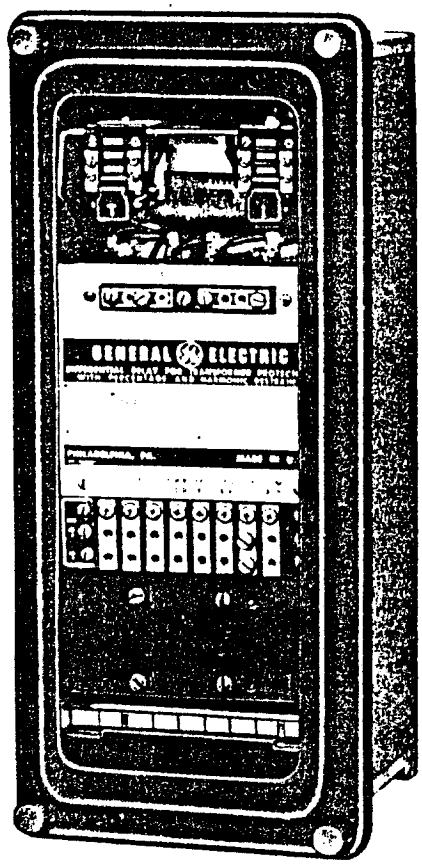
INSTRUCTIONS

GEH-1816

# TRANSFORMER DIFFERENTIAL RELAY WITH PERCENTAGE AND HARMONIC RESTRAINT




Types

BDD15B
BDD16B

LOW VOLTAGE SWITCHGEAR DEPARTMENT

GENERAL ELECTRIC

# CONTENTS

# TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT TYPES BDD15B AND BDD16B

## INTRODUCTION

Relays of the BDD Type are transformer differential relays provided with the features of percentage and harmonic restraint and using a sensitive polarized relay as the operating element. Percentage restraint permits accurate determination between internal and external faults at high currents. Harmonic restraint enables the relay to distinguish, by the difference in waveform, between the differential current caused by an internal fault and that caused by transformer magnetizing inrush. The relay operates with high speed on internal fault currents.

## APPLICATION

Because the relays produce restraint proportional to the harmonic component of the relay current, the current transformers which supply the Type BDD relay must be adequate to reproduce currents up to 8 times the relay tap rating without saturating enough to produce an excessive amount of harmonics and cause false restraint on internal faults. Generally, the Type BDD relay can be applied with bushing current transformers on all power circuit breakers although on some of the lower rated breakers it is sometimes necessary to use higher than the minimum CT tap in order to assure adequate performance. Table I indicates the applicability of the relay when used with the bushing current transformers on General Electric power circuit breakers. For leads of high resistance or current transformers other than those listed, the adequacy of the CT's should be checked as described under CALCULATIONS.

The Type BDD relay may also be used as shown in Fig. 17 as a ground fault detector or as an overcurrent unit when percentage differential relaying cannot be employed. In this application an advantage is realized from the harmonic restraint characteristics since reliable operation is assured during transformer energizing without loss of speed under fault conditions.

### CURRENT TRANSFORMERS

Current transformer ratios in the various windings of the power transformer should be selected with the following points in mind.

1. The ratios should be high enough that the secondary currents will not damage the relay under maximum internal fault conditions (refer to RATINGS).

2. The relay current corresponding to rated KVA of the power transformer (on self-cooled basis) should not exceed the relay tap value selected (magnetizing inrush might operate the instantaneous overcurrent unit).

3. The relay current corresponding to maximum KVA (on a forced cooled basis) should not exceed twice tap value. The CT secondary current should not exceed the continuous current rating of the CT secondary winding.

4. The current transformer tap chosen must be able to supply the relay with 8 times rated relay tap current with an error less than 20 percent.

### RATIO-MATCHING TAPS

Since it is rarely possible to match the secondary currents exactly by selection of current transformer ratios, ratio-matching taps are provided on the relay by means of which the currents may usually be matched within 5 percent. When the protected transformer is equipped with load ratio control it is obvious that a close match cannot be obtained at all points of the ratio-changing range. In this case the secondary currents are matched at the middle of the range and the percentage-differential characteristic of the relay is relied upon to prevent relay operation on the unbalanced current which flows when the load-ratio control is at the ends of the range.

## OPERATING CHARACTERISTICS

### PICK-UP AND OPERATING TIME

The operating characteristic is shown in Fig. 1. The curve, for various percentage slopes, shows the percent slope versus the through current flowing in the transformer. The percentage slope is a figure given to a particular percent slope tap setting and indicates an approximate slope characteristic. Pickup at zero restraint is approximately 30 percent of tap value (see Table 2).

Curves of the operating time of the main unit and of the instantaneous unit are shown in Fig. 2, plotted against differential current.

### OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are 8 times the ampere turns produced by rated tap current flowing in that tap. For example

TABLE I

| KV | Breaker | Amps | A | B | C |
|---|---|---|---|---|---|
| 7.2 | FK-227-7.2-50 | 600 | | | x |
| 14.4 | FLO-15-14.4-100 | 600 | | | x |
| 14.4 | FLO-15-14.4-250 | 600 | | | x |
| 23 | FK-439-23-250 | 600 | | | x |
| 34.5 | FK-439-34.5-500 | 600 | | | x |
| 46 | FK-439-46-500 | 600 | | | x |
| 69 | FK-439-69-1000 | 600 | | | x |
| 115 | FK-439-115-1500 | 800 | x | | |
| 230 | FGK-230-5000 | 800 | x | | |
| 14.4 | FLO-15-14.4-250 | 1200 | | x | |
| 14.4 | FK-439-14.4-1000 | 1200 | | x | |
| 23 | FK-439-23-500 | 1200 | | x | |
| 34.5 | FK-439-34.5-1000 | 1200 | | x | |
| 34.5 | FK-439-34.5-1500 | 1200 | | x | |
| 46 | FK-439-46-1500 | 1200 | | x | |
| 69 | FK-439-69-1500 | 1200 | x | | |
| 69 | FK-439-69-2500 | 1200 | x | | |
| 115 | FK-439-115-3500 | 1200 | x | | |
| 115 | FK-439-115-5000 | 1200 | x | | |
| 138 | FK-439-138-3500 | 1200 | x | | |
| 138 | FK-439-138-5000 | 1200 | x | | |
| 161 | FK-439-161-5000 | 1200 | x | | |
| 138 | FGK-138-10000 | 1600 | x | | |
| 161 | FGK-161-10000 | 1600 | x | | |
| 230 | FGK-230-10000 | 1600 | x | | |
| 230 | FGK-230-15000 | 1600 | x | | |
| 330 | FGK-330-25000 | 1600 | x | | |
| 14.4 | FK-339-14.4-1500 | 2000 | x | | |
| 34.5 | FK-339-34.5-2500 | 2000 | x | | |
| 69 | FK-439-69-3500 | 2000 | x | | |
| 14.4 | FK-339-14.4-1000 | 3000 | x | | |
| 14.4 | FK-339-14.4-1500 | 4000 | x | | |

A - Any tap on bushing current transformer can be used with any BDD relay tap, provided one-way lead resistance from CT to relay does not exceed 0.25 ohms (or one way lead length of approximately 300 feet of 19/22 wire). No calculation necessary for percent ratio error.

B - These 1200/5 current transformers may be used to supply any tap of the BDD relay, provided CT turns used are 80 or more and one-way lead resistance from CT to relay does not exceed 0.25 ohms (one-way lead length of approximately 300 feet of 19/22 wire). May be used on 40 turn tap in some cases (lower lead resistance or lower relay taps).

C - Current transformer turns selected should be checked as described under "Calculations" for percent ratio error.

when only one CT supplies current, and the tap plug for the CT is in the 5 ampere tap, 40 amperes are required for pickup. This pickup value is based on the a-c component of current transformer output only since the differential current transformer in the relay produces only a half cycle of any d-c (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating, the overcurrent unit will not pickup on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pickup under certain circumstances. If this condition should arise, it is recommended that the CT ratio or relay tap setting be increased rather than increasing the pickup of the overcurrent unit. If the overcurrent setting must be raised, the requirements on CT error will be more stringent in accordance with the following equation:

$$E = 20 - (2.5)(P-8)$$

where E = CT error current in percent at pickup of the overcurrent unit.

P = pickup of overcurrent unit in multiples of tap setting.

## PERCENTAGE DIFFERENTIAL CHARACTERISTICS

The percentage differential characteristics are provided by through current restraint circuits. In

Fig. 1 (378A588)

Fig. 2 (378A587)

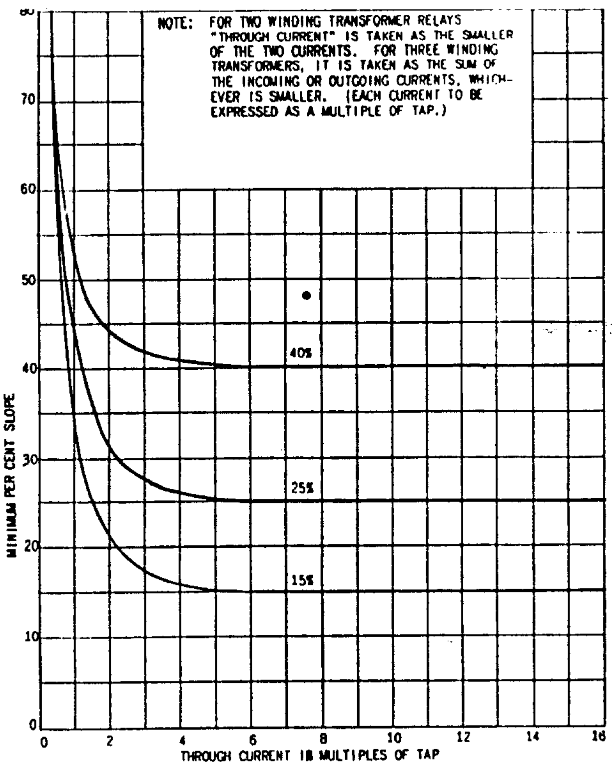



Fig. 1 Operating Characteristics of Type BDD Relay

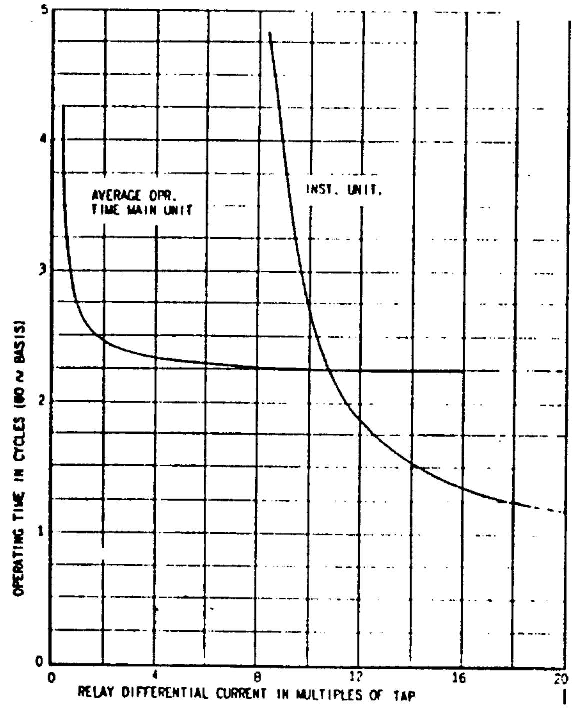



Fig. 2 Operating Time Characteristics of Type BDD Relay

addition to the operating coil of the polarized relay, which is energized by the differential current of the line current transformers, the relay is equipped with a restraining coil which is indirectly energized by the transformer secondary currents themselves. For the relay to operate, the current transformer secondary currents must be unbalanced by a certain minimum percentage determined by the relay slope setting (as shown in Fig. 1). This characteristic is necessary to prevent false operation on through fault currents. High currents saturate the cores of the current transformers and cause their ratios to change, with the result that the secondary currents become unbalanced. Percentage restraint is also needed to prevent operation by the unbalanced currents caused by imperfect matching of the secondary currents as previously described under RATIO MATCHING TAPS.

## HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary which establishes the required flux in the core. This current is called magnetizing inrush, and flows only through the current transformers in the primary winding. This causes an unbalance current to flow in the differential relay which would cause false operation if means were not provided to prevent it.

Power system fault currents are of a nearly pure sine waveform plus a d-c transient component. The sine waveform results from sinusoidal voltage generation and nearly constant circuit impedance. The d-c component depends on the time in the voltage cycle at which the fault occurs and upon the circuit impedance magnitude and angle.

Transformer magnetizing inrush currents vary according to the extremely variable exciting impedance resulting from core saturation. They are often of high magnitude, occasionally having an RMS value with 100 percent offset approaching 16 times full load current for worst conditions of power transformer residual flux and point of circuit closure on the voltage wave. They have a very distorted waveform made up of sharply peaked half-cycle loops of current on one side of the zero axis, and practically no current during the opposite half cycles. The two current waves are illustrated in Fig. 3.

Any current of distorted, nonsinusoidal waveform may be considered as being composed of a direct-current component plus a number of sine-wave components of different frequencies; one of the fundamental system frequency and the others, called "harmonics" having frequencies which are 2, 3, 4, 5, etc., times the fundamental frequency. The relative magnitudes and phase positions of the harmonics with reference to the fundamental determine the wave form. When analyzed in this manner the typical fault current wave is found to contain only a very small percentage of harmonics while the typical magnetizing inrush current wave contains a considerable amount.

The high percentages of harmonic currents in the magnetizing inrush current wave afford an excellent means of distinguishing it electrically from the fault current wave. In the Type BDD relays, the harmonic components are separated from the fundamental component by suitable electric filters. The harmonic current components are passed through the restraining coil of the relay, while the fundamental component is passed through the operating coil. The direct current component present in both the magnetizing inrush and offset fault current waves is largely blocked by the auxiliary differential current transformer inside the relay and produces only a slight momentary restraining effect. Relay operation occurs on differential current waves in which the ratio of harmonics to fundamental is lower than a given predetermined value for which the relay is set (e. g. an internal fault current wave) and is restrained on differential current waves in which the ratio exceeds this value (e. g. a magnetizing inrush current wave).

## RATINGS

### CURRENT CIRCUIT

<u>Models 12BDD15B and 12BDD16B</u>

Continuous - The through current transformer and the differential current transformer will stand twice tap rating for any combination of taps or they will stand twice tap value if all but one of the restraint windings carry zero current and the full

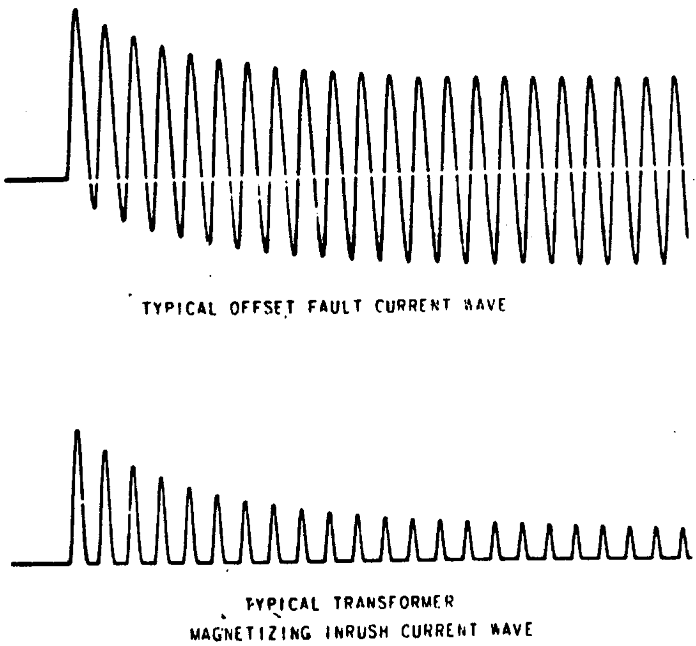



Fig. 3 (K-6209195)

Fig. 3 Fault Current And Magnetizing Inrush Current Waves

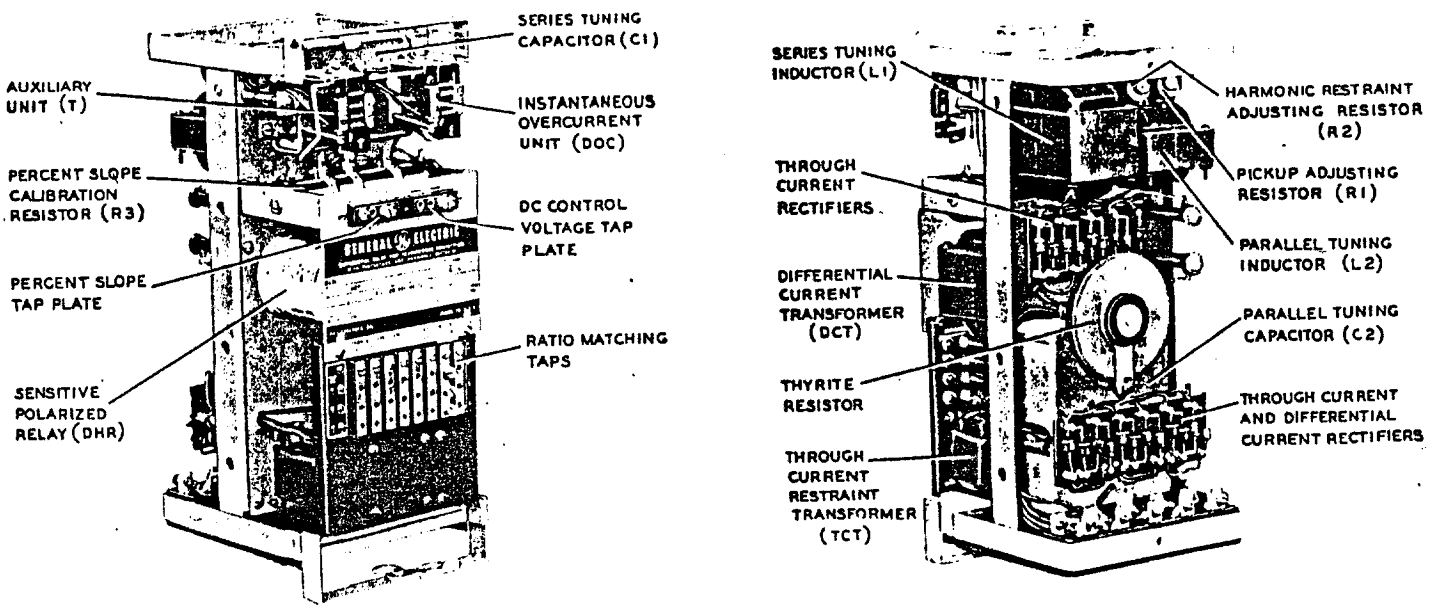



Fig. 4 Right (8021516)

Fig. 4 Left (8021515)

Fig. 4 Type BDD Relay In Cradle Front And Rear Views restraint current, equal to twice tap rating, flows through the differential current transformer.

Short Time (thermal) - 220 amperes for 1 second measured in the primary of any transformer of the Type BDD relay. Higher currents may be applied for shorter lengths of time in accordance with the following equation:

$$I^2 t = 48{,}400$$

Short time (electrical) - For both BDD15B and BDD16B relays, 150 times tap value RMS total internal fault current. For BDD16B relays, 150 times tap value external fault current for each of two circuits. For example in Fig. 9, current might flow through 52-1 and 52-2 without being limited by the transformer impedance.

AUXILIARY RELAY CONTROL CIRCUIT

Type BDD15B and BDD16B relays are available for use with either 24 and 48 or 125 and 250 d-c control voltage. A tap block is provided so that the relays may be used on either voltage of the dual rating.

CONTACTS

Type BDD15B relay is provided with two sets of open contacts and the Type BDD16B is provided with one set of open contacts. The current-closing rating of the contacts is 30 amperes for voltages not exceeding 250 volts. If more than one circuit breaker per set of contacts is to be tripped, or if the tripping current exceeds 30 amperes, an auxiliary relay must be used with the BDD relay. After tripping occurs, it is necessary that the tripping circuit of these relays be opened by an auxiliary switch on the circuit breaker or by other automatic means. A hand-reset relay is recommended and normally used.

# BURDENS

TABLE II

NOTE: Burdens and minimum pickup values are substantially independent of the percent slope settings and are all approximately 100 percent power factor. Figures given are burdens imposed on each current transformer at 5.0 amperes.

| Relay | Tap Setting | Zero-Restraint Pickup ‡ | Operating Circuit* 60 Cycle Relays+ | | Restraint Circuit 60 Cycle Relays+ | |
|---|---|---|---|---|---|---|
| | Amps | Amps | Burden VA | Imped. Ohms | Burden VA | Imped. Ohms |
| 12BDD15B<br>12BDD16B | 2.9 | 0.87 | 3.2 | 0.128 | 1.3 | 0.052 |
| | 3.2 | 0.96 | 2.7 | 0.108 | 1.2 | 0.048 |
| | 3.5 | 1.05 | 2.4 | 0.096 | 1.1 | 0.044 |
| | 3.8 | 1.14 | 2.0 | 0.080 | 1.0 | 0.040 |
| | 4.2 | 1.26 | 1.9 | 0.076 | 0.9 | 0.036 |
| | 4.6 | 1.38 | 1.6 | 0.064 | 0.8 | 0.032 |
| | 5.0 | 1.50 | 1.5 | 0.060 | 0.7 | 0.028 |
| | 8.7 | 2.61 | 0.7 | 0.028 | 0.5 | 0.020 |

* Burden of operating coil is zero under normal conditions.

\+ Burden of 50 cycle relay is the same or slightly lower.

‡ It should be recognized that pickup current flows not only through the differential current transformer but also through one of the primary windings of the through current transformer producing some restraint. However, compared to the operating energy, this quantity of restraint is so small that it may be assumed to be zero.

# RECEIVING, HANDLING AND STORAGE

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

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

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

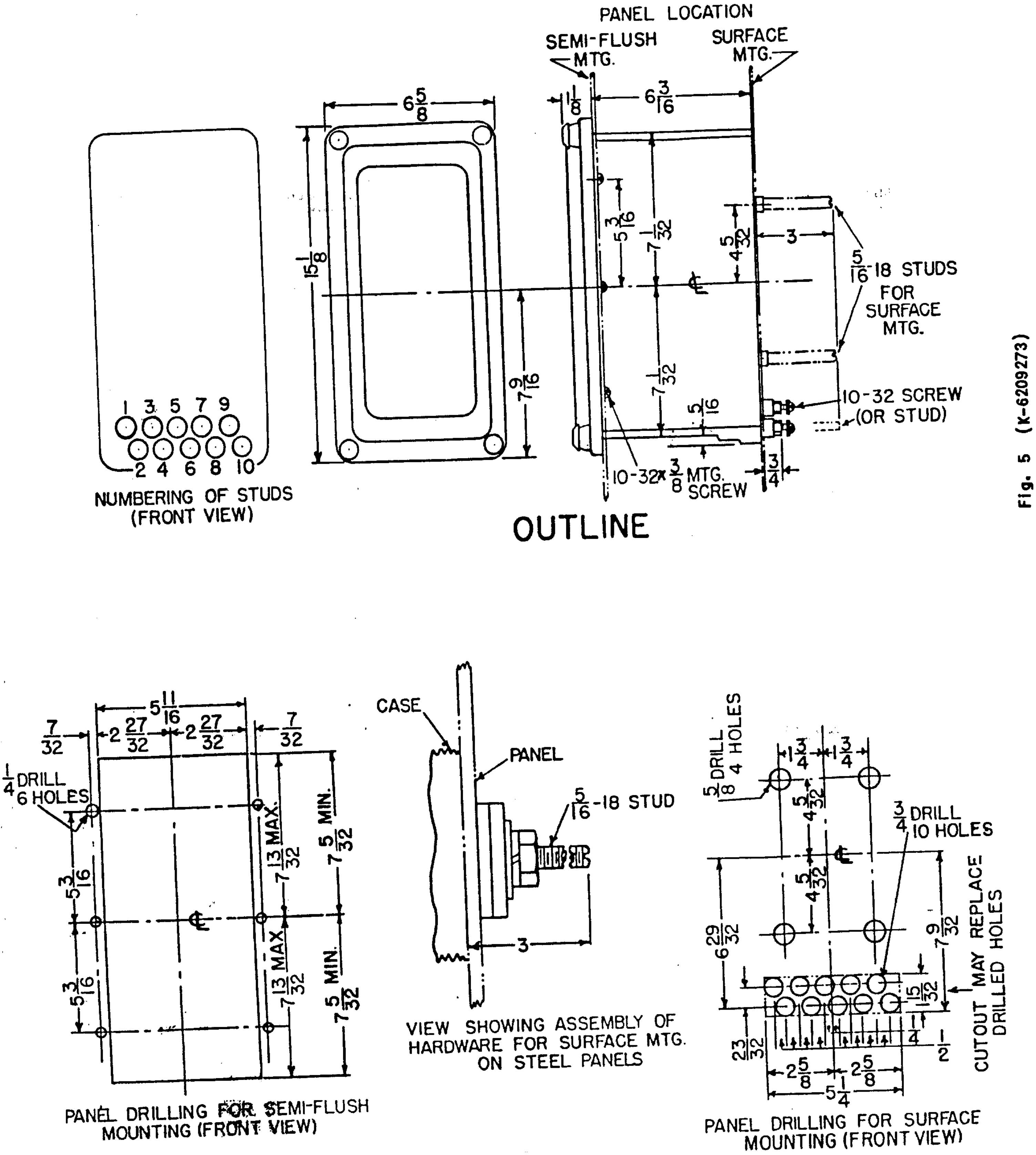



Fig. 5 Outline And Panel Drilling Dimensions For Type BDD Relay

# DESCRIPTION

Each Type BDD relay is a single phase unit. The Type BDD15B relay is designed to be used for the protection of two-winding power transformers and has two through current restraint circuits and one differential current circuit. This relay has two sets of open contacts with a common connection between the two sets.

The Type BDD16B relay is designed for use with three-winding power transformers and has three through current restraint circuits and one differential current circuit. It may also be used for four circuit transformer protection (see Fig. 9) when only three circuits need through current restraint and the fourth circuit is the weakest and needs no through-current restraint.

## INTERNAL CONSTRUCTION AND CIRCUITRY

Fig. 4 shows the internal arrangement of the components of the BDD16B relay. Fig. 6 shows the arrangement of rectifiers on the rectifier boards. Reference also to the internal connection diagrams, Figs. 10 and 11 will identify the parts more completely.

### CURRENT TRANSFORMERS

In the Type BDD15B relay, the through current transformer has two primary windings, one for each line current transformer circuit. Winding No. 1 terminates at stud 6 and winding No. 2 terminates at stud 4.

In the Type BDD16B relay there are three separate through current transformers, each with only one primary winding and each terminating at a separate stud, windings No. 1, No. 2, and No. 3 corresponding to studs 6, 4, and 3 in that order.

In either relay there is a differential current transformer with one primary lead brought out to stud 5.

The primary circuit of each of these transformers is completed through a special tap block arrangement. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type BDD16B or BDD15B), one row for each through current transformer winding. A tap on the differential current transformer is connected to a corresponding tap of the through current restraint windings by inserting tap plugs in the tap blocks.

When the BDD16B relay is used on four-circuit applications as shown in Fig. 9, the fourth circuit CT is connected to stud 7, and the jumper normally connected between terminals 6 and 7 at the rear of the relay cradle should be disconnected at the terminal 6 end and reconnected to the upper row in the tap block (above the row marked winding 1) which connects it directly to the differential current transformer in the BDD relay. The terminal on the

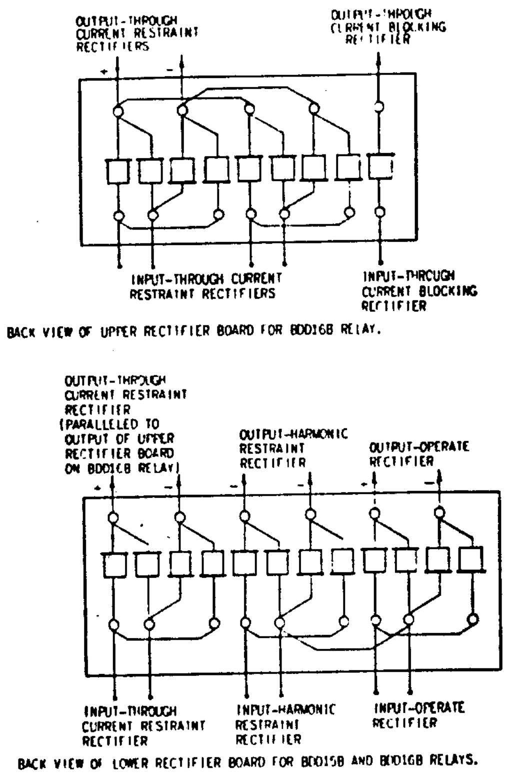



Fig. 6 Bridge Arrangement on BDD15B and BDD16B Rectifier Boards

Fig. 6 (418A780)

movable lead should be placed under the tap screw which gives the best current match for the current in the movable lead.

The taps permit matching of unequal line current transformer secondary currents. The tap connections are so arranged that in matching the secondary currents, when a tap plug is moved from one position to another in a horizontal row, corresponding taps on both the differential current transformer winding and one of the through current transformer windings are simultaneously selected so that the per cent through current restraint remains constant.

### THROUGH CURRENT RESTRAINT CIRCUIT

A full wave bridge rectifier receives the output of the secondary of each through current restraint transformer. In the BDD16B, the d-c outputs of all three units are connected in parallel. The total output is fed to a tapped resistor ($R_3$) through the percent slope tap plate at the front of the relay. By means of the three taps a 15, 25, or 40 percent slope adjustment may be selected. Resistor taps are adjustable and preset for the given slopes. The right tap corresponds to the 40 percent slope setting. The output is rectified and applied to the restraint coil of the polarized relay.

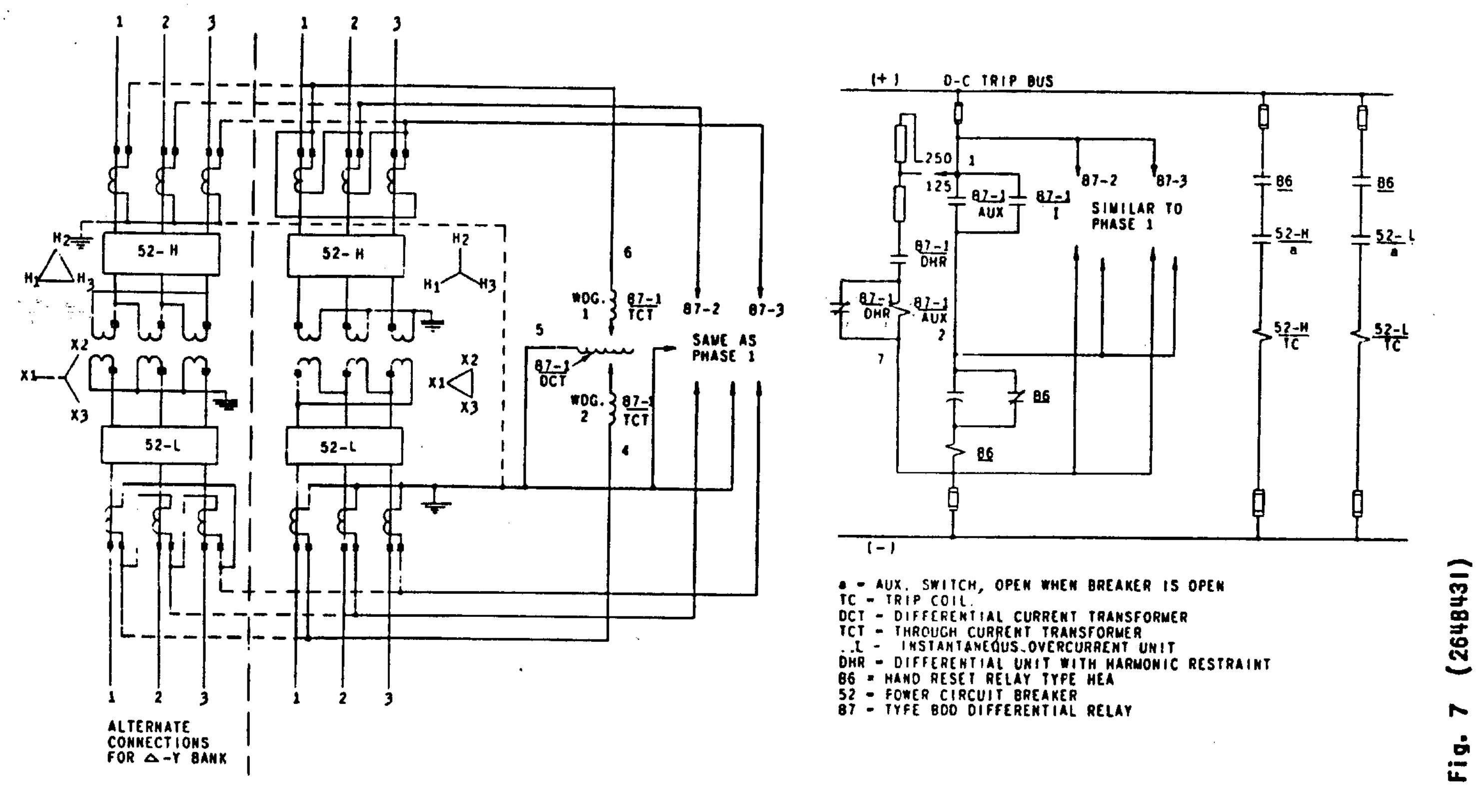



Fig. 7 Elementary Diagram of Type BDD15B Relays for 2 Winding Transformer Protection

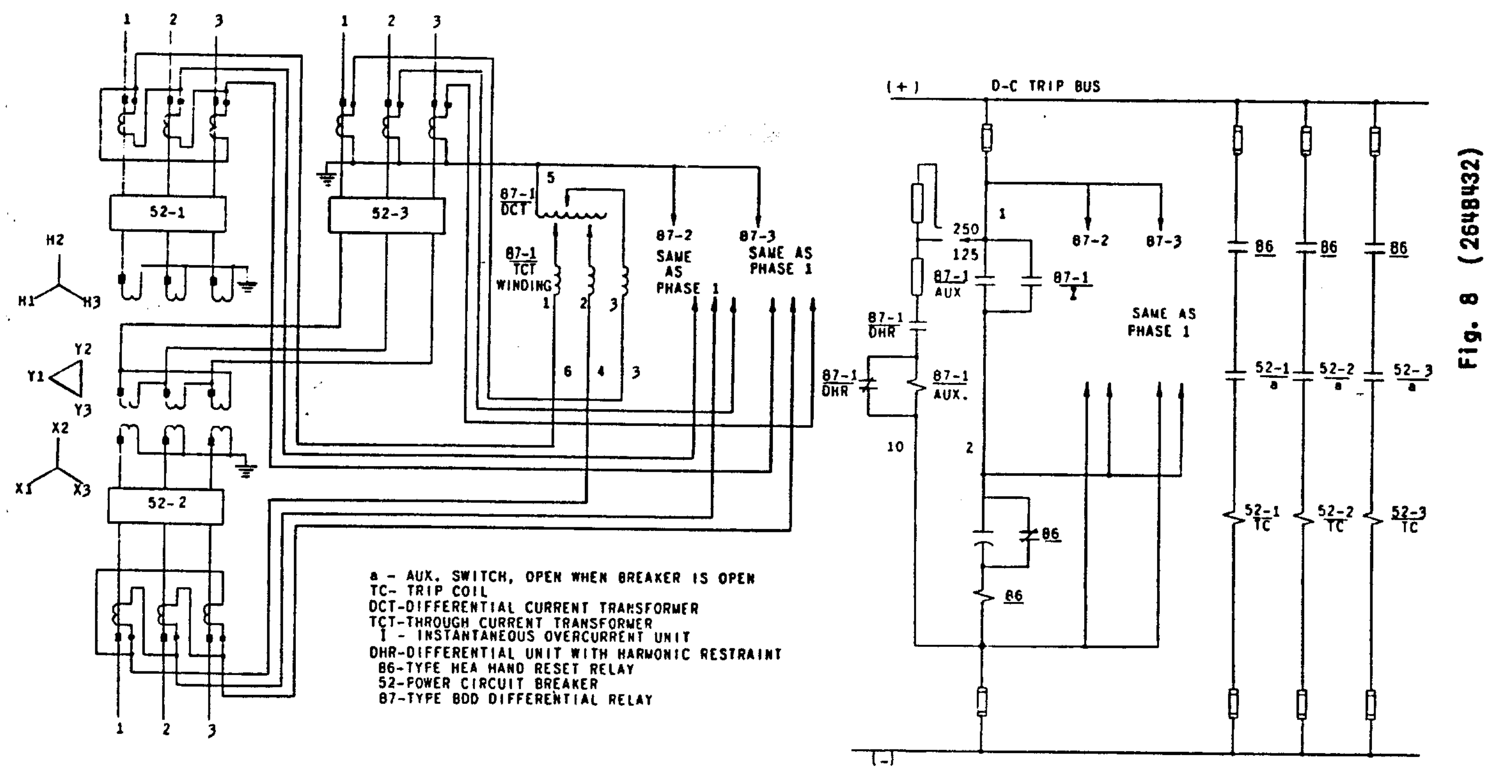



Fig. 8 Elementary Diagram of Type BDD16B Relays for 3 Winding Transformer Protection

Fig. 9 (2648989)

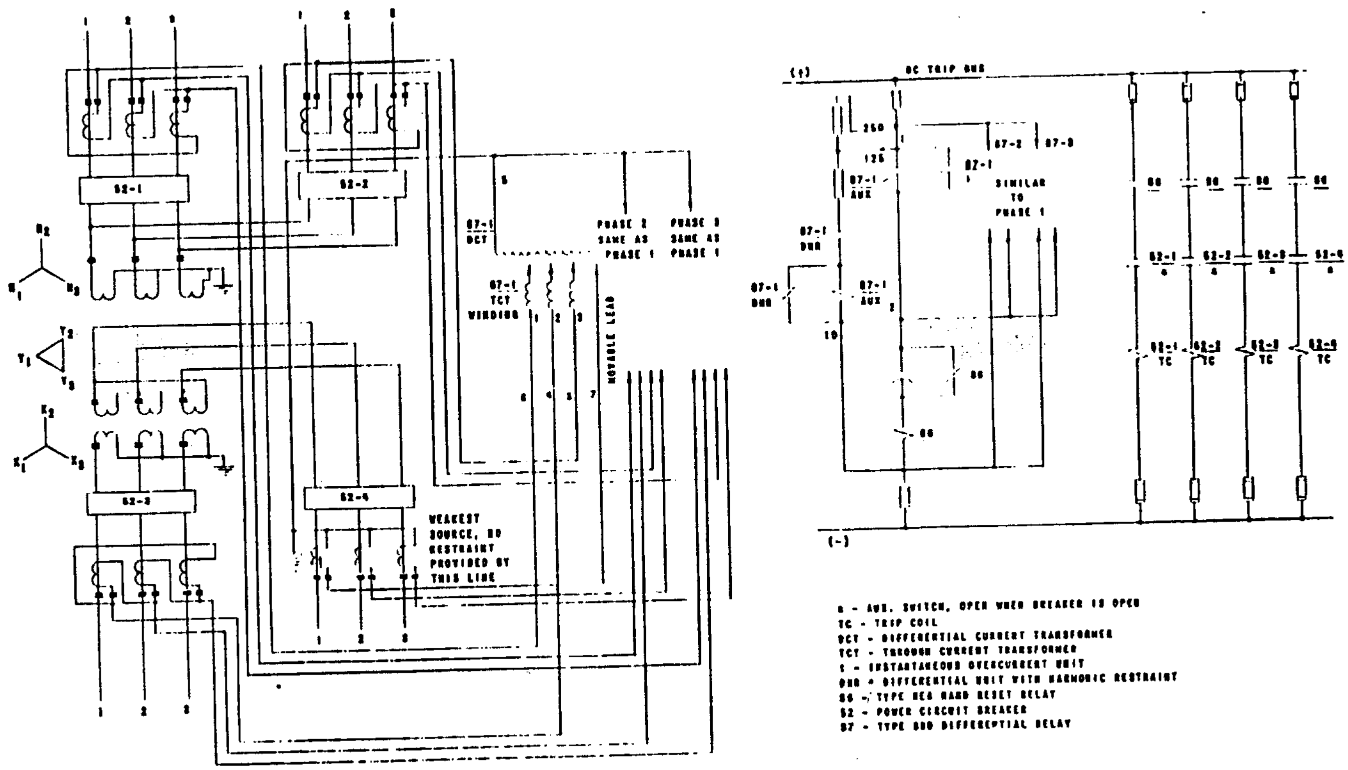



Fig. 9 Elementary Diagram of Type BDD16B Relays for 4 Circuit Transformer Protection with Three Restraints

## DIFFERENTIAL-CURRENT CIRCUIT

The differential current transformer secondary output supplies the instantaneous unit directly, the operating coils of the polarized relay through a series tuned circuit, and the harmonic restraint circuit through a parallel resonant trap. The operating and restraint currents are each passed through a full wave bridge rectifier before passing through the polarized relay coils.

The series resonant circuit is made up of a 5 microfarad Pyranol capacitor (C1) and a reactor (L1) which are tuned to pass currents of the fundamental system frequency and to offer high impedance to currents of other frequencies. Resistor R1 is connected in parallel on the d-c side of the operate rectifier and can be adjusted to give the desired amount of operate current. The output of the rectifier is applied to the operate coil of the polarized relay.

The parallel resonant trap is made up of a 15 microfarad Pyranol capacitor (C2) and a reactor (L2) which are tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. Resistor R2 is connected in parallel on the a-c side of the harmonic restraint rectifier and can be adjusted to give the desired amount of harmonic restraint. The output of the rectifier is paralleled with the through current restraint currents and applied to the restraint coil of the polarized relay.

It will be evident that if the differential current applied to the Type BDD relay is of sinusoidal wave form and system frequency, it will flow mostly in the operating coil circuit and will cause the relay to operate. If, on the other hand, the differential current contains more than a certain percentage of harmonics, the relay will be restrained from operating by the harmonic currents flowing in the restraint coil.

A Thyrite resistor connected across the secondary of the differential current transformer limits any momentary high voltage peaks which may occur, thus protecting the rectifiers and capacitors from damage without materially affecting the characteristics of the relay.

## OVERCURRENT UNIT

The instantaneous unit is a hinged armature relay with a self contained target indicator. On extremely heavy internal fault currents, this unit will pick up and complete the trip circuit. The instantaneous unit target (I) will be exposed, to indicate that tripping was through the instantaneous unit.

Because of saturation of the CT's and relay transformers at high fault currents, it is possible that less operating current will be provided from

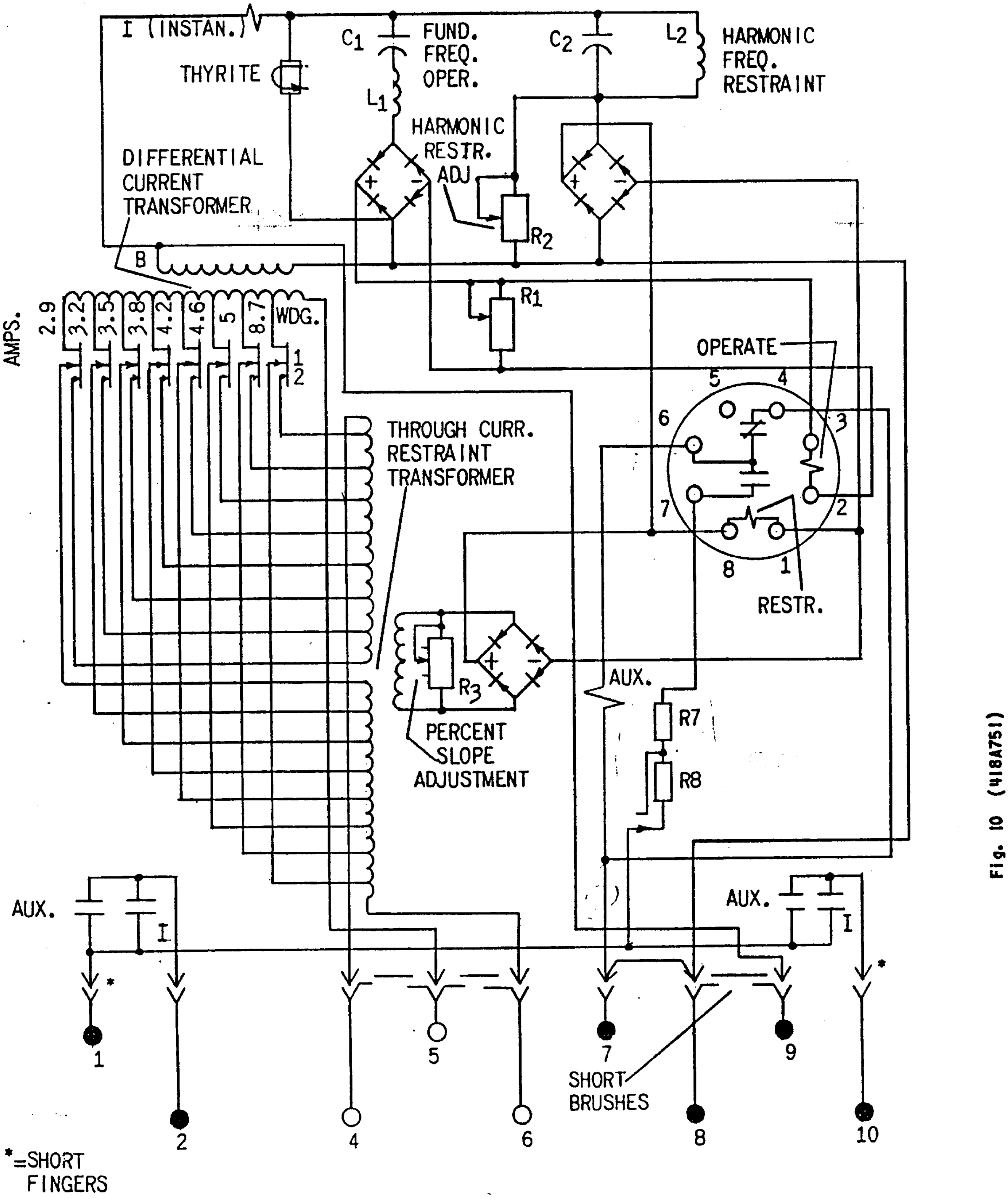



Fig. 10 Internal Connections for Type BDD15B Relay

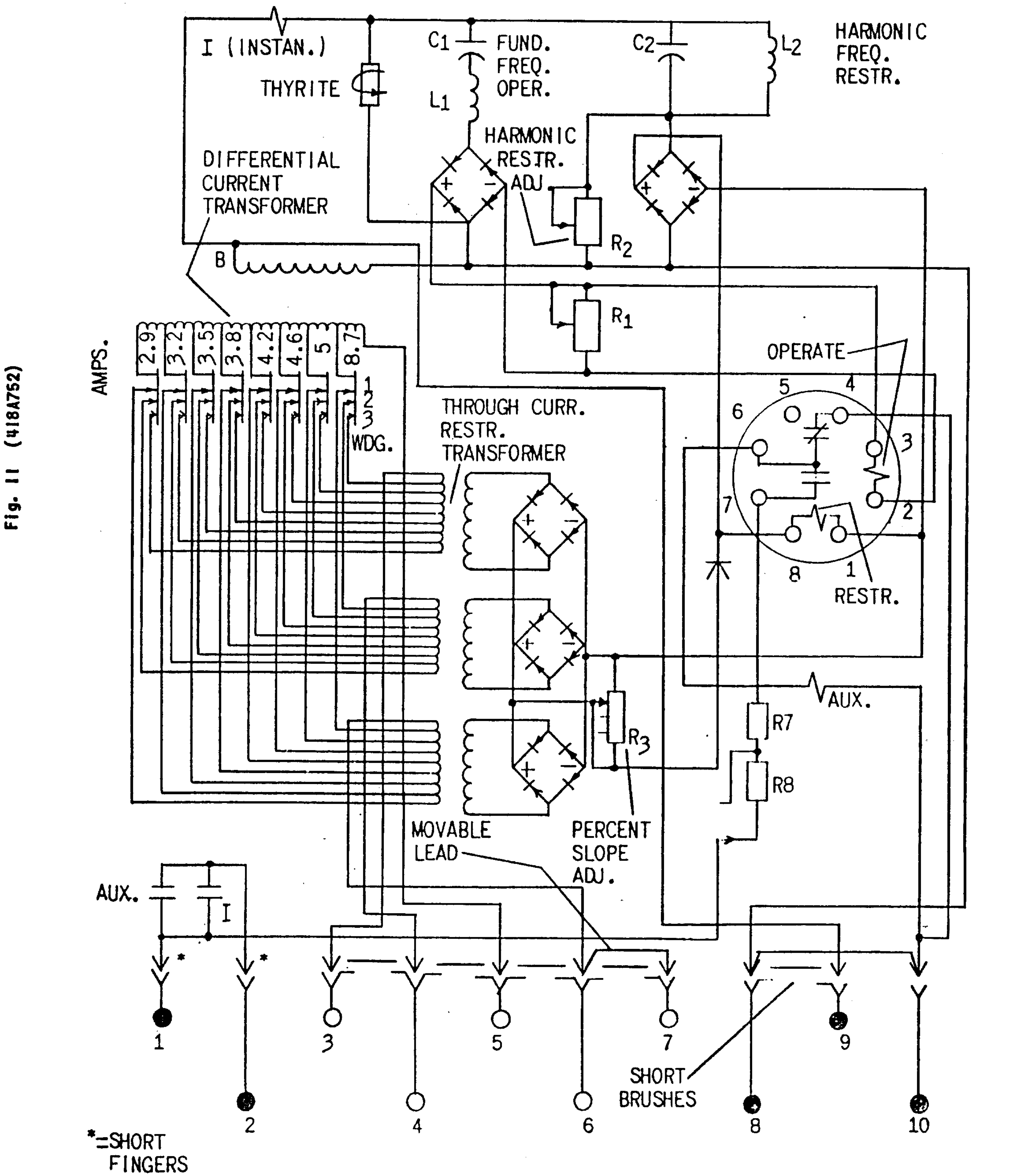



Fig. 11 Internal Connections of Type BDD16B Relay

the differential-current transformer than the percentage slope tap would imply, and more harmonic restraint will be provided than the actual harmonic content of the fault current would supply. As a result, under conditions of a high internal fault current, the main unit may be falsely restrained. Tripping is assured, however, by the overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Fig. 2 shows the relative levels of pickup and speed of operation of the main unit and the overcurrent unit.

MAIN OPERATING UNIT

The main operating unit of the Type BDD relay is a sensitive polarized relay with components as shown within the large circle on Internal Connection diagrams Figs. 10 and 11. The relay has one operating and one restraining coil and its contacts are identified as DHR (differential harmonic restraint) on the diagrams of external connections, Figs. 7, 8 and 9. The relay is a high-speed low energy device, and its contacts are provided with an auxiliary reay (T) whose contacts are brought out to studs for connection in an external circuit.

The polarized relay is mounted on an eight-prong base which fits a standard octal radio socket, and is protected by a removable dust-cover. It is mounted behind the nameplate of the BDD relay and should require no further adjustment after it leaves the factory.

The auxiliary relay (T) carries an indicating target and is identified by the letter T stamped on its face. The coil of this relay is not connected in the main contact circuit as a seal-in coil, but is connected to the d-c control bus through an open contact of the polarized relay and through a series resistor. A tap block is provided on the nameplate for selecting either of two d-c control voltages.

The coil of the auxiliary relay is controlled by both the open and closed contacts of the polarized relay. The polarized relay has approximately 0.005 inch contact gap which under transient overvoltage conditions on the d-c control bus of the order of 1200 volts could break down momentarily. This will not cause false operation in the event that such a condition occurs, because the auxiliary relay is normally short-circuited by the closed contact of the polarized unit and the series resistance is high enough to cause the arc to go out at normal voltage.

## CASE

The case is suitable for surface or semiflush panel mounting and an assortment of hardware is provided for either method. The cover attaches to the case and carries the target reset mechanism for the trip indicator and instantaneous unit. Each cover screw has provision for a sealing wire.

The case has studs or screw connections at the bottom for the external connections. The electrical connections between the relay unit and the case studs are made through spring backed contact fingers mounted in stationary molded inner and outer blocks between which nests a removable connecting plug which completes the circuit. The outer block, attached to the case, holds the studs for the external connection, and the inner block has terminals for the internal connections.

The relay mechanism is mounted in a steel framework called the cradle and is a complete unit with all leads terminating at the inner block. This cradle is held firmly in the case with a latch at the top and bottom and by a guide pin at the back of the case. The case and cradle are so constructed that the relay cannot be inserted in the case upside down. The connecting plug, besides making the electrical connection between the blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plug in place.

To draw out the relay unit, the cover is removed and the plug is drawn out. Shorting bars are provided in the case to short the current transformer circuits. The latches are then released and the relay unit can be easily drawn out.

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

# INSTALLATION

TESTS

Before placing the relays in service, most users consider it advisable to check the relay calibration as it is received from the factory to insure that it is correct. The following test procedure is outlined for this purpose.

CAUTION: The relay calibration is accomplished by adjusting resistors $R_1$, $R_2$, and $R_3$. Changes made in any one of these resistors will affect the other two settings. In the event one setting is changed, the PICKUP, HARMONIC RESTRAINT, and THROUGH CURRENT RESTRAINT adjustment procedures should be repeated until no further deviation from proper calibration is noted. Best results can be obtained if the through current restraint adjustment is made only after the other two settings are correct.

PICKUP

The test circuit for pickup is as shown in Fig. 13 with S2 open. Pickup should be 1.5 amperes with current flowing in terminals 5 and 6 and tap plugs in the 5 ampere and 25 percent slope tap positions. The pickup operation should be repeated several times until two successive readings

Fig. 12 (418A772)

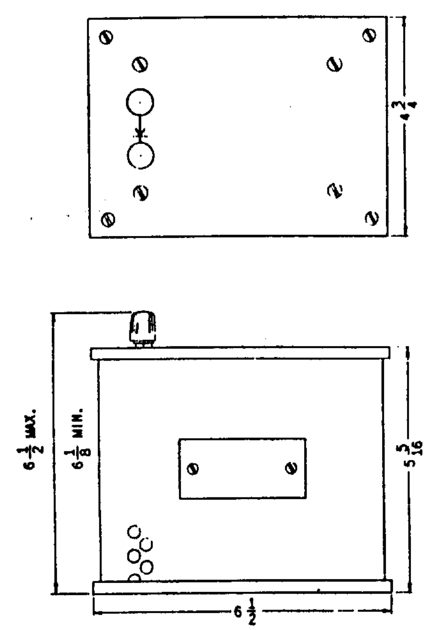



Fig. 12 Outline of Test Rectifier

Fig. 13 (418A771)

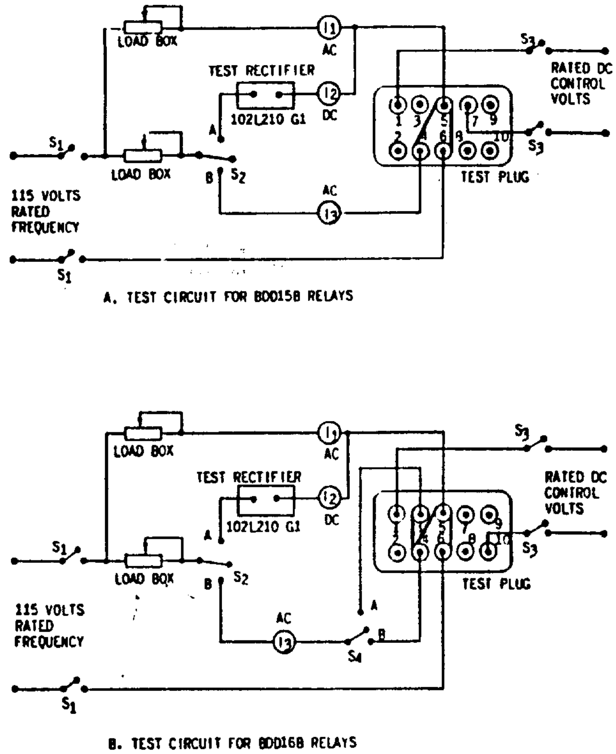



Fig. 13 Test Connections

agree within 0.01 ampere with total pickup current being interrupted between successive checks.

The pickup of the polarized unit varies slightly depending upon the previous history of its magnetic circuit. The repeated pickup operation restores the condition of the magnetic circuit to some reference level thus eliminating any initial variation in magnetic history.

The condition of the magnetic circuit is influenced by the manner in which pickup current is removed after a test. For this reason, pickup readings will be slightly lower if the current in the differential circuit is reduced gradually than if the current is abruptly reduced or interrupted. The reason for this is that energy is stored in the series tuned circuit when the current is applied. This energy is dissipated in the harmonic restraint circuit, the path of least impedance, when the current is abruptly reduced or removed. The restraint coil of the polarized unit, having approximately three times as many turns as the operating coil, receives a greater saturating effect than the operating coil. The net effect is the same as though a restraint saturating current were applied to the relay.

Since the Type BDD relay uses a polarized unit with a very low energy level, the minimum pickup setting may vary as much as plus-or-minus 10%. If pickup is found to be anywhere within this range (1.35-1.65), the setting should not be disturbed. This variation is greater than normally expected in protective relays, but because of the sensitivity, the accuracy of the relay under inrush or through fault conditions is not substantially impaired by this change.

With d-c control voltage applied to the proper studs of the relay, the pickup of the auxiliary relay (T) can be used as an indication of operation of the polarized relay unit. This voltage may be applied externally, as shown in Fig. 13, or from the station d-c trip bus. The latter is accomplished by providing a U-shaped through jumper for each of the test plug studs corresponding to d-c control.

If pickup is found to be out of adjustment, it may be corrected by adjusting the position of the band on resistor $R_1$, which is connected in parallel with the operating coil of the polarized relay. Resistor $R_1$ is located at the top of the relay, and is the left-hand adjustable resistor (see Fig. 4).

## HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted by means of a Test Rectifier (Cat. 102L210 G1) used in conjunction with suitable ammeters and load boxes. The outline of the Test Rectifier is shown in Fig. 12. The test circuit is as shown in Fig. 13 with S2 closed to position A. Tests should be made on the 5.0 ampere and 25% slope taps.

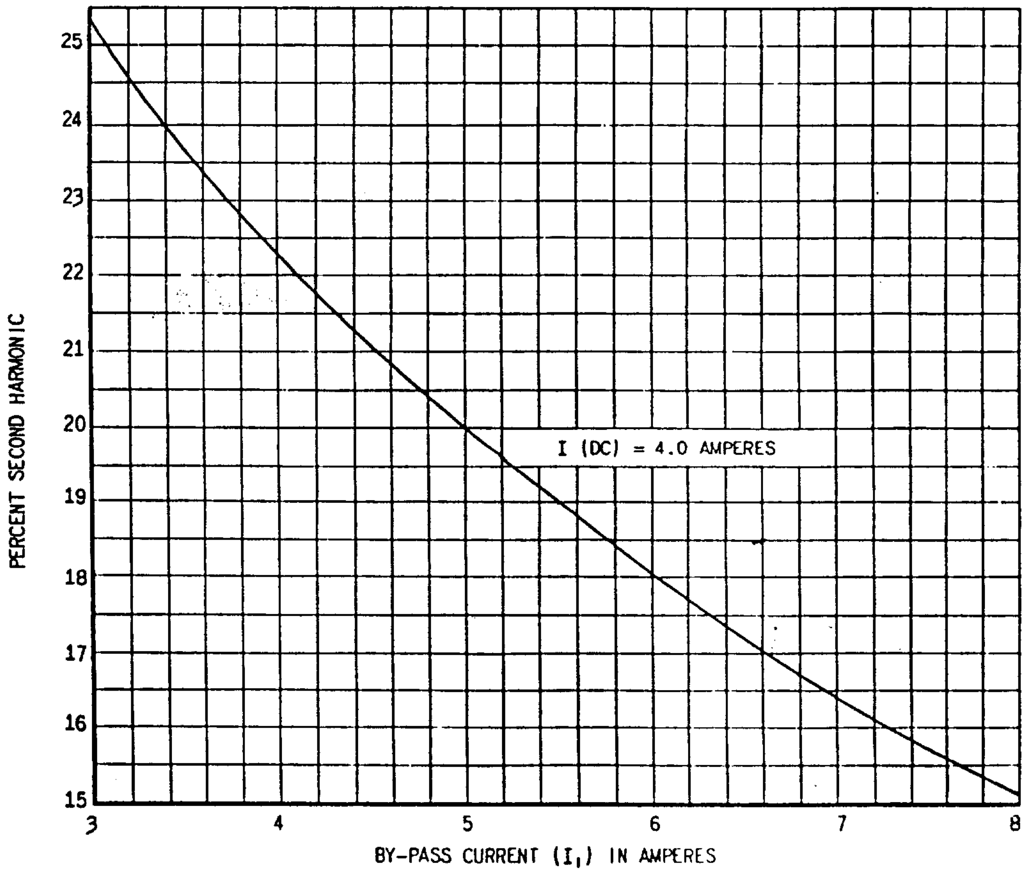



Fig. 14 (418A786)

**Fig. 14 Relationship Between Percent Second Harmonic And By-pass Current With I(DC) Set At 4.0 Amperes**

The analysis of a single phase half wave rectified current shows the presence of fixed percentages of d-c, fundamental, and second harmonic components as well as negligible percentages of all higher even harmonics. This closely approximates a typical transformer inrush current as seen at the relay terminals inasmuch as its principal components are d-c, fundamental, and second harmonic. Although the percent second harmonic is fixed, the overall percentage may be varied by providing a path for a controlled amount of by-passed current of fundamental frequency. The by-passed current is added in phase with the fundamental component of the half wave rectified current and thus provides a means of varying the ratio of second harmonic current to fundamental current.

The following expression shows the relationship between the percent second harmonic, the d-c component, and the by-pass current:

$$\% \text{ Second Harmonic} = \frac{0.212\, I_{d\text{-}c}}{0.45 I_1 + 0.5\, I_{d\text{-}c}} \times 100$$

Fig. 14 is derived from the above expression and shows the percent second harmonic corresponding to various values of by pass current ($I_1$) for a constant d-c set at 4.0 amperes.

Unless otherwise specified by the requisition, the relay is calibrated at the factory using the lower d-c control voltage tap. Since the percent second harmonic required to restrain the relay will be approximately one percent higher if the calibration is checked using the higher tap, harmonic restraint must be tested on the lower tap in order for the field test to agree with the factory calibration.

The relay is calibrated with a composite RMS current of two times tap value. When properly set the relay will restrain with greater than twenty percent second harmonic but will operate with second harmonic equal to twenty percent or lower. With the d-c ammeter ($I_2$) set at 4.0 amperes, the auxiliary relay should just begin to close its contacts with gradually increasing by-pass current ($I_1$) at a value of 4.5 - 5.5 amperes. This corresponds to 19 - 21 percent second harmonic (see Fig. 14) providing a two percent tolerance at the set point to compensate for normal fluctuations in pickup. It should be noted that the current magnitude in the rectifier branch ($I_2$) is slightly influenced by the application of by-pass current ($I_1$) and should be checked to insure that it is maintained at its proper value.

In the event a suitable d-c ammeter is not available, the proper half wave rectified current may be set using an a-c ammeter in position $I_2$ by shorting out the rectifier and setting the unrectified current at 9.0 amperes. If the rectifier is then unshorted, the half wave rectified current will automatically establish itself to the proper value.

If harmonic restraint is found to be out of adjustment, it may be corrected by adjusting resistor R2, which is connected in parallel, on the a-c side of the rectifier, with the restraint coil of the polarized relay. This resistor is located at the top of the relay and is the right hand adjustable resistor (see Fig. 4). There are two separate slide bands provided, a main band and an auxiliary. The main band, the one located nearest the fixed rear terminal of R2, is normally the only one used. The auxiliary band, normally unconnected, is used as a vernier when the adjustment by the main band becomes too coarse due to the main band being too close to the fixed rear terminal of R2. An extra lead, normally bolted to the fixed rear terminal of R2, is provided for connection to the auxiliary band when a finer adjustment becomes necessary. In effect, a high resistance is placed in parallel with a low resistance providing a means of finely controlling the overall resistance by varying the high resistance.

THROUGH CURRENT RESTRAINT

The through current restraint, which gives the relay the percentage differential or percent slope characteristics shown in Fig. 1, may be checked and adjusted using the circuit illustrated in Fig. 13 with S2 closed to position B. Ammeter $I_1$ reads the differential current and $I_3$ reads the smaller of the two through currents. In testing BDD16B relays the setting should be checked with the switch S4 first in one position and then the other, thus checking all the restraint coils. With the current tap plugs in the 5.0 ampere position and the percent slope tap plug in the 40 percent position, the relay should just pick up for values of the $I_1$ and $I_3$ currents indicated in Table III. Repeat with the percent slope tap plug in the 25 percent and 15 percent positions. If any one of these set points is found to be other than as prescribed, the adjustment may be made by adjusting the particular band on resistor $R_3$ (located near the top of the case, behind the nameplate) associated with it, as indicated in Table III. It should be noted that the current magnitude in the through current branch ($I_3$) is slightly influenced by the application of differential current ($I_1$) and should be checked to insure that it is maintained at its proper value.

Any change in $R_3$ to give the desired slope will have small effect upon minimum pickup and harmonic restraint. However, after the slope setting has once been set, any adjustment of minimum pickup will change the slope characteristics. The slope set points must then be rechecked to insure that they are in accordance with Table III.

NOTE: These currents should be permitted to flow for only a few seconds at a time with cooling periods between tests; otherwise, the coils will be overheated.

TABLE III

| Percent Slope Tap | Band on Res. $R_3$ | Amperes | | True Slope |
|---|---|---|---|---|
| | | $I_3$ | $I_1$ | $(I_1/I_3 \times 100)$ |
| 40 | Right | 30 | 12.0-13.2 | 40.0-44.0 |
| 25 | Middle | 30 | 7.5- 8.3 | 25.0-27.5 |
| 15 | Left | 30 | 4.5- 5.0 | 15.0-16.5 |

NOTE:- The percent slope tolerance is 10 percent of nominal, all in the plus direction. This is to insure that the slope characteristic never falls below tap value.

INSTANTANEOUS OVERCURRENT UNIT

This unit is located at the upper right-hand side of the relay and is marked I. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at 8 times the tap rating as described under OPERATING CHARACTERISTICS. If the setting is incorrect, it may be adjusted by loosening the lock-nut at the top of the unit and turning the cap screw until the proper pickup is obtained. In making this adjustment, the current should not be allowed to flow for more than approximately one second at a time.

## LOCATION

The location should be clean and dry, free from dust and excessive vibration, and well lighted to facilitate inspection and testing.

## MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Fig. 5.

## CONNECTIONS

Internal connection diagrams are shown in Figs. 10 and 11. Typical wiring diagrams are given in Figs. 7, 8 and 9 for differential applications, and in Fig. 17 for straight overcurrent applications.

Of course, any through current transformer winding may be used for any power transformer winding provided the taps are properly chosen.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor not less than No. 12 B&S gage copper wire or its equivalent.

Every circuit in the drawout case has an auxiliary brush. This is the shorter brush in the case which the connecting plug should engage first. On every current circuit or other circuit with shorting bars, make sure the auxiliary brushes are bent high enough to engage the connecting plug or test plug before the main brushes; otherwise, the CT secondary circuit may be opened where one brush touches the shorting bar before the circuit is completed from the plug to the other main brush.

# ADJUSTMENTS

## TAP PLUG POSITIONING

### RATIO MATCHING ADJUSTMENT

To obtain a minimum unbalance current in the differential circuit, means are provided in the BDD relay to compensate for unavoidable differences in current transformer ratios. Taps on the relay transformer primary windings are rated 8.7, 5.0, 4.6, 4.2, 3.8, 3.5, 3.2, and 2.9 amperes for each line current transformer. The tap plugs should be moved to the locations which most nearly match the expected CT currents for the same KVA assumed in each of the power transformer windings. The selection of taps should be guided by the method outlined under CALCULATIONS. The connection plug should be removed from the relay before changing tap positions in order to prevent open-circuiting a CT secondary. A check should be made after changing taps to insure that only one plug is left in any horizontal row of tap holes. Inaccurate calibration and overheating may result if more than one plug is connected to any one winding.

### UNBALANCE CURRENT MEASUREMENT

Unbalance current measurement is useful in checking the best tap setting when matching current transformer ratios in the field. It is also useful in detecting errors or faults in the current transformer winding, or small faults within the power transformer itself where the fault current is too low to operate the relay.

The Type BDD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provision is made for temporarily connecting a 5 volt high-resistance voltmeter (1000 or more ohms per volt) across the secondary of the differential current transformer. This may be done by connecting the meter across terminals 8 and 9 (see Figs. 11 and 12). When a perfect match of relay currents is obtained by the ratio matching taps, the voltmeter will read zero, indicating no unbalance. If the voltmeter reads 0.4 volts or less, the unbalance current entering or leaving a given tap equals approximately 0.05 times the voltmeter reading times the tap rating. For higher voltmeter readings, the approximate unbalance current may be calculated by substituting the voltage reading and tap rating into the following equation:

$$I\,(\text{unbalance}) = (0.115V - 0.025) \times \text{Tap}$$

The unbalance percentage equals 100 times the unbalance current divided by the measured tap current. For a three winding bank, this must be checked with load on at least two pairs of windings in order to insure that the connections are correct.

The curves in Fig. 15 show the approximate voltages across terminals 8 and 9 required to operate the relay for various percent slope tap settings and through currents expressed as percentages of tap. To insure a margin of safety against false operation, the unbalance voltage should not exceed 75 percent of that required to operate the relay for any given through current and percent slope tap setting. This extent of unbalance may result from the relatively high error currents of low ratio bushing CT's at low multiples of tap current.

Small rectifier-type AC voltmeters are suitable for the measurement of unbalance. The voltmeter should not be left permanently connected since the shunt current it draws reduces the relay sensitivity.

### PERCENT SLOPE SETTING

Taps for 15, 25, and 40 percent slope settings are provided in both the BDD15B and BDD16B relays. It is common practice to use the 25 percent setting unless special connections make it advisable to use one of the others. See the corresponding heading under CALCULATIONS for further details.

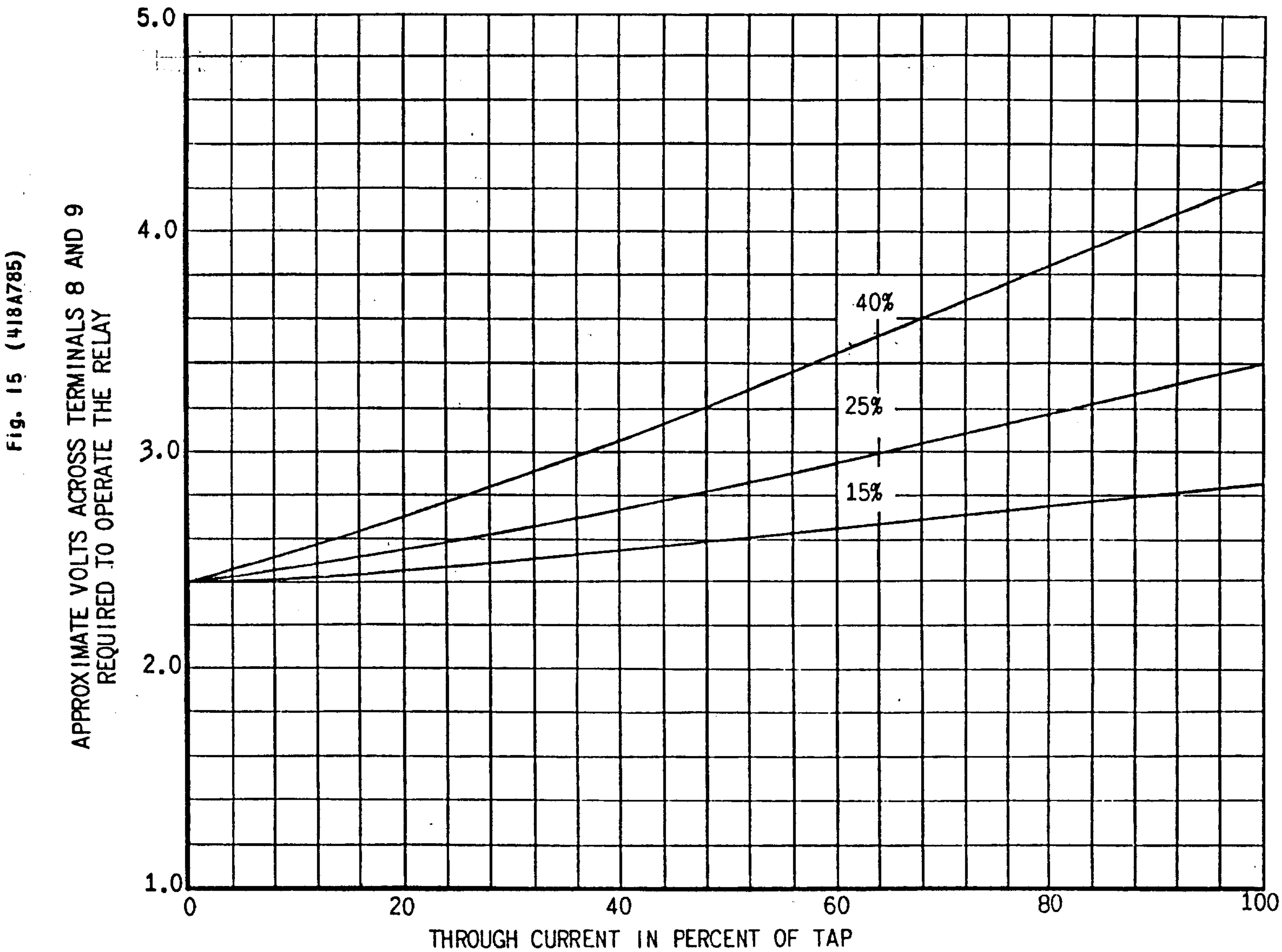



Fig. 15 Differential Voltage Operating Characteristics of Type BDD Relay

# CALCULATIONS

## METHOD

The calculations required for determining the proper relay and CT taps are outlined below. A sample calculation, for the transformer shown in Fig. 16, is shown on the opposite page.

### CURRENT TRANSFORMER CONNECTIONS

| Power Transformer Connections | Current Transformer Connections |
|---|---|
| Delta-Wye | Wye-Delta |
| Wye-Delta | Delta-Wye |
| Delta-Delta | Wye-Wye |
| Wye-Wye | Delta-Delta |
| Delta-Zigzag with zero degrees phase shift between primary and secondary | Delta-Delta |

### DETERMINATION OF CT TURNS AND TYPE BDD RELAY TAP SETTING

1. Determine maximum line currents (Max. $I_p$) on the basis that each power transformer winding may carry the maximum forced cooled rated KVA of the transformer.

$$\text{Max. } I_p = \frac{\text{Maximum Transformer KVA}}{\sqrt{3}\ \text{(Line KV)}}$$

2. Determine the full load rated line currents (100% $I_p$) on the basis that each power transformer winding may carry the full self-cooled rated KVA of the transformer.

$$100\ \%\ I_p = \frac{100\%\ \text{Transformer KVA}}{\sqrt{3}\ \text{(Line KV)}}$$

3. Select CT ratios so that the secondary current corresponding to maximum $I_p$ does not exceed the CT secondary rating (5 amperes). Also select CT ratios so that the relay currents can be properly matched by means of the relay taps. (Highest current not more than 3 times lowest current).

For Wye connected CT's

$$\text{Tap Current} = \frac{100\%\ I_p}{N}$$

For Delta connected CT's

$$\text{Tap Current} = \frac{100\%\ I_p\ \sqrt{3}}{N}$$

where N is the number of CT secondary turns

4. Check the matching of relay currents to relay taps to keep the mismatch error as low as possible. This error, plus the variation due to tap changing means (when used), should not exceed 15%. Therefore, when tap changing means are used, the mismatch error at the middle of a plus-or-minus 10 percent power transformer tap range should not exceed 5 percent.

Calculate the percent of mismatch as follows:- On two winding transformers, determine the ratio of the two relay currents and the ratio of the two tap values selected. The difference between these ratios, divided by the smaller ratio, is the percent of mismatch.

For three-winding transformers, the percent of mismatch error should be checked for all combinations of currents or taps.

If taps cannot be selected to keep this percentage error within allowable limits, it will be necessary to choose a different CT ratio on one or more lines to obtain a better match between relay currents and relay taps.

5. Check to see that the sum of the relay currents that will be applied to the relay for a fault at the terminals of the power transformer is less than 220 amperes RMS for 1 second. If the period during which a fault current flows in the relay can be definitely limited to a shorter time, a higher current can be accommodated in accordance with the relation: $(\text{Amperes})^2 \times \text{seconds} = 48{,}400$.

### CURRENT TRANSFORMER RATIO ERROR

The CT ratio error must be less than 20 percent at 8 times relay rated tap current. This is based on the instantaneous unit being set at its normal setting which is 8 times tap rating. If the instantaneous unit pickup is raised above this value, the 20 percent figure must be reduced as described under the heading OPERATING CHARACTERISTICS.

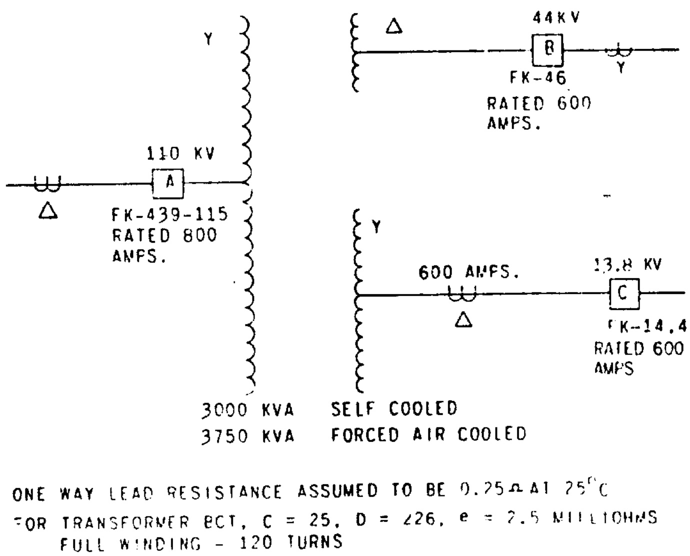



Fig. 16 (389A740)

Fig. 16 Transformer Used in Sample Calculations

# EXAMPLE REFER TO FIG 16

## I DETERMINATION OF CUT TURNS AND BDD RELAY TAP SETTING

| | A | B | C |
|---|---|---|---|
| 1. Transformer and Line | A | B | C |
| 2. Max. $I_p = 3750 / \sqrt{3}$ (Line KV) | 19.7 | 49.5 | 157 |
| 3. 100% $I_p = 3000 / \sqrt{3}$ (Line KV) | 15.7 | 39.6 | 125 |
| 4. Assume CT turns | 20 | 20 | 60 |
| 5. Max. I secondary (less than 5a) | 0.98 | 2.47 | 2.62 |
| 6. 100% I secondary | 0.79 | 1.98 | 2.08 |
| 7. CT connections | Delta | Wye | Delta |
| 8. Relay Current for 100 % I Sec. | 1.37 | 1.98 | 3.60 |
| 9. Ideal Relay Taps (Set C = 8.7) | 3.31 | 4.78 | 8.7 |
| 10. Try Relay Taps | 3.2 | 4.6 | 8.7 |

11. Check Mismatch Error:

Lines A-B $\frac{4.6}{3.2} = 1.43 \qquad \frac{1.98}{1.37} = 1.44 \qquad \frac{1.44-1.43}{1.43} = 0.7\%$

Lines B-C $\frac{8.7}{4.6} = 1.89 \qquad \frac{3.60}{1.98} = 1.82 \qquad \frac{1.89-1.82}{1.82} = 3.8\%$

Lines C-A $\frac{8.7}{3.2} = 2.72 \qquad \frac{3.60}{1.37} = 2.63 \qquad \frac{2.72-2.63}{2.63} = 3.4\%$

(All are less than 5%; therefore mismatch error is not excessive)

12. Assume that the sum of the maximum relay currents is less than 220 amps for one second, and therefore short-time rating of relay is not exceeded.

## II PER CENT RATIO ERROR

1. Burdens on CT's (assume one-way lead resistance is 0.25 ohms)

(a) Line A, $Z = 2\,(0.156) + \frac{(20 \times 4) + (2.50 \times 50)}{800} + 2.27\,(0.25)$

$= 0.312 + 0.256 + 0.568 = 1.136$

(b) Line B, $Z = 0.096 + \frac{(20 \times 2.5) + (2.50 \times 35)}{800} + 0.568$

$= 0.096 + 0.172 + 0.568 = 0.836$

(c) Line C, $Z = 2\,(0.048) + \frac{60 \times 2.5}{800} + 0.568 = 0.096 + 0.187 + 0.568 = 0.851$

| | A | B | C |
|---|---|---|---|
| 2. Impedance, ohms | 1.136 | 0.836 | 0.851 |
| 3. 8 times tap, amperes | 25.6 | 36.8 | 69.6 |
| 4. $E_S$, CT voltage required (IZ) | 29.0 | 30.8 | 59.3 |
| 5. $I_E$, required, from excitation curve | 1.10 | ∞ | 0.13 |
| 6. % Ratio Error | 4.3% | ∞ | 1.8% |

Exciting current on line B is too high; should try higher tap on CT to improve CT performance.

## IA REPEAT - CT TURNS AND RELAY TAP SETTING

| | | | |
|---|---|---|---|
| 1. 100% $I_p$ | 15.7 | 39.6 | 125 |
| 2. Try CT Turns (necessary to change C also for proper matching) | 20 | 40 | 80 |
| 3. 100% I secondary | 0.79 | 0.99 | 1.56 |
| 4. Relay Current | 1.37 | 0.99 | 2.70 |
| 5. Ideal Relay Taps (Set C = 8.7) | 4.40 | 3.19 | 8.7 |
| 6. Use Taps | 4.6 | 3.2 | 8.7 |
| 7. Mismatch error is less than 5% | | | |

## METHOD (CONTINUED)

The calculations listed below are for the worst fault condition, as far as CT performance is concerned, which is an internal ground fault between the CT and the transformer winding with none of the fault current supplied through the neutral of the protected transformer.

1. Determine the burden on each CT, using the following expressions:

(a) For Y connected CT's.

$$Z = B + \frac{Ne + 2.50f}{800} + 2.27R$$

(b) For delta connected CT's,

$$Z = 2B + \frac{Ne + 2.50f}{800} + 2.27R$$

where B = BDD relay total burden (see Table IV)
N = number of turns in bushing CT
e = bushing CT resistance per turn, milliohms
f = bushing CT resistance per lead, milliohms
R = one-way lead resistance (at $25^{o}C$) from CT to relay.

(The multipliers used on the F and R terms include factors to cover two leads instead of one, increase of resistance due to temperature rise, and resistance of longest CT leads.)

2. Determine CT secondary current for 8 times tap setting.

$$I_S = 8 \times \text{BDD relay tap rating}$$

(Note: For the type fault assumed, all the fault current is supplied by one CT, so that CT current and relay current are the same, regardless of whether the CT's are connected in wye or delta).

3. Determine secondary CT voltage required at 8 times tap setting.

$$Es = I_s Z$$

4. From excitation curve of particular tap of current transformer being used, determine excitation current, $I_E$, corresponding to this secondary voltage, $E_s$. The excitation curves for bushing CT's on General Electric outdoor circuit breakers of current design may be drawn by the template method using C and D constants as given in Table V.

5. Determine the percent error in each CT by the expression:

$$\% \text{ error} = \frac{I_E}{I_S} \times 100$$

This should not exceed 20 percent of any set of CT's. If it does, it will be necessary to choose a higher tap on that set of CT's, and repeat the calculations on selection of relay taps, mismatch error, and percent ratio error.

### PERCENT SLOPE SETTING

The proper percent slope required is determined by the sum of the following causes of differential current:

(a) the maximum range of manual taps and the load-ratio-control, or automatic tap changing means, in percent.
(b) the maximum percent of mismatch of the relay taps.
(c) the maximum differential current due to CT saturation during external faults.

The percentage slope tap selected should be greater than the ratio of maximum total error current to smaller of the through currents. In general, if the total error current does not exceed 20 percent, the 25 percent tap is used. If it exceeds 20 percent, but not 35 percent, the 40 percent tap is used.

If the movable lead is used (as in Fig. 9 for example) the percent slope tap should be chosen about twice as high since the movable lead provides no restraint.

TABLE IV
Total Burden for 60 Cycle Relays

| BDD Taps Amps | 8X Tap Amps | Burden Ohms (B) | Min. P. U. Amps |
|---|---|---|---|
| 2.9 | 23.2 | 0.180 | 0.87 |
| 3.2 | 25.6 | 0.156 | 0.96 |
| 3.5 | 28.0 | 0.140 | 1.05 |
| 3.8 | 30.4 | 0.120 | 1.14 |
| 4.2 | 33.6 | 0.112 | 1.26 |
| 4.6 | 36.8 | 0.096 | 1.38 |
| 5.0 | 40.0 | 0.088 | 1.50 |
| 8.7 | 69.6 | 0.048 | 2.61 |

## EXAMPLE (CONTINUED)

II A REPEAT - PERCENT RATIO ERROR

1. Burden on CT's

Line A, Z = 0.192 + 0.235 + 0.568 = 1.016
Line B, Z = 0.156 + 0.235 + 0.568 = 0.959
Line C, Z = 0.096 + 0.250 + 0.568 = 0.914

| | | | |
|---|---|---|---|
| 2. Impedance, Ohms | 1.016 | 0.959 | 0.914 |
| 3. 8 times tap, amperes | 36.8 | 25.6 | 69.6 |
| 4. $E_S$, CT voltage required (IZ) | 37.4 | 24.6 | 63.6 |
| 5. IE required, from excitation curve | 1.30 | 0.25 | 0.15 |
| 6. % of Ratio Error | 3.52% | 0.98% | 0.21% |

Per Cent Error is less than 20%, so CT taps and Relay taps are satisfactory.

III PER CENT SLOPE SETTING

| | |
|---|---|
| 1.- Assume load ratio control maximum range | 10.0% |
| 2 - Relay Tap mismatch, from IA above | 4.2% |
| 3 - Assume CT error for max. external fault | 5.0% |
| | 19.2% |

Use 25% tap.

TABLE V

| Circuit Breakers | | | Current Transformers | | | | | |
|---|---|---|---|---|---|---|---|---|
| Type | Ratings | | No. of turns in full winding | Excitation curve Dwg. No. K-6558677 | Constants for Dwg. Characteristic by Template Method | | Approx. Internal Resist. Milliohms | |
| | | | | | | | Per turn | Per lead |
| | KV | Amps | | | C | D | e | f |
| FK-227-7.2-50 | 7.2 | 600 | 120 | AT | 10 | 140 | 3.5 | 10 |
| FLO-15-14.4-100 | 14.4 | 600 | 120 | BN | 14 | 222 | 2.5 | 13.5 |
| FLO-15-14.4-250 | 14.4 | 600 | 120 | BN | 14 | 222 | 2.5 | 13.5 |
| FLO-15-14.4-250 | 14.4 | 1200 | 240 | BR | 14 | 222 | 2.5 | 13.5 |
| FK-439-14.4-1000 | 14.4 | 1200 | 240 | BL | 14 | 222 | 2.5 | 35 |
| FK-339-14.4-1000 | 14.4 | 3000 | 600 | AD | 25 | 285 | 3.0 | 35 |
| FK-339-14.4-1500 | 14.4 | 2000 | 400 | BM | 14 | 222 | 2.5 | 35 |
| FK-339-14.4-1500 | 14.4 | 4000 | 800 | AE | 13 | 325 | 2.5 | 35 |
| FK-439-23-250 | 23 | 600 | 120 | BK | 14 | 222 | 2.5 | 35 |
| FK-439-23-500 | 23 | 1200 | 240 | BL | 14 | 222 | 2.5 | 35 |
| FK-439-34.5-500 | 34.5 | 600 | 120 | BK | 14 | 222 | 2.5 | 35 |
| FK-439-34.5-1000 | 34.5 | 1200 | 240 | BL | 14 | 222 | 2.5 | 35 |
| FK-439-34.5-1500 | 34.5 | 1200 | 240 | BL | 14 | 222 | 2.5 | 35 |
| FK-339-34.5-2500 | 34.5 | 2000 | 400 | AL | 25 | 285 | 3 | 35 |
| FK-439-46-500 | 46 | 600 | 120 | BK | 14 | 222 | 2.5 | 35 |
| FK-439-46-1500 | 46 | 1200 | 240 | BL | 14 | 222 | 2.5 | 35 |
| FK-439-69-1000 | 69 | 600 | 120 | BC | 25 | 290 | 3 | 45 |
| FK-439-69-1500 | 69 | 1200 | 240 | BD | 25 | 290 | 3 | 45 |
| FK-439-69-2500 | 69 | 1200 | 240 | BD | 25 | 290 | 3 | 45 |
| FK-439-69-3500 | 69 | 2000 | 400 | BE | 32 | 350 | 3.5 | 45 |
| FK-439-115-1500 | 115 | 800 | 120 | AV | 40 | 515 | 4 | 50 |
| FK-439-115-3500 | 115 | 1200 | 240 | AW | 40 | 515 | 4 | 50 |
| FK-439-115-5000 | 115 | 1200 | 240 | AW | 40 | 515 | 4 | 50 |
| FK-439-138-3500 | 138 | 1200 | 240 | AY | 43 | 590 | 4.5 | 60 |
| FK-439-138-5000 | 138 | 1200 | 240 | AY | 43 | 590 | 4.5 | 60 |
| FGK-138-10000 | 138 | 1600 | 400 | BF | 43 | 590 | 4.5 | 60 |
| FK-439-161-5000 | 161 | 1200 | 240 | BA | 40 | 670 | 4 | 80 |
| FGK-161-10000 | 161 | 1600 | 400 | * | 40 | 670 | 4 | 80 |
| FGK-230-5000 | 230 | 800 | 240 | BA | 40 | 670 | 4 | 80 |
| FGK-230-1000 | 230 | 1600 | 400 | * | 40 | 670 | 4 | 80 |
| FGK-230-15000 | 230 | 1600 | 400 | * | 40 | 670 | 4 | 80 |
| FGK-330-25000 | 330 | 1600 | 400 | △ | 42 | 930 | 3.5 | 15.5 |

* - 157L502 BJ
△ - K-6558678 CA

# OPERATION

## TARGETS

Targets are provided for both the auxiliary relay and the instantaneous overcurrent unit. In the event of an internal fault, one or both of these units will operate depending upon the fault magnitude. This will produce a target indication on the particular unit which operates. The auxiliary relay does not function as a seal-in since it does not carry the breaker tripping current. After a fault is cleared, the target should be reset by the reset slide located at the lower left hand corner of the relay.

## DISABLING OF TYPE BDD RELAY

When by-passing a breaker for maintenance, it will be necessary to disable the relay to prevent false tripping. If the disabling of the relay is done by a remote switch rather than by removing the relay connection plug, the following precautions should be taken:-

1. The relay may be disabled by short-circuiting studs 8 and 9 of the relay and by opening the trip circuit at stud 1.

The trip circuit should be opened at stud 1 since the series resistors in the auxiliary relay circuit cannot withstand rated control voltage continuously in the event that the polarized relay operates.

2. If the CT secondaries are short-circuited as part of the disabling procedure, the trip circuit should be opened at stud 1 and studs 8 and 9 should be short-circuited before the CT secondaries are short-circuited. It is not sufficient to rely on short-circuiting the CT secondaries alone, because any difference in time of shorting them may cause false tripping.

# MAINTENANCE

## CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched roughened surface, resembling in effect a superfine file. The polishing action is so delicate that no scratches are left, yet corroded material will be removed rapidly and thoroughly. The flexibility of the tool insures the cleaning of the actual points of contact. Sometimes an ordinary file cannot reach the actual points of contact because of some obstruction from some other part of the relay.

Fine silver contacts should not be cleaned with knives, files, or abrasive paper or cloth. Knives or files may leave scratches which increase arcing and deterioration of the contacts. Abrasive paper or cloth may leave minute particles of insulating abrasive material in the contacts and thus prevent closing.

The burnishing tool described is included in the standard relay tool kit obtainable from the factory.

## PERIODIC TESTS

An operation test and inspection of the relay and its connections should be made at least once every six months. Tests may be performed as described under "Installation Tests" or, if desired, they may be made on the service taps as described in this section.

When inserting or withdrawing a test plug in a relay with connections to the trip circuit, studs 8 and 9 should each be provided with one of the U-shaped through jumpers to maintain the connections from the relay to the case. If this is not done, there is a risk of false tripping upon inserting or withdrawing the plug.

### PICKUP

The method for checking pickup is as described under the heading "Installation Tests" except, of course, pickup current will be different depending upon the WDG 1 service tap. Pickup value may be determined as follows:-

$$I_1 = 0.30 \times \text{WDG 1 Tap}$$

Of course, when checking pickup on a particular service tap, the ± 10 percent expected variation still applies, the acceptable as found values being

$$I_1 = 0.90 \times 0.30 \times \text{WDG 1 Tap to } 1.10 \times 0.30 \times \text{WDG 1 Tap}$$

Example

WDG 1 Tap = 3.5 A

$I_1 = 0.90 \times 0.30 \times 3.5$ to $1.10 \times 0.30 \times 3.5$

$I_1 = 0.94$ to $1.16$ amperes

### HARMONIC CURRENT RESTRAINT

The procedure for checking harmonic restraint is as described under the heading "Installation Tests" except the test current values must be modified as follows:-

$$I_2 \text{ (DC)} = 0.80 \times \text{WDG 1 Tap}$$

$$I_1 = 0.90 \times \text{WDG 1 Tap to } 1.10 \times \text{WDG 1 Tap}$$

In the event a suitable DC meter is not available, I2 (AC) = 2.25 x I2 (DC) (Theoretically, this conversion factor would be 2.22 if the rectifier back resistance were infinite.)

Example

WDG 1 Tap = 3.5 A
$I_2$ (DC) = 0.80 x 3.5 = 2.8 Amperes
I1 = 0.90 x 3.5 to 1.10 x 3.5
$I_1$ = 3.15 to 3.85 Amperes

If DC meter is not available,

$I_2$ (AC) = 2.25 x 2.8 = 6.30 Amperes

THROUGH CURRENT RESTRAINT

In order to check the service tap slope setting the test current values indicated in Table III must be modified to take into account any difference in tap settings. Furthermore, the test circuit shown in Fig. 13 must be set up such that the lead from ammeter $I_3$ to the test plug is connected to the stud corresponding to the winding with the lower tap setting. The common lead, of course, is connected to the stud corresponding to the winding with the higher tap setting. For any combination of taps, the percent slope is given by the following equation:

$$\% \text{ Slope} = \left[\frac{T1}{T2}\left(\frac{I1}{I3} + 1\right) - 1\right] \times 100$$

where T1 = lower tap setting
T2 = higher tap setting
I1 = differential current
$I_3$ = smaller of the two through currents

Table VI is derived from the above expression and is based on a multiple of tap current of six times the lower tap setting for all combinations of taps except those which involve the 8.7 amp tap. For the latter case, a four times tap setting is used since the total test current for a six times tap setting may be as high as 75.2 amperes which is not only prohibitively high for many installations but also may subject the relay to excessive heating.

For a given tabular value of $I_3$ corresponding to a given combination of winding and percent slope taps, the values of $I_1$ (min.) and $I_1$ (max.) correspond to the minimum and maximum percent slope tolerance limits given in Table III. However, for a four times tap setting, both the upper and lower percent slope tolerance limits have been raised by a value equivalent to the difference between the true slope and the nominal slope at four times tap value indicated by the percent slope characteristic curves shown in Figure 1.

EXAMPLE

WDG 1 Tap = 3.5A
WDG 2 Tap = 5.0A
Slope Tap = 40%

Since WDG 1 has the lower tap setting the lead from ammeter I3 to the test plug should be connected to stud 6 and the common lead should be connected to stud 4.

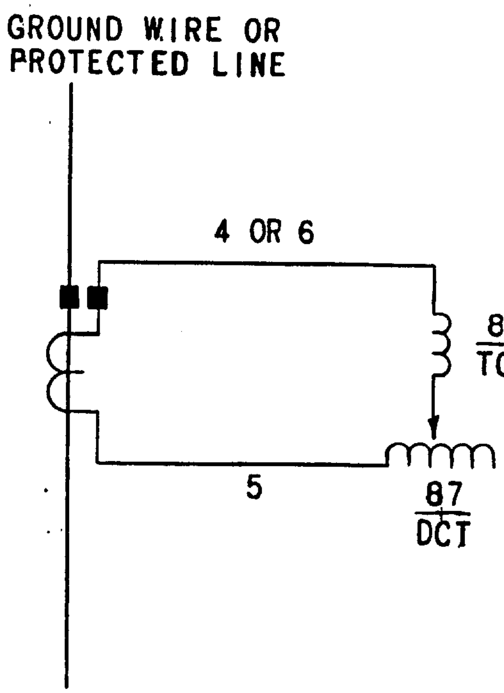
From Table VI:-

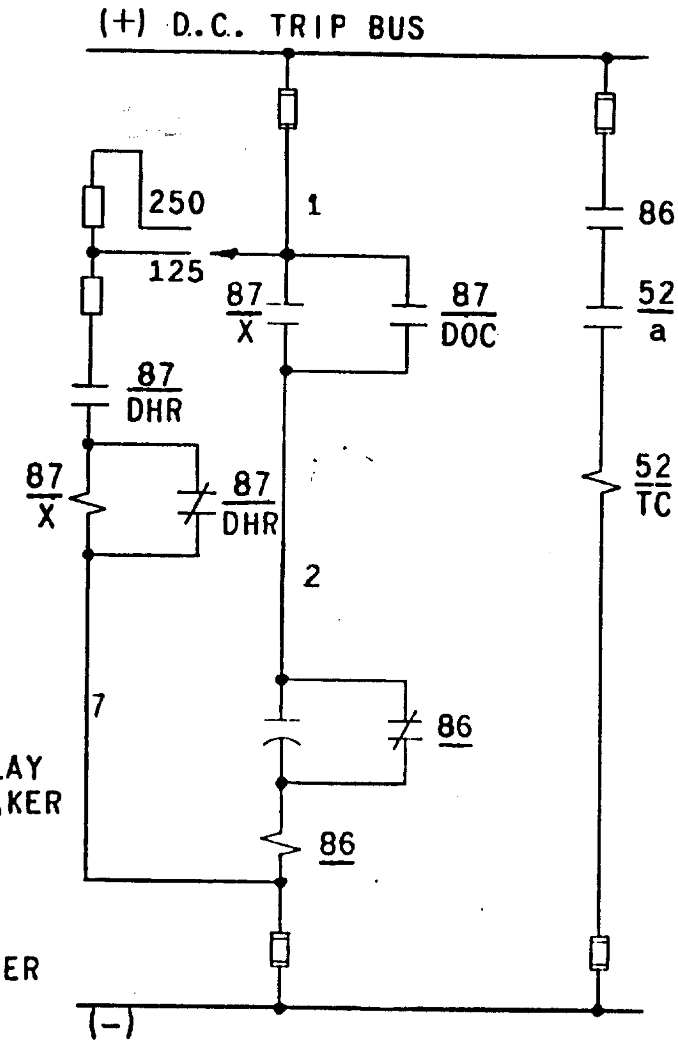
$I_3$ = 21.0 Amps
$I_1$ (min.) = 21.0 Amps
$I_1$ (max.) = 22.2 Amps

# RENEWAL PARTS

It is recommended that sufficient quantities of renewal parts be carried in stock to enable the prompt replacement of any that are worn, broken, or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company, specify quantity required, name of part wanted, and give complete nameplate data, and the serial number which may be found stamped on the instantaneous unit in black ink. If possible, give the General Electric Company requisition number on which the relay was furnished.




87 = TYPE BDD DIFFERENTIAL RELAY
a = AUX.SWITCH, OPEN WHEN BREAKER OPEN
TC = TRIP COIL
DCT = DIFFERENTIAL CURRENT TRANSFORMER
TCT = THROUGH CURRENT TRANSFORMER
DOC = DIFFERENTIAL OVERCURRENT UNIT
DHR = DIFFERENTIAL UNIT WITH HARMONIC RESTRAINT
52 = POWER CIRCUIT BREAKER
86 = TYPE HEA, HAND RESET RELAY

% SLOPE SETTING - 15

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CURRENT TAP SETTING | 2.9 | 3.2 | 3.5 | 3.8 | 4.2 | 4.6 | 5.0 | 8.7 |
| PICKUP AMPS. | 0.87 | 0.96 | 1.05 | 1.14 | 1.26 | 1.38 | 1.5 | 2.61 |

Fig. 17 (389A731)

Fig. 17 Elementary Diagram for Type BDD15B and BDD16B Relays used as Ground Fault Detector or Overcurrent Relays

TABLE VI

| TAPS / T2 | | 2.9 | | | 3.2 | | | 3.5 | | | 3.8 | | | 4.2 | | | 4.6 | | | 5.0 | | | 8.7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | Slopes / Currents | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 | 15 | 25 | 40 |
| 2.9 | $I_3$ | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 17.4 | 11.6 | 11.6 | 11.6 |
| | $I_1$(min) | 2.6 | 4.3 | 7.0 | 4.6 | 6.6 | 9.5 | 6.7 | 8.8 | 12.0 | 8.8 | 11.1 | 14.5 | 11.6 | 14.1 | 17.9 | 14.3 | 17.1 | 21.2 | 17.1 | 20.1 | 24.6 | 28.7 | 32.2 | 37.4 |
| | $I_1$(max) | 2.9 | 4.8 | 7.7 | 5.0 | 7.1 | 10.3 | 7.1 | 9.4 | 12.8 | 9.2 | 11.7 | 15.4 | 12.0 | 14.8 | 18.9 | 14.8 | 17.8 | 22.4 | 17.6 | 20.9 | 25.8 | 29.3 | 33.1 | 38.9 |
| 3.2 | $I_3$ | | | | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 12.8 | 12.8 | 12.8 |
| | $I_1$(min) | | | | 2.9 | 4.8 | 7.7 | 4.9 | 7.0 | 10.2 | 7.0 | 9.3 | 12.7 | 9.8 | 12.3 | 16.1 | 12.5 | 15.3 | 19.4 | 15.3 | 18.3 | 22.8 | 27.5 | 31.0 | 36.2 |
| | $I_1$(max) | | | | 3.2 | 5.3 | 8.5 | 5.3 | 7.6 | 11.0 | 7.4 | 9.9 | 13.6 | 10.2 | 13.0 | 17.1 | 13.0 | 16.0 | 20.6 | 15.8 | 19.1 | 24.0 | 28.1 | 31.9 | 37.7 |
| 3.5 | $I_3$ | | | | | | | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 21.0 | 14.0 | 14.0 | 14.0 |
| | $I_1$(min) | | | | | | | 3.1 | 5.2 | 8.4 | 5.2 | 7.5 | 10.9 | 8.0 | 10.5 | 14.3 | 10.7 | 13.5 | 17.6 | 13.5 | 16.5 | 21.0 | 26.3 | 29.8 | 35.0 |
| | $I_1$(max) | | | | | | | 3.5 | 5.8 | 9.3 | 5.6 | 8.1 | 11.8 | 8.4 | 11.2 | 15.3 | 11.2 | 14.2 | 18.8 | 14.0 | 17.3 | 22.2 | 26.9 | 30.7 | 36.5 |
| 3.8 | $I_3$ | | | | | | | | | | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 22.8 | 15.2 | 15.2 | 15.2 |
| | $I_1$(min) | | | | | | | | | | 3.4 | 5.7 | 9.1 | 6.2 | 8.7 | 12.5 | 8.9 | 11.7 | 15.8 | 11.7 | 14.7 | 19.2 | 25.1 | 28.6 | 33.8 |
| | $I_1$(max) | | | | | | | | | | 3.8 | 6.3 | 10.0 | 6.6 | 9.4 | 13.5 | 9.4 | 12.4 | 17.0 | 12.2 | 15.5 | 20.4 | 25.7 | 29.5 | 35.3 |
| 4.2 | $I_3$ | | | | | | | | | | | | | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 16.8 | 16.8 | 16.8 |
| | $I_1$(min) | | | | | | | | | | | | | 3.8 | 6.3 | 10.1 | 6.5 | 9.3 | 13.4 | 9.3 | 12.3 | 16.8 | 23.5 | 27.0 | 32.2 |
| | $I_1$(max) | | | | | | | | | | | | | 4.2 | 7.0 | 11.1 | 7.0 | 10.0 | 14.6 | 9.8 | 13.1 | 18.0 | 24.1 | 27.9 | 33.7 |
| 4.6 | $I_3$ | | | | | | | | | | | | | | | | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 18.4 | 18.4 | 18.4 |
| | $I_1$(min) | | | | | | | | | | | | | | | | 4.1 | 6.9 | 11.0 | 6.9 | 9.9 | 14.4 | 21.9 | 25.4 | 30.6 |
| | $I_1$(max) | | | | | | | | | | | | | | | | 4.6 | 7.6 | 12.2 | 7.4 | 10.7 | 15.6 | 22.5 | 26.3 | 32.1 |
| 5.0 | $I_3$ | | | | | | | | | | | | | | | | | | | 30.0 | 30.0 | 30.0 | 20.0 | 20.0 | 20.0 |
| | $I_1$(min) | | | | | | | | | | | | | | | | | | | 4.5 | 7.5 | 12.0 | 20.3 | 23.8 | 29.0 |
| | $I_1$(max) | | | | | | | | | | | | | | | | | | | 5.0 | 8.3 | 13.2 | 20.9 | 24.7 | 30.5 |
| 8.7 | $I_3$ | | | | | | | | | | | | | | | | | | | | | | 34.8 | 34.8 | 34.8 |
| | $I_1$(min) | | | | | | | | | | | | | | | | | | | | | | 5.5 | 9.0 | 14.2 |
| | $I_1$(max) | | | | | | | | | | | | | | | | | | | | | | 6.1 | 9.9 | 15.7 |

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