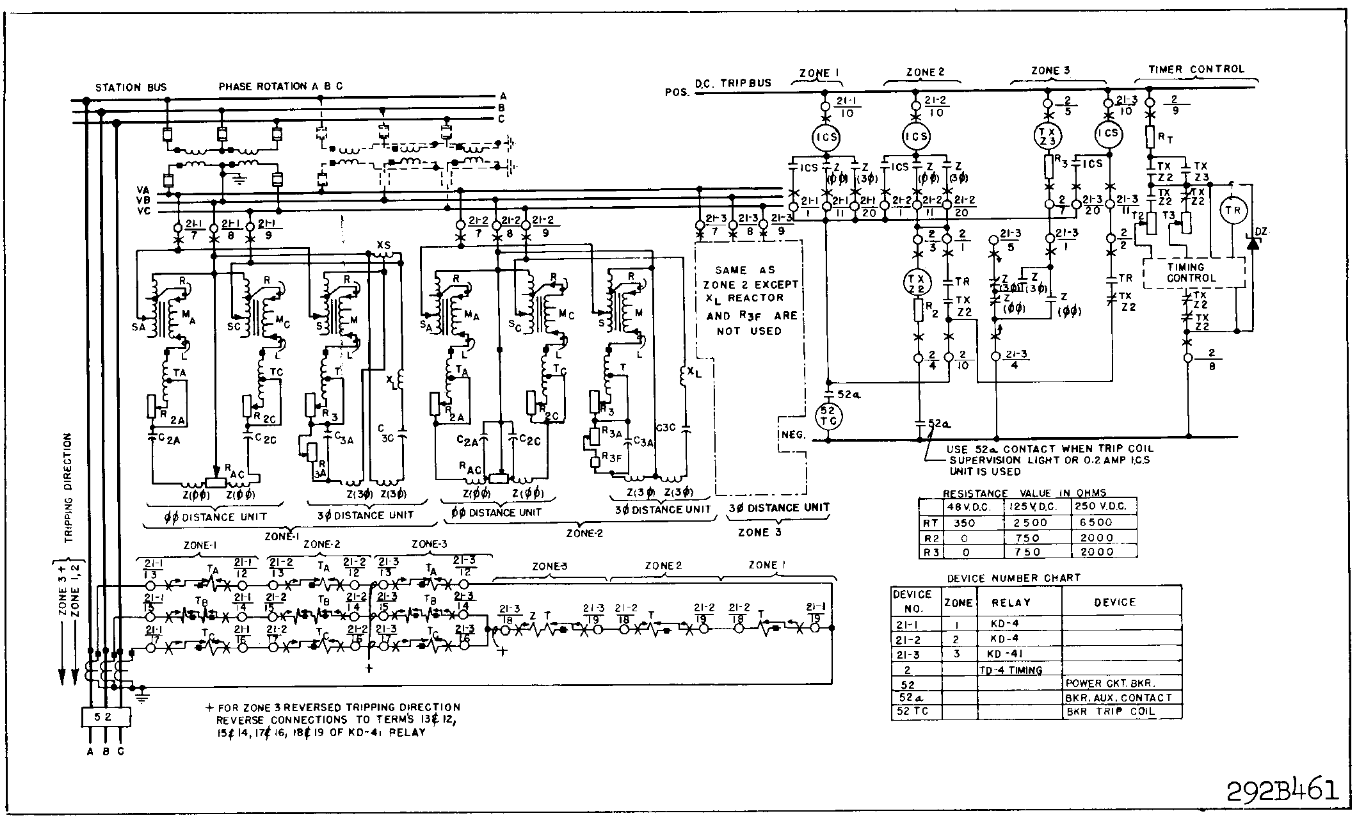


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.



RESISTANCE VALUE IN OHMS	48 V.D.C.	125 V.D.C.	250 V.D.C.
RT	350	2500	6500
R2	0	750	2000
R3	0	750	2000

DEVICE NUMBER CHART

DEVICE NO.	ZONE	RELAY	DEVICE
21-1	1	KD-4	
21-2	2	KD-4	
21-3	3	KD-41	
2		TD-4 TIMING	
52			POWER CKT. BKR.
52a			BKR. AUX. CONTACT
52 TC			BKR TRIP COIL

Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2

T = .920

M = −.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. If relay has been recalibrated to 45° from standard factory setting of 60° then the relay setting should be:

$$Z = Z_\theta \cdot \frac{\text{Sin } 60°}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off

S = 2

T = .920

M = −.12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from −.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 - 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.272	.333	.466	.600	.800	1.070	–	1.60	2.14	–	3.21	+.15		Upper .06	0	"L" over "R"
	.205	.274	.341	.479	.615	.822	1.100	–	1.64	2.20	–	3.29	+.12		Upper .06	.03	"L" over "R"
	.211	.282	.350	.493	.632	.843	1.120	–	1.69	2.24	–	3.38	+.09		Lower .06	0	"L" over "R"
	.217	.290	.361	.506	.650	.869	1.160	–	1.74	2.32	–	3.48	+.06		Upper .06	Lower .06	"L" over "R"
	.224	.298	.371	.521	.670	.892	1.191	–	1.78	2.38	–	3.58	+.03		.03	0	"L" over "R"
	.230	.307	.383	.537	.690	.920	1.230	–	1.84	2.46	–	3.69	0	– 0	0	0	"L" over "R"
	.237	.317	.395	.552	.713	.948	1.270	–	1.90	2.54	–	3.80		–.03	0	.03	"R" over "L"
	.245	.327	.407	.571	.735	.980	1.310	1.47	1.96	2.62	–	3.93		–.06	Lower .06	Upper .06	"R" over "L"
	.253	–	.421	.590	.760	1.010	1.355	1.52	2.02	2.70	3.03	4.06		–.09	0	Lower .06	"R" over "L"
	.261	–	.435	–	.785	1.048	1.395	1. –	2.09	2.80	3.14	4.19		–.12	.03	Upper .06	"R" over "L"
	.271	–	.450	–	–	–	1.45	–	–	2.90	–	4.35		–.15	0	Upper .06	"R" over "L"

The tap plate values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit.

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

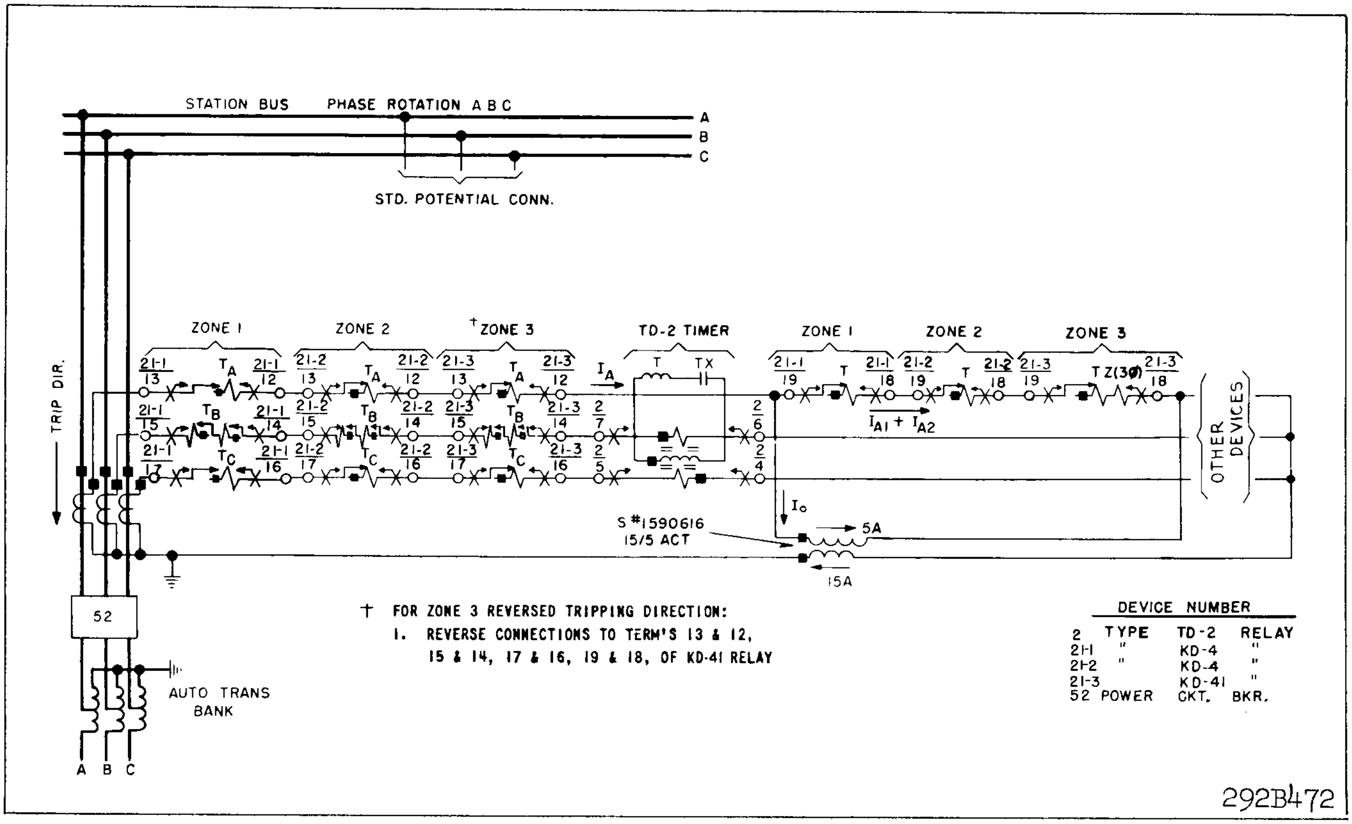


Fig. 14 **A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.**

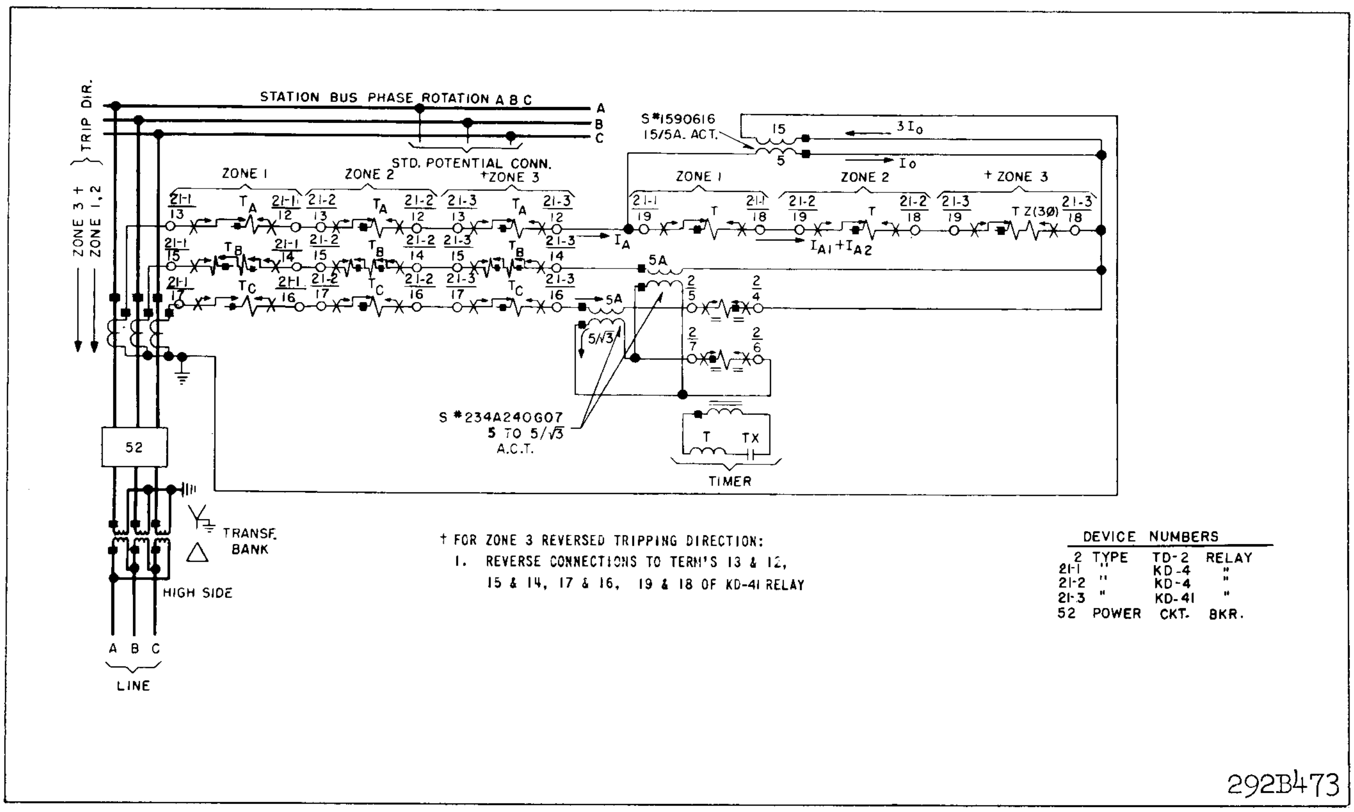


Fig. 15 **A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.**

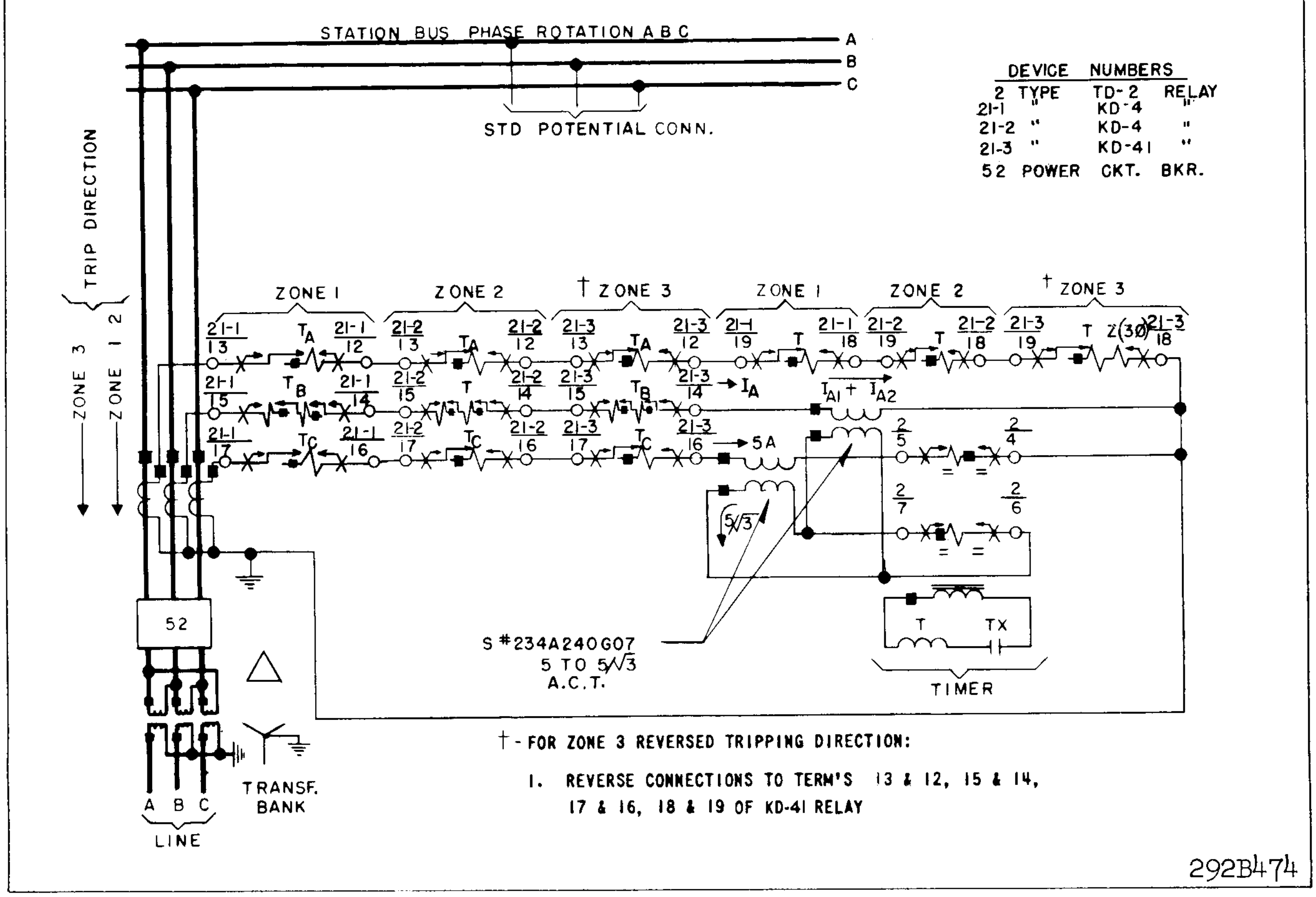


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

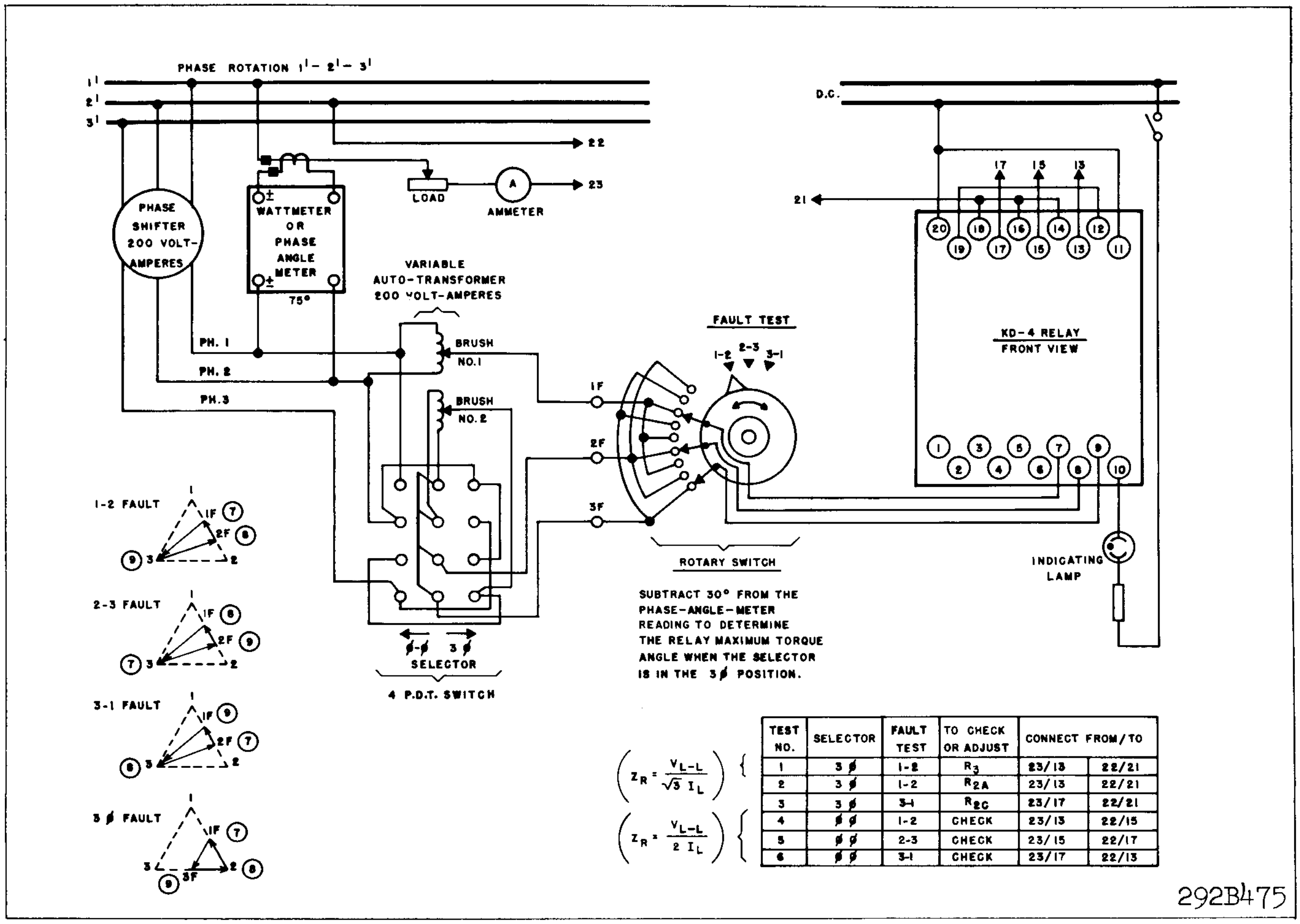
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L} \right)$ (Tests 1–3); $\left(Z_R = \frac{V_{L-L}}{2\, I_L} \right)$ (Tests 4–6)

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 Ø	1-2	R_3	23/13	22/21
2	3 Ø	1-2	R_{2A}	23/13	22/21
3	3 Ø	3-1	R_{2C}	23/17	22/21
4	Ø Ø	1-2	CHECK	23/13	22/15
5	Ø Ø	2-3	CHECK	23/15	22/17
6	Ø Ø	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

<u>Distance Units</u>

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Tripping Units & Initial Spring Setting

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due
* to self-heating, spring set as per Initial Spring Setting.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of $\frac{\sin 60°}{\sin \theta}$.

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60°}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the
* center of the resistor. Spring set as per Initial Spring Setting.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

b. Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

* This angle should be 73—77 degrees.
This angle θ can be changed by adjusting R_{2A}.

In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \sin \theta}{(1 \pm M)\ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3}I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes ($\theta = 60^\circ$) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2\ I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes ($\theta = 75^\circ$) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	Combination of 2 resistors. Total Resistance 2500 ohms (One Resistor is fixed, one adjustable).
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

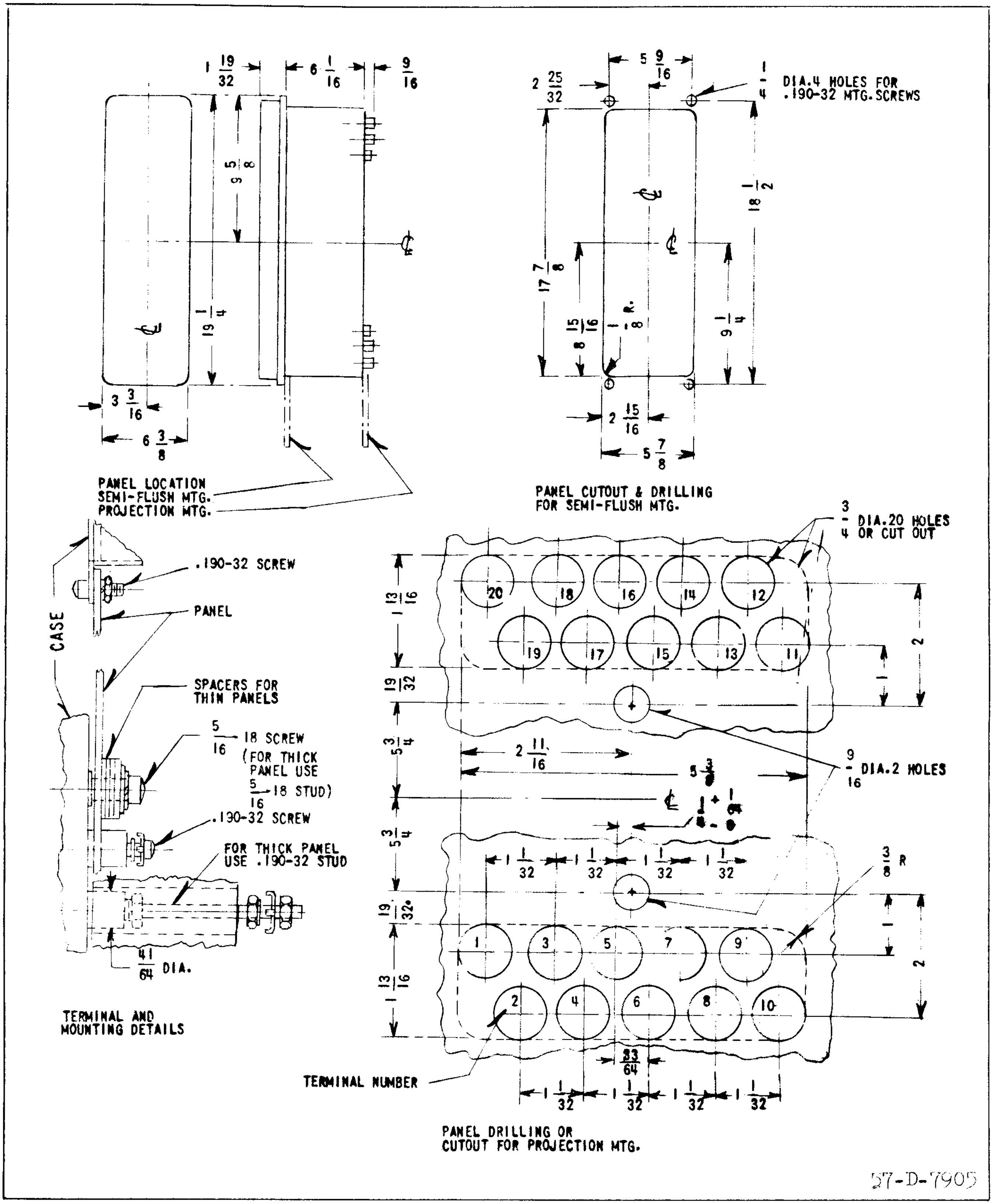


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11J
*Denotes change from superseded issue.

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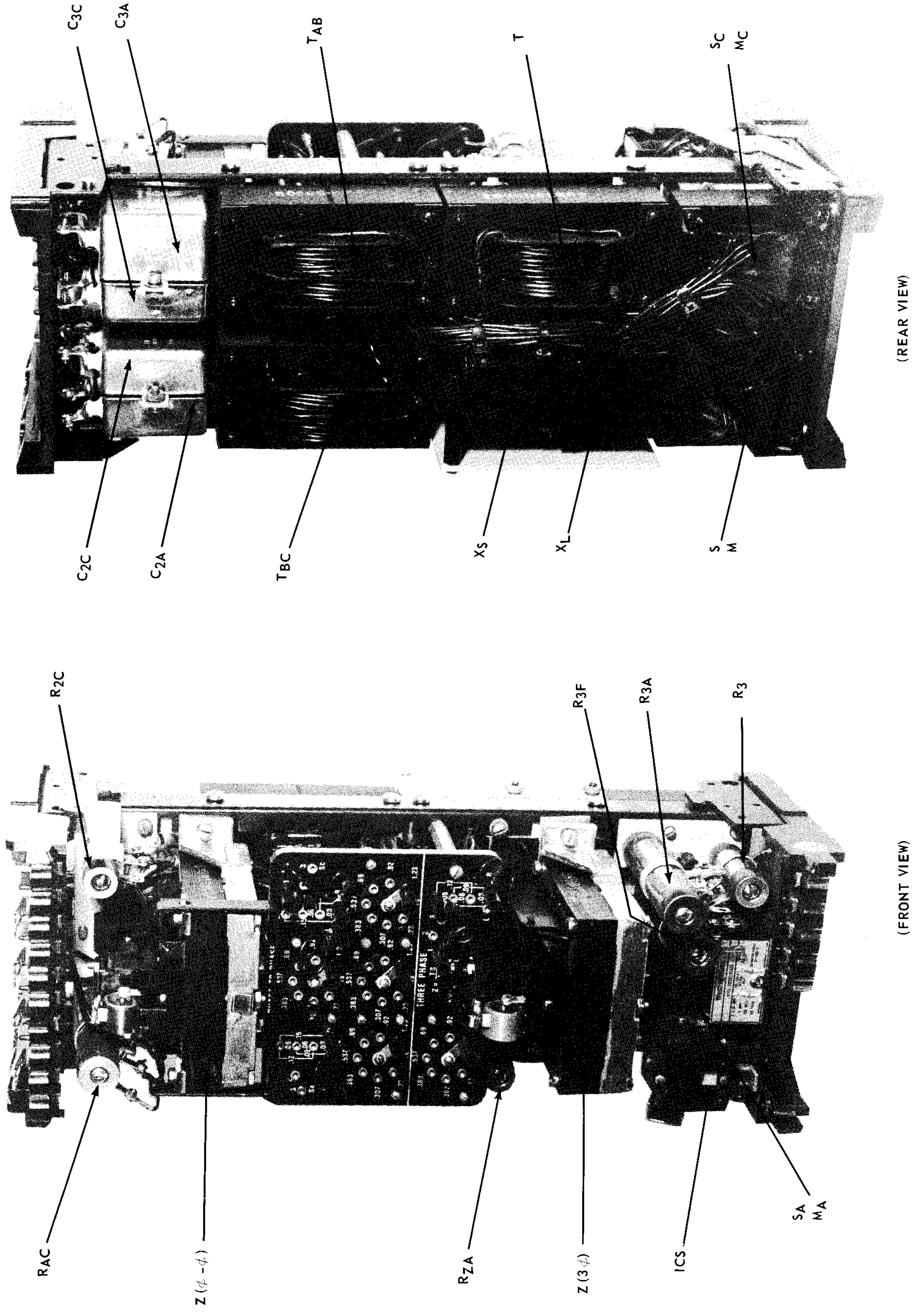


Fig. 1 Type KD-4 Relay Without case

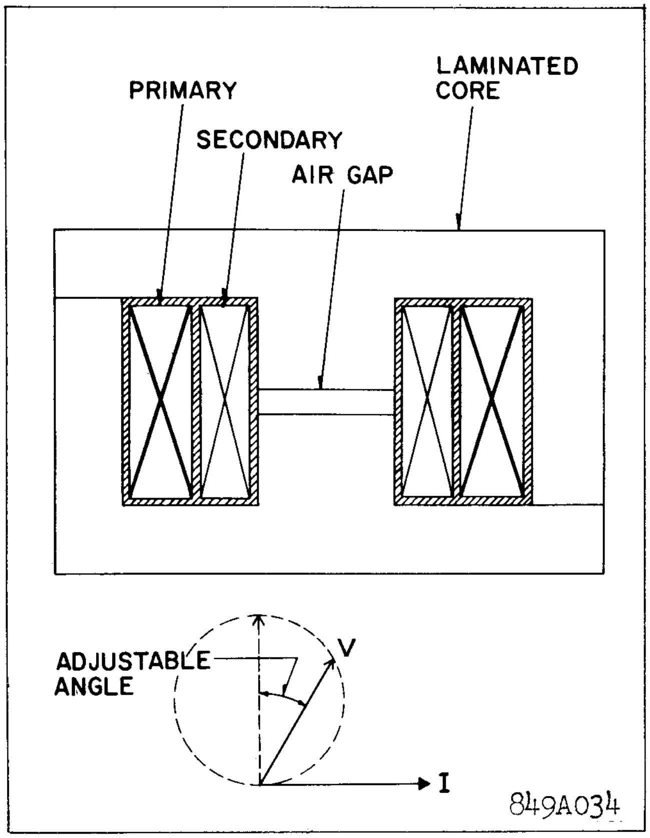


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

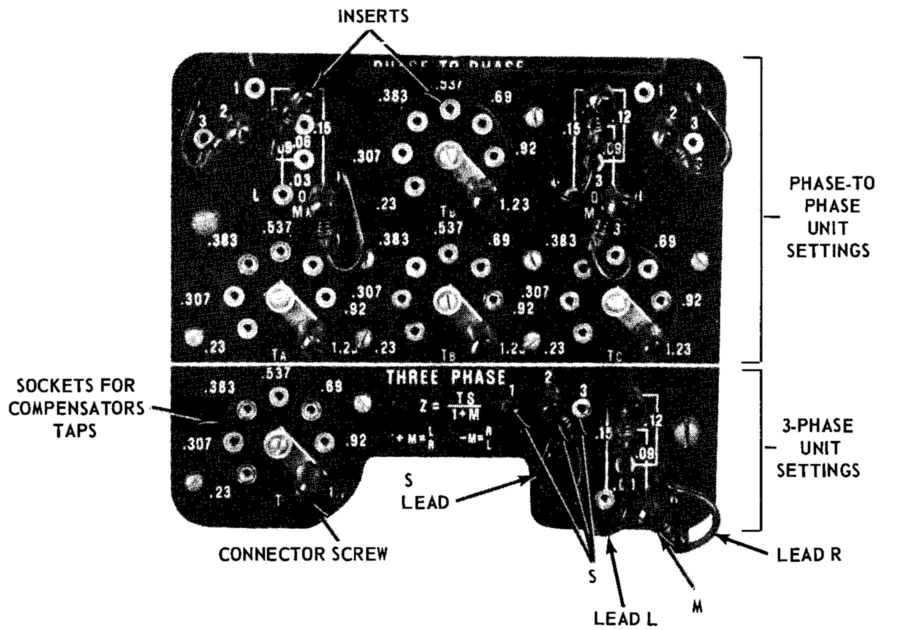


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3Ø) & Z (ØØ). The phase-to-phase unit Z (ØØ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3Ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

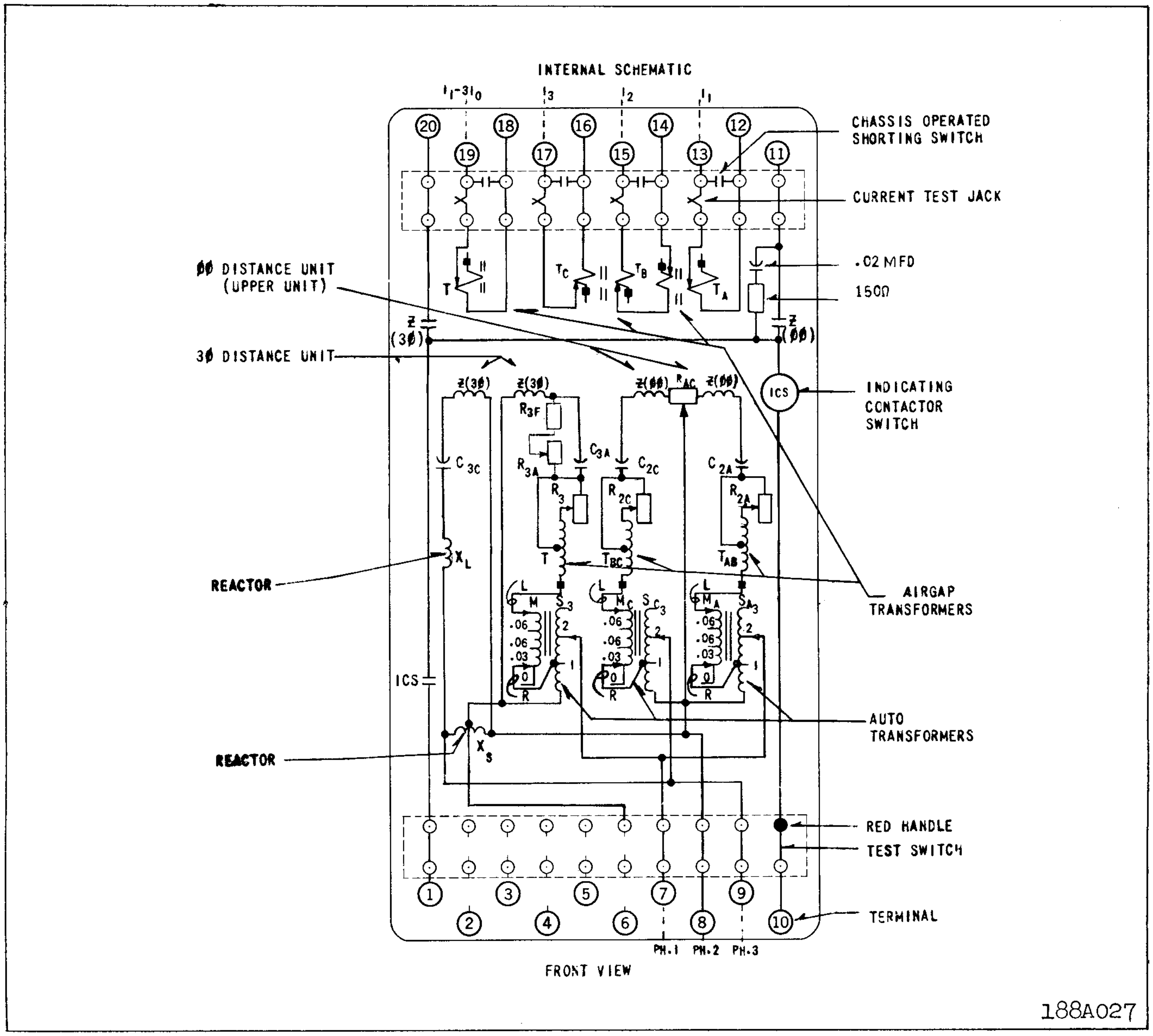


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with $(-I_2 - I_3)$. Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

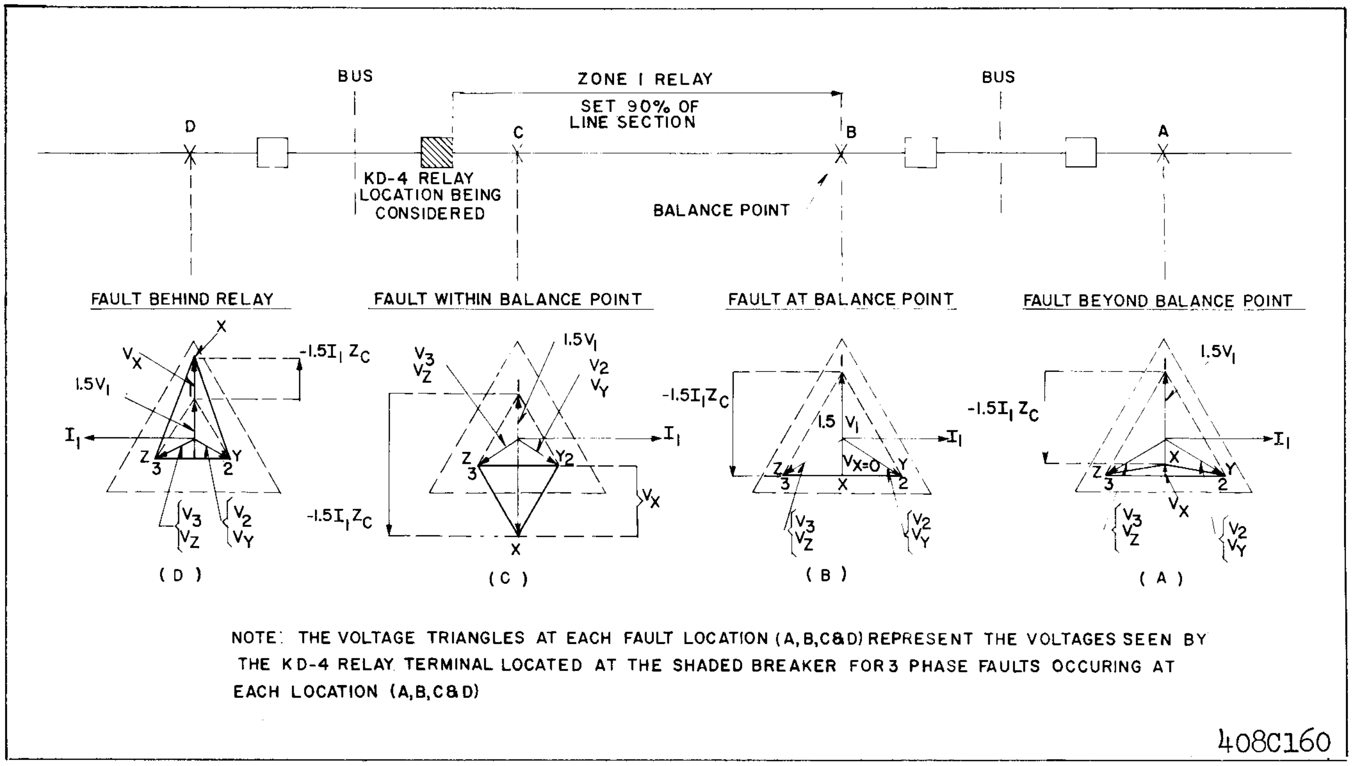


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

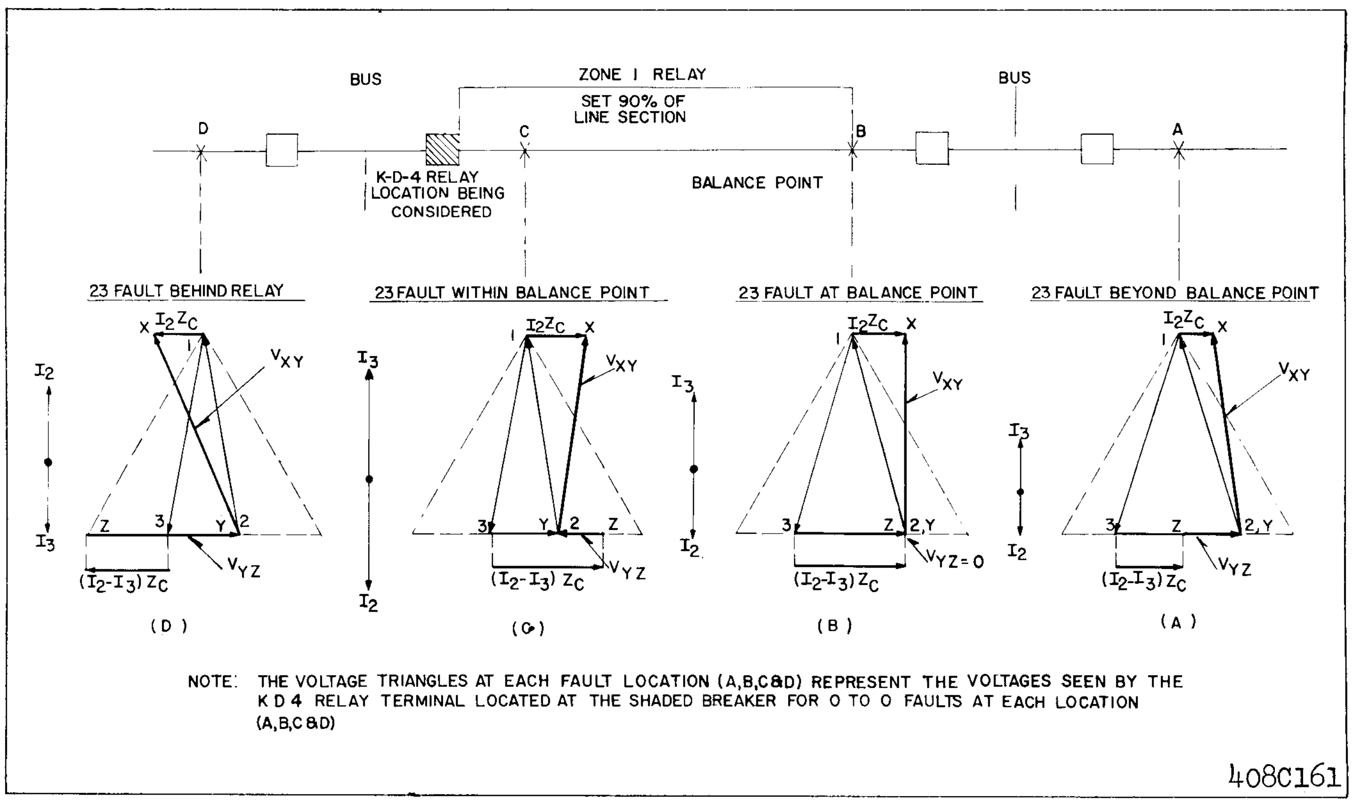


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

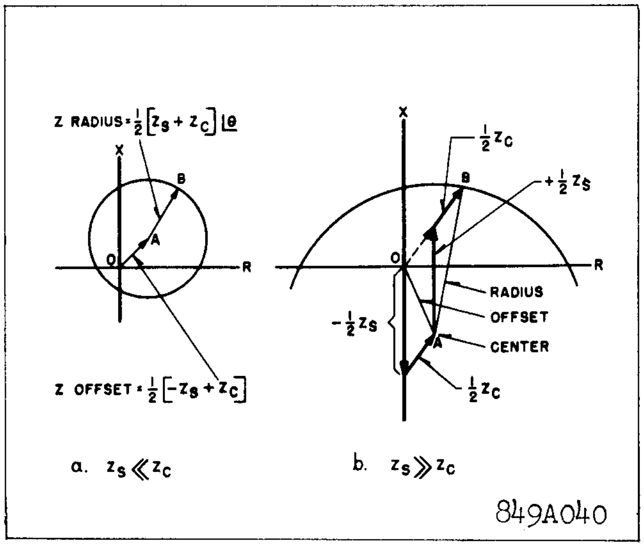


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

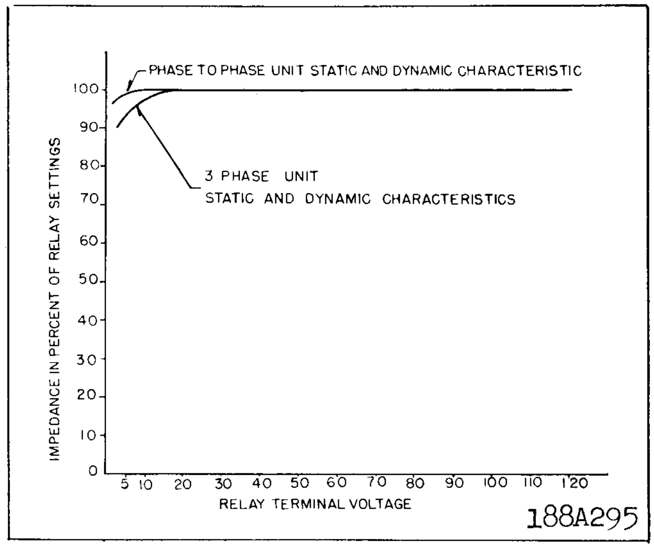


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, -1.5 I_1Z_C, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\, V_1 - 1.5\, I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage -1.5I_1Z_C, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that -1.5IZ_C is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage - 1.5 IZ_C, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\, Z_C$ and $(I_2 - I_3)\, Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

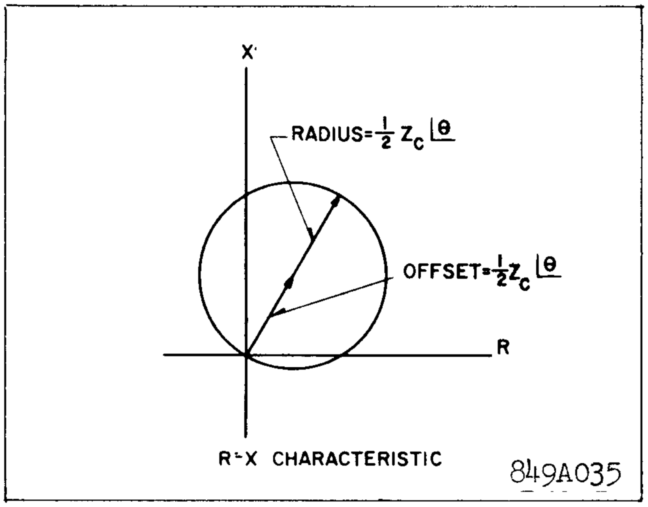


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2)\, Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3)\, Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

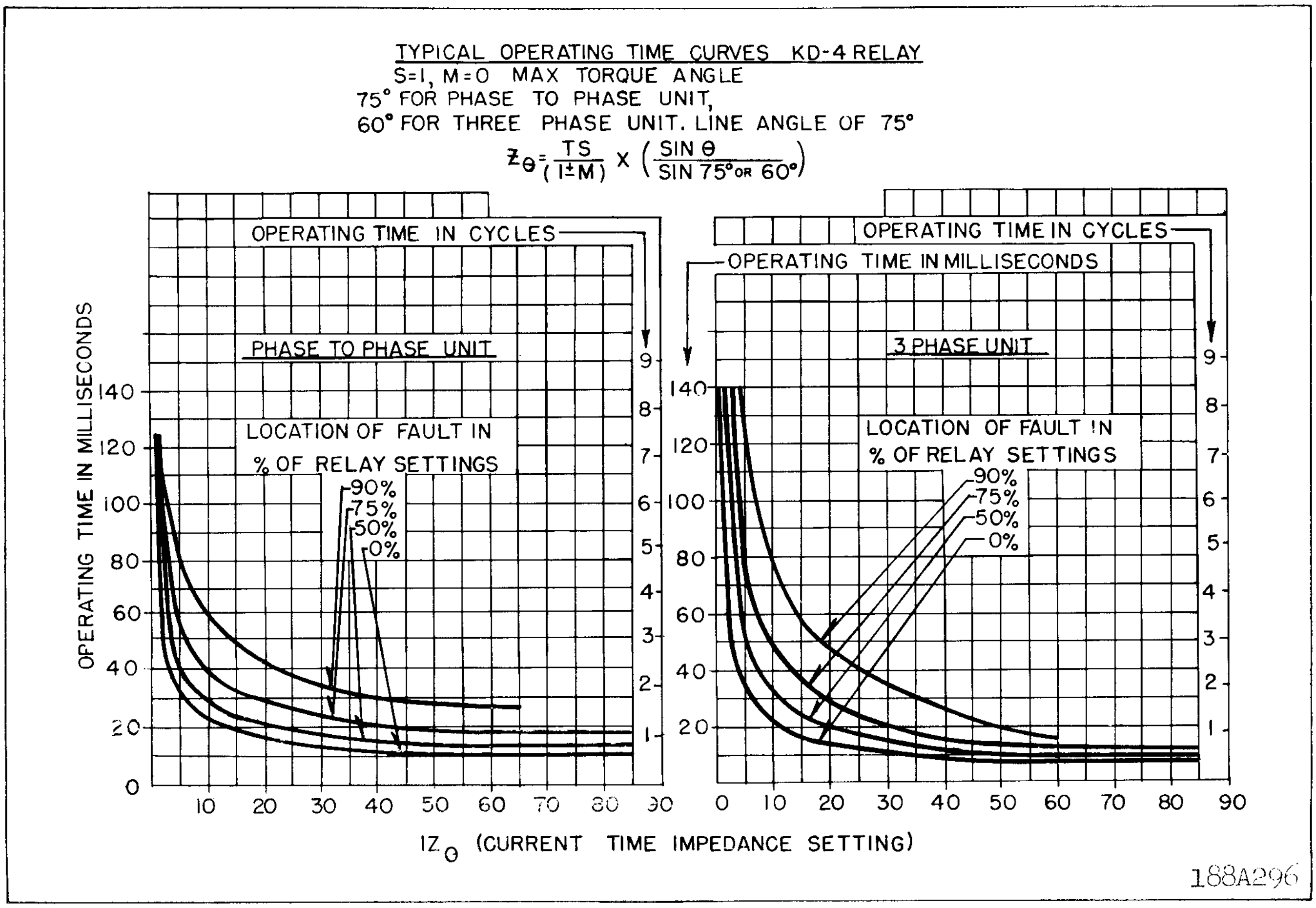


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

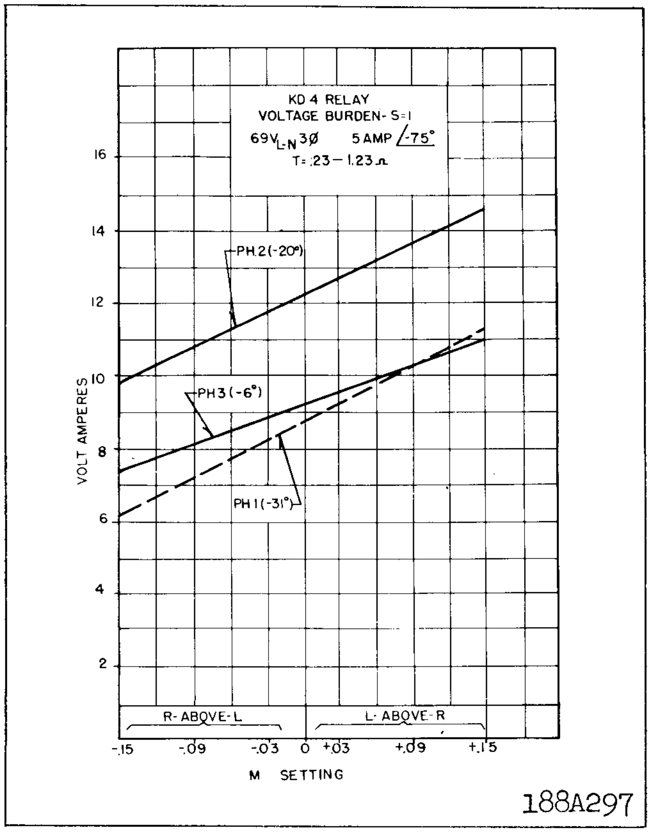
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

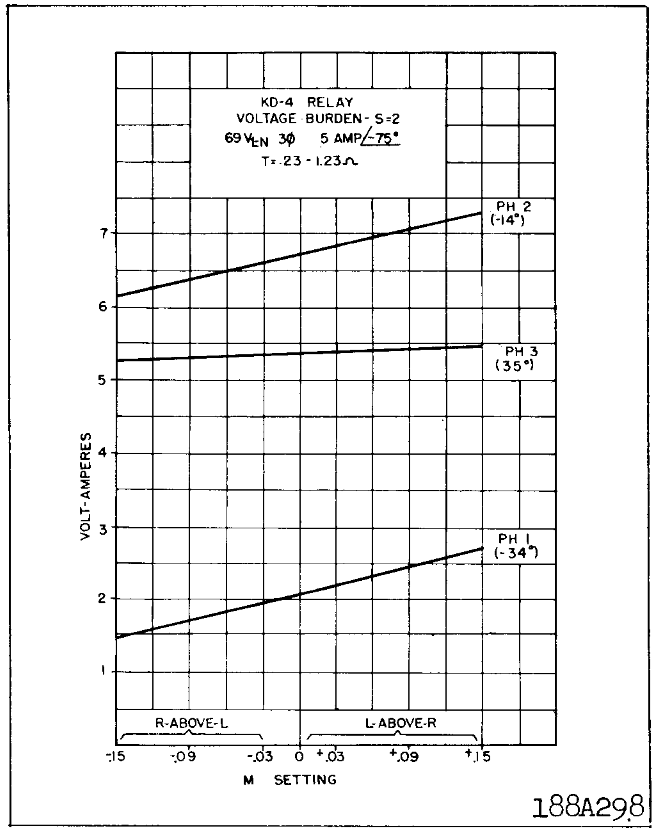
Distance Characteristic - 3 Phase Unit

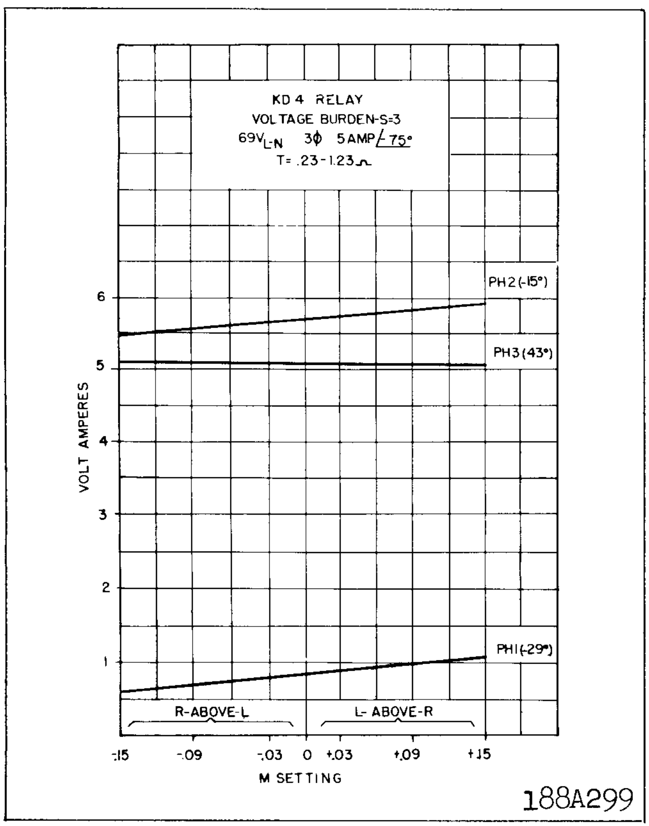
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$, S=1
THREE PHASE CURRENT= 5 ∠-75° AMPS.

TAP SETTING	PHASE 1 VA	PHASE 1 VARS	PHASE 1 WATTS	PHASE 2 VA	PHASE 2 VARS	PHASE 2 WATTS	PHASE 3 VA	PHASE 3 VARS	PHASE 3 WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin\theta}{(1 \pm M) \sin\alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, TA, T_B, and T_C)
.23, .307, .383, .537, .690, .920, 1.23

(S, S_A, S_C)
1 2 3

(M, M_A, M_C)
±Values between taps .03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_v = potential transformer ratio

T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z—setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ
   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ has been recalibrated to an angle different from the
   * 75° setting, multiply the $Z\ \theta$ – value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

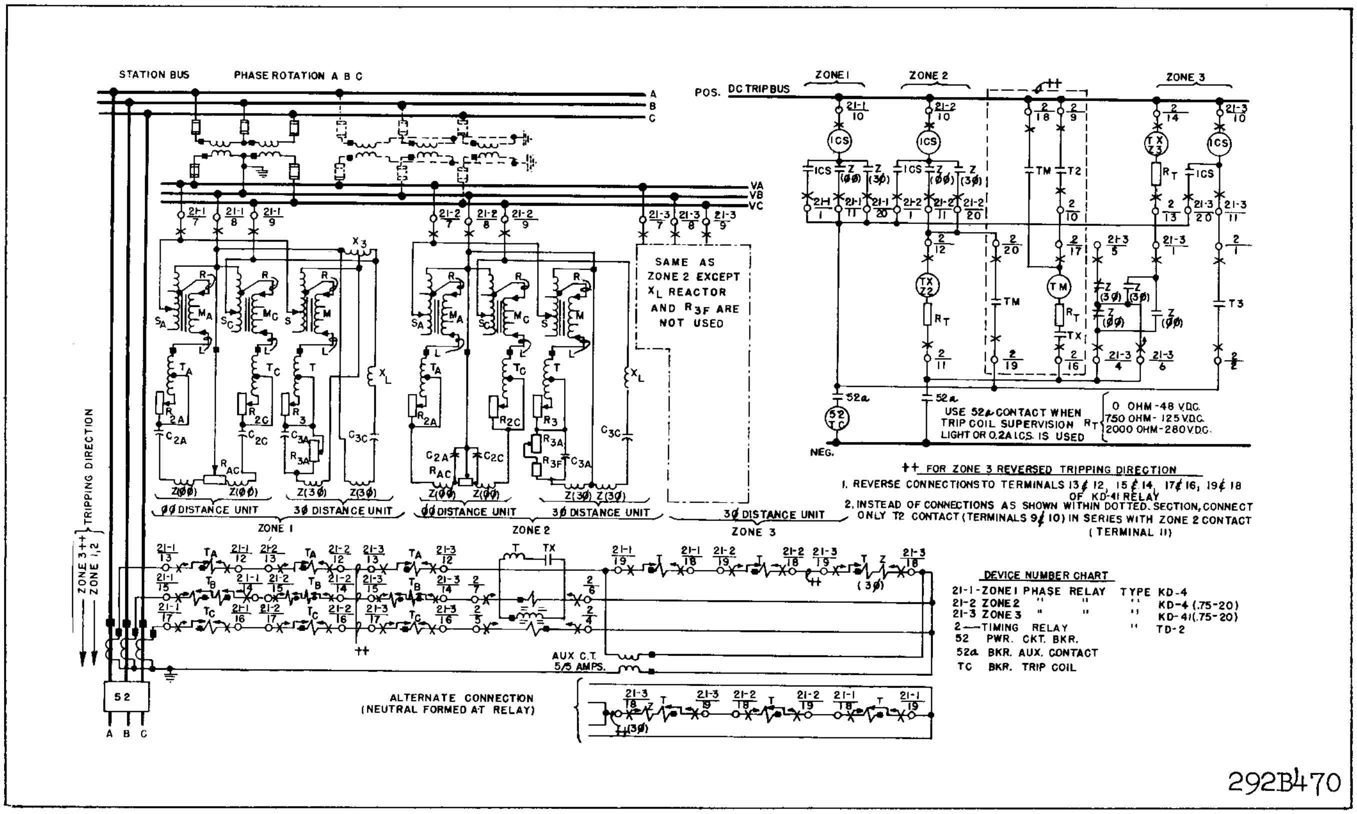
$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. If relay has been recalibrated to a maximum torque angle of 60° from standard setting of 75° the relay setting, Z should be:

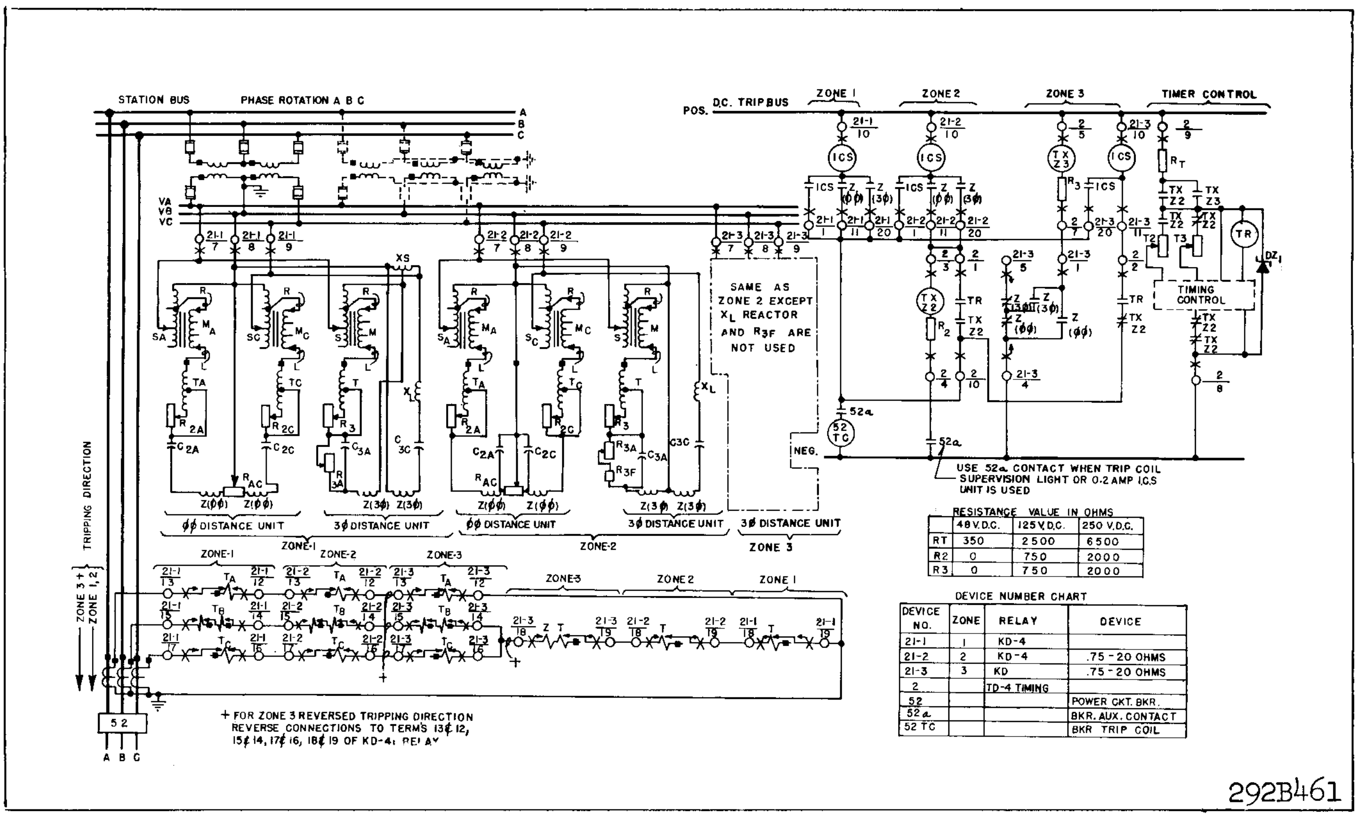
* $Z = 1.7 \times \frac{\sin 75°}{\sin 60°} = 1.89$ ohms.

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.



* *Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.*



* *Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.*

b) From the Table I read off $S = 2$
$T = .920$
$M = -.03$

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60^\circ} = Z \frac{\text{Sin } 60^\circ}{\text{Sin } 75^\circ} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. If relay has been recalibrated to 45° from standard factory setting of 60° then the relay setting should be:

$$Z = Z_\theta \cdot \frac{\text{Sin } 60^\circ}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off
$S = 2$
$T = .920$
$M = -.12$

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45^\circ} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from -.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (-) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 – 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
* T	.230	.307	.383	.537	,690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.267	.333	.467	.600	.800	1.070	–	1.60	2.14	–	3.21	+.15		Upper .06	0	"L" OVER "R"
	.205	.274	.342	.480	.616	.821	1.098	–	1.64	2.20	–	3.29	+-12		Upper .06	.03	
	.211	.282	.351	.493	.633	.844	1.128	–	1.69	2.26	–	3.38	+.09		Lower .06	0	
	.217	.290	.361	.507	.651	.868	1.160	–	1.74	2.32	–	3.48	+.06		Upper .06	Lower .06	
	.223	.298	.372	.521	.670	.893	1.194	–	1.78	2.39	–	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	–	1.84	2.46	–	3.69	0	- 0	0	0	
	.237	.317	.395	.554	.711	.948	1.268	–	1.90	2.54	–	3.80		-.03	0	.03	"R" OVER "L"
	.245	.327	.407	.571	.734	.979	1.308	1.47	1.96	2.62	–	3.93		-.06	Lower .06	Upper .06	
	:253	–	.421	.590	.758	1.011	1.352	1.52	2.02	2.70	3.03	4:05		-.09	0	Lower .06	
	.261	–	.435	–	.784	1.046	1.398	1.57	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	–	.451	–	–	–	1.447	–	–	2.89	–	4:34		-.15	0	Upper .06	

* The tap plate values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit.

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

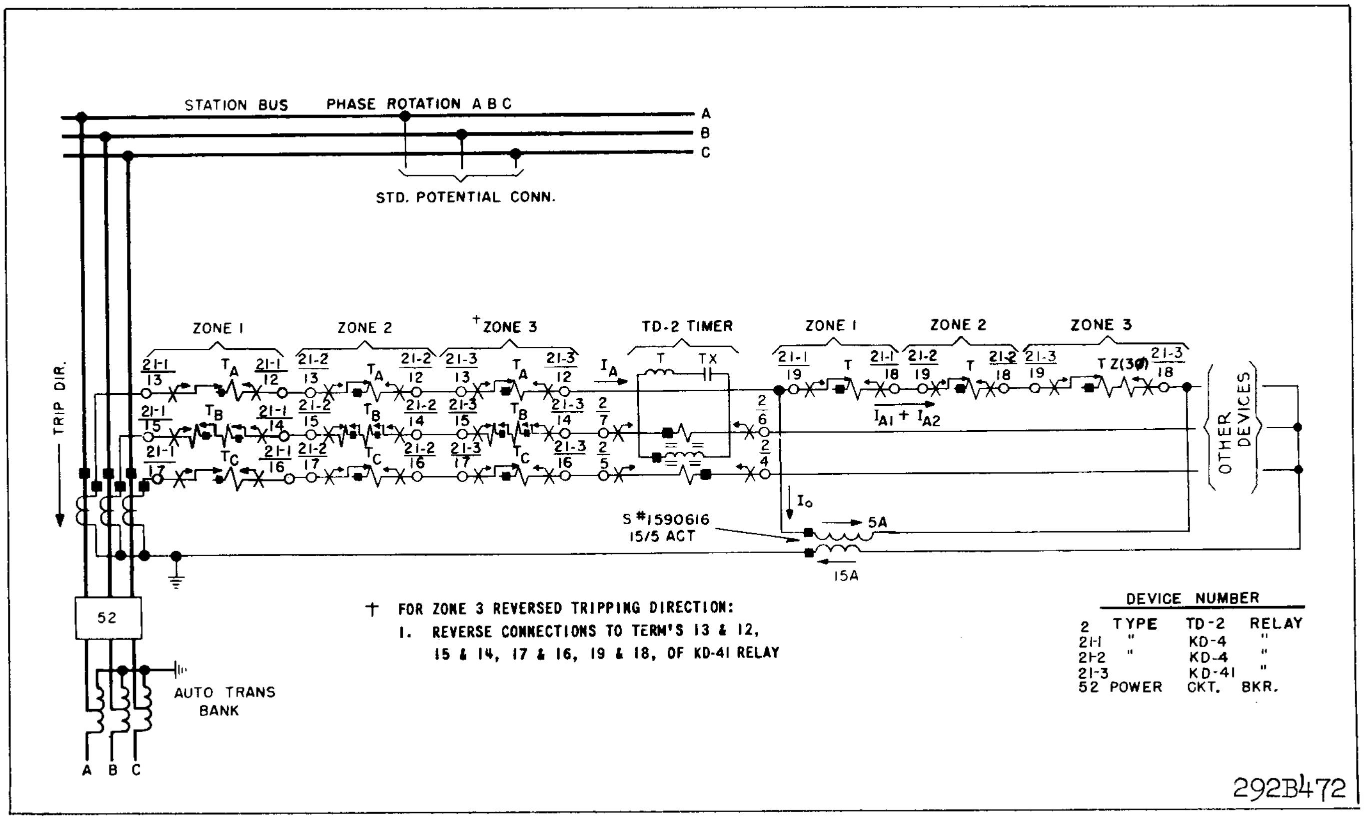


Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.

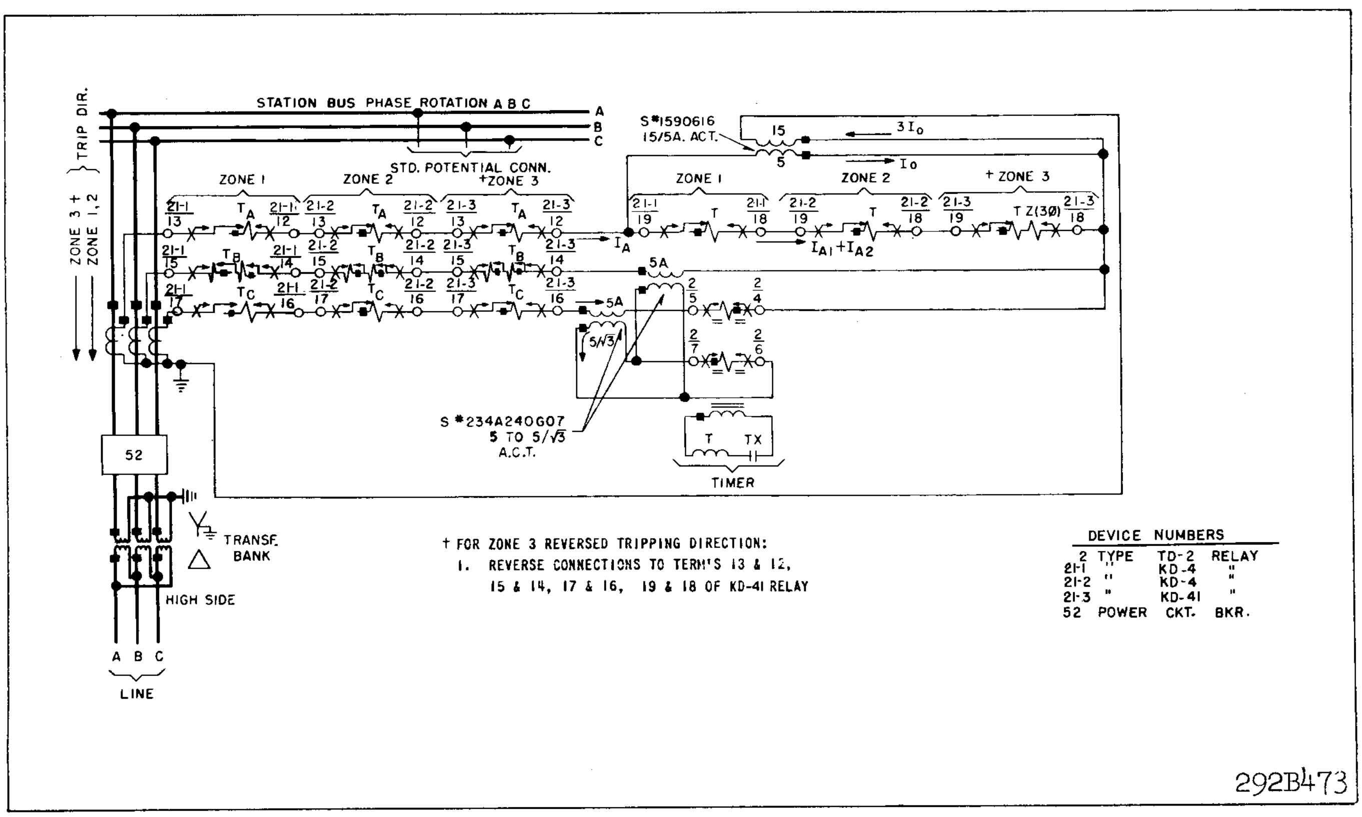


Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

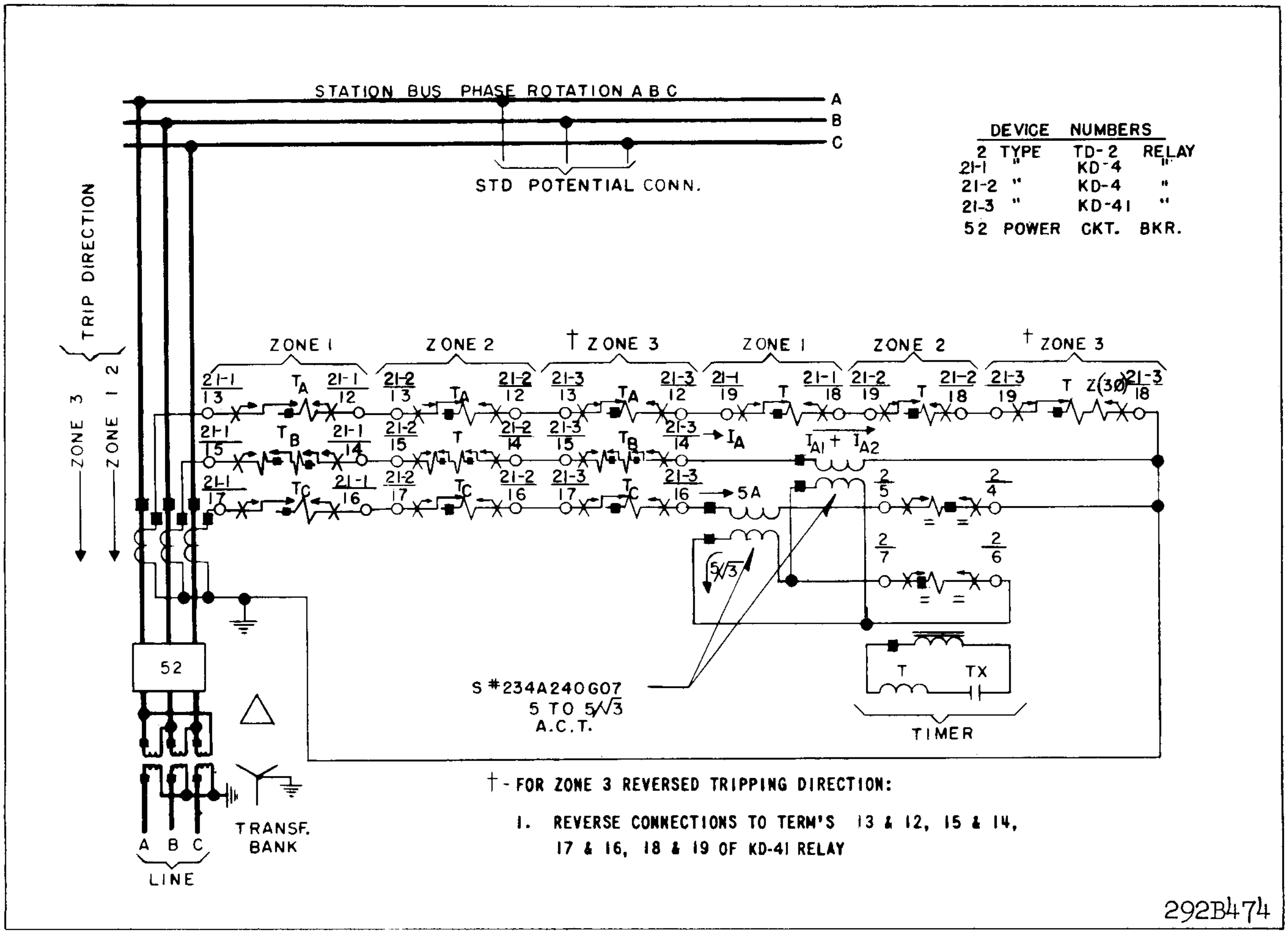


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

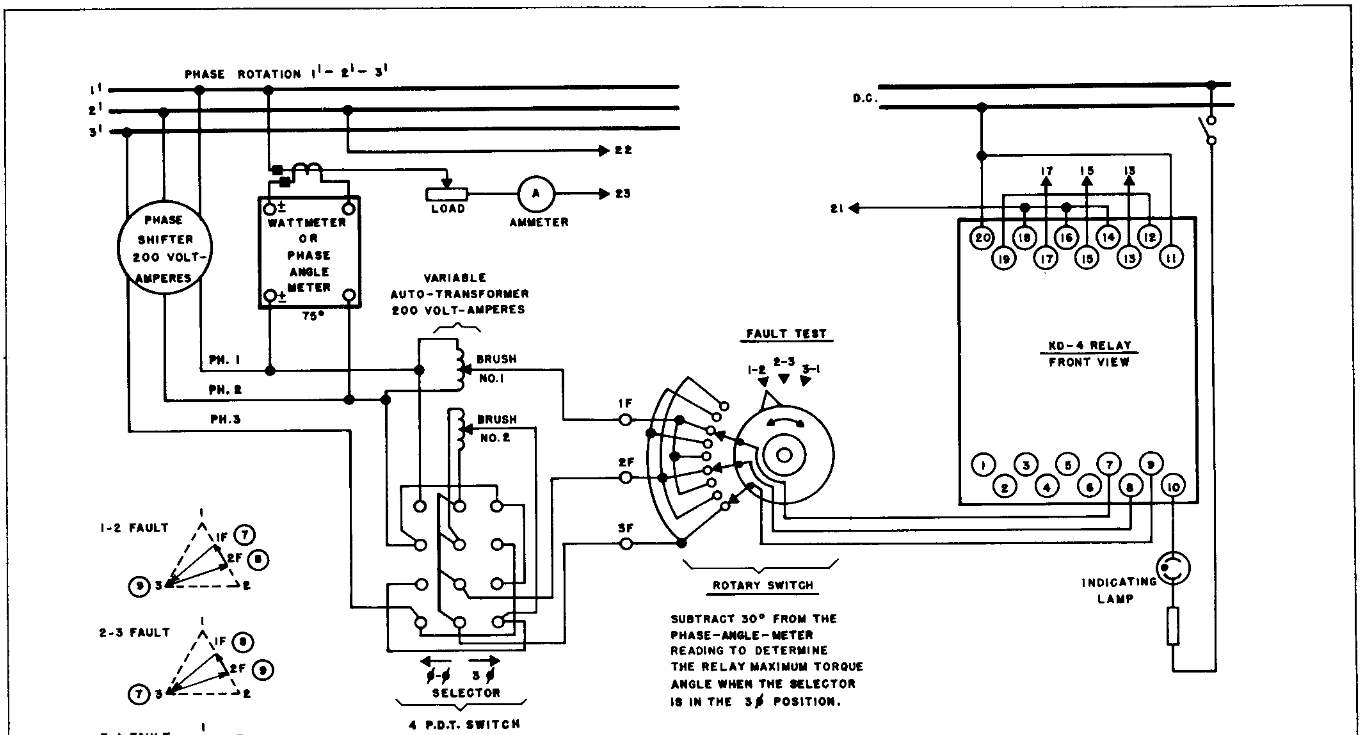
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



Tests 1–3: $\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right)$

Tests 4–6: $\left(Z_R = \frac{V_{L-L}}{2\, I_L}\right)$

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 ø	1-2	R_3	23/13	22/21
2	3 ø	1-2	R_{2A}	23/13	22/21
3	3 ø	3-1	R_{2C}	23/17	22/21
4	ø ø	1-2	CHECK	23/13	22/15
5	ø ø	2-3	CHECK	23/15	22/17
6	ø ø	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

* **Initial Spring Setting**

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

* **Shaft Clearance**

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due * to self-heating, spring set as per Initial Spring Setting.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° – for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 – .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 – 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of $\frac{\sin 60°}{\sin \theta}$.

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60°}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the * center of the resistor. Spring set as per Initial Spring Setting.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

B. Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.
   This angle should be 73—77 degrees.
   This angle θ can be changed by adjusting R_{2A}.
   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been com-
* pleted, perform the following check.

Set all T = 1.23, all S = 1, all M = 0.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3} I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2 I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08 *
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

*If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	Combination of 2 resistors. Total Resistance 2500 ohms (One Resistor is fixed, one adjustable).
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

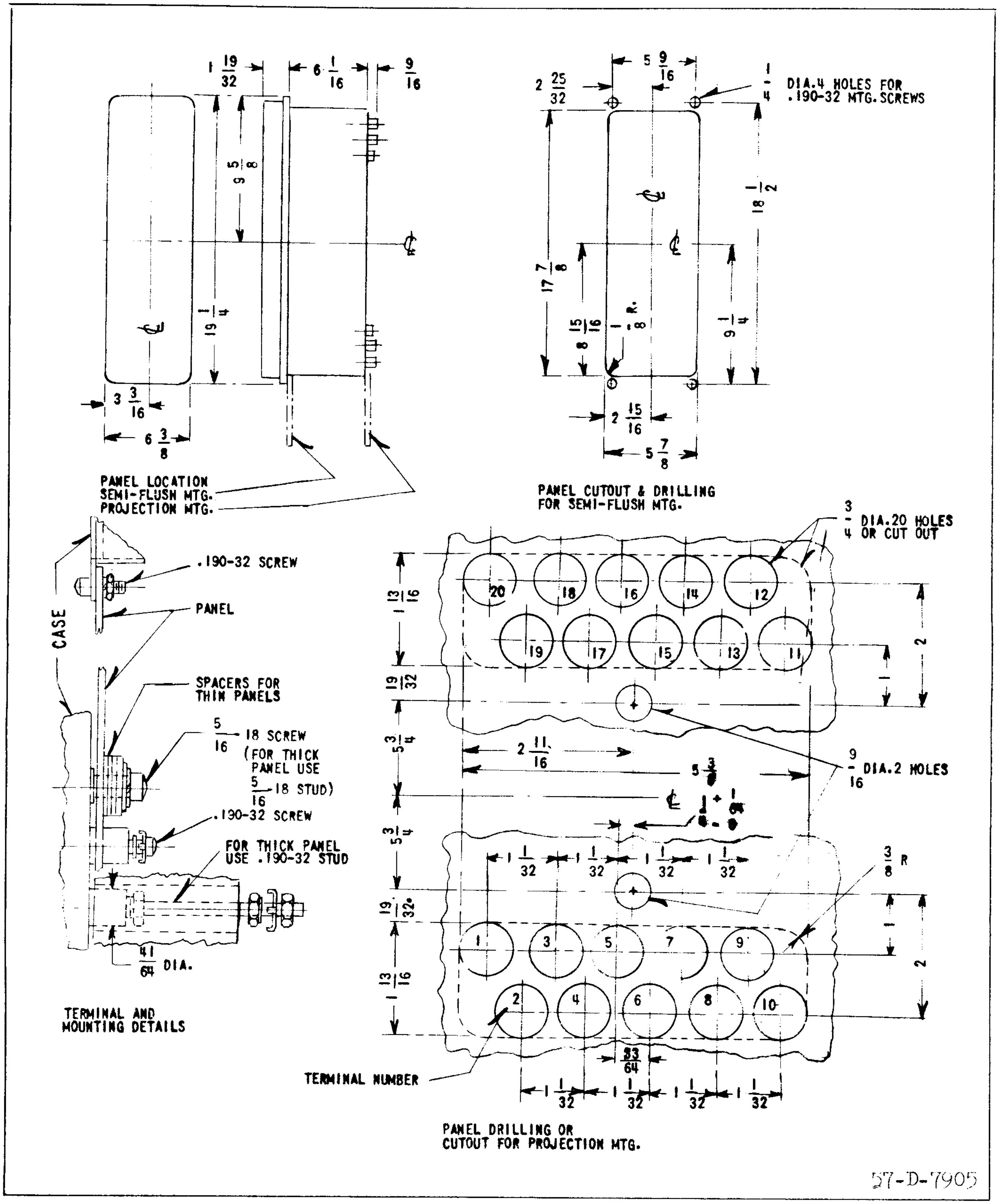


Fig. 18 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY

(FOR RELAYS WITH SUB "A" IN STYLE NUMBER SEE APPENDIX)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1), is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to-ground faults, and three-phase faults.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

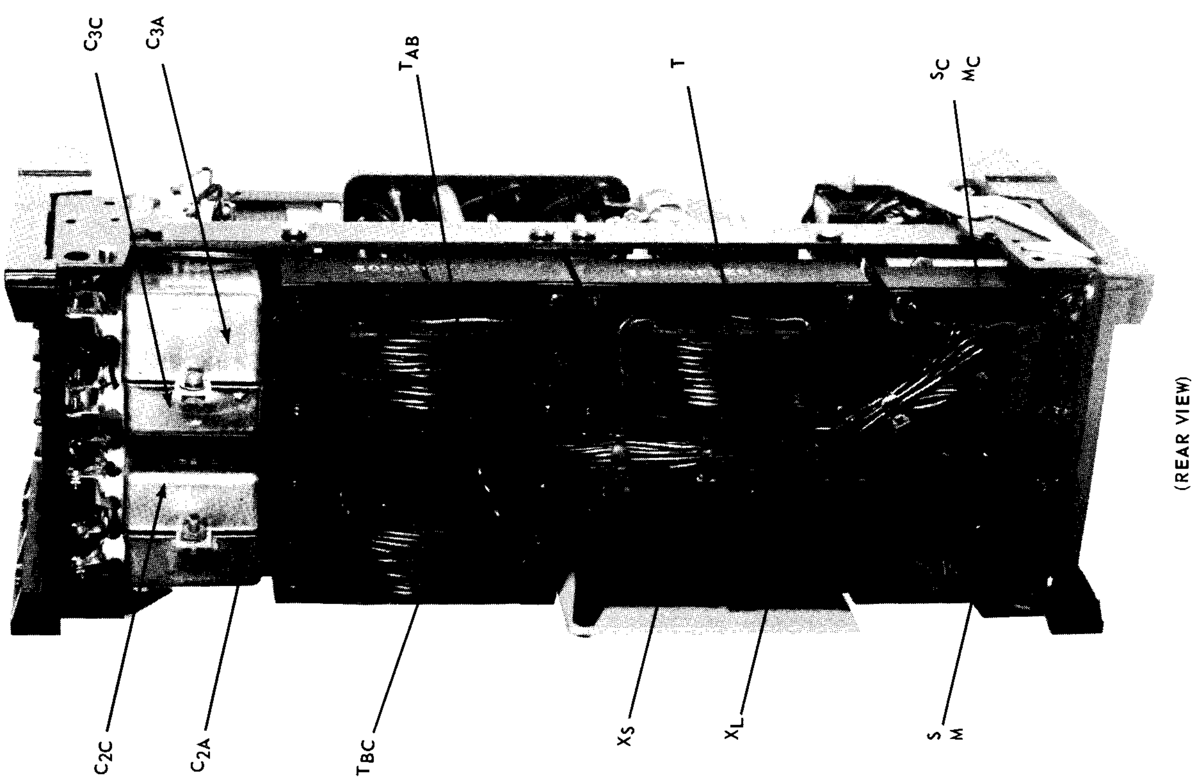
The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11K
*Denotes change from superseded issue.

EFFECTIVE FEBRUARY 1974



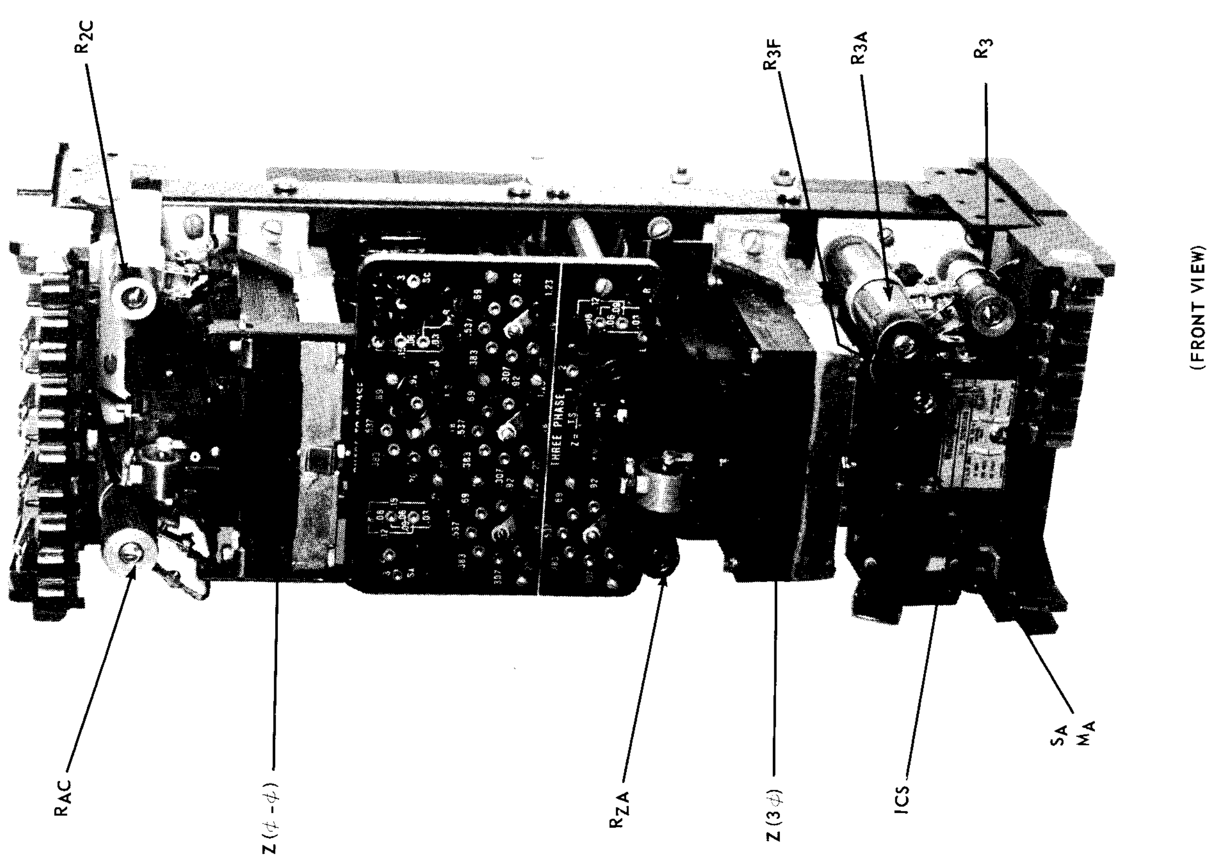


Fig. 1 Type KD-4 Relay Without case

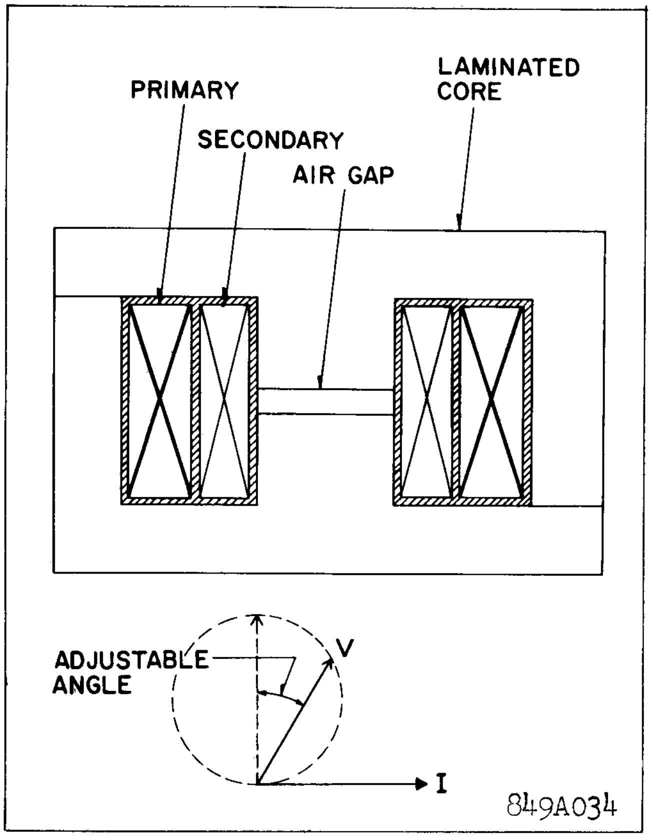


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

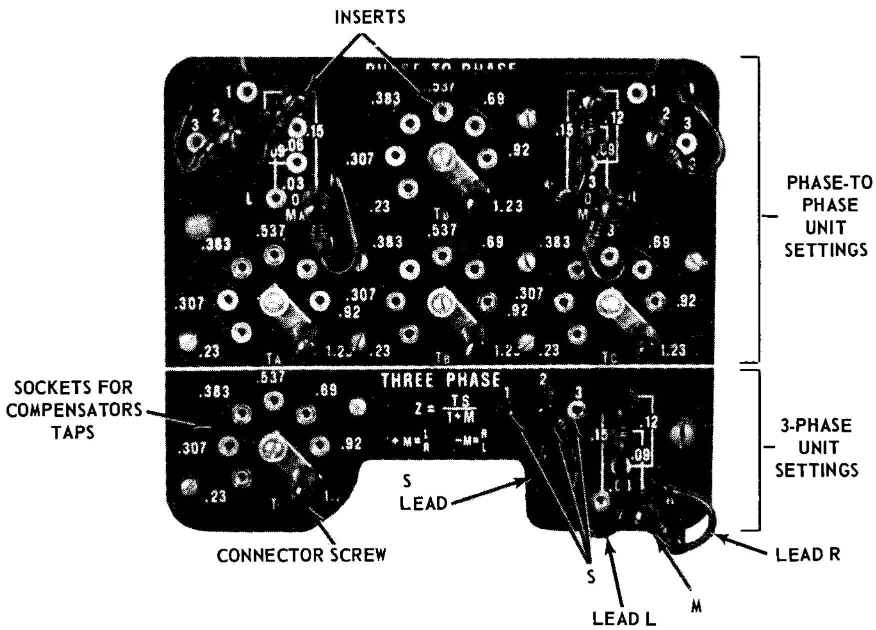


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3ϕ) & Z (ϕϕ). The phase-to-phase unit Z (ϕϕ) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3ϕ) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

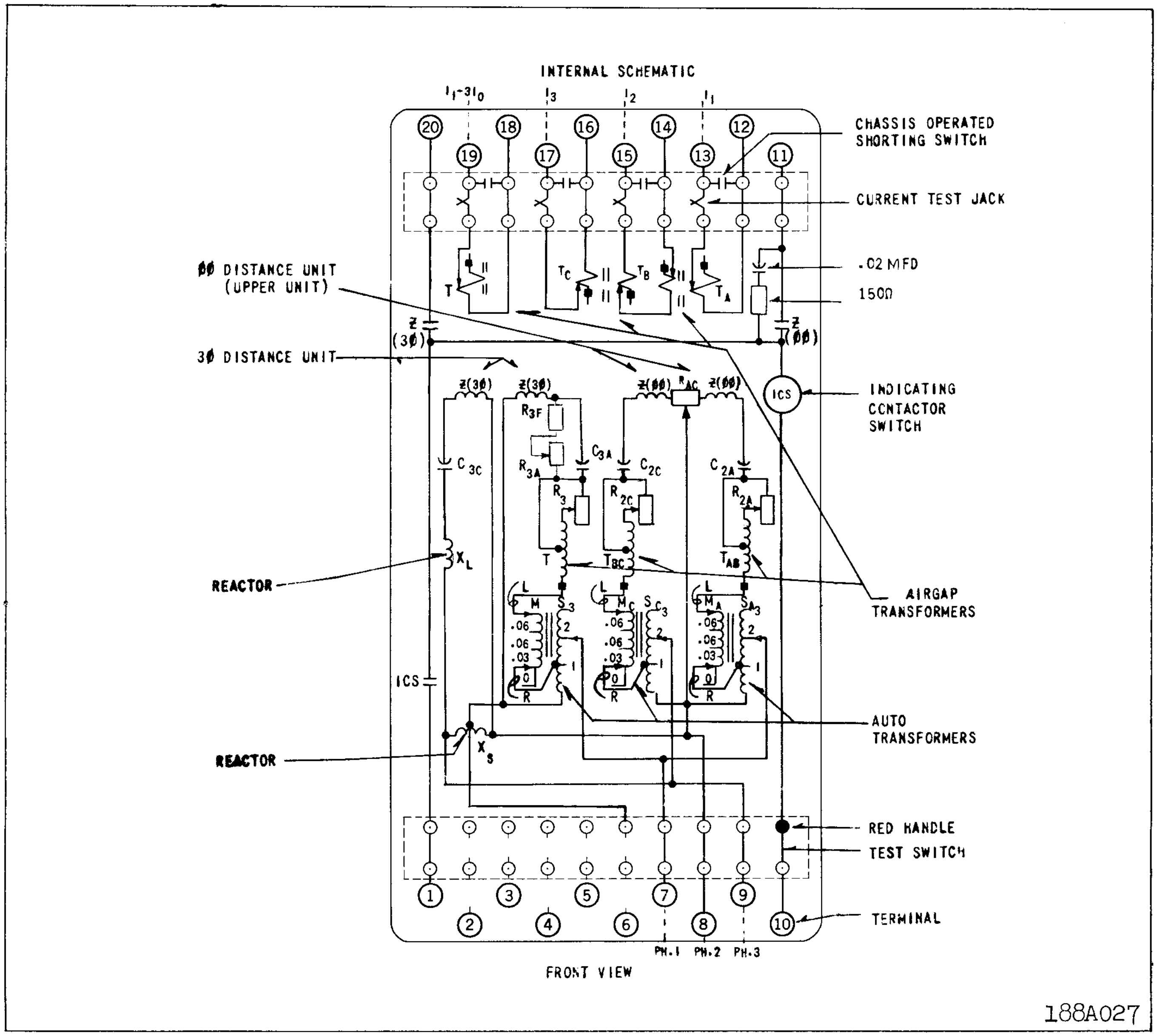


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

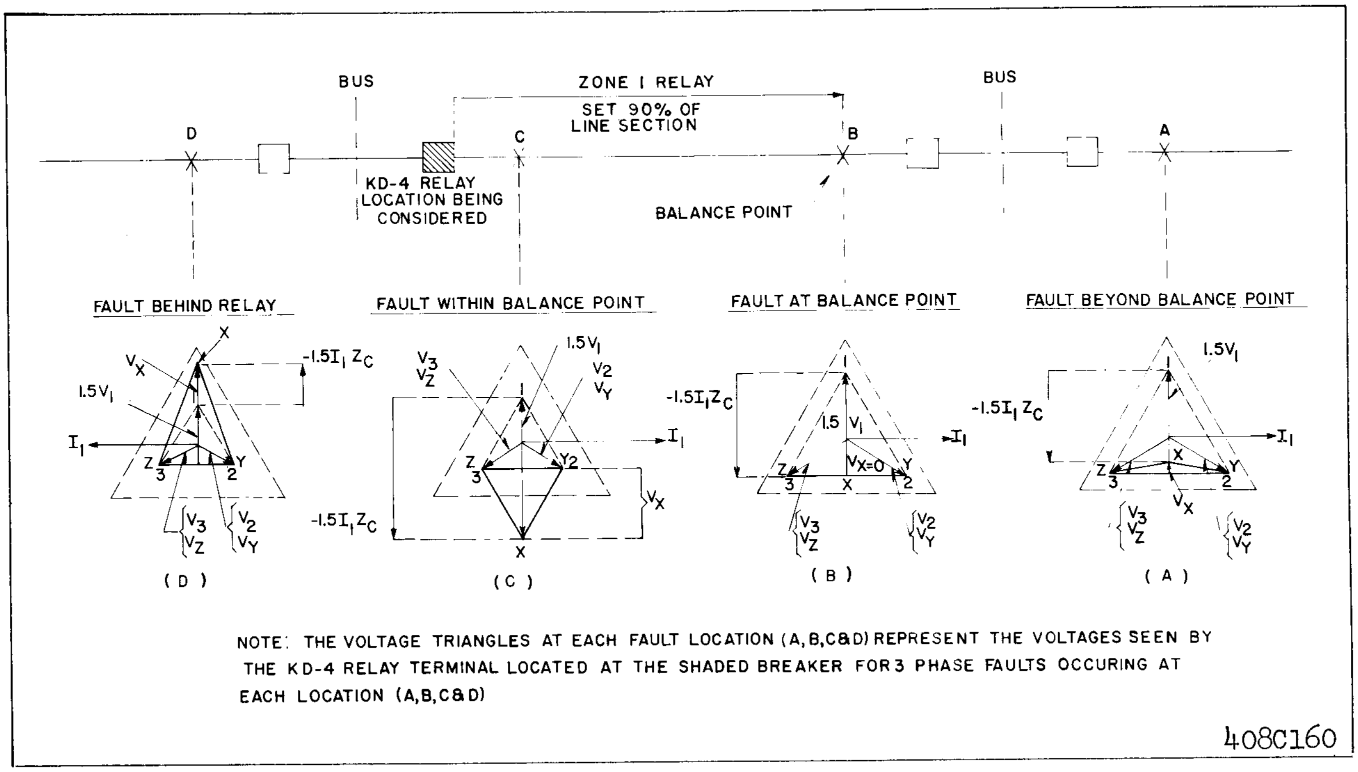


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

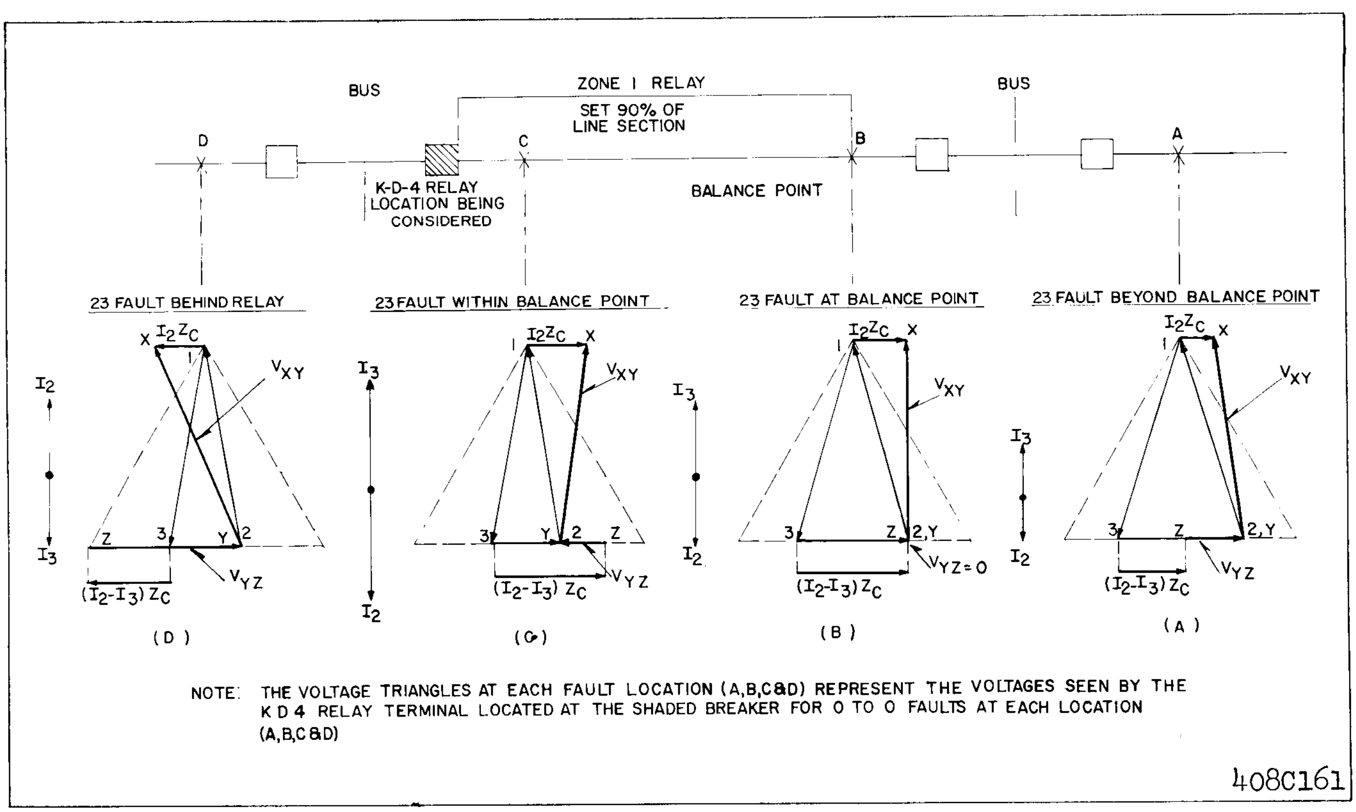


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

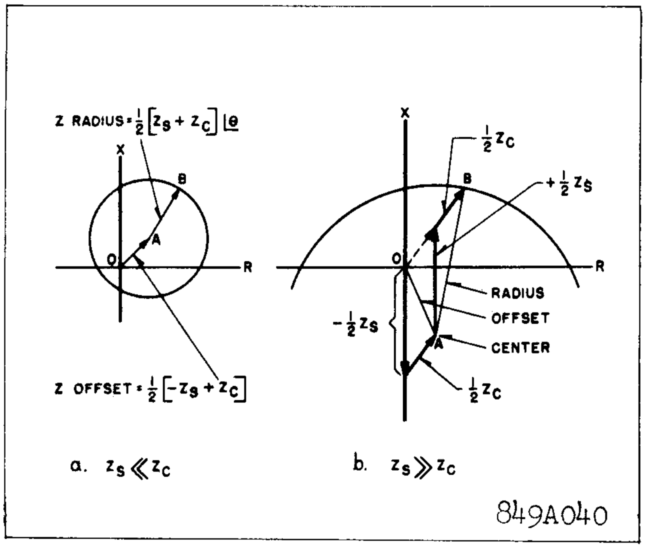


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

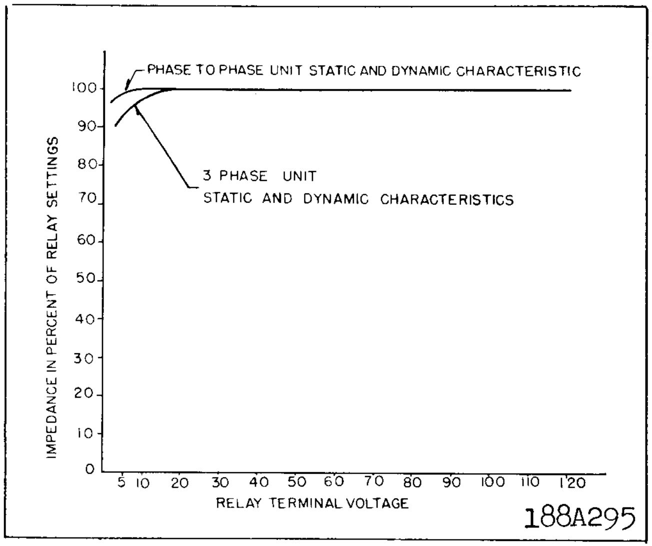


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1 Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1 Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5 I_1 Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5 I Z_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $- 1.5\ I Z_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3) Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

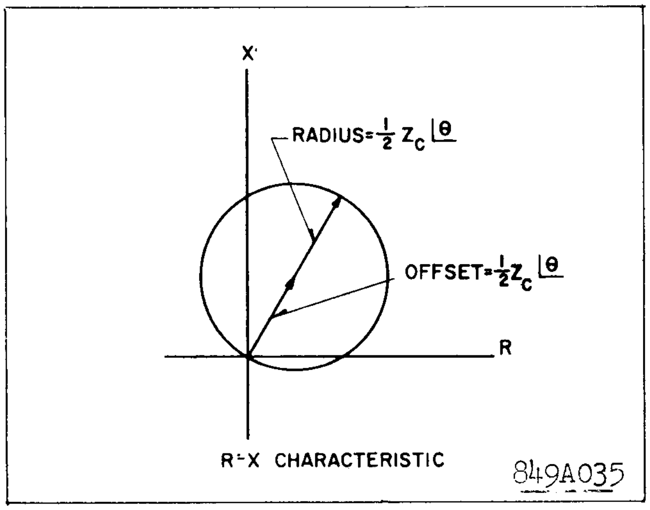


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

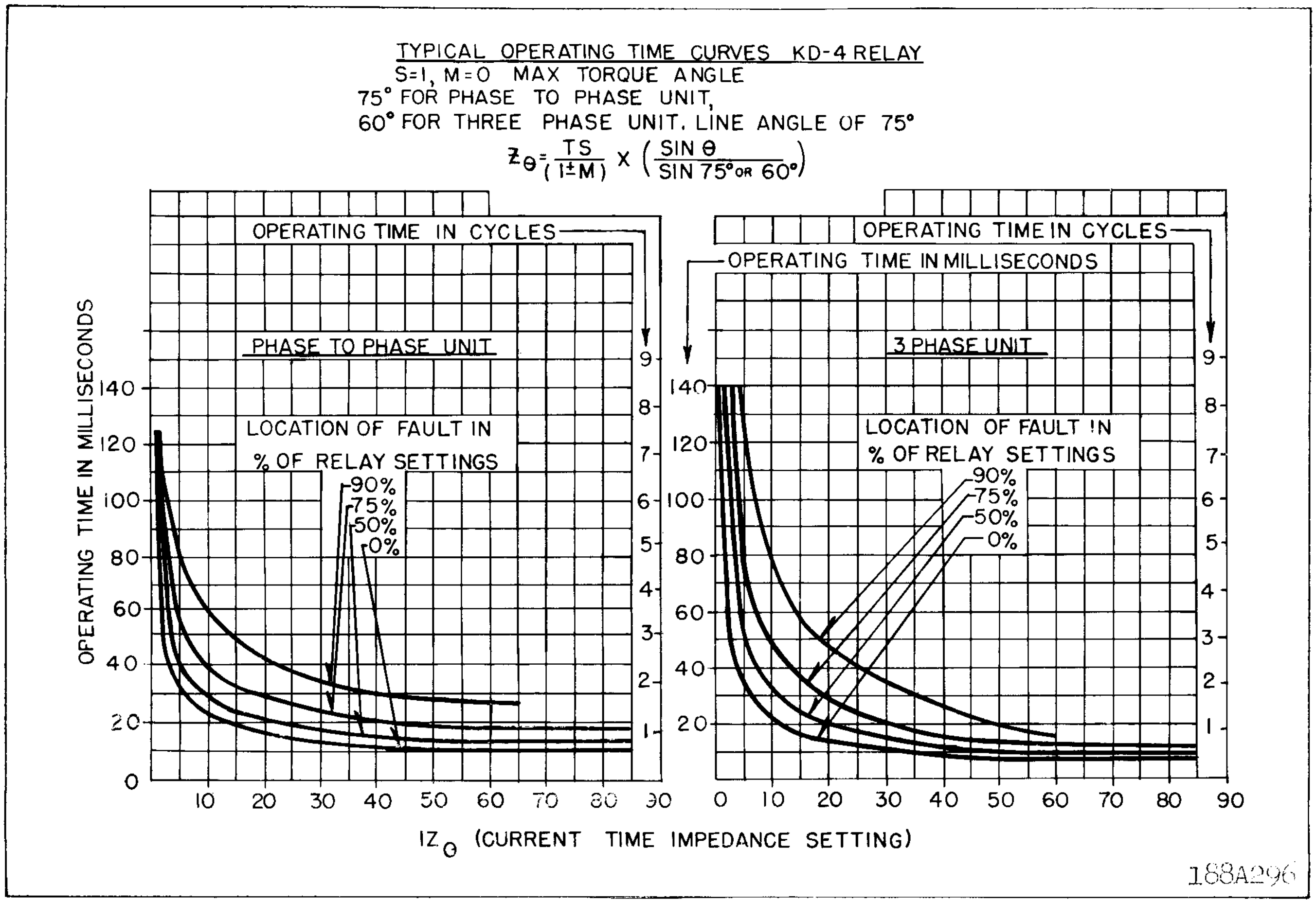


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

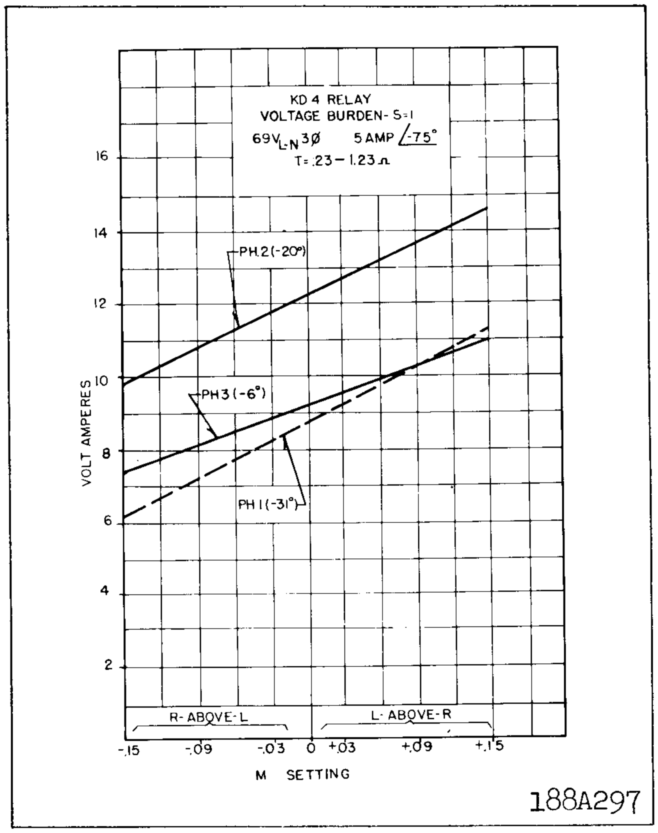
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

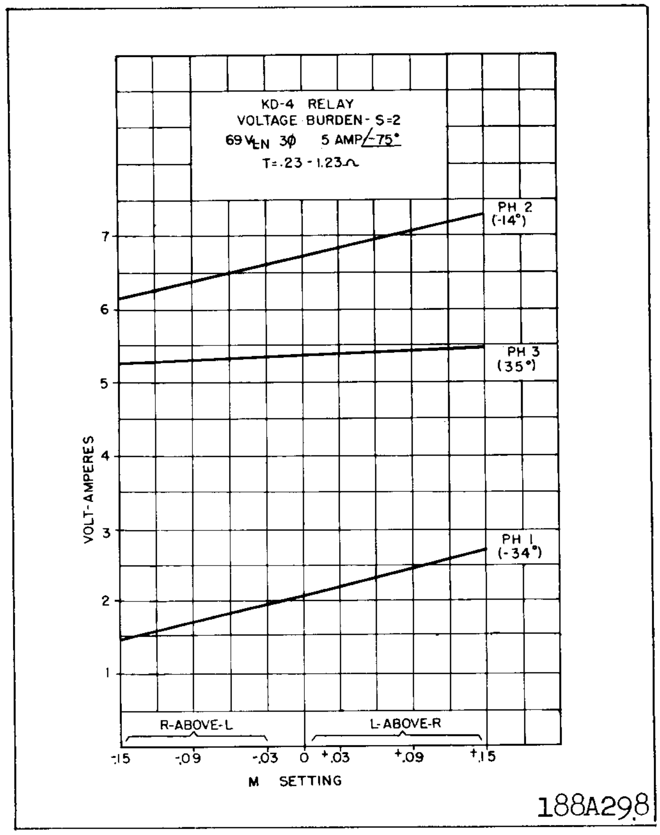
Distance Characteristic - 3 Phase Unit

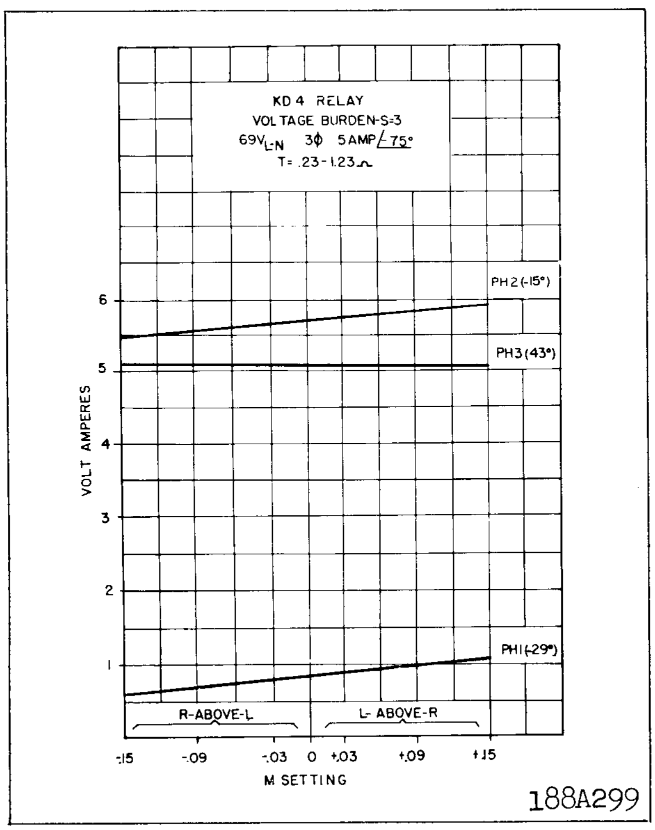
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT 69V_{L-N}, S=1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1			PHASE 2			PHASE 3		
	VA	VARS	WATTS	VA	VARS	WATTS	VA	VARS	WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \quad \text{amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin \theta}{(1 \pm M) \sin \alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

(T, T_A, T_B, and T_C)						
.23	.307	.383	.537	.690	.920	1.23

(S, S_A, S_C)		
1	2	3

	(M, M_A, M_C)		
±Values between taps	.03	.06	.06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating: 0.1 ohms d-c. resistance
0.2/2.0 ampere rating: 0.2 tap – 6.5 ohms
2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_c = current transformer ratio

R_v = potential transformer ratio

T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z—setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ
   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ has been recalibrated to an angle different from the * 75° setting, multiply the Z θ – value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.
2. Now refer to the Table I.
   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.
   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).
   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.
   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. If relay has been recalibrated to a maximum torque angle of 60° from standard setting of 75° the relay setting, Z should be:

$$Z = 1.7 \times \frac{\sin 75°}{\sin 60°} = 1.89 \text{ ohms.}$$

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

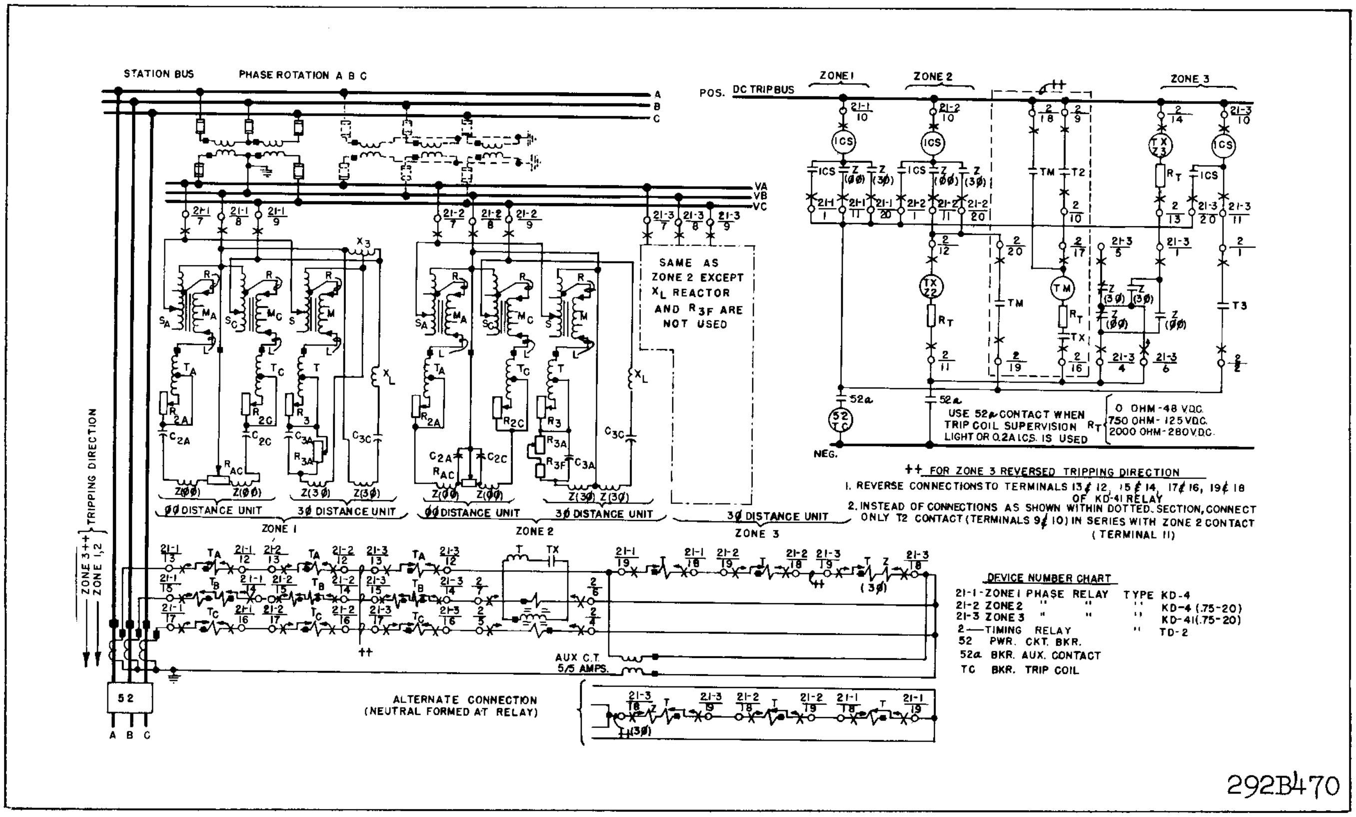


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.

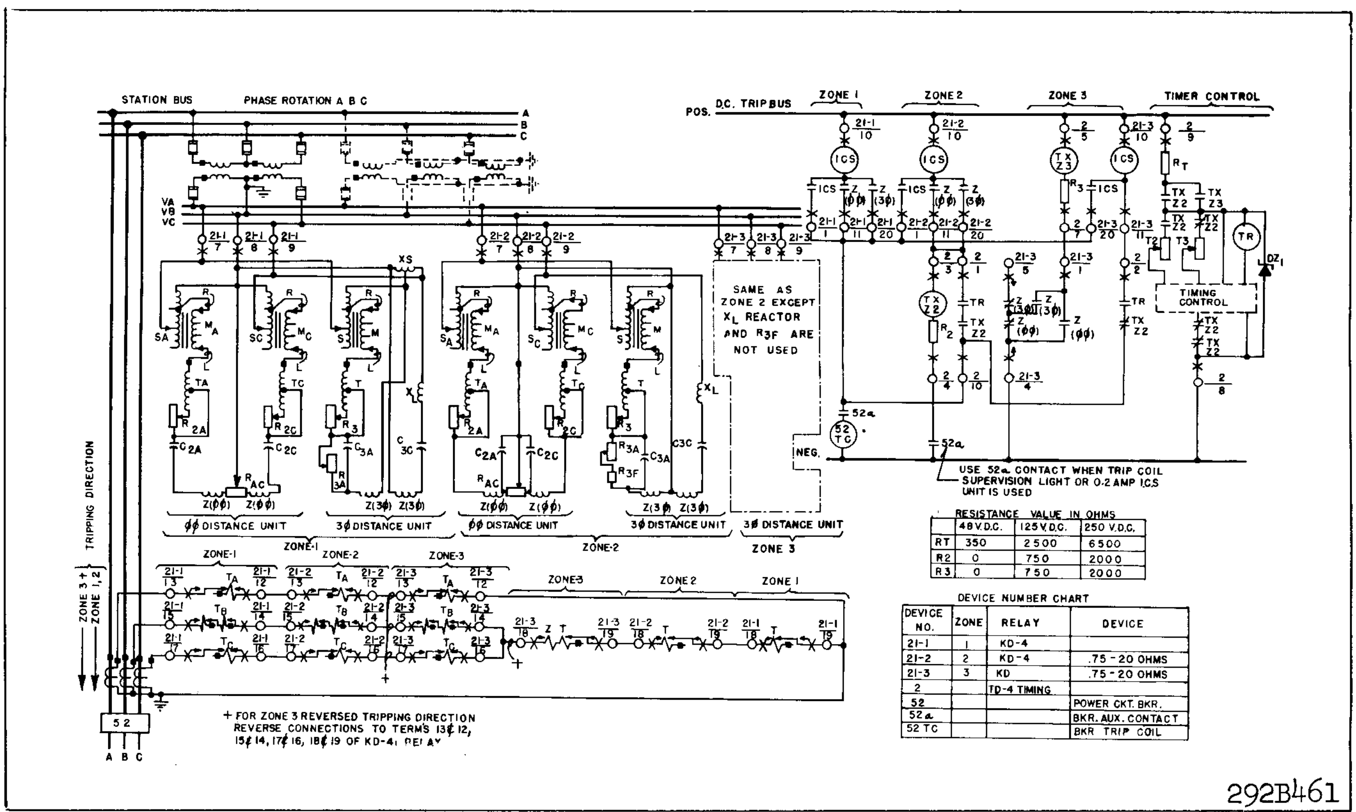


Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2
T = .920
M = −.03

and "R" lead should be connected over "L"- lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. If relay has been recalibrated to 45° from standard factory setting of 60° then the relay setting should be:

$$Z = Z\theta . \frac{\text{Sin } 60°}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off
S = 2
T = .920
M = −.12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from −.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 – 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	.690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.267	.333	.467	.600	.800	1.070	–	1.60	2.14	–	3.21	+.15		Upper .06	0	"L" OVER "R"
	.205	.274	.342	.480	.616	.821	1.098	–	1.64	2.20	–	3.29	+-12		Upper .06	.03	
	.211	.282	.351	.493	.633	.844	1.128	–	1.69	2.26	–	3.38	+.09		Lower .06	0	
	.217	.290	.361	.507	.651	.868	1.160	–	1.74	2.32	–	3.48	+.06		Upper .06	Lower .06	
	.223	.298	.372	.521	.670	.893	1.194	–	1.78	2.39	–	3.58	+.03		.03	0	
	.230	.307	.383	.537	.690	.920	1.230	–	1.84	2.46	–	3.69	0	- 0	0	0	
	.237	.317	.395	.554	.711	.948	1.268	–	1.90	2.54	–	3.80		-.03	0	.03	"R" OVER "L"
	.245	.327	.407	.571	.734	.979	1.308	1.47	1.96	2.62	–	3.93		-.06	Lower .06	Upper .06	
	.253	–	.421	.590	.758	1.011	1.352	1.52	2.02	2.70	3.03	4.05		-.09	0	Lower .06	
	.261	–	.435	–	.784	1.046	1.398	1.57	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	
	.271	–	.451	–	–	–	1.447	–	–	2.89	–	4.34		-.15	0	Upper .06	

The tap plate values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit.

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

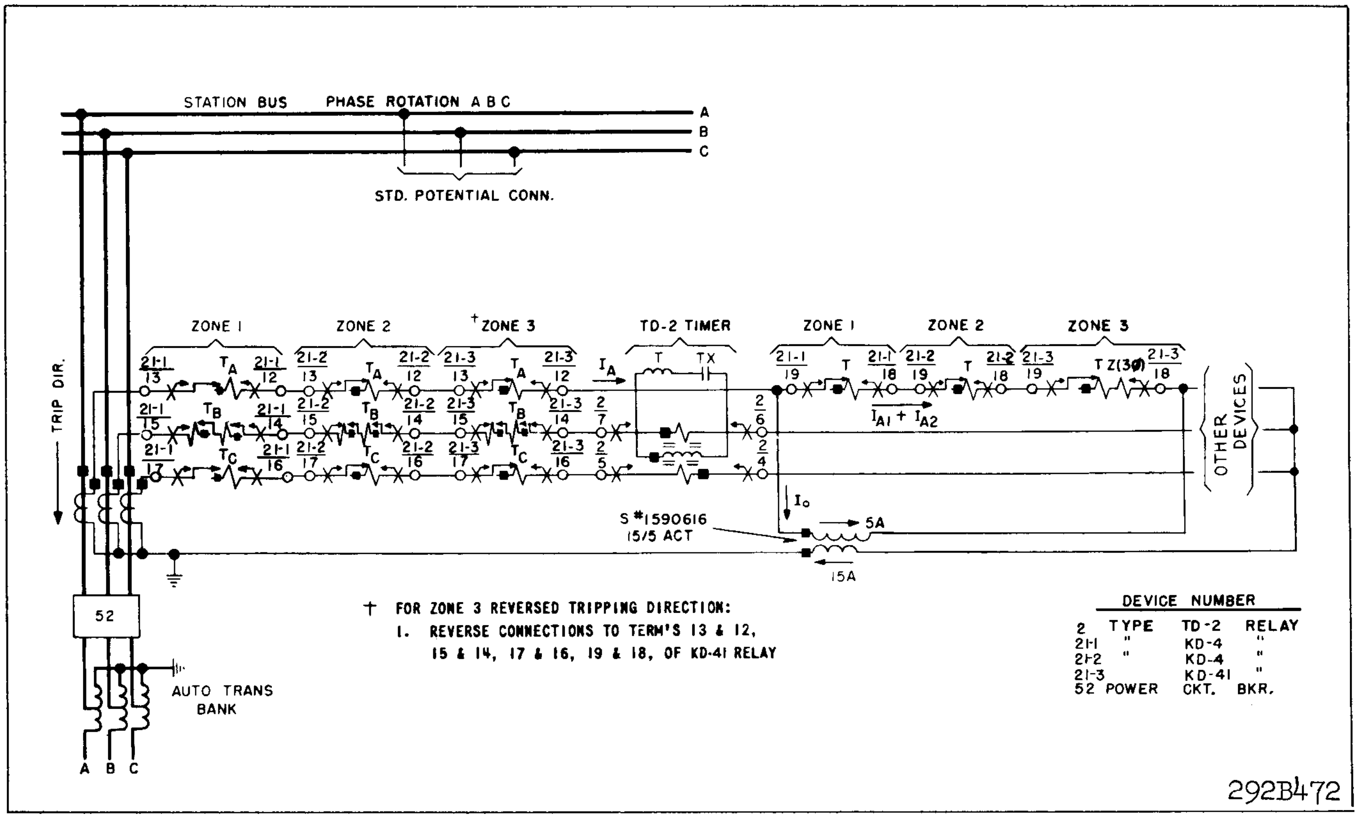


Fig. 14 **A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.**

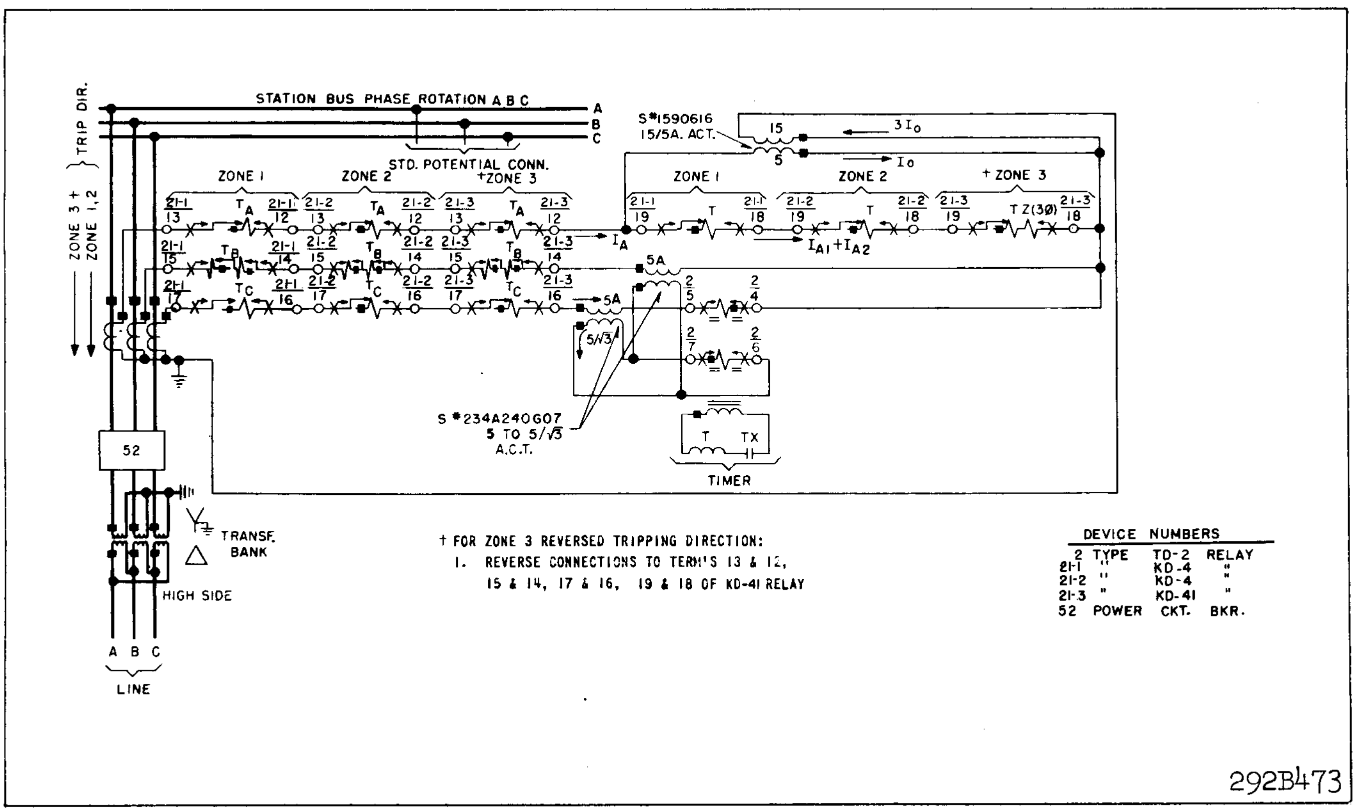


Fig. 15 **A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.**

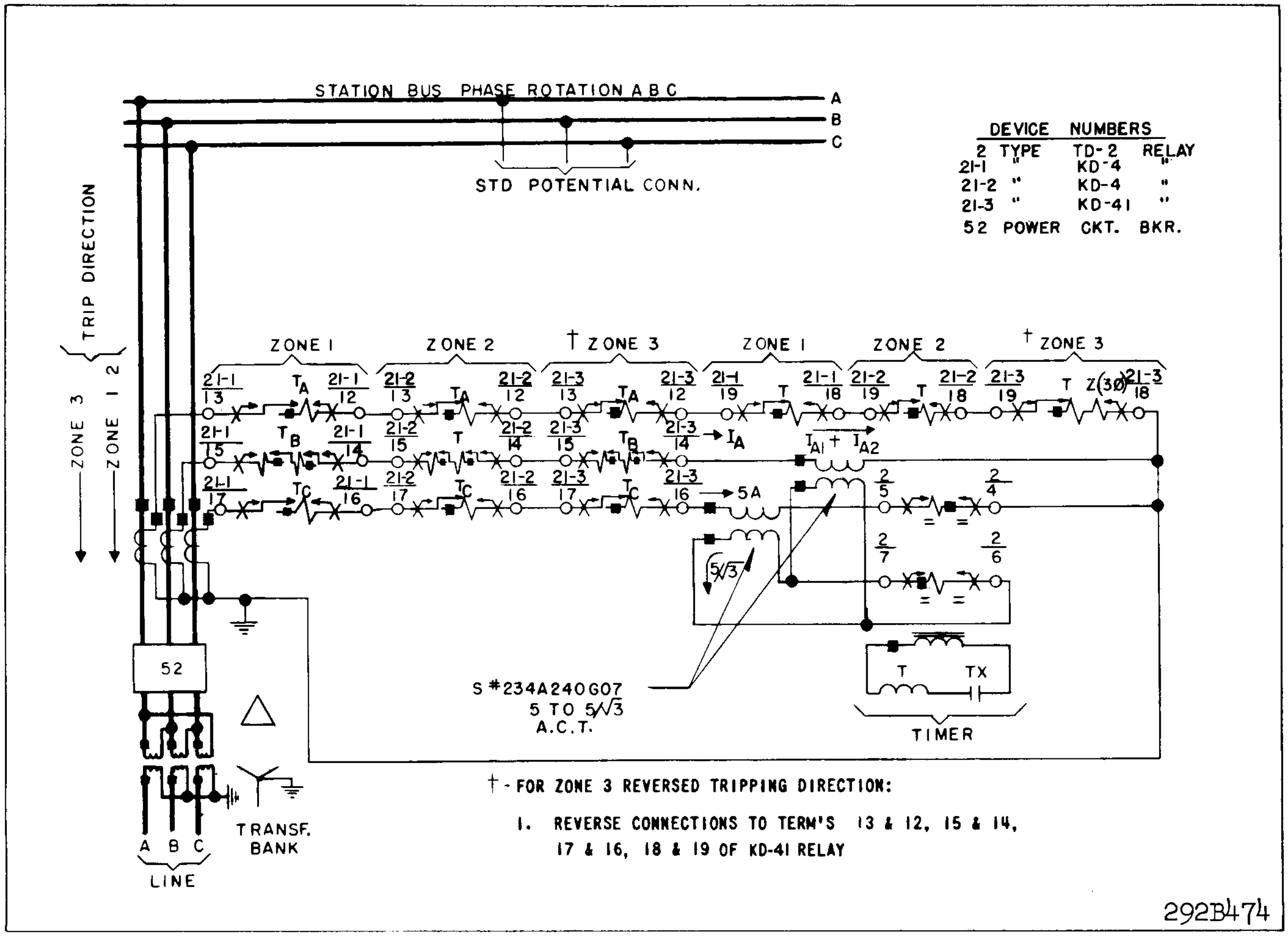


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

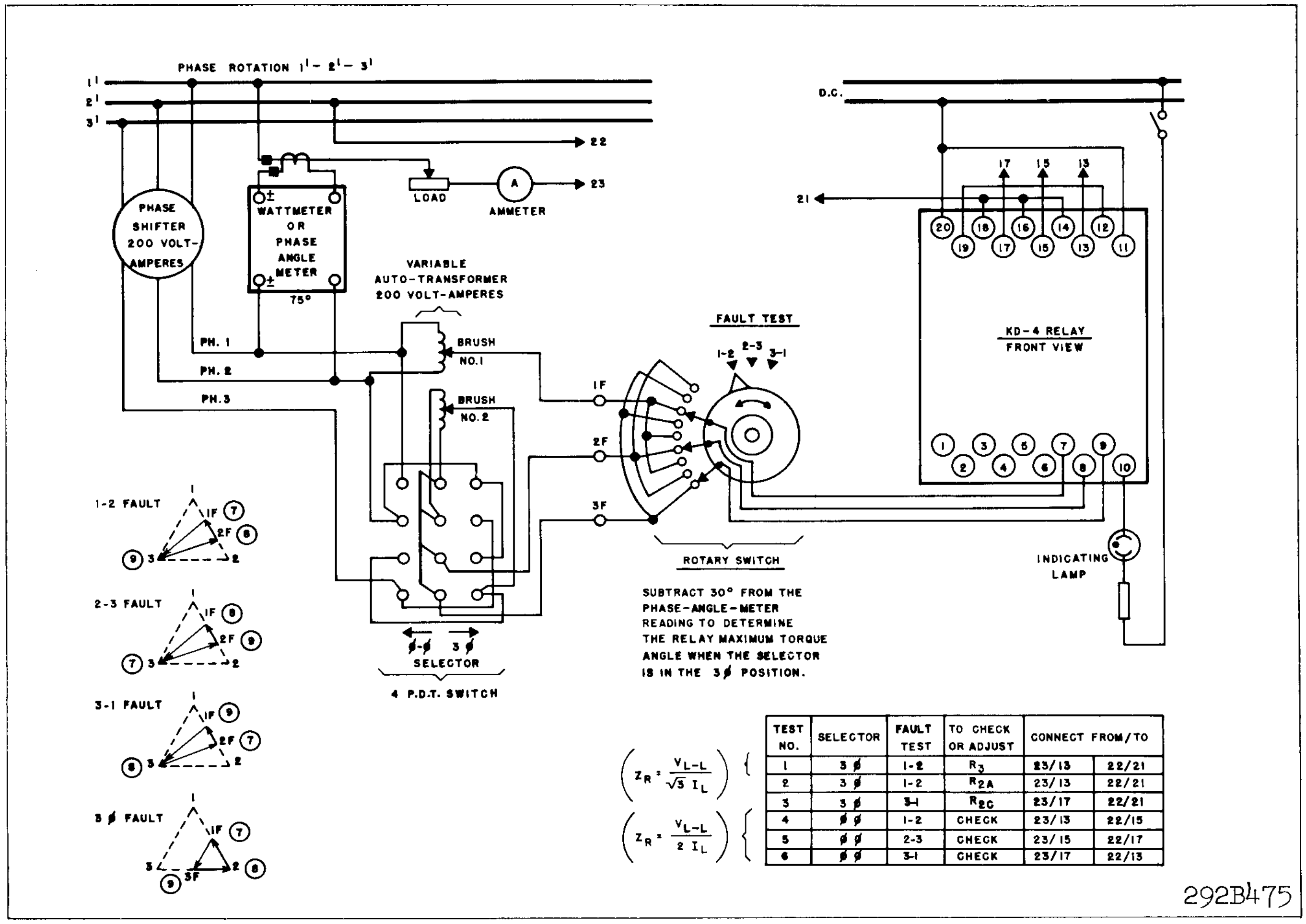
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



Tests 1–3: $\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}\right)$

Tests 4–6: $\left(Z_R = \frac{V_{L-L}}{2\, I_L}\right)$

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3ϕ	1-2	R_3	23/13	22/21
2	3ϕ	1-2	R_{2A}	23/13	22/21
3	3ϕ	3-1	R_{2C}	23/17	22/21
4	ϕϕ	1-2	CHECK	23/13	22/15
5	ϕϕ	2-3	CHECK	23/15	22/17
6	ϕϕ	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.
2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.9 and 16.6 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.)

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase to phase (top) unit should be between 13.7 and 14.4 amperes at an angle of 75° current lag.

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L-L}}{\sqrt{3}\,I_L}$ where V_{L-L} is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L-L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Initial Spring Setting

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

Shaft Clearance

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating, spring set as per Initial Spring Setting.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° - for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 - .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 - 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\sin 60^\circ}{\sin \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60^\circ}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor. Spring set as per Initial Spring Setting.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

B. Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.

2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.

3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees.

   This angle should be 73–77 degrees.
   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.

5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \ (\sin 75^\circ)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed $\theta = 90^\circ$).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
"L" of M_A	R_{2A}	$V_C = IT\ (\frac{\sin\theta}{\sin 75^\circ})$ = 50.9 volts ($\theta = 90^\circ$)
"L" of M_C	R_{2C}	

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.
Set all T = 1.23, all S = 1, all M = 0.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{\sqrt{3}I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	—	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L-L}}{2\ I_L}$ where V_{L-L} is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08 *
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

*If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

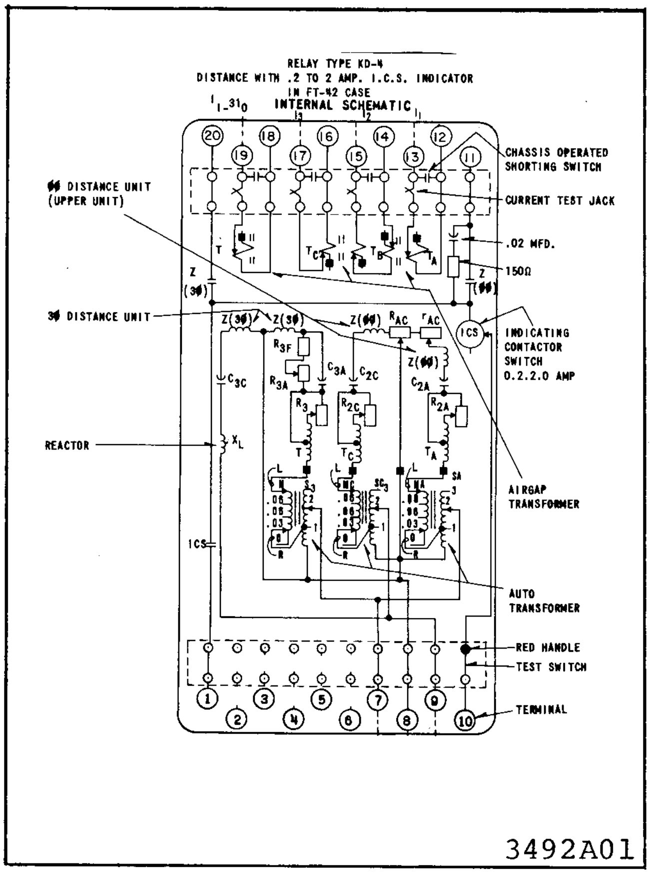
RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3ϕ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3ϕ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	Combination of 2 resistors. Total Resistance 2500 ohms (One Resistor is fixed, one adjustable).
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (ϕ-ϕ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M



* *Fig. 18 Relay Type KD-4 Distance with .2 to 2 Amp. I.C.S. Indicator*

* APPENDIX

KD-4 RELAY (.2 – 4.35 OHMS)

Operation

Three Phase Unit, operates as three phase unit per I.L. 41-491.4 (.75 – 20 ohms).

Repair Calibration

Autotransformer Check for "S" – taps should be done with reference to terminal "8" not "6". "M" – tap voltages should be checked with reference to terminal "8" not "6", using 100 volts instead of 115.

Core and R_{3A} Resistor Adjustment

Omit complete procedure and calibrate as follows:

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance. Restraint Spring Set as per Initial Spring Setting.

The relay should be preheated for at least one hour in the case with closed cover to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm floats or restrains very slightly.

B. Connect relay terminals 7 and 8 together and apply rated a-c voltage between 7 and 9 and adjust core until the contact arm just floats or restrains very slightly. If this is not possible rotate core 90° and adjust. Recheck part A to see if contact is floating or restraining. If not, repeat parts A and B.

C. Connect relay for Test #7. Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by 60°. Make sure that applied voltage is of correct phase sequence. Adjust R_{3A} resistor so that 3ϕ unit trips at 3.8 amps.

D. For KD-4 only.

The adjustable core is checked to prevent contact closing on current-only. (The KD-41 relay is purposely biased to produce current-only contact-closing torque and will open its right hand contact at a current value of 5 amperes or less when T = 1.23.

Check it as follows:

1. Short circuit relay terminals 7, 8 and 9 together.
2. Pass 5 amperes in the current circuit in terminal 18 out terminal 19 and increase the current to 30 amperes in convenient steps.
3. Relay contacts should stay open. If contacts close turn core further 90 degrees and repeat parts A, B and C.

Final Core and R_{AC} – Adjustment

As per I.L.41-491.L, except start R_{AC} adjustment with r_{AC}:(2½ inch resistor behind the tap plate above R_{2A} resistor), set it approximately in the center. Use this resistor to get final fine adjustment.

Internal Schematic, as per name plate information.

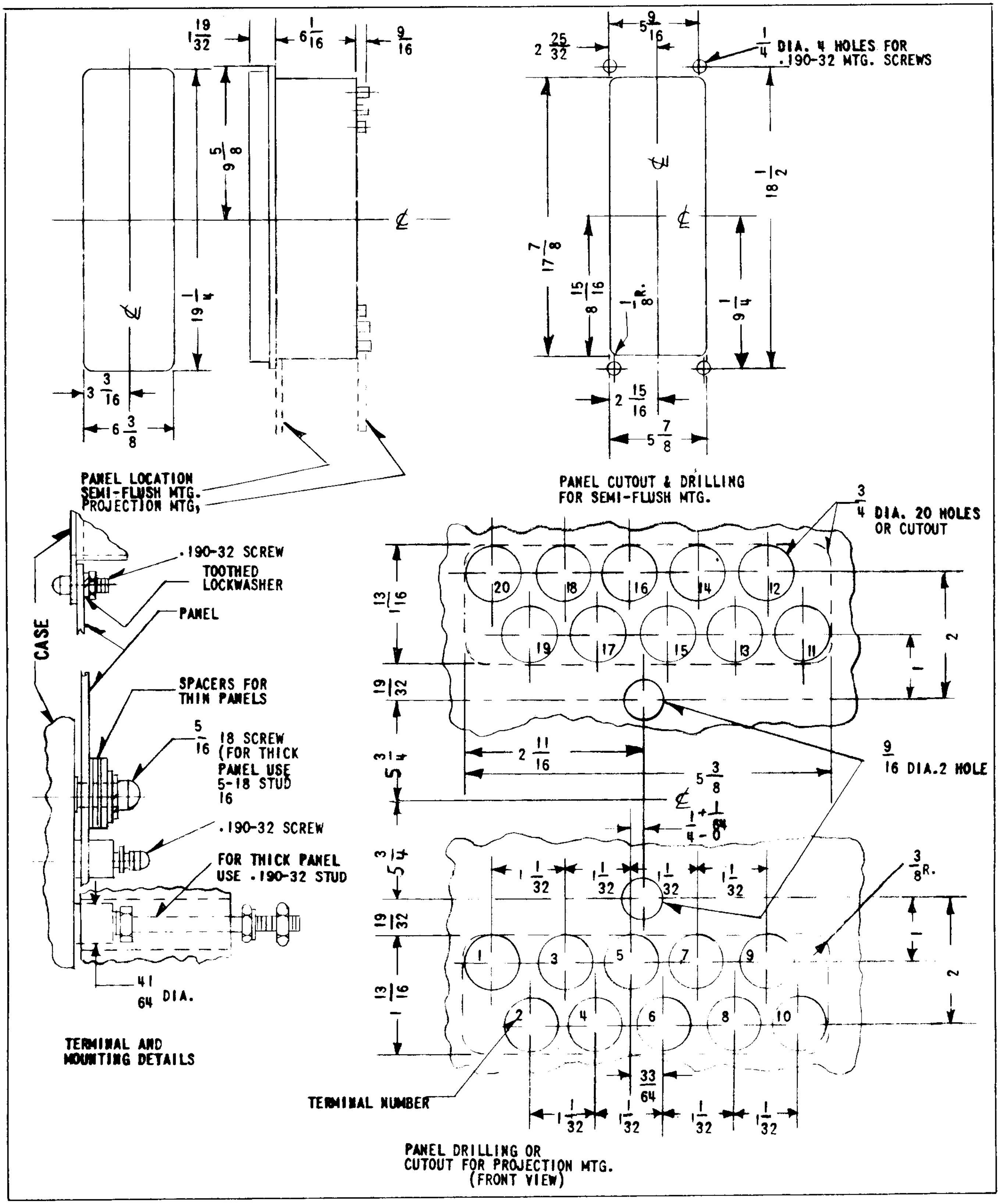


Fig. 19 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE KD-4 COMPENSATOR DISTANCE RELAY

(FOR RELAYS WITH SUB "A" IN STYLE NUMBER SEE APPENDIX)

CAUTION: Before putting protective relays into service make sure that all moving parts operate freely, inspect the contacts to see that they are clean and operate the relay to check the settings and electrical connections.

APPLICATION

The type KD-4 relay (Figure 1) is a polyphase compensator type relay which provides a single zone of phase protection for all three phases. It provides * essentially instantaneous tripping for phase-to-phase faults, two-phase-to-ground faults, and three-phase faults within the reach setting and sensitivity level of the relay.

The KD-4 relay is available with indicating contactor switches with either a 1 ampere or a 0.2/2.0 ampere rating. The 1 ampere rating is recommended for all directional comparison applications and for most distance relaying applications. The 0.2/2.0 ampere rating is recommended for distance relaying where a lockout relay is energized or where a high impedance auxiliary tripping relay is utilized.

Refer to I.L. 41-911 for a description of how KD-4 relays are used in directional comparison blocking systems.

For time-distance applications the KD-4 relay is used with either the TD-2 a-c current-operated timer, or with the TD-4 or TD-5 d-c transistorized timer.. See Figs. 12 and 13 for the external schematics for 3 zone protection, using the TD-2 and TD-4 relays, respectively. For further discussion see "External Connections."

Use fault detectors to supervise the trip circuit for those applications where the relays can be de-energized without attendant opening of the 52a contact. Otherwise undesired tripping occurs. A S#1878395 three unit SC Relay (2-8 amperes) in the type FT32 case or a S#288B714A18 three unit ITH Relay (4-8 amperes) in the type FT11 case is recommended.

CONSTRUCTION

The type KD-4 relay consists of three single air gap transformers (compensators), three tapped auto-transformers, two cylinder type operating units, and an ICS indicating contactor switch.

Compensator

The compensators which are designated T_{AB} and T_{BC} are three-winding air-gap transformers (Fig. 2). There are two primary current windings each current winding has seven taps which terminate at the tap block. (Fig.3). They are marked 0.23, 0.307, 0.383, 0.537, 0.690, 0.920 and 1.23. Current flowing through the primary coil provides an MMF which produces magnetic lines of flux in the core. Compensator designated T, has only one primary winding.

A voltage is induced in the secondary which is proportional to the primary tap and current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between primary current and the induced secondary voltage. The phase angle may be set for any value between 45° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum torque angle of 75° current

SUPERSEDES I.L. 41-498.11L, dated February 1974
* Denotes change from superseded issue.

EFFECTIVE JANUARY 1976

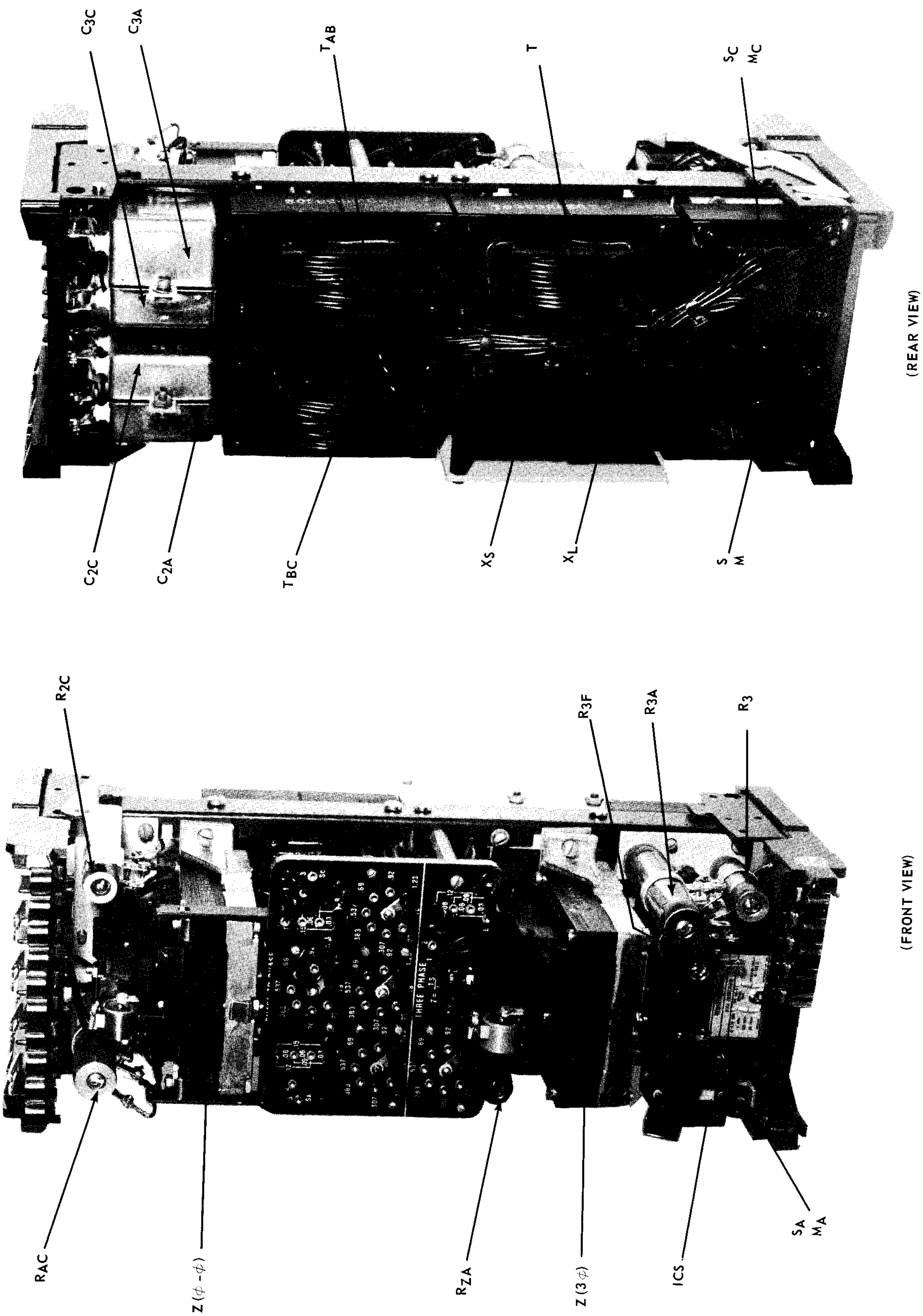


Fig. 1 Type KD-4 Relay Without case

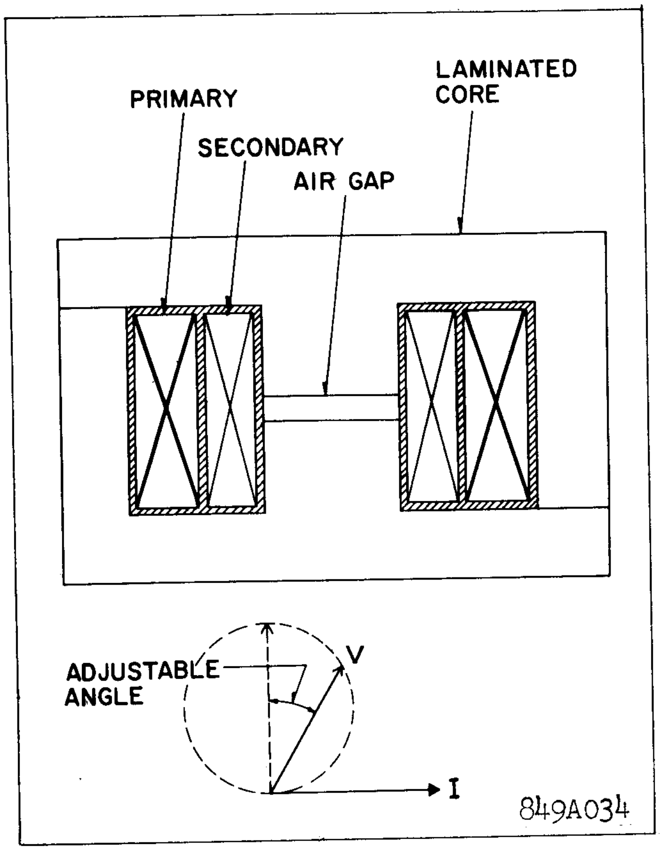


Fig. 2 Compensator Construction

lagging voltage for phase-to-phase unit and 60° for three phase unit.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -15 to +15 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0, .03, .06, and .06.

The auto-transformer makes it possible to expand the basic range (T = .23 to 1.23 ohms) by a multiplier of $\frac{S}{1 \pm M}$. Therefore, any relay ohm setting can be made within ± 1.5 percent from 0.2 ohms to 4.35 ohms by combining the compensator taps T, T_{AB}, and T_{BC} with the auto-transformer taps S and M, S_A and M_A, and S_C and M_C

Tripping Unit

The device which acts to initiate tripping is a four-pole cylinder unit which is connected open delta and operates as a three-phase induction motor. Contact-closing torque is produced by the unit when the voltage applied to its terminals has a negative-phase sequence. Closing torque for the relay forces the moving contact to the left hand side as viewed from the front of the relay. Contact-opening torque is produced when positive-phase sequence voltages are applied. Hence, the cylinder unit has restraint or operating torque as determined by the phase sequence of the voltages applied to its terminals.

Mechanically, the cylinder unit is composed of three basic components: a die-cast aluminum frame and electromagnet, a moving element assembly, and a molded bridge.

The frame serves as the mounting structure for the magnetic core. The magnetic core which houses the lower pin bearing is secured to the frame by a spring and snap ring. This is an adjustable core which has a .020 inch flat on one side and is held in its adjusted position by the clamping action of two compressed springs. The bearing can be replaced, if necessary, without having to remove the magnetic core from the frame.

The electromagnet has two series-connected coils mounted diametrically opposite one another to excite each set of poles. Locating pins on the electromagnet are used to accurately position the lower pin bearing, which is mounted on the frame, with respect to the upper pin bearing, which is threaded into the bridge. The electromagnet is permanently secured to the frame and can not be separated from the frame.

The moving element assembly consists of a spiral spring, contact carrying member, and an aluminum cylinder assembled to a molded hub which holds the shaft. The hub to which the moving-contact arm is clamped has a wedge-and-cam construction, to provide low-bounce contact action. A casual inspection of the assembly might lead one to think that the contact arm bracket does not clamp on the hub as tightly as it should. However, this adjustment is accurately made at the factory and is locked in place with a lock nut and should not be changed.

Optimum contact action is obtained when a force

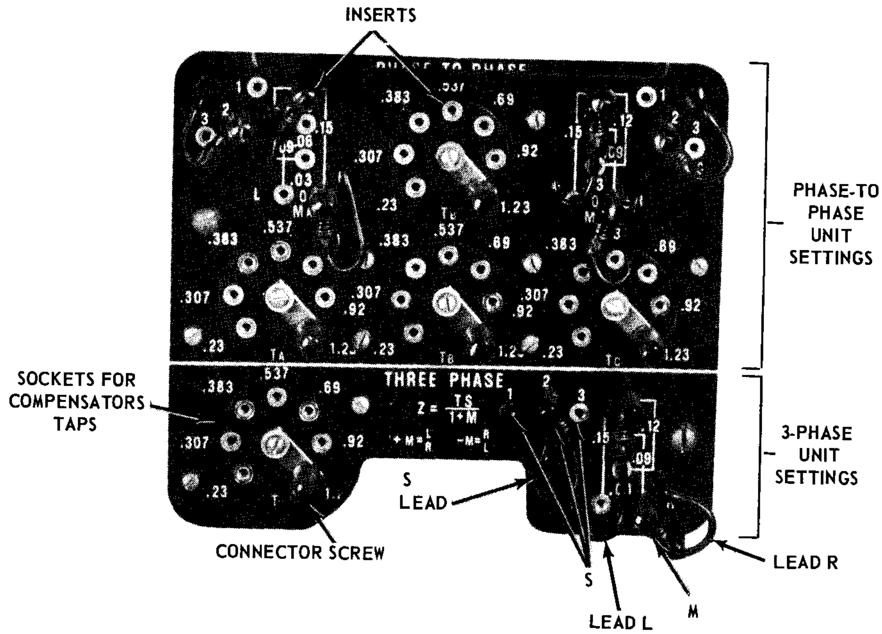


Fig. 3 Tap Plate

of 7 to 9 grams pressure applied to the face of the moving contact will make the arm slip one-fourth of its total free travel. Free travel is the angle through which the hub will slip from the condition of reset to the point where the clamp projection begins to ride up on the wedge. The free travel can vary between 15° to 20°.

The shaft has removable top and bottom jewel bearing. The shaft rides between the bottom pin bearing and the upper pin bearing which is adjusted to .025 inch from the top of the shaft bearing. The cylinder rotates in an air gap formed by the electromagnet and the magnetic core.

The bridge is secured to the electromagnet and the frame by two mounting screws. In addition to holding the upper pin bearing, the bridge is used for mounting the adjustable stationary contact housing. This stationary contact has .002 to .006 inch follow which is set at the factory by means of the adjusting screw. After the adjustment is made the screw is sealed in position with a material which flows around the threads and then solidifies. The stationary contact housing is held in position by a spring type clamp. The spring adjuster is located on the underside of the bridge and is attached to the moving contact arm by a spiral spring. The spring adjuster is also held in place by a spring type clamp.

When the contacts close, the electrical connection is made through the stationary contact housing clamp, to the moving contact, through the spiral spring and out to the spring adjuster clamp.

Indicating Contactor Switch Unit (ICS)

The indicating contactor switch is a small d-c operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop. The target is reset from outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pickup value of the switch.

OPERATION

The KD-4 relay has two major components-compensators and tripping units. In the internal schematic of Fig. 4 the compensators are designated T, T_{AB}, and T_{BC}, the tripping units, Z (3ø) & Z (øø). The phase-to-phase unit Z (øø) operates for all combinations of phase-to-phase faults (phase 1-2, 2-3 & 3-1). The 3 phase unit Z (3ø) operates for 3 phase faults and for close-in-two-phase-to-ground faults, although most two-phase-to-ground faults are cleared by operation of the phase-to-phase unit. Each of the tripping units and its associated compensator circuit are electrically separate, and will now be considered

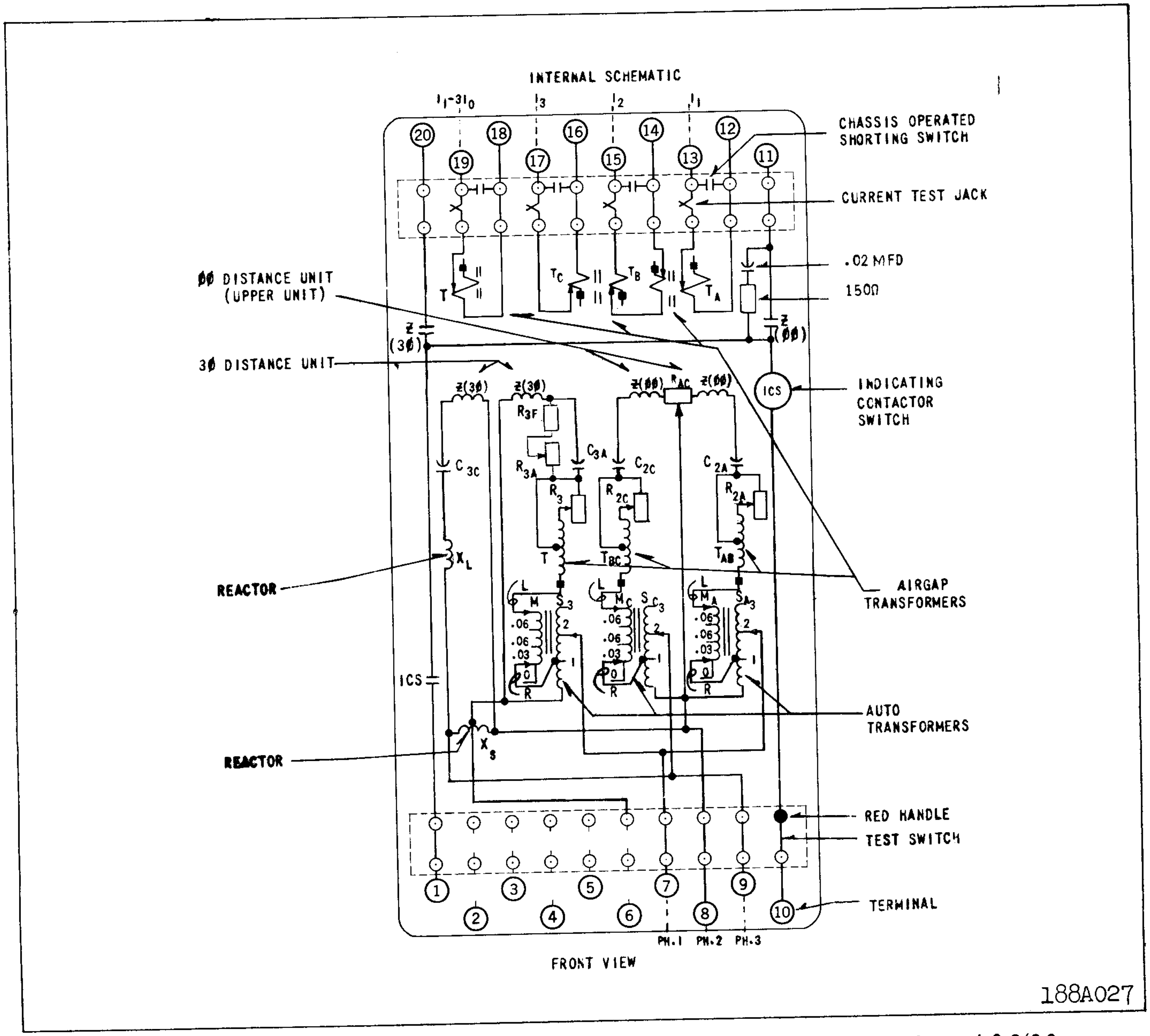


Fig. 4 Internal Schematic of Type KD-4 Relay with 1.0 ampere I.C.S. in the type FT42 case. (Relay with 0.2/2.0 ampere I.C.S. unit has identical wiring except that the I.C.S. coil is tapped on terminal 10 188A294).

successively.

Three Phase Unit

A single compensator T has its primary energized with ($I_1 - 3I_0$)current in Fig. 12 Current I_1 is the phase 1 current: $3I_0$ is the residual current. There are three compensators shown—one for each of the three zones. One connection uses an auxiliary current transformer to insert the $3I_0$ component. The alternate connection supplies the compensator primaries with ($-I_2 - I_3$). Since $I_1 + I_2 + I_3 = 3I_0$, $(I_1 - 3I_0) = (-I_2 - I_3)$. (Currents I_1, I_2 and I_3 are the phase currents). Accordingly, the alternate connection is equivalent to the first arrangement.

As shown in Fig. 12, The T compensator secondary is connected to modify the 1.5 time phase 1 voltage. With a fault in the trip direction, the induced voltage in the compensator secondary bucks the 1.5 time phase 1 voltage.

Vector diagrams in Fig. 5 illustrate the operation during 3 phase faults at four locations. The system impedance and the compensator angle are assumed to to be at 90° for illustrative purposes only. Prefault

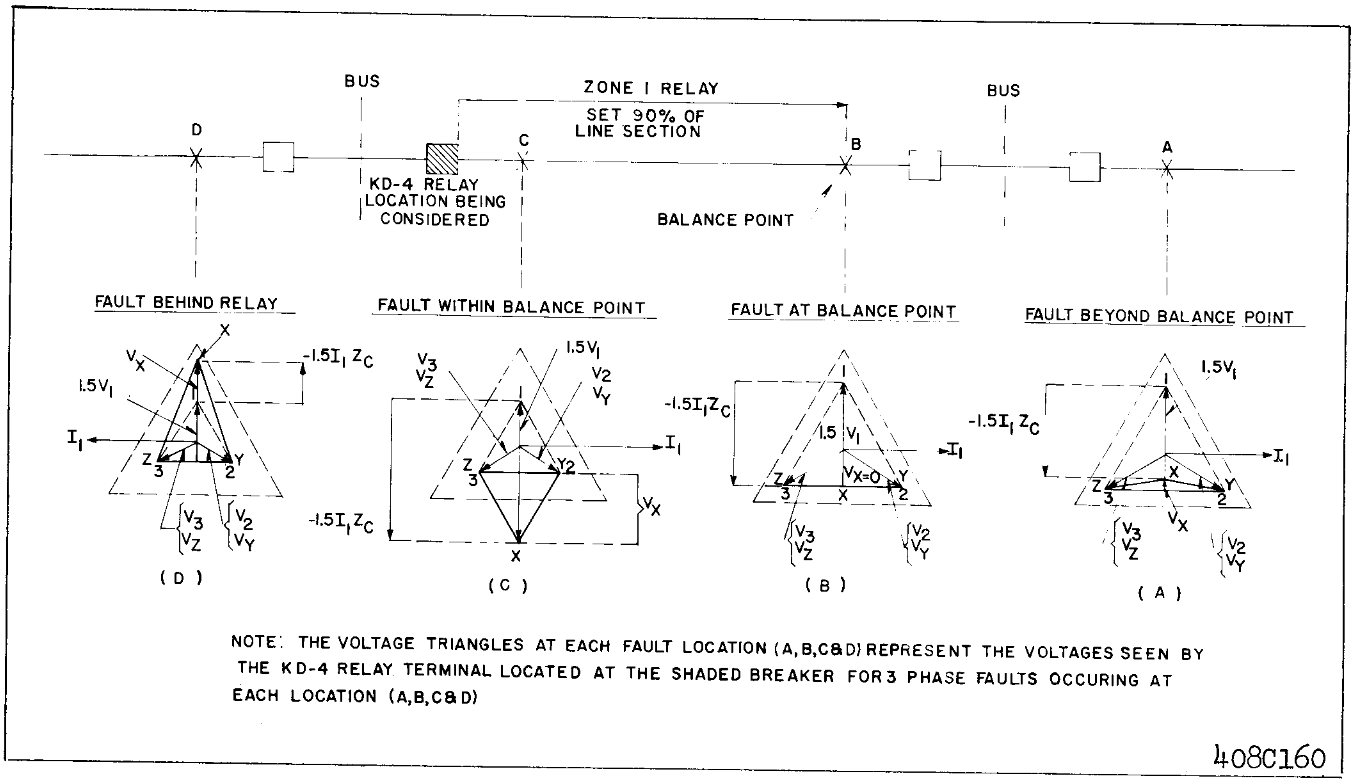


Fig. 5 Voltage and current Conditions for the Three-Phase Unit at the Shaded Breaker for Three-Phase Faults at Various Locations.

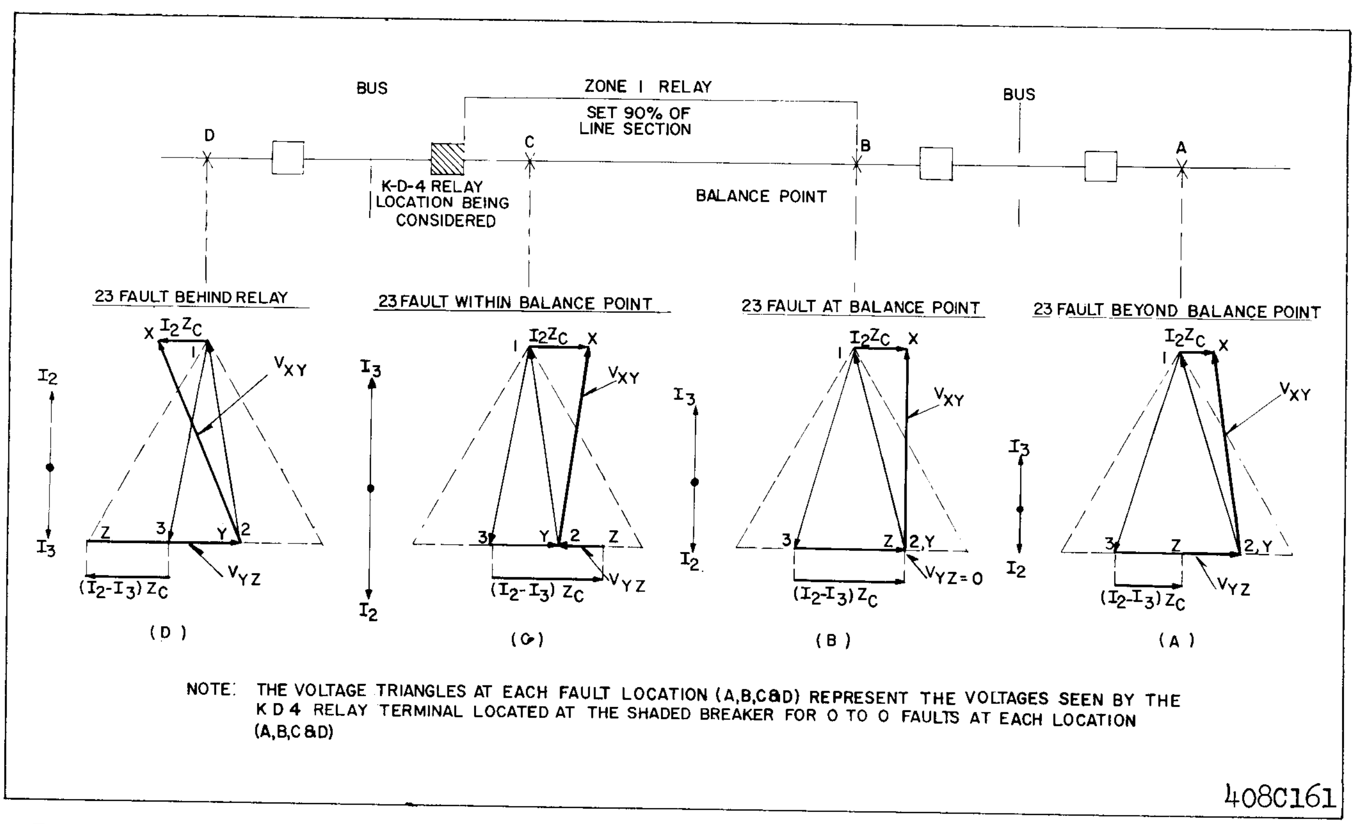


Fig. 6 Voltage and Current Conditions for the Phase-to-Phase Unit at the Shaded Breaker for 23 Faults at various Locations.

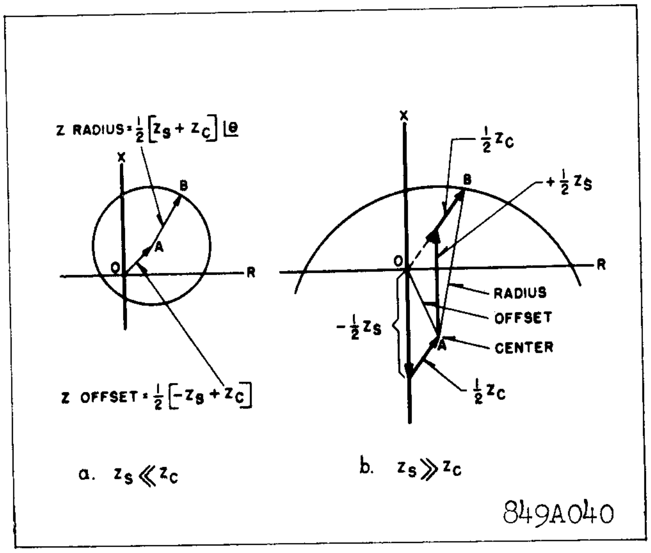


Fig. 7. Impedance Circles for Phase-to-Phase Unit in the Type KD-4 Relay.

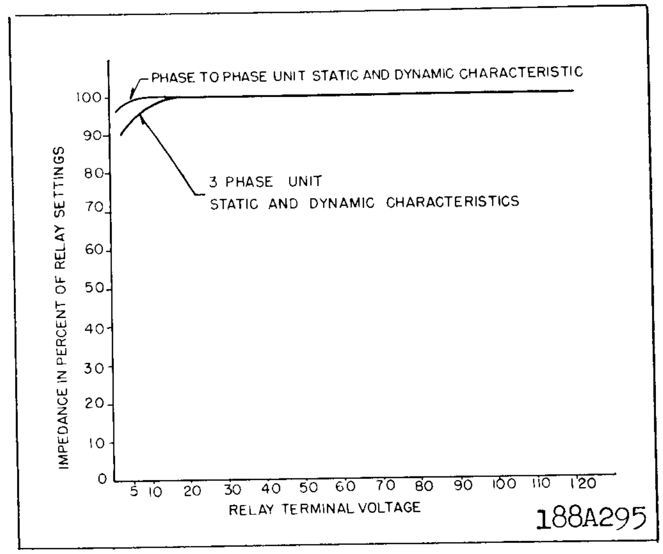


Fig. 8. Impedance Curves for Type KD-4 Relay.

voltages are depicted by the large triangle. The smaller triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltage, $-1.5\ I_1Z_C$, where Z_C is the compensator mutual impedance. The terminals of the tripping unit are designated: X, Y & Z. Phase 1 tripping unit voltage is:

$$V_X = 1.5\ V_1 - 1.5\ I_1Z_C$$

Phase 2 and phase 3 tripping unit voltages are:

$$V_Y = V_2$$

$$V_Z = V_3$$

For a fault at A, beyond the relay operating zone the compensator voltage $-1.5I_1Z_C$, modifies the 1.5 times of phase 1 voltage, reducing the voltage triangle on the tripping unit X-Y-Z. With an X-Y-Z rotation the tripping unit torque is in the restraining direction.

For a fault at B, the current is larger than for a fault at A, so that $-1.5IZ_C$ is larger. The point X is in line with points Y and Z. No torque is produced, since the X-Y-Z triangle has a zero area.

For a fault in the operating zone, such as at C, point X is below the YZ line. Now the rotation is X-Z-Y, which produces operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay the current is of reversed polarity. Compensator voltage $-1.5\ IZ_C$, increases the area of the bus voltage triangle, 1-2-3. Tripping unit voltage has an X-Y-Z rotation which produces restraining torque.

A solid 3 phase fault at the relay location, tends to completely collapse the 1-2-3 voltage triangle. The area of the X-Y-Z triangle also tends to be zero under these conditions. A memory circuit in the KD relay that consists of inductance X_L and capacitor C_{3C} provides momentary operating torque under these conditions, for an internal fault.

The R_{3A} and C_{3A} parallel resistor-capacitor combination in the compensated phase corrects for a shift in the phase-angle relation between the voltage across the left hand coils of Z (3Ø) and the voltage across the right hand coils of Z (3Ø), in figure 4. This phase shift is produced by capacitor C_{3C}. The $R_{3A} - C_{3A}$ combination also provides control of transients in the inductive coils of the cylinder unit.

Phase-to-Phase Unit

Compensator primaries of T_{AB} and T_{BC} are energized by I_1, I_2 and I_3, as shown in Fig. 12. Compensator secondaries are connected to modify their respective phase voltages (e.g.. T_{AB} modifies V_{12}). With a fault in the trip direction, the induced voltages in the compensator secondaries buck the phase-phase voltages.

Vector diagrams in Fig. 6 illustrate the operation during phase 2-3 faults at four locations. The system impedances and the compensator angle are assumed to be at 90°, for illustrative purposes. Prefault voltages are depicted by the large triangles. The smaller light triangle in each case is the system voltages at the relay location during the fault. This triangle is modified by the compensator voltages $(I_1 - I_2)\ Z_C$ and $(I_2 - I_3)\ Z_C$ where Z_C is the compensator mutual impedance. In this case $I_1 = 0$. The terminals of the trip-

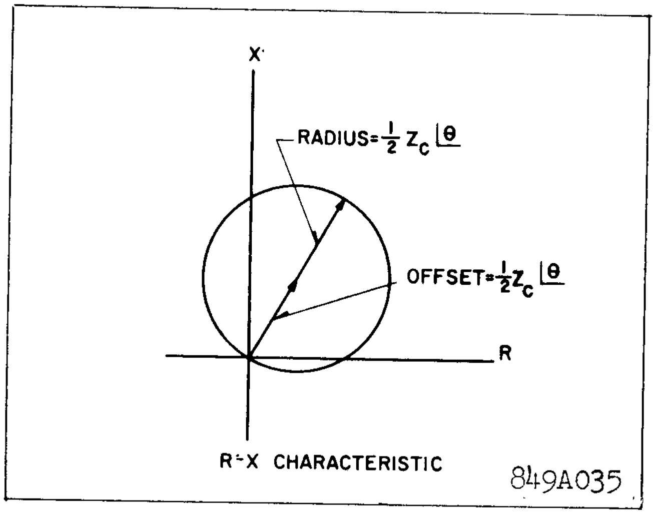


Fig. 9. Impedance Circle for Three-Phase Unit in Type KD-4 Relay.

ping unit are designated; X, Y and Z. Tripping unit voltages are for phase 2-3 fault:

$$V_{XY} = V_{12} - (I_1 - I_2) Z_C$$

Phase 2-3 tripping unit voltage is:

$$V_{YZ} = V_{23} - (I_2 - I_3) Z_C$$

For a fault at A, in Fig. 6, beyond the relay operating zone, the compensator voltages change the 1-2-3 voltage sequence to the identical X-Y-Z sequence. Voltages of this sequence applied to operating unit produce restraining torque.

For a fault at B, the currents are larger than for a fault at A, so that compensator voltages are larger. Points Y & Z coincide now and the area of the X-Y-Z triangle is zero. No torque is produced.

For a fault in the operating zone, such as at C, the compensator voltages reverse the rotation of tripping unit voltages to X-Z-Y sequence. Voltages of this sequence applied to operating unit produce operating torque.

For a fault behind the relay at D, restraining torque is produced. Since the fault is behind the relay, the current is of reversed polarity and tripping unit voltage has an X-Y-Z rotation. This rotation produces restraining torque.

Note that this unit does not require memory action, since the sound-phase voltage reacts with the compensator voltages to produce a strong restraining or a strong operating torque, depending upon the fault location. This is true even for a complete collapse of the faulted phase-to-phase voltage.

Similar vector diagrams apply for a fault between phases 1 & 2 or between phases 3 & 1. Each of the three phase-to-phase fault combinations subjects the cylinder unit to a different but similar set of conditions.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the R-X diagram as shown in Fig. 7, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional and no separate directional unit is required.

An inspection of Fig. 7 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 8. The unit will operate with the correct

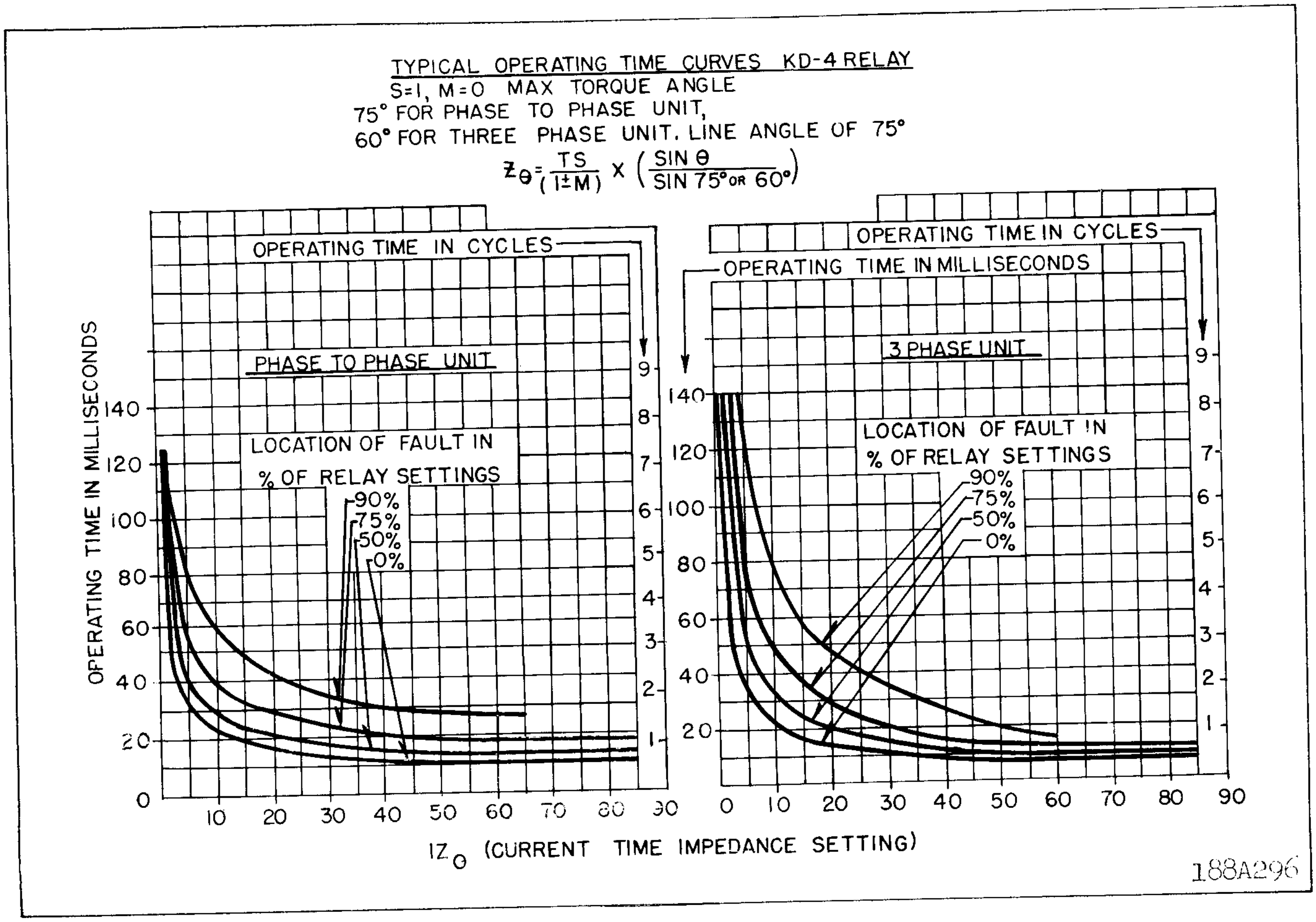


Fig. 10 Typical Operating Time curves of Type KD-4 Relay. Normal voltage before the faults is 120 volts.

directional sense for zero voltage phase-to-phase faults. For this condition the fault current must be not less than 0.030 relay amperes with an ohm setting of 1.23 with rated voltage on the unfaulted phase. Pick up current is proportionally higher in S = 2 and S = 3 taps.

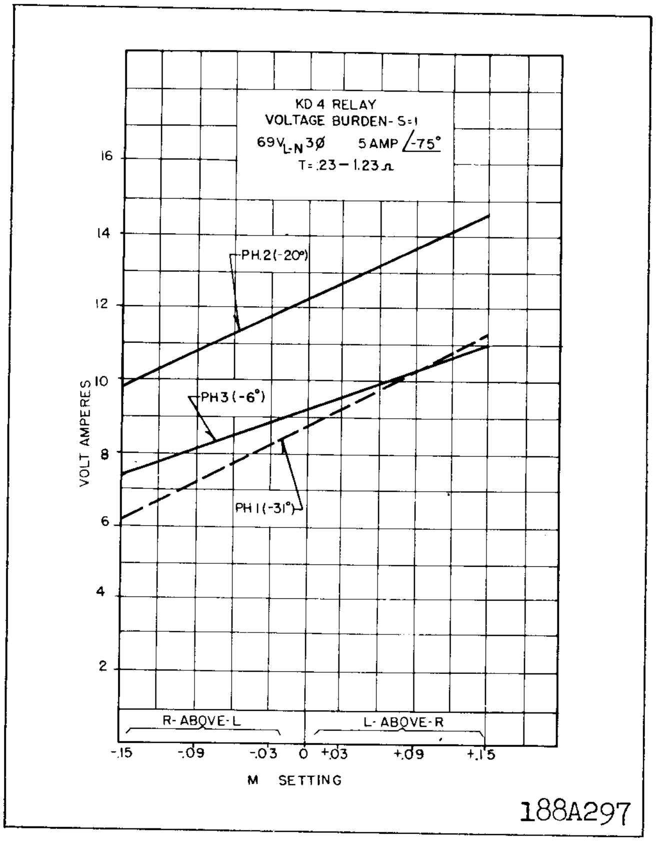
The KD-4 relay may be set without regard to possible overreach due to d-c transients. Compensators basically are insensitive to d-c transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary. Asymetrical currents resulting from faults on low-angle systems having a short time constant can induce considerable voltage in the secondary, but for the first half cycle, the transient-derived voltage subtracts from the steady-state value. This transient decays so rapidly that it is insignificant during the second half cycle when it adds to the steady-state value.

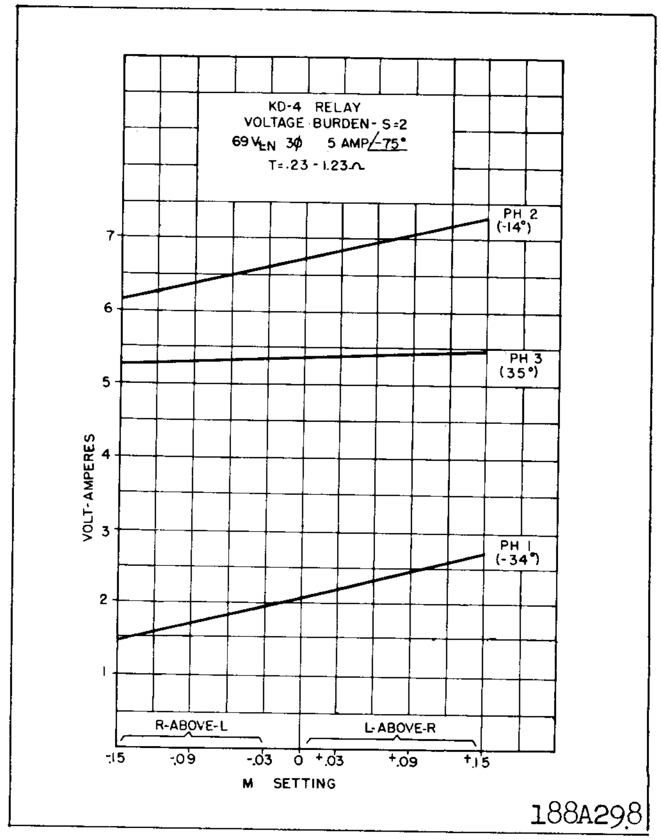
Distance Characteristic - 3 Phase Unit

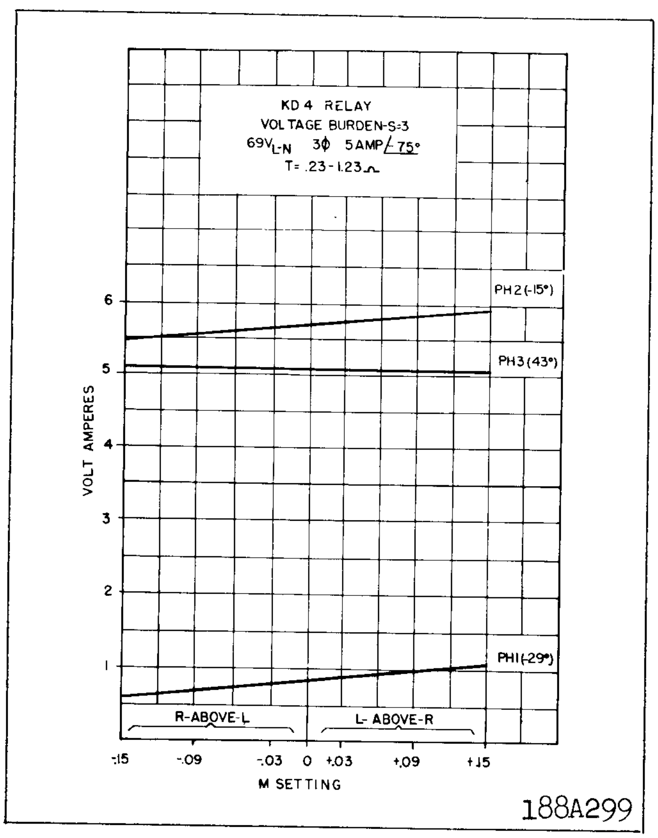
The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 9. This circle is independent of source impedance. The three-phase unit is also inherently directional and does not require a separate directional unit.

If a solid-three phase fault occurs right at the relay location, the entire voltage triangle collapses to zero to give a balance point condition, as shown by the relay characteristic in Figure 9 which passes through the origin. However, since the YZ voltage also drops to zero, the relay would be unable to determine whether an internal or external fault existed. To correct this condition, a resonant circuit is added to the 23 voltage circuit of the relay which allows the YZ voltage to collapse gradually, thus giving a reference voltage to determine whether the fault is inside the protected line section or behind the relay.

The maximum torque angle of this unit is set for less than the line impedance angle of the phase-







KD-4 RELAY
CURRENT BURDEN TABLE
POTENTIAL CIRCUIT $69V_{L-N}$, S= 1
THREE PHASE CURRENT= 5 /-75° AMPS.

TAP SETTING	PHASE 1 VA	PHASE 1 VARS	PHASE 1 WATTS	PHASE 2 VA	PHASE 2 VARS	PHASE 2 WATTS	PHASE 3 VA	PHASE 3 VARS	PHASE 3 WATTS
.23	1.05	.306	1.01	.650	.157	.63	.200	.062	.190
.307	1.25	.605	1.09	.700	.240	.660	.350	.126	.327
.383	1.45	.852	1.17	.802	.354	.722	.600	.262	.54
.537	1.65	1.16	1.16	1.000	.615	.788	.850	.488	.696
.690	1.85	1.41	1.19	1.400	1.00	.980	.950	.600	.74
.920	2.25	1.92	1.19	2.100	1.74	1.18	1.35	.94	.97
1.23	3.2	2.98	1.19	3.350	3.02	1.47	2.20	1.55	1.55

188A300

Fig. 11 Type KD-4 Relay Burden Data

to-phase unit in order to accomodate more arc resistance. The factory setting is 60° (75° for phase-to-phase unit); the angle may be readjusted as low as 45°.

Sensitivity – KD-4, 3 Phase Unit

The impedance curve for the KD-4 three-phase unit is shown in Figure 8.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. The unit will have zero torque or perhaps a slight opening torque if there is zero voltage at the relay prior to the fault or after the memory action has subsided. With an impedance setting of 1.23 ohms the three-phase unit will directionally operate for faults which produce .5 volts line to line and 2.7 ampere at the relay terminals.

Sensitivity with .75 volts line-to-line for any tap is defined by the following equation:

$$I = \frac{3.4}{T} \text{ amperes}$$

Where T = Compensator Tap Value

The KD-4 relay may be set without regard to possible overreach due to d-c transients.

General Characteristics

Impedance settings in ohms reach can be made for any value from .2 ohms to 4.35 ohms in steps of 3 percent. The maximum torque angle which is set for 75 degrees at the factory for Ø-Ø unit, and 60 degrees for 3Ø may be set for any value from 60 degrees to 80 degrees for phase-to-phase unit and from 45° to 80 degrees for 3 phase unit. A change in maximum torque angle will produce a slight change in reach for any given setting of the relay. Referring to Fig. 2 note that the compensator secondary voltage output V, is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R_3, R_{2A} or R_{2C}) is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT, IT_{AB} or IT_{CA}. Thus the net voltage, V, is phase-shifted to change the compensator maximum torque angle. As a result of this phase shift the magnitude of V is reduced, as shown in Fig. 2. Tap markings in Fig. 3 are based upon 75° for phase-to-phase unit and upon a 60° compensator angle setting for three phase unit. If the resistors R_3, R_{2A}, and R_{2C} are adjusted for some other maximum torque angle the nominal reach is different than indicated by the taps. The reach, Z varies with the maximum torque angle θ, as follows:

$$Z = \frac{TS \sin \theta}{(1 \pm M) \sin \alpha}$$

where α = factory set angle of 75° for phase to phase unit and 60° for three phase unit.

Tap Plate Markings

	$(T, T_A, T_B, \text{ and } T_C)$
	.23, .307, .383, .537, .690, .920, 1.23
	(S, S_A, S_C)
	1 2 3
	(M, M_A, M_C)
±Values between taps	.03 .06 .06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the KD-4 relay three-phase and phase-to-phase units is shown by the time curves in Figure 10. The curves indicate the time in milliseconds required for the relay to close its contacts for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

Tap Setting	Continuous			1 Second
	S = 1	S = 2	S = 3	
1.23	10.0	10.0	10.0	240
.920	10.0	15.	15.	240
.690	10.0	15.	15.	240
.537	15.	15.	15.	240
.383	15.	15.	15.	240
.307	15.	15.	15.	240
.230	15.	15.	15.	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is shown by Fig. 11 for the KD-4 relay. The potential burden and burden phase angle are based on 69 volts line-to-neutral applied to the relay terminals.

Trip Circuit Constants

1 ampere rating:	0.1 ohms d-c. resistance
0.2/2.0 ampere rating:	0.2 tap – 6.5 ohms
	2 tap – 0.15 ohms

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Fig. 3. The tap markings are:

T, T_A, T_B and T_C
.23-.307-.383-.537-.690-.920-1.23

S, S_A, and S_C		
1	2	3

M, M_A, M_C		
.03	.06	.06

(Values between taps)

Maximum torque angle is set for 75° (current lagging voltage) for phase to phase unit and for 60° for three phase unit. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set the phase-to-phase unit for a 60° maximum torque angle unit by adjusting R_{2A} and R_{2C}, and set the 3 phase unit for 45° by adjusting R_3. Set Zone 1 reach to be 90% of the line (85% for line angles of less than 50°). No need to readjust relay for zone 2 or 3 application.

Calculations for setting the KD-4 relays are straightforward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relays is:

For phase-to-phase unit

$$Z_\theta = Z_{pri} \frac{0.9\, R_C}{R_V}$$

For three phase Unit

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V}$$

The terms used in this formula are defined as follows:

Z_θ = the desired ohmic reach of the relay in secondary ohms.

$Z = \frac{TS}{1 \pm M}$ = the tap plate setting.

T = compensator tap value

S = Auto-transformer primary tap value

θ = Maximum torque angle setting of relay. This setting is made in line with recommendations made above.

M = Auto-transformer secondary tap value.

(This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Z_{pri} = ohms per phase of the total line section

0.9 = the portion of the total line for which the relay is set.

R_C = current transformer ratio

R_V = potential transformer ratio

T—compensator tap values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit. The relays having other than standard maximum torque angle adjustment Z—setting should be modified as outlined below.

The following procedures should be followed in order to obtain an optimum tap plate setting of the relay, Z.

1. a) Establish Z_θ

   b) Establish Z – Relay tap plate settings. If the relay maximum torque angle θ has been recalibrated to an angle different from the 75° setting, multiply the $Z\ \theta$ – value by factor $\frac{\sin 75°}{\sin \theta°}$ for phase to phase unit, and by factor $\frac{\sin 60°}{\sin \theta°}$ for three phase unit.

2. Now refer to the Table I.

   Table I lists optimum relay tap settings for relay range from .2 to 4.35 ohms.

   a) Locate a table value for relay reach nearest to the desired value Z (it will always be within 1.5% or less off the desired value).

   b) Read off the table "S,T," and "M" settings. "M"-column includes additional information for "L" and "R" leads setting for the specified "M" value.

   c) Recheck the obtained S,T,M-settings by using equation.

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach Z_θ, is 1.7 ohms at 60°. If relay has been recalibrated to a maximum torque angle of 60° from standard setting of 75° the relay setting, Z should be:

$$Z = 1.7 \times \frac{\sin 75°}{\sin 60°} = 1.89 \text{ ohms.}$$

The phase-to-phase unit setting is found as follows:

a) The nearest reading is 1-90 ohms that is $\frac{1.90}{1.89} \times 100 = 100.5\%$ of the desired reach.

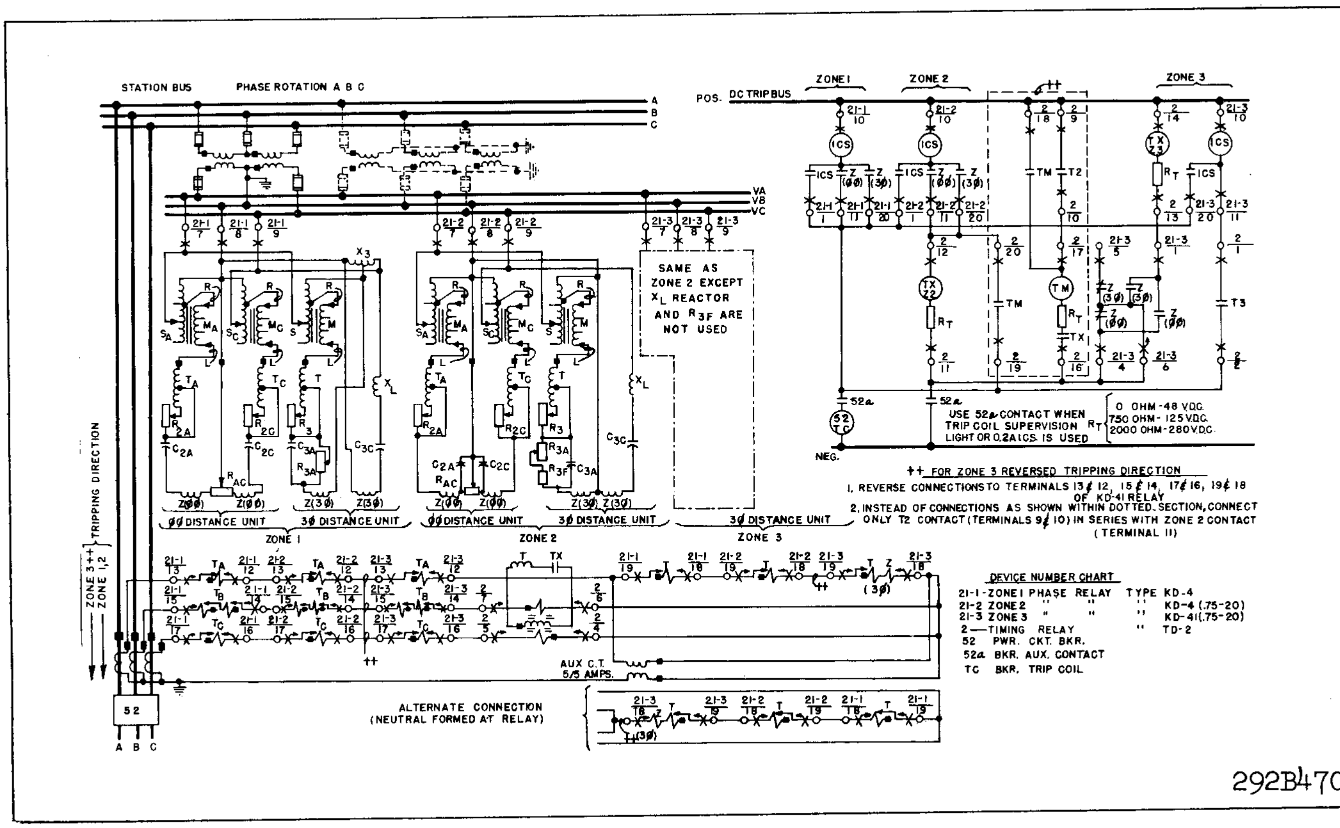
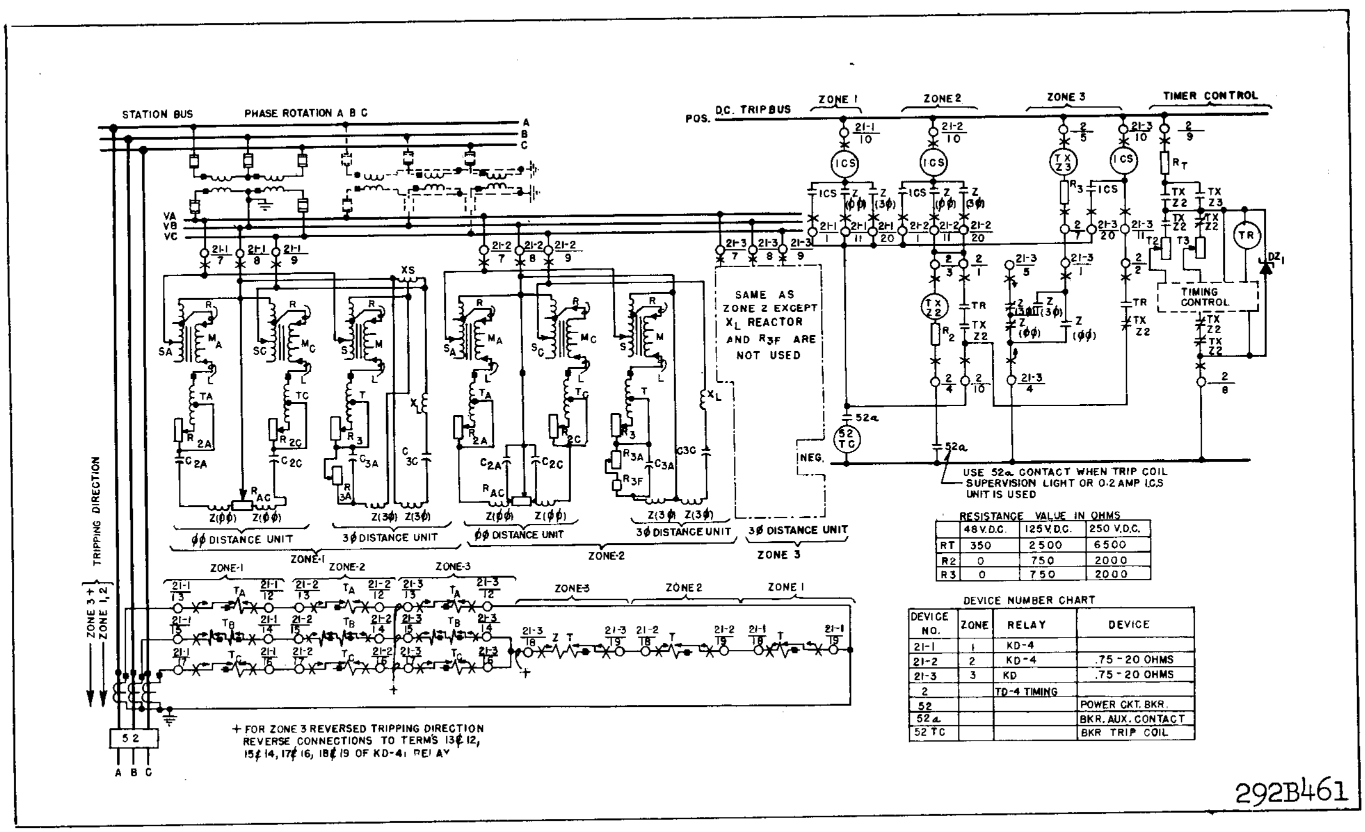


Fig. 12 External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay.



RESISTANCE VALUE IN OHMS

	48 V.D.C.	125 V.D.C.	250 V.D.C.
RT	350	2500	6500
R2	0	750	2000
R3	0	750	2000

DEVICE NUMBER CHART

DEVICE NO.	ZONE	RELAY	DEVICE
21-1	1	KD-4	
21-2	2	KD-4	.75 - 20 OHMS
21-3	3	KD	.75 - 20 OHMS
2		TD-4 TIMING	
52			POWER CKT. BKR.
52a			BKR. AUX. CONTACT
52 TC			BKR TRIP COIL

Fig. 13 External Schematic of Type KD-4 and KD-41 Relays with Type TD-4 Timing Relay.

b) From the Table I read off S = 2

T = .920

M = –.03

and "R" lead should be connected over "L"-lead with "L" connected to "O" tap and "R" - lead to ".03" tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .03} = 1.895$$

or

$$Z_{60°} = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 1.895 \times .898 = 1.70 \text{ ohms}$$

Three phase unit setting is found as follows:

Since the line characteristic angle is 60° the recommended maximum torque angle setting for three phase unit will be 45°. If relay has been recalibrated to 45° from standard factory setting of 60° then the relay setting should be:

$$Z = Z\theta . \frac{\text{Sin } 60°}{\text{Sin } \theta} = 1.7 \times 1.225 = 2.08$$

a) The nearest table value is 2.09

b) From the Table I read off

S = 2

T = .920

M = – .12

"R" lead should be over "L", with "L" - lead, connected to ".03" - tap and "R" - lead connected to upper ".06" - tap.

c) Recheck settings

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times .920}{1 - .12} = 2.09$$

or

$$Z_{45°} = Z \frac{\text{Sin } 45}{\text{Sin } 60} = 2.09 \times .818 = 1.71$$

or 100-.5% of desired setting.

SETTING THE RELAY

The KD-4 relay requires settings for each of the three compensators (T, T_{AB} and T_{BC}), each of the auto-transformers, primaries (S, S_A, and S_C) and secondaries (M, M_A, and M_C). All of these settings are made with taps on the tap plate which is located between the operating units. Fig. 3 shows the tap plate.

Compensator (T, T_{AB} and T_{CA})

Each set of compensator taps terminate in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly.

Auto-Transformer Primary (S, S_A, and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 3).

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

Auto-Transformer Secondary (M, M_A, and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from –.15 to +.15 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (–) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Determine from the following table the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

See Table I for tabulated "M" settings.

TABLE I
RELAY SETTINGS FOR KD-4 RELAY (.2 – 4.35 OHMS)

	S = 1							S = 2			S = 3				LEAD CONNECTION		
T	.230	.307	.383	.537	,690	.920	1.23	.690	.920	1.23	.920	1.23	+M	-M	"L"-Lead	"R" Lead	
	.200	.267	.333	.467	.600	.800	1.070	—	1.60	2.14	—	3.21	+.15		Upper .06	0	"L" OVER "R"
	.205	.274	.342	.480	.616	.821	1.098	—	1.64	2.20	—	3.29	+-12		Upper .06	.03	"L" OVER "R"
	.211	.282	.351	.493	.633	.844	1.128	—	1.69	2.26	—	3.38	+.09		Lower .06	0	"L" OVER "R"
	.217	.290	.361	.507	.651	.868	1.160	—	1.74	2.32	—	3.48	+.06		Upper .06	Lower .06	"L" OVER "R"
	.223	.298	.372	.521	.670	.893	1.194	—	1.78	2.39	—	3.58	+.03		.03	0	"L" OVER "R"
	.230	.307	.383	.537	.690	.920	1.230	—	1.84	2.46	—	3.69	0	- 0	0	0	
	.237	.317	.395	.554	.711	.948	1.268	—	1.90	2.54	—	3.80		-.03	0	.03	"R" OVER "L"
	.245	.327	.407	.571	.734	.979	1.308	1.47	1.96	2.62	—	3.93		-.06	Lower .06	Upper .06	"R" OVER "L"
	:253	—	.421	.590	.758	1.011	1.352	1.52	2.02	2.70	3.03	4.05		-.09	0	Lower .06	"R" OVER "L"
	.261	—	.435	—	.784	1.046	1.398	1.57	2.09	2.80	3.14	4.19		-.12	.03	Upper .06	"R" OVER "L"
	.271	—	.451	—	—	—	1.447	—	—	2.89	—	4:34		-.15	0	Upper .06	"R" OVER "L"

The tap plate values refer to standard maximum torque angle adjustment which is 75° for phase-to-phase unit and 60° for three phase unit.

Line Angle Adjustment

Maximum torque angle is set for phase-to-phase unit 75° (current lagging voltage) and for 60° for three-phase unit in the factory. For Ø-Ø unit this adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65°, set phase-to-phase unit for a 60° maximum torque angle by adjusting the compensator loading resistors R_{2A} and R_{2C}, and for 45° maximum torque angle for the three phase unit by adjusting the resistor R_3. Refer to repair calibration parts I and II, when a change in maximum torque angle is desired.

Indicating Contactor Switch (ICS)

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in a tap 2 and use a Type WL relay with a S#304C209G01 coil, or equivalent.

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 mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case refer to IL 41-076.

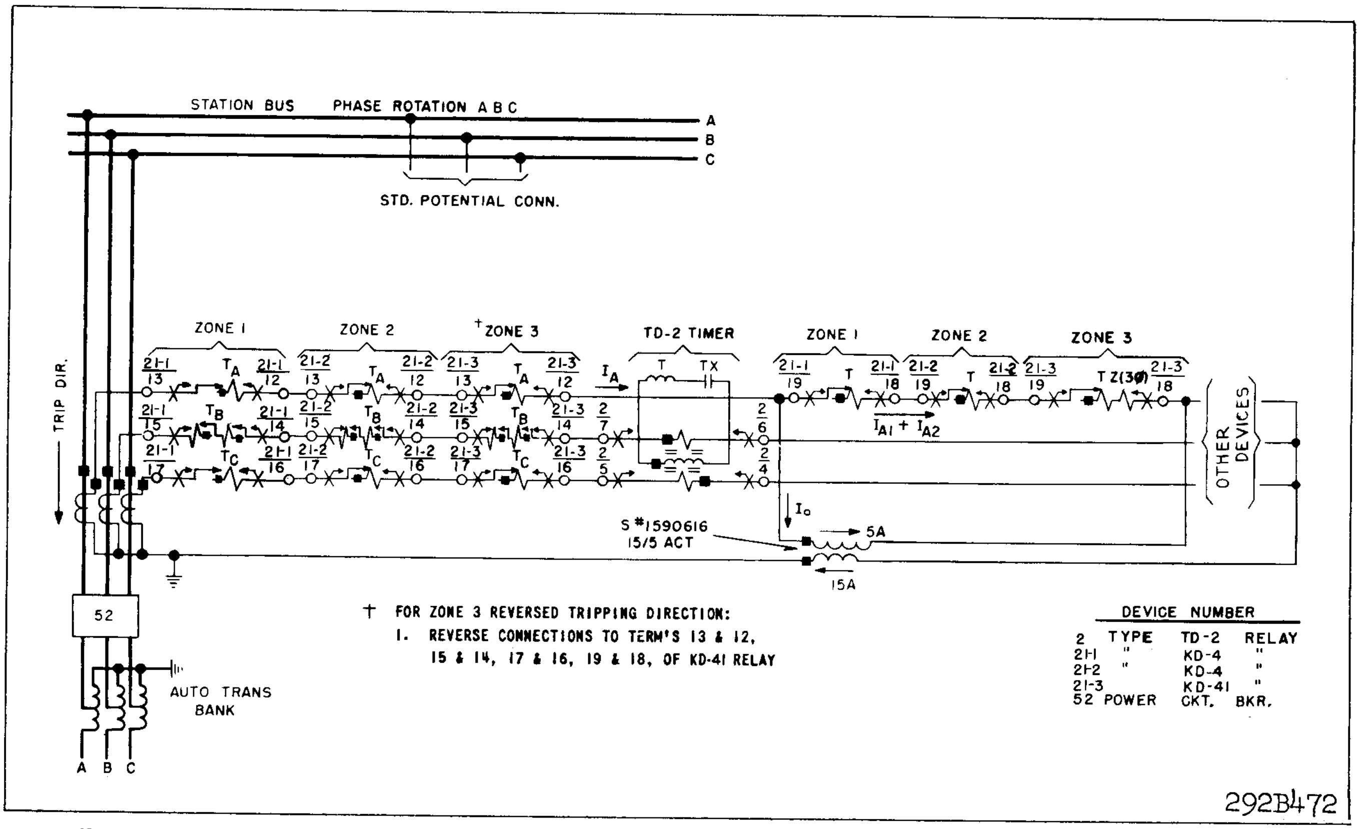


Fig. 14 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Timing Relay-Auto-Transformer Termination.

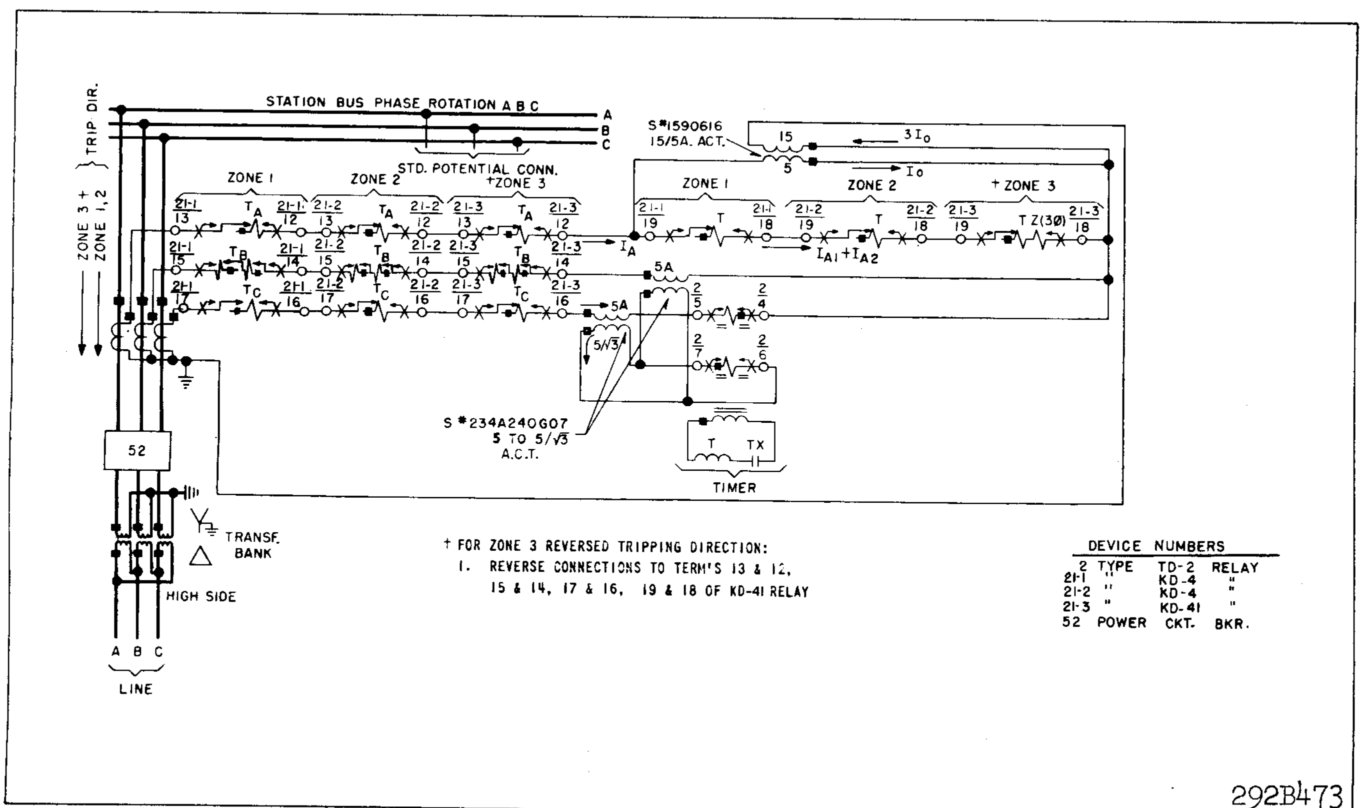


Fig. 15 A.C. External Schematic of Type KD-4 and KD-41 Relays with Type TD-2 Relay-Wye Delta Bank Termination with Grounded Wye on Relay Side.

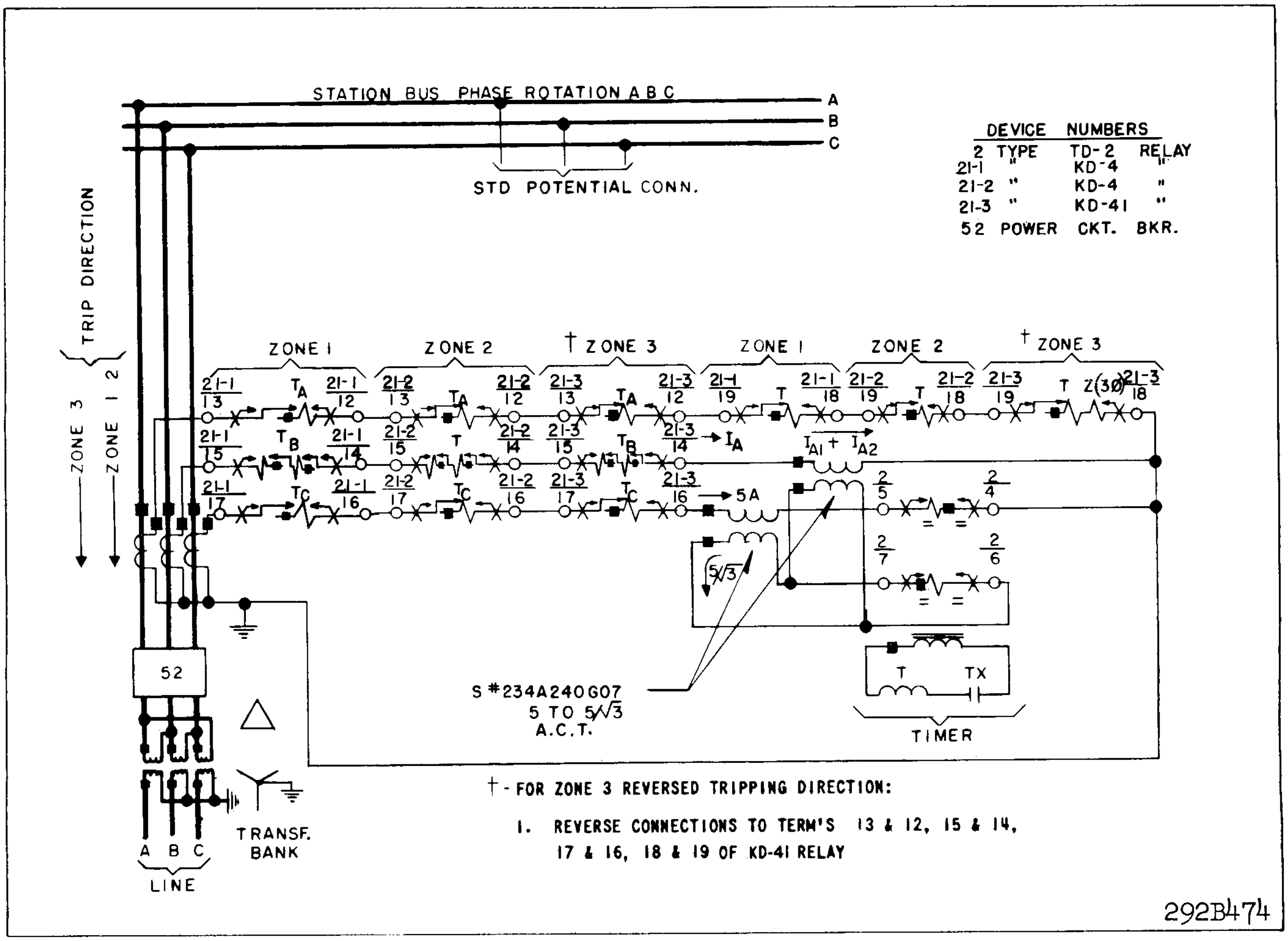


Fig. 16 A.C. External Schematic of Type KD-4, and KD-41 Relays with Type TD-2 Timing Relay-Wye-Delta Bank Termination with Delta on Relay Side.

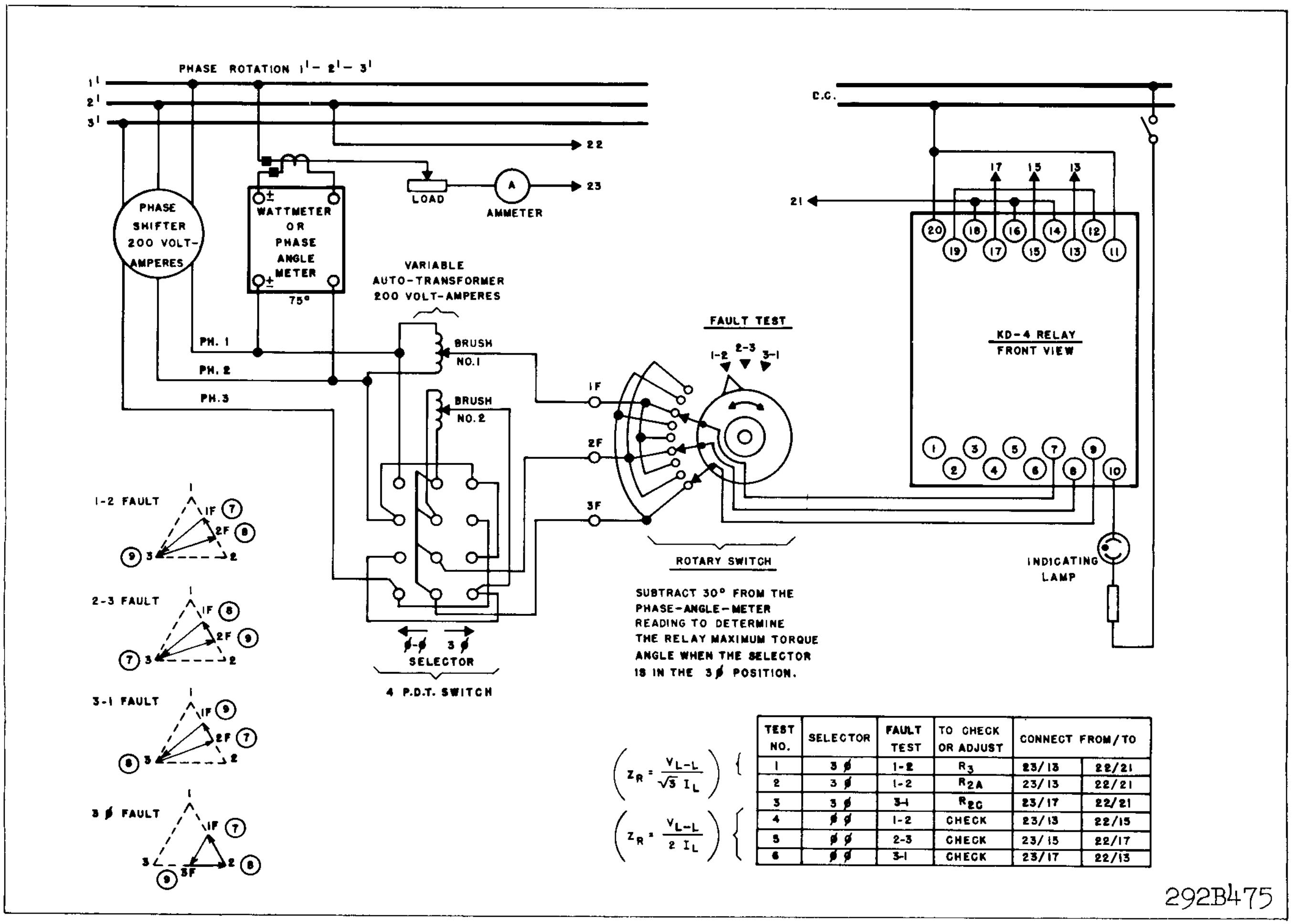
EXTERNAL CONNECTIONS

Fig. 12 shows the connections for 3 zone protection utilizing the TD-2 timer. Fig. 13 is similar to Fig. 12 except that the TD-4 timer is used instead of the TD-2. Fig. 13 does not show the use of the 5/5 auxiliary current transformer so that the CT neutral may be formed elsewhere; however, this connection is equally applicable whether the TD-2 or TD-4 timer is employed.

A-C connections for additional applications are shown in Figs. 14, 15 and 16. These connections apply when the transmission line is terminated in a power transformer, and when low side voltage and current are used to energize the relays. In calculating the reach settings, the bank impedance must be added to the line impedance.

For the case of a wye-delta bank (Figs. 15 and 16) the voltages and currents are phase-shifted by 30°; however, this fact should be ignored, as the KD relays are not affected by this phase shift.

Figs. 14 through 16 show the TD-2 relay; however, the TD-4 is equally applicable. In the case of Figs. 15 and 16 the two S#234A240G07 auxiliary CT's are not required if the TD-4 is used.



$\left(Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L} \right)$ (Tests 1–3)

$\left(Z_R = \frac{V_{L-L}}{2\, I_L} \right)$ (Tests 4–6)

TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
1	3 ∅	1-2	R_3	23/13	22/21
2	3 ∅	1-2	R_{2A}	23/13	22/21
3	3 ∅	3-1	R_{2C}	23/17	22/21
4	∅ ∅	1-2	CHECK	23/13	22/15
5	∅ ∅	2-3	CHECK	23/15	22/17
6	∅ ∅	3-1	CHECK	23/17	22/13

Fig. 17 Test Connections for Type KD-4 Relay

RECEIVING ACCEPTANCE

KD-4 relays have a very small number of moving parts and mechanical devices which might become inoperative. Acceptance tests in general consist of:

1. A visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires.

2. An electrical test to make certain that the relay measures the balance point impedance accurately.

Distance Units

Check the electrical response of the relay by using the test connections in Figure 17. Set T, T_A, both T_B, & T_C for 1.23 S, S_A & S_C for 1; M, M_A & M_C for 0.15.

A. Use connections for Test No. 1 and adjust the voltages V_{1F2F} and V_{2F3F} for 30 volts each.

B. The current required to make the contacts close for the three-phase (bottom) unit should be between 15.6 and 16.7 amperes at the maximum-torque angle of 60° current lag. (Set phase shifter for 90° lag in Fig. 17.) *

C. Use connection for Test No. 4

D. Adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts (120-45-45 = 30V)

E. The current required to make the contacts close for the phase-to-phase (top) unit should be between 13.6 and 14.5 amperes at an angle of 75° current lag. *

F. Repeat E while using connections for Test No. 5 and Test No. 6. The difference in values of current that make the contacts close for each of the three test connections should not be greater than 3% of the smallest value.

If the electrical response is outside the limits a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contact Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere not greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

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

Distance Units

CAUTION: before making "hi-pot" tests, jumper all contacts together to avoid destroying arc-suppressor capacitors.

Use connections for tests 1, 4, 5 & 6 of Fig. 17 to check the reach of the relay, or use a K-Dar Test unit for this purpose. When using test 1 of Fig. 17 the phase angle meter must be set for 30° more than the maximum torque angle. Note that the impedance measured by the 3-phase unit in test 1 is $Z_R = \frac{V_{L\text{-}L}}{\sqrt{3}\, I_L}$ where $V_{L\text{-}L}$ is the phase-to-phase voltage and I_L is the phase current; similarly, in tests 4, 5, & 6 of Fig. 17 the phase-to-phase unit measures

$$Z_R = \frac{V_{L\text{-}L}}{2I_L}$$

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particualr ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

Connect the relay for testing as shown in Figure 17. The four-pole-double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

For best results in checking calibration, the relay should be allowed to warm up for approximately one hour at rated voltage. However, a cold relay will probably check to within two percent of the warm relay.

Initial Spring Setting

With the stationary contacts open so that the moving contact cannot touch, set the moving contact spring adjuster so that the contact floats freely in the gap. Make sure that there is no friction which prevents free movement of the cylinder and contact arm.

Shaft Clearance

The upper pin bearing should be screwed down until there is approximately .025 inch (one complete turn of the screw) between it and the top of the shaft bearing. The upper pin bearing should then be securely locked in position with the lock nut. The lower bearing position is fixed and cannot be adjusted.

Autotransformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 1 test connections of Figure 17, and the procedure outlined below.

Set S, S_A, and S_C on tap number 3. Set the "R" leads of M, M_A, and M_C all on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 8 to the #1 tap of S_A. It should be 30 volts. From 8

to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2. Voltage from terminal 6 to tap #1 of S should be 26 volts. From 6 to the tap #2 of S should be 52 volts.

Set S, S_A, and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to the M_A taps. This voltage should be equal to 100 (1 + sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Increase voltage V_{1F2F} and V_{2F3F} to 115 volts. Check taps M voltages to terminal 6 in the same manner as tap M_A above. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

Check to see that the taps on front of the tap block are set as follows:

T, T_A, T_B, and T_C set on 1.23 (Tap T_B is set twice)

S, S_A, and S_C set on 1

"L" for M, M_A, and M_C set on 0.0

"R" for M, M_A, and M_C set on 0.0

I. Three-Phase Unit

Core and R_{3A} Resistor Adjustments

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance.

The relay should be preheated for at least one hour in the case to eliminate change in tuning due to self-heating, spring set as per Initial Spring Setting.

A. Connect relay terminals 8 and 9 together, apply, rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm restrains very slightly.

B. Connect relay for test #4 (Fig. 17). Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by the angle θ, which is the maximum torque angle of the 3ϕ unit. (60° - for standard unit.) Make sure that the applied voltage is of correct phase sequence. Adjust resistor R_{3A} so that 3ϕ unit trips at .82 - .90* amperes. This corresponds to 100% of relay setting of T=1.23 S=1 M=O.

C. Use test connections #6 (Fig. 17). Check the pickup it should be between 1.3 - 2.0 amp. If this doesn't meet this condition, rotate core approximately 90° as per part A and repeat parts A, B, C. If necessary, rotate core again.

For relays set for different maximum torque angle θ that is different from 60° the pickup current should be multiplied by a factor of

$$\frac{\text{Sin } 60°}{\text{Sin } \theta}.$$

Maximum Torque Angle Adjustment

1. Use the No. 1 test switch positions and lead connections as tabulated in Figure 17.

2. Adjust the voltages V_{1F2F} and V_{2F3F} for 20 volts with Brush No. 1 and Brush No. 2 respectively.

3. Open R_3 resistor by disconnecting the lead going to the adjustable tap on the resistor. Adjust current for 15 amperes and rotate phase shifter to find the two angles, θ_1 and θ_2, at which the bottom unit contacts just close.

The maximum torque angle measured with R_3 open should be $\left(\frac{\theta_1 + \theta_2}{2} - 30\right)$ degrees. This angle should be between 88° and 91°. Connect R_3 resistor back and measure again for maximum torque angle. This angle should be between 58° and 61°. If necessary readjust R_3 resistor for correct angle.

4. A smaller angle θ may be obtained by reducing R_3, in which case the test current should be equal to $\frac{15 \sin 60°}{\sin \theta}$ amperes. The angle may be increased by increasing R_3.

5. If it was found necessary to change R_3 resistor to a setting different from the originally set value repeat parts B and C of preceding calibration procedure.

Contact Adjustment

With moving-contact arm against right-hand backstop, screw the stationary contact in until it just touches the moving contact. (Check for contact by using an indicator lamp.) Then back the left hand contact out two-thirds (2/3) of one turn to give 0.020-inch gap between contacts.

Spring Restraint: Reconnect for a three-phase fault,

Test No. 1, and set the phase shifter so that the current lags voltage by the maximum - torque angle, (90° in Fig. 17). Adjust the spring so that the current required to close the left-hand contact is as follows:

Voltages V_{1F2F} and V_{2F3F} = 2.5 volts

Current to trip KD-4 = 1.46 amp

Deenergize relay. Contact should stay open.

II. Phase-to-Phase Unit:

Core and R_{AC} - Adjustment

A) No current is applied to relay. Set R_{AC}-resistor so that the adjustable band is in the center of the resistor. Spring set as per Initial Spring Setting.

B) Connect terminals 7 & 8 together and apply rated a-c voltage between terminals 8-9. Adjust core until contact arm floats in the middle of the gap. Use a screwdriver with insulated blade to avoid accidental contact with tap plate inserts.

C) Connect terminals 8 & 9 together and apply rated a-c voltage between terminals 7 and 8. The contact arm should float. If not, readjust the core. Only slight readjustment should be required to do that. If this not possible rotate core 180° and adjust. Then recheck part B to see if contact is floating.

D) Connect terminals 7 & 9 together. Apply rated a-c voltage to terminals 7 & 8. Adjust resistor R_{AC}, until contact arm floats.

B. Maximum Torque Angle Adjustment (Fig. 17)

1. Use the No. 2 Test switch position and lead connections. This connection is for checking and adjusting the maximum torque angle of the T_{AB} compensator.
2. Adjust the voltage V_{1F2F} and V_{2F3F} for 10 volts with Brush No. 1 and Brush No. 2 respectively.
3. Adjust the current to 15 ampers and rotate the phase shifter to find two angles, θ_1 and θ_2, at which the top unit contacts just close. The maximum torque angle θ for the phase-to-phase unit then is $(\frac{\theta_1 + \theta_2}{2} - 30)$ degrees.

   This angle should be 73–77 degrees.
   This angle θ can be changed by adjusting R_{2A}.

   In this case, the test current should be equal to $\frac{15 \sin 75^\circ}{\sin \theta}$ amperes. A lower value of resistance gives a smaller angle and a higher resistance value gives a greater angle.
5. Use the No. 3 Test Connections and repeat the above procedure to check and adjust the angle of the TBC - compensator. This adjustment is made with R_{2C}.

★ Final Core and R_{AC} Adjustment

1. Connect Relay for 1-2 fault as indicated for Test No. 4, Fig. 17.
2. Adjust the voltage between PH1 and 1F and between PH2 and 2F for 59 volts each using Brush No. 1 and Brush No. 2 respectively to provide 2 volts between 1F and 2F (V_{1F2F} = 120–59–59 = 2 volts). With no current relay contacts should stay open. If relay contacts are closed recheck voltage settings; incorrect voltage setting may result in negative sequence voltage phasing.
3. Set phase shifter for maximum torque angle (75°).
4. Check pickup current. It should be between .77-.87 amps. If not, rotate core slightly until pickup current falls within specified range.
5. Connect relay for 2-3 fault (Test No. 5) and recheck pickup. It should be within limits specified. For best trip calibration results adjust core so that trip current for Test No. 4 and No. 5 are equal.
6. Connect relay for Test No. 6. Check trip current. It should be .75-.90 amp. If not, readjust R_{AC} slightly for the same trip current as for Test No. 4 and No. 5.

Spring Restraint

1. No current is applied to relay. Use Test No. 1 connections except reverse the voltage phase sequence by interchanging the Brush connections so that Brush 1 is connected to 3F and Brush 2 is connected to 1F.
2. Adjust the voltages V_{1F2F} and V_{2F3F} for 3.5 volts each with Brush No. 2 and Brush No. 1 respectively. Position the moving contact spring adjuster so that the contact just floats and then return the circuit connections to normal with Brush 1 to 1F and Brush 2 to 3F.
3. Deenergize relay. Contact should stay open.

Contact Adjustment

The procedure for contact adjustment for the phase-to-phase unit is identical to that described for three-phase unit.

D. Measure the compensator voltage V_C with a high resistance voltmeter 5,000 ohm/volt as tabulated below. Refer to Figure 1 for the location of R_3, R_{2A}, and R_{2C}.

Measure V_C		
From Terminal	To Fixed End of	Voltmeter Reading
"L" of M	R_3	$V_C = 1.5\ IT\ (\frac{\sin\theta}{\sin 60^\circ})$ = 42.6 volts ($\theta = 90^\circ$)
* "L" of M_A	R_{2A}	$V_C = 2IT\ (\frac{\sin\theta}{\sin 75^\circ})$
"L" of M_C	R_{2C}	= 50.9 volts ($\theta = 90^\circ$)

E. Any compensator that has an output which is 1 volt more or less than the nominal values given above should be replaced.

IV Overall Check

After the calibration procedure has been completed, perform the following check.
Set all T = 1.23, all S = 1, all M = 0.

A. Three-Phase Unit

Connect the relay for a three-phase fault, Test No. 1 of Figure 17, and set the phase shifter so that the phase angle meter indicates 30° more than the maximum torque angle. The current required to trip the relay should be within the limits specified for each of the voltages. Note that for the three-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{\sqrt{3}I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Volts	Amperes (θ=60°) †† & †	
V_{1F2F} & V_{2F3F}	I_{min}	I_{max}
2.5	–	1.46
10	4.6	4.8
30	13.8	14.4

† to determine the limits of current when θ is not equal to 60° multiply the nominal values tabulated above by the ratio $\frac{\sin 60^\circ}{\sin\theta}$

†† Phase angle meter set for $\theta + 30^\circ$.

B. Phase-to-Phase Unit

Using the connections for Tests Nos. 4, 5, and 6 set the phase shifter so that the current lags voltage by θ°. The current required to trip the phase-to-phase unit should be within the limits specified for each of the voltages. Note that for the phase-to-phase unit the impedance measured by the relay is $Z_R = \frac{V_{L\text{-}L}}{2\ I_L}$ where $V_{L\text{-}L}$ is phase-to-phase fault voltage and I_L is phase current.

Test No.	Volts	Amperes (θ = 75°) †	
	V_{1F2F}	I_{min}	I_{max}
4,5 & 6	2.5	.98	1.08 *
	5.0	1.99	2.10
	30.0	11.9	12.5
	70.0	28.0	29.

† To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio $\frac{\sin 75^\circ}{\sin\theta}$.

*If test 4 and 5 produce different results, rotate core about 1-2 degrees until tests 4 and 5 are within limits above. For best results trip current for parts 4 and 5 should be within 2%.

If test #6 is out of limits readjust R_{AC} resistor until current limits are met.

If substantial core or resistor changes are made, recheck parts A, B, C, D of Core and R_{AC} Adjustment.

Indicating Contactor Switch (ICS)

Close the main relay contacts and pass-sufficient d-c current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The phase-to-phase unit is now calibrated and should be accurate to within ± 2% of the corrected tap value setting over the range of fault voltages from 2.5 V_{L-L} to 120 V_{L-L}. The corrected tap value is actual relay reach at a given maximum torque angle θ and is equal to $Z_\theta = \frac{TS \quad \sin \theta}{(1 \pm M) \; (\sin 75°)}$. The relay is now calibrated and ready for service.

III. Compensator Check

Accuracy of the mutual impedance Z_C of the compensators is set within very close tolerances at the factory and should not change under normal conditions. The mutual impedance of the compensators can be checked with accurate instruments by the procedure outlined below.

A. Set T, T_A, T_B, and T_C on the 1.23 tap.

B. Disconnect the "L" leads of sections M, M_A, and M_C and the brush leads of R_3, R_{2A}, and R_{2C} without disturbing the brush setting. (With resistor loading removed θ = 90°).

C. Connect terminals 12 to 14, 15 to 17, 16 to 18 and pass 20 amperes a.c. current in terminal 19 and out of terminal 13.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1 ampere unit, between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE II

NOMENCLATURE FOR RELAY TYPE KD-4

UNIT	ITEM	DESCRIPTION
THREE-PHASE	Z (3φ)	Two Element-Coils; Total d-c Resistance = 125 to 155 ohms
	Z (3φ) 2-3	Two Element-Coils; Total d-c Resistance = 360 to 440 ohms
	R_{3A}, R_{3F}	Combination of 2 resistors. Total Resistance 2500 ohms (One Resistor is fixed, one adjustable).
	R_3	2 inch Resistor 300 ohms Adjustable
	C_{3A}	2.0 MFD Capacitor
	C_{3C}	0.50 MFD Capacitor
	T	Compensator (Primary Taps - .23; .307; .383; .537; .690; .920; 1.23)
	S	Auto-Transformer Primary (Taps - 1; 2; 3)
	M	Auto-Transformer Secondary (Between Taps-0.0; .03; .06; .06)
	XL_1, X_S	Reactors
PHASE-TO-PHASE	Z (φ-φ)	Two Element-Coils; Total d-c Resistance = 180 to 220 ohms
	R_{AC}	3-½ inch Resistor 750 ohms Adjustable
	R_{2A} R_{2C}	2 inch Resistor 600 ohms Adjustable
	C_{2A} C_{2C}	1.35 MFD Capacitor
	T_{AB} T_{BC}	Compensator Same as T
	S_A S_C	Same as S
	M_A M_C	Same as M

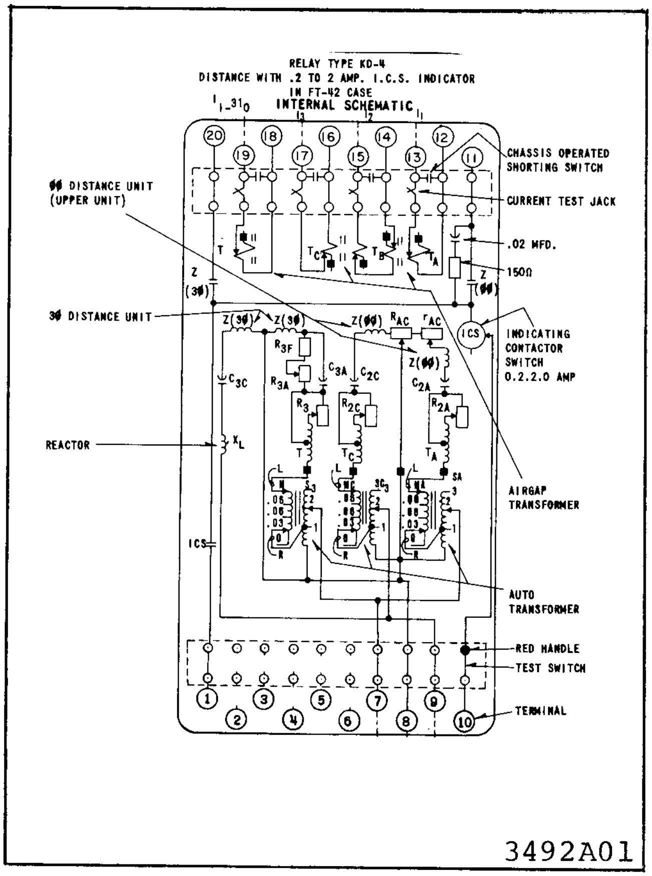


Fig. 18 Relay Type KD-4 Distance with .2 to 2 Amp. I.C.S. Indicator

APPENDIX

* KD-4A RELAY (.2 – 4.35 OHMS)

Operation

Three Phase Unit, operates as three phase unit per I.L. 41-491.4 (.75 – 20 ohms).

Repair Calibration

* Autotransformer Check as per page 19 of this IL except for "S" – taps should be done with reference to terminal "8" not "6." "M" – tap voltages should be checked with reference to terminal "8" not "6," using 100 volts instead of 115.

Core and R_{3A} Resistor Adjustment

* As per page 20 of this IL except omit complete procedure and calibrate as follows:

Set R_3 resistor for 100 ohms. Adjustable part of R_{3A} should be connected for full resistance. Restraint Spring Set as per Initial Spring Setting.

The relay should be preheated for at least one hour in the case with closed cover to eliminate change in tuning due to self-heating.

A. Connect relay terminals 8 and 9 together, apply rated a-c voltage between terminals 7 and 8. Adjust core by turning it slightly until the contact arm floats or restrains very slightly.

B. Connect relay terminals 7 and 8 together and apply rated a-c voltage between 7 and 9 and adjust core until the contact arm just floats or restrains very slightly. If this is not possible rotate core 90° and adjust. Recheck part A to see if contact is floating or restraining. If not, repeat parts A and B.

* C. Connect relay for Test No. 6, Fig. 17. Set V_{1F2F} for 2 volts. Set phase shifter so that voltage leads current by 60°. Make sure that applied voltage is of correct phase sequence. Adjust R_{3A} resistor so that 3Φ unit trips at 3.8 amps.

D. For KD-4 only.

The adjustable core is checked to prevent contact closing on current-only. (The KD-41 relay is purposely biased to produce current-only contact-closing torque and will open its right hand contact at a current value of 5 amperes or
* less when T = 1.23.)

Check it as follows:

1. Short circuit relay terminals 7, 8 and 9 together.
2. Pass 5 amperes in the current circuit in terminal 18 out terminal 19 and increase the current to 30 amperes in convenient steps.
3. Relay contacts should stay open. If contacts close turn core further 90 degrees and repeat parts A, B and C.

Final Core and R_{AC} – Adjustment

* As per page 21 of this IL, except start R_{AC} adjustment with r_{AC}=(2½ inch resistor behind the tap plate above R_{2A} resistor), set it approximately in the center. Use this resistor to get final fine adjustment.

Internal Schematic, as per name plate information.

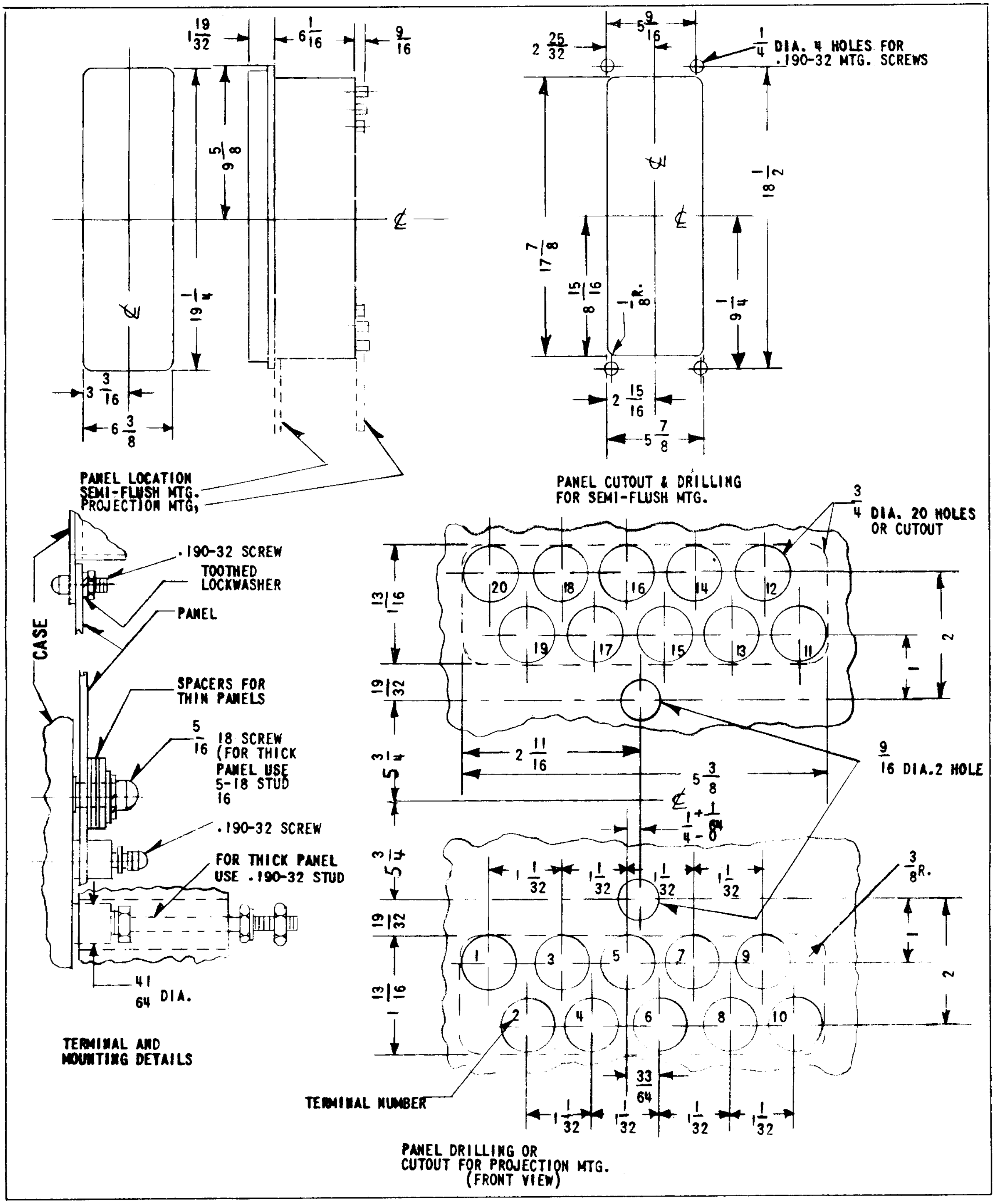


Fig. 19 Outline and Drilling Plan for Type KD-4 Relay in the Type FT42 case.

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**

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