26

Electromagnetic Relays

Introduction — Definitions — Principle Types of Relays — Attracted Armature Type — Balanced Beam Relay — Induction Disc — Induction cup — Permanent Magnet Moving Coil — Thermal — Gas Operated — Operating Characteristics — Seal — in — Feature — Design Features — Auxiliary Switch — Sealing, Holding, Relay Unit, Protective Systems, Protective Schemes — Pick-up and Drop off — Rectifier Systems — Directional element — All-or-nothing Relays -- Plug setting — Time Setting — Summary — Questions.

26.1. INTRODUCTION

'Relay is a device by means of which an electric circuit can be controlled (opened or closed) by the change in the same circuit or other circuit.' An electro-mechnical relay, has one or more coils, movable elements, contact system, etc. The operation of such relay depends on whether the operating torque/force is greater than the restraining torque/force *i.e.*

The relay operates, if the net Force F in Eq. (1) below is positive; or net T in Eq. (2) below is positive.

$$F = F_o - F_r \qquad \text{...(1)}$$

E = Net Force

F_o = Operating Force

F_r = Restraining force

or

$$T = T_o - T_r \qquad \text{...(2)}$$

T = Net torque

T_o = Operating torque

T_r = Restraining torque

Relay operates when Operating force > Restraining force

In electromechanical relays, the operating torque is produced by electromagnetic attraction/electromagnetic induction/thermal effects of electric current. The restraining torque is given by springs. The various terms such a Measuring Relay, All or-nothing relay, trip circuit, time lag relay, instantaneous relay, etc. are covered in section 25.8. They will be studied in this chapter.

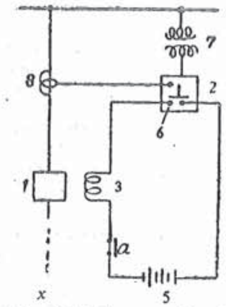
The contact circuit of electromechanical relays are quite complex. Simplified diagrams have been given in this section for explaining the principle.

26.2. BASIC CONNECTIONS OF TRIP CIRCUIT

Fig. 26.1, given below, illustrates the basic connections of the circuit breaker control for the opening operation. It is rather an over-simplified diagram; for the sake of understanding the principle.

Referring to Fig. 26.1, the protected circuit X is shown by dashed line. When a fault occurs in the protected circuit, the relay (2) connected to the CT and PT actuates and closes its contacts (6).

Current flows from the battery (5) in the trip circuit (4). As the trip coil of the circuit breaker (3) is energized, the circuit breaker operating mechanism is actuated and it operates for the opening operation Auxiliary switch a is an important item in the circuit.



1. Circuit breaker
2. Relay
3. Trip coil of c.b.
4. Trip circuit
5. Battery
6. Relay contacts
7. Potential transformer
8. Current transformer

a Auxiliary switch contacts
x Protected element/circuit

Fig. 26.1. Simplified diagram of circuit breaker control of opening operation.

26.3. AUXILIARY SWITCH, SEALING, AND AUXILIARY RELAYS

Fig. 26.1 is a simplified figure. In actual practice, the measuring relay is assisted by seal-in relay, time-delay relay tripping relay, auxiliary switch, etc. and the resulting contact circuit is quite complex. Further, there are sequential operations within the set of relays. The control circuit is further modified for schemes such as *'Autoreclosure', 'intertripping' 'anti-pumping' trip-free'* Schemes. In this section, the functional details are briefly discussed.

26.3.1. Auxiliary Switch

Auxiliary switch is an important device in the trip circuit of the circuit breaker. It is a multipoint switch (4 point, 6 point, 12 point, 24 point) which is mechanically interlocked with the operating mechanism of the circuit breaker such that when the circuit breaker opens, the auxiliary switch also opens, thereby disconnecting trip circuit, certain indicating circuits and control circuits. The terminal blocks are provided in the control cabinet. The various control wiring is done *via* the terminal blocks.

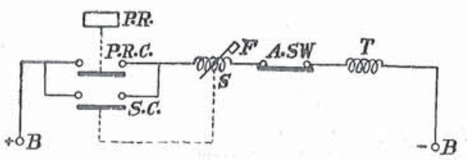
The current in trip circuit is interrupted by Auxiliary Switch and not by the protective relay contacts. The relay contacts are light and delicate so that the weight of moving parts is low and consumption of relay is low. Hence relay contacts are not designed to interrupt the current in trip circuit. The trip coil consumption is of the order 7.5 watts for small oil circuit breakers to about 25 watts for large oil circuit breakers, the voltage ratings being of the order of 30, 125, 250 V.D.C. This voltage for trip current is supplied from battery system. While opening of trip circuit, (an inductive circuit), an inductive circuit is being opened and this needs a robust switching device. Auxiliary switch is designed for such a duty. Auxiliary switch is placed in the switch cubicle or control-cabinet of the circuit-breaker.

Besides the trip circuit connections, the indication circuits (to indicate whether the c.b. is 'open' or close). circuit of interlocking (between breakers, isolators and other devices) and some control circuits are also connected/disconnected by auxiliary switch.

26.3.2. 'Sealing', 'Holding', 'Repeat Operation'

As mentioned earlier, the relay contacts are designed for light weight and they are therefore delicate. The protective relay only closes its contacts and it is relieved of other duties such as time lag, tripping, (carring current for longer time, breaking trip circuit), etc. These duties are performed by 'auxiliary relays'. There are various schemes of sealing or holding. Repeat operations are performed by repeat contactors/auxiliary relays. The name 'repeat' means, these relays repeat the operations of protective relay. The repeat contractors close as the protective relay closes and they perform the function of sealing, holding. Fig. 26.2 gives a scheme in which the operations follow the following sequence. (Refer Fig. 26.2).

To begin with the circuit breaker (not shown in the figure) is closed. Therefore auxiliary switch (*ASW*) is closed, (as shown in the figure). If a fault occurs, protective relay operates and closes its



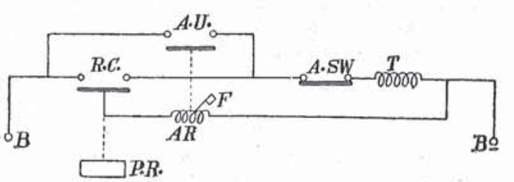
PR	Protective Relay
PRC	Contacts of Protective Relay
SC	Sealing contacts
S	Sealing Coil (in series with trip circuit.)
F	Flag indicator.
ASW	Auxiliary Switch Contacts (operation in conjunction with breaker)
T	Trip Coil of CB
B—B	Supply from battery, 110 V.D.C.

Fig. 26.2. *Series Sealing* Circuit, for closed position of C.B. and Auxiliary switch.

contacts (*PRC*). Thereby current flows from battery system (*BB*) through sealing coil (*S*), *ASW* contacts and trip coil (*T*). Circuit breaker trips. Meanwhile, the contacts (*SC*) operated by sealing relay (*S*) close and thus the contacts (*PRC*) of protective relay are relieved of further duty. Flag (*F*) operates either mechanically or electrically to indicate relay operation.

The auxiliary switch contacts open after a few cycles, as the circuit-breaker opens. The current in the trip circuit is interrupted by auxiliary switch.

There are various methods of sealing such as series sealing (described above), shunt sealing, etc. Fig. 26.3 illustrates the 'shunt Reinforcement' scheme.



RC	= Relay contacts
PR	= Protective Relay
AR	= Auxiliary Relay
AU	= Contacts of AR
ASW	= Auxiliary switch (shown closed) operator in conjunction with breaker
T	= Trip coil
F	= Flat
B—B	= Battery voltage 110 V.D.C.

Fig. 26.3. Shunt Reinforcement Scheme for closed position of C.B. and auxiliary switch.

In this scheme, to start with, the auxiliary switch *ASW* is closed as the breaker (not shown) is closed. As the fault occurs, protective relay (*PR*) closes its contacts *RC* and current flows through (*ASW*) and trip coil (*T*). Meanwhile the auxiliary relay (*AR*) is energised and its contacts (*AU*) close, thereby, the relay contacts (*RC*) are relieved of further duty. The trip circuit is opened by *ASW* as the breaker opens.

The auxiliary relays mentioned above are generally attracted armature type instantaneous relays.

The 'Flag' also called 'indicator' or 'target' indicates on the relay that the relay has operated. In some relays, the movement of element of the relay pushes a small shutter to expose the indicator. In some relays the shutter is opened by electrically operated device. The resetting of indicators is usually manual. The operator notes the indication and then resets the indicator. On a relay panel, there are generally several relays. Indicators indicate, which relay has operated. Thereby the attendant knows the cause of circuit-breaker tripping.

The contact systems of static relay are quite different.

26.4. MEASUREMENT IN RELAYS

The discrimination involves measurement of actuating quantities (voltage and current) which are present at the relaying point. (Ref. Sec. 25.11) by protective relays. The measurement in majority of protective relays can be grounded as follows :

— Magnitude measurement such as over current, overvoltage, undercurrent.

— Product measurement such as power ($VI \cos \phi$)

— Ratio measurement such as impedance (V/I).

— Comparison between similar electrical quantities such as vector difference between currents I, I.

26.4.1. Magnitude Measurement

The relays under this category respond to magnitude of actuating quantity such as current derived from group of CT's.

Some other relays are energized by magnitude of voltage derived for group of VT's.

Some relays are energized by voltage and respond to parameter such as frequency, waveform, rate of rise. Such relays also can be included in this category.

The actuating quantity fed into the relay is derived from secondaries of CT's or VTs or both. Hence the performance of the protective system depends upon the resultant output of the secondary current/voltages fed into the relay.

The relays can be single actuating quantity type or multi-actuating quantity type.

26.4.2. Product Measurement

The double actuating quantity type induction relay have two coils and are actuated by voltage and current. Thereby two fluxes are produced and the torque produced by their interaction is given by,

$$T = kVI \cos \phi$$

k being a constant. Thus, the relay can be arranged to respond to the product of two quantities.

26.4.3. Ratio Measurement

The relay can be arranged to operate for a particular setting of the ratio say V/I.

One coil of the relay is actuated by voltage V and gives a force $F_1 = k_1 V$.

The other coil is energized by current I and gives a forces $F_2 = k_1 I$ when the relay is on the verge of operation, F_1 and F_2 are equal,

$$k_1 V = k_2 I$$

Hence $$\frac{V}{I} = \frac{k_1}{k_2} = k$$

26.4.4. Vector Difference (or Vector Sum)

The relay element can be connected in the secondary circuit of the CT's in such a way that the vector difference of secondary currents passes through the relay coil. Such arrangement gives a resultant current.

$$\bar{I} = (\bar{I}_1 + \bar{I}_2 + \bar{I}_3)$$

The relay operates when $\bar{I}$ increases above certain value.

26.5. TYPE OF RELAYS UNITS

(*a*) Attracted Armature type (Electromagnetic) Relay
(*b*) Balanced Beam (Electromagnetic) Relay
(*c*) Induction Disc (Electromagnetic) Relay
(*d*) Induction Cup (Electromagnetic) Relay
(*e*) Moving Coil and Moving iron (Electromagnetic) Relay
(*f*) Gas operated (Buchholz) Relay (Gas pressure)
(*g*) Rectifier Relays (Rectifier plus moving coil unit)
(*h*) Static Relay (static electronic circuit for measurement)

The electro-magnetic relay operates when operating torque/force exceeds the restraining torque/force.

26.6. PICK-UP

When the relay operates, we say, the relay has picked-up. It simply means that the relay with normally open contacts, has closed its contacts.

The pick-up value or pick-up level is the minimum value of operating quantity at which the relay is one the verge of operation, *e.g.*, consider an over current relay. The current injected in the relay coil is very gradually increased. At a current value of 2.51 amperes, the relay has not operated, at a value of 2.52 amperes, the relay begins to operate. Then, 2.52 amperes is the pick-up value.

In some attracted armature type relays, moving iron and moving coil relays, the pick-up value can be changed by changing the spring-tension.

In induction disc relays, the pick-up value corresponds to plug-setting (described later). If plug setting is 2.5 A, the relay starts operating at 2.5 A. If plug setting is 3.5 A, relay starts operating at 3.5 A and so on. However, in such relays the pick-up value is not exact, within about 5% of plug setting. The relay may not pick-up exactly at the plug setting value due to errors introduced by dust, friction, adjustment errors; and because operating torque is minimum at pick-up value.

26.7. RESET OR DROP-OFF

Now, we are talking about the relay which has already operated, and the actuating current is still flowing in the relay coil. As the operating quantity is gradually reduced, at some maximum value, the relay value, the relay contacts which have closed, start opening. This condition is called Reset or Drop off.

The value of operating quantity at which the relay (normally open) contacts which were closed due to relay operation, start opening and coming to original state (open).

26.8. DROP OFF/PICK-UP RATIO

The ratio of 'drop-off value to pick-up value' is important in self-reset type electromagnetic relays. It is also called 'Holding Ratio'. Since 'pick-up' value is more than 'drop off' value, the holding ratio is always less than 1.

The drop out to cut off ratio is of the order of 0.6 to 0.99 for most electromagnetic relays.

26.9. ATTRACTED ARMATURE RELAY (ELECTROMAGNETIC ATTRACTION)

These are simplest type of relays. These relays have coil or an electromagnet energized by coil. The coil is energized by the operating quantity which may be proportional to circuit current or voltage. A plunger or rotating iron vane is subjected to the action of magnetic field produced by the operating quantity. It is basically a single actuating quantity relay.

1. Attracted armature relays respond to both a.c. and d.c. because torque is proportion to I_2.

2. The attracted armature relays are fast relays. They have fast operation and fast reset because of small length of travel and light moving parts.

3. They are described as instantaneous. But their operating time does vary with current. Slow operating and resetting times can be obtained by delaying in build up of or decay of flux in the magnetic circuit by fitting copper ring around the magnet, and by means of bellows, dash pots, escapements etc. Operating time as slow as 0.1 sec. and resetting time as slow as 0.5 sec. can be obtained by such means.

4. On the other hand, very high operating speeds are possible. One modern relay has 0.5 millisecond of operating time. The current/time characteristic is hyperbolic (Fig. 26.5).

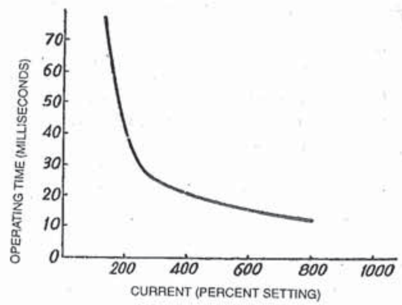


Fig. 26.5. Time current characteristic of a typical attracted armature relay.

5. **Ratio Rest to Pick-up** can be as high as 90-95% for a.c. relays and 60 to 90% for d.c. relays, by means of special design features. But in general the difference between picked-up and reset values is high because once, the relay has picked up the air gap is shortened and smaller magnitude of coil current can hold it in picked up position.

(Refer definitions, section 26.8)

6. These relays do not have directional feature unless they are provided with additional polarized coil.

7. As they are fast and operate on d.c. and a.c., they are affected by transients. The transients contain d.c. component in addition to a.c. wave. Therefore, though the steady state value may be less than relay's pick-up the relay may pick-up during transient state.

8. VA burden depends on construction, setting etc. For a typical relay it is of the order of 0.2 to 0.6 VA for current range 0.1 to 0.4 A.

9. Modern attraction armature relays are compact, robust, reliable.

10. **Operating Principle.** The electromagnetic force exerted on the moving element is proportional to square of the flux in air gap. If saturation is neglected it is proportional to square of operating current. We get

$$F = K_1 I^2 - K_2$$

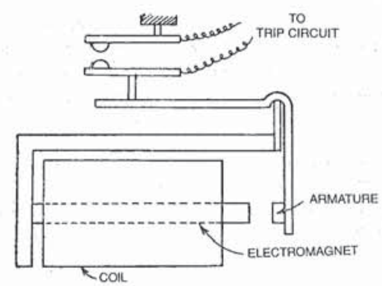
where F = net force
K_1 = a constant
I = current in operating coil
K_2 = restraining force including friction.

When relay is on the verge of operation, F is zero

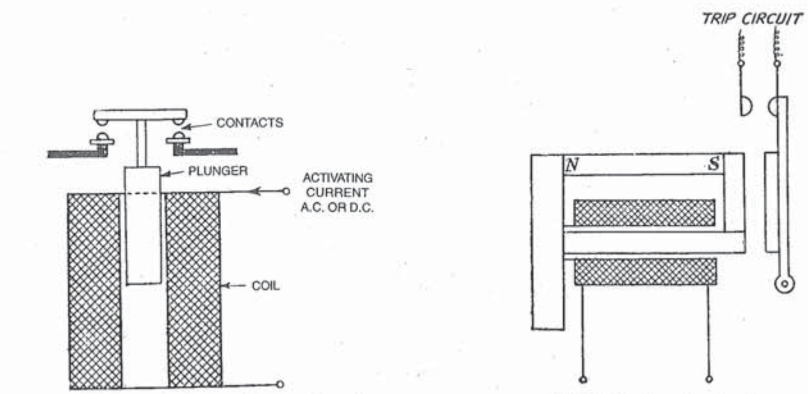
$$K_1 I^2 = K_2$$

Hence $$I = \sqrt{\frac{K_2}{K_1}} \text{ a constant.}$$

11. **Types of Constructions.** There is a variety. Fig. 26.6 illustrates a few types of structures of attraction armature type of relay.



(*a*) Hinged armature type relay.



(*b*) Plunger type electromagnetic attraction relay. (*c*) Polarised moving iron type

Fig. 26.6. Attracted armature relay.

Applications of Attracted Armature type Electromechanical Relay

Attracted armature relays have many applications in protection of a.c. and d.c. equipment. They are however instantaneous relays and are sensitive to staring currents, load fluctuations and current surges.

Attracted armature relays can be designed to respond to over under current, over/under voltage, for both arc and d.c. applications. They are used as measuring relays or auxiliary relays. Their most usual applications are :

— Overs-current protection, the time lag is obtained by using instantaneous attracted-armature relays in conjunction with a definite time lag relay or inverse time lag relays.

— Definite-time lag over-current and earth fault protection, the attracted armature relay is used in conjunction with definite-time-lag relay for over-current/earth fault protection.

— Differential protection, the instantaneous attracted armature type relay is used for differential protection.

— Auxiliary Relays. Attracted armature relays are used as auxiliary all-or-nothing relays, in the contact systems of protective relaying.

26.10. BALANCED BEAM RELAY (ELECTROMAGNETIC ATTRACTION PRINCIPLE)

This type of balanced beam relay (Fig. 26.7) consisted of a horizontal beam pivoted centrally, with one armature attached to either side. There were two coils, one on each side. The beam remained in horizontal position till operating force became more than restraining force. The action being similar to 'see saw' in children park in which a plank is balanced on a support at the middle. Children ride at the ends so that when one end goes up, the other comes down. In a balanced beam relay, coils act like those playing children. The current in one coil gives operating force the current in other coil gives restraining force. The beam is given slight mechanical bias by means of spring or weigh adjustment such that under normal condition the contacts are open. When operating torque increases, the beam tilts and the contacts close. In current balance both coils are energized by current derived from C.T's. In impedance (balance) relay the coils are energized by V and I.

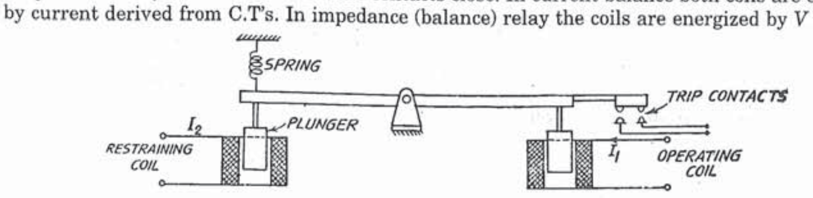


Fig. 26.7. Balance beam relay of early days.

Operating principle. Neglecting spring effect, the net torque is given by

$$T = K_1 I_1^2 - K_2 I_2^2$$

where T = net torque

I_1 = current in operating coil

I_2 = current in restraining coil

K_1, K_2 = constants.

At the verge of operation, net torque is zero, therefore,

$$K_1 I_1^2 = K_2 I_2^2$$

$$\frac{I_1}{I_2} = \sqrt{\frac{K_2}{K_1}} = \text{constant.}$$

The operating characteristic is shown in Fig. 26.8 which is an approximate straight line, slightly curved for low currents due to effect of spring. The current which gives operating torque or positive torque is called operating current. The other one is called restraining current. If one of the coils is actuated by voltage say V_1 other by current I_2 then the equation is $\frac{V_1}{I_2} = K$ is constant. This principle is used in impedance relays.

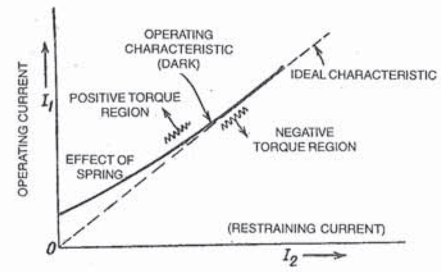


Fig. 26.8. Operating characteristics of balanced beam relay.

1. Balanced beam relay is difficult to be designed over a wide range current because the force is proportional to I_2.

2. The relay of this type is fast and instantaneous. In modern relays, electromagnets are provided in place of air-cored coils. Such relays can have time of the order of 1 cycle.

3. High ratio of resetting quantity of operating quantity can be obtained.

4. This relay is largely superseded by permanent magnet moving coil relay having better accuracy and lower VA burden.

5. VA burden of balanced beam relay depends on application. In current balance type the VA burden is of the order of 0.2, 0.4, 0.6 VA for 0.1 to 0.6 A range.

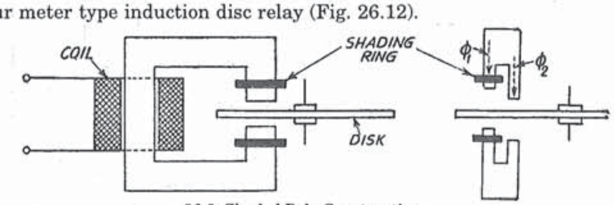
26.11. INDUCTION DISC RELAY (ELECTROMAGNETIC)

In this type of relay a metal disc is allowed to rotate between two electromagnets. The electromagnets are energized by alternating currents. The fields produced by the two magnets are displaced in space and phase. The torque is developed by the interaction of the flux of one of the magnets and the eddy currents induced in the disc by the other.

There are two popular constructions :

— Shaded pole induction disc relay (Fig. 26.9)

— Watthour meter type induction disc relay (Fig. 26.12).



26.9. Shaded Pole Construction.

Referring to Fig. 26.9, the shading ring is a copper band or a coil. Effect of shading ring is to produce flux in the shaded portion of the magnet (ϕ_1) which is displaced in phase and space from the flux in the remaining portion (ϕ_2). The flux ϕ_1 induces e.m.f. E_1 is the disc at 90° to ϕ_1. The e.m.f. E_1 produces currents I_1 lagging behind E_1 by small angle. The interaction between I_1 and Q_2 produces torque, which is proportional to $\phi_2 I_1 \cos \alpha$, where $I_1 \cos \alpha$ is component of I_1 in phase with ϕ_2. Greater the angle θ, greater is the torque.

The torque equation of single quantity induction relay may be expressed as

$$T = K_1 I^2 - K_2$$

where T = Net torque

I = Current in relay coil

K_1, K_2 = Constants.

ϕ_1 = Flux in shaded portion of magnet
ϕ_2 = Flux in unshaded portion of magnet
E_1 = e.m.f. induced in the disc due to ϕ_1.
I_1 = Current in the disc induced by E_1.
Torque $\propto \phi_2 I_1 \cos \alpha$.
α = angle between ϕ_2 and I_1.

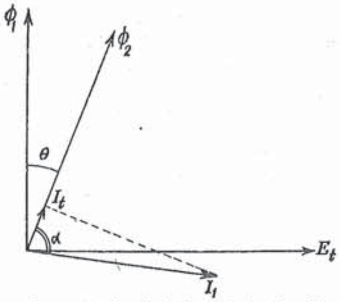


Fig. 26.10. Vector diagram of fluxes and current, for shaded pole induction disc relay.

Similar results are obtained by Watthour meter type induction disc relay (Fig. 26.12). The construction of this relay is similar to the watthour meter commonly used everywhere. It consists of an E-shaped electromagnet and a U-shaped electromagnet with a disc free to rotate in between. The E-shaped magnet produces flux ϕ_1 and the U-shaped magnet produces flux say ϕ_2. The phase angle θ between the fluxes is adjusted by a reactance in parallel with the secondary winding.

Torque is produced by interaction between flux and the eddy currents in the disc (produced by flux ϕ_1 and ϕ_2). The relay coil is tapped at several points. The current setting is selected by inserting a knob to take desired number of turns of the coil in the circuit.

1. The operation of induction relay can be controlled by opening secondary coil, as opening of this coil makes relay inoperative.

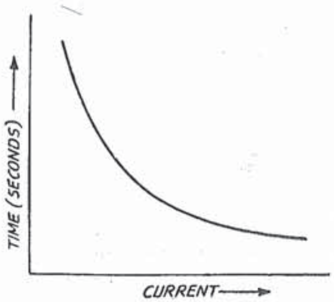


Fig. 26.11. Inverse characteristic.

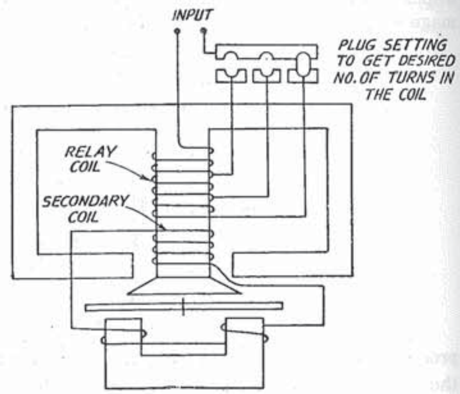


Fig. 26.12. Watthour meter type induction disc relay.

2. The time/current characteristics of induction disc relay is inverse characteristic (Figs. 26.11 and 26.14). The time reduces as current increases.

3. The VA burden depends on rating. It is of the order of 2.5 VA.

4. Modern induction disc relays are robust and reliable.

5. The current setting can be changed by taking the suitable number of turns. The time setting can be obtained by changing

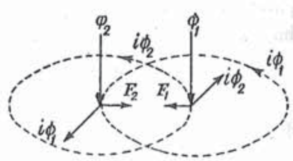


Fig. 26.13. Torque production in an induction relay.

the relative position of contacts by adjusting the length of travel of moving contacts.

6. The effect of d.c. offset may be neglected with inverse time single quantity induction relay, because they are generally slow. The d.c. offset may effect fast relays.

7. Ratio of reset of pick-up is high because operation does not involve any change in air gap. The ratio is above 95%.

8. **Operating time.** Inverse time characteristic is obtained by disc relays (Fig. 26.12). It is 10 to 60 sec.

Torque Equation of an Induction Disc Relay

Let $\phi_1 = \phi \sin \omega t$

and $\phi_2 = \phi \sin (\omega t + \theta)$

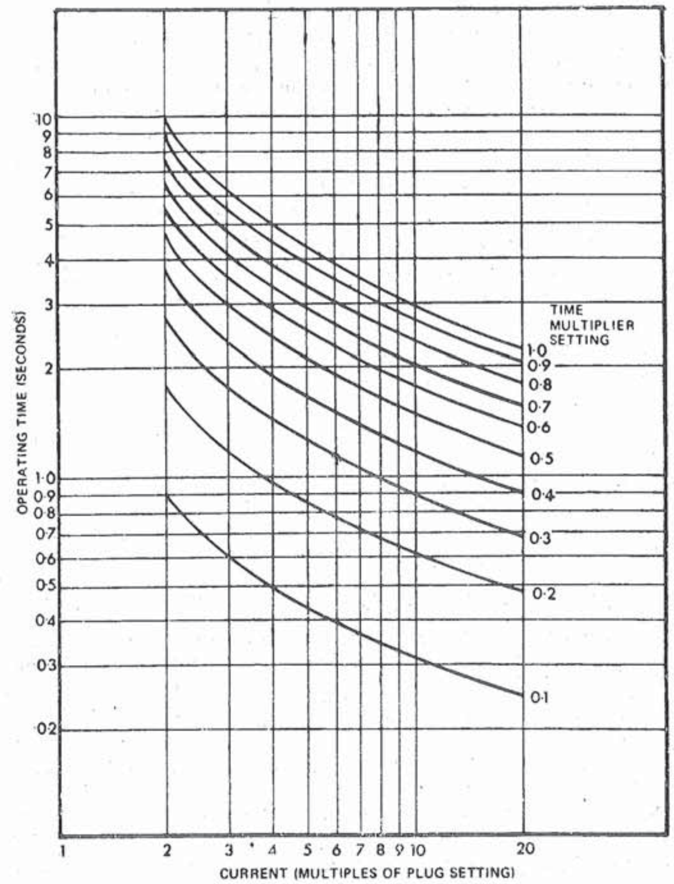


Fig. 26.14. Inverse characteristics of induction disc relays on log scales.

be the two fluxes at a phase difference of θ and which produce eddy currents $i\phi_1$ and $i\phi_2$ in the disc.

$$i\phi_1 = \frac{d\phi_1}{dt} \propto \phi \cos \omega t$$

$$i\phi_2 = \frac{d\phi_2}{dt} \propto \cos (\omega t + \theta)$$

$$F = (F_2 - F_1) \propto \phi_2\, i\phi_1 - \phi_1\, i\phi_2$$

where F is net force due to interaction between ϕ_2 and ϕ_1. F_1 is force due to interaction between ϕ_1 and ϕ_2.

$$F \propto \phi_1 \phi_2 [\sin (\omega t + \theta) \cos \omega t - \sin \omega t \cos (\omega t + \theta)]$$

$$\propto \phi_1\phi_2 \sin \theta.$$

26.11.1. Plug Setting and Time Setting in Induction Disc Relays

In these relays, there is a facility for selecting the plug setting and time setting such that the same relay can be used for a wide range of current, time and characteristics.

Time multiplier setting is generally in the form of an adjustable back-stop which decides the arc-length through which the disc travels, by reducing the length of travel, the time is reduced. The time multiplier setting is marked from about 0.1 to 1, with major divisions marked in between. If relay takes a certain time, say S seconds with time multiplier setting 1, the same relay will take time equal to $T \times S$ seconds for time multiplier setting T, other conditions remaining the same.

The arrangement is such that for various plug settings, the ampere-turns (amperes of plug setting × turns of coil corresponding to the plug setting) are constant for various plug settings. Thereby, the relay characteristics remains the same for various plug settings, for a given time setting. Actually, the relay should start operating at current equal to plug setting. However, due to friction, dust etc. the operations may not take place at exact plug setting value.

The relay characteristic is plotted with multiples of plug setting as an abscissa (log scale) and time in seconds (log scale) as ordinate. Suppose, current injected in relay coil is 10 Amp and plug setting is 2.5 Amp., then plug setting multiplier will be 10/2.5 = 4.

Fig. 26.14 illustrates typical characteristics of induction disc relays, on log scales.

26.11.2. Effect of Time-setting

By reducing the time multiplier, the characteristic is shifted to lower side, indicating that operating time is reduced (Fig. 26.14).

Plug Setting bride is provided with induction disc relays and it provides a wide range of current settings. The plug setting refers to the magnitude of current at which the relay starts to operate. The plug setting bridge comprises connections tapped from relay coil. By inserting the plug, in a particular gap in the bridge, a certain number of turns of the relay coil are brought into circuit.

26.12. INDUCTION CUP RELAY (ELECTROMAGNETIC)

This relay has two, four or more electromagnets, in stator. These are energized by the relay coils. A stationary iron core is placed as shown in Fig. 26.15. The rotor consists of a hollow metallic cylindrical cup. The rotor is free to rotate in the gap between the stationary iron and the electromagnets. In this type of relay, the eddy currents are produced in the metallic cup. These currents interact with the flux produced by the other electromagnet and torque is produced. The theory is similar to that of the disc type induction relay.

In Fig. 26.15 structure employing four poles is shown. It has an iron core at the centre and a metal cup between the core and electromagnet.

Fig. 26.15 shows a two pole structure. The two fluxes ϕ_1 and ϕ_2 are at right angles and produce eddy current in the cup. Thereby torque is produced.

1. Modern induction cup relays have 4 or more poles. A control spring and moving contacts are carried on an arm attached to the spindle of the cup.

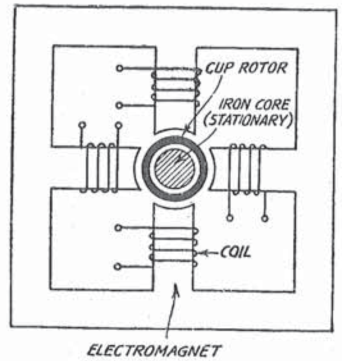


Fig. 26.15. Induction cup structure.

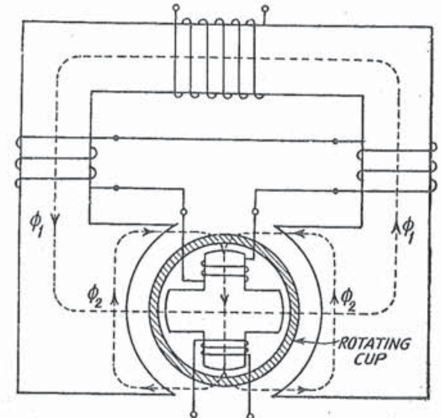


Fig. 26.16. Two pole induction relay.

2. The relay can be responsive to voltage or current. Similar structures are used in either cases.

3. The double actuating quantity relay can be responsive to both voltage and current.

4. The operating time characteristic depends on the type of structure. The relays have inverse time characteristic.

A modern induction cup relay may have an operating time of the order of 0.010 second.

26.13. PERMANENT MAGNET MOVING COIL RELAY

In this relay the coil is free to rotate in the magnetic field of a permanent magnet. The actuating current flows through the coil. The torque is produced by the interaction between the filed of the permanent magnet and the field of the coil.

1. **The relay responds to d.c. only.** However it is used in a.c. systems in conjunction with a rectifier.

2. The characteristic is varied by adjusting the control spring. The time setting is obtained by adjusting the position of the contact.

3. The operating torque is proportional to current in the coil. The force on the coil side is given by

$$F \propto NHIL$$

where F = Force

H = Magnetic field vector in the gap

I = Current in the coil

L = Length of the coil.

and torque is given by $T = 2rF$

where r = Radius of coil

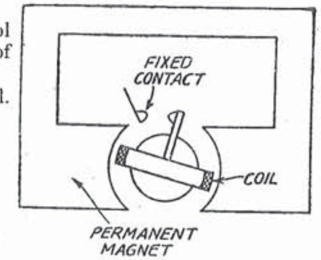


Fig. 26.17. Permanent magnent moving relay.

4. The time/current characteristic of such relays is shown in Fig. 26.18. It is an inverse characteristic.

5. The relay of this kind has uniform torque for the various positions of the coil. Hence it can be accurately set. Theoretically the reset value is equal to operating value.

6. Another popular type of moving coil construction is shown in Fig. 26.19. The coil is supported axially and moves horizontally when current is passed.

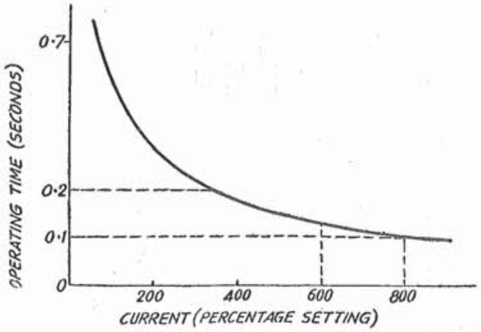


Fig. 25.18. Current-time characteristics of a typical moving coil permanent magnet relay.

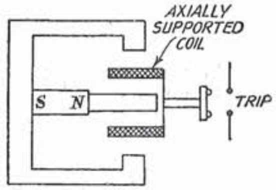


Fig. 25.19. Moving coil relay with axial moving coil.

This relay is faster than the rotating coil type because of the small travel, light parts. Time of the order of 30 m sec. can be obtained. VA burden is small. Sensitivity can be made as low as 0.1 milliwatt. Axial moving coil relays are delicate and should be handled with care.

26.14. RECTIFIER RELAY SYSTEMS

(*Courtesy :* Brown Boveri Ltd., Switzerland.)

The moving coil relays are being increasingly used with rectifier relays. In such relays, the quantities to be measured are rectified and then fed to the *moving coil unit.*

The principle and applications of such relays will now be briefly outlined (Fig. 26.20).

In the systems which measure rectified quantities, henceforth referred to as rectifier relays, the measuring element is a polarized moving-coil relay. This ready integrates the arithmetic mean value of the measured quantity. On account of the time taken by integration, it is not possible to gain the high measuring speed of electronic relays. However, the rectifier relays are faster than the mechanical relays since the moving coil has a very small mass.

26.14.1. Relays for One Quantity [Fig. 26.20.1]

As Fig. 26.20 shows the design of a relay for one quantity is quite simple. It comprises an input network, the rectifier and the moving-coil measuring system.

In the input network the measured quantity supplied by the main instrument transformer is converted into a form in which it can be processed. The network has setting resistors and an auxiliary transformer which, apart from converting the measured quantity, also serves as an insulating transformer.

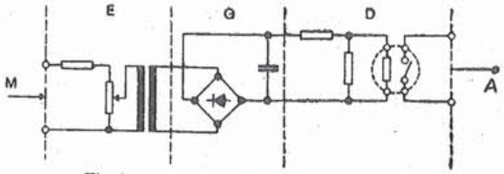


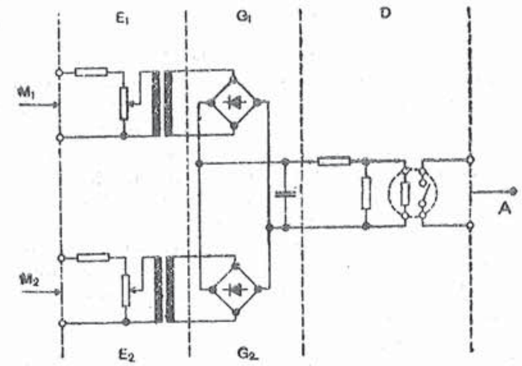
Fig. 26.20.1. Rectifier relay for one quantity.

The quantity is rectified in a full wave bridge (full-wave rectifier with centre tap). It may be equipped with smoothing elements.

The rectified quantity is then fed to the moving-coil measuring system, which is usually equipped with series and parallel resistor for adjustment of the pick-up value. The contact of the moving-coil system actuates the tripping relay and signalling device.

26.14.2. Relays for Two Quantities

In the relays for two measured quantities (Fig. 26.20.2) the two rectifier bridges are interconnected on the D.C. side in opposition and the moving-coil system is inserted between the two connections.



D = Moving-coil system
A = Relay out
M, M_1, M_2 = Measured quantities
E, E_1, E_2 = Input networks
G, G_1, G_2 = Rectifiers

Fig. 26.20.2. Rectifier relay for two quantities.

The measurement is thus based on the comparison of the two quantities in a bridge circuit according to the electrical balance principle. Since rectification eliminates the influence of frequency and phase angle, this comparison amounts to arithmetical subtraction of one current from the other.

The contacts of the moving-coil system either move in the tripping direction or stay in the blocking position, depending on which current is greater.

By choosing suitable input networks, not only can the measured quantities be compared with one another, their product or quotient can also be determined.

26.15. THERMAL RELAYS, BIMETAL RELAYS, THERMOCOUPLES

Thermal Relays. These relays operate the thermal effect of electric current. Generally, they do not measure the temperature directly.

Thermal relays sense the current by the temperature rise produced by the current. Thermal relays can also respond to unbalanced three phase currents, which cause rise in temperature due to their negative sequence component.

The simplest thermal relay used in motor starters, overload protection devices employ a bimetallic strip mounted above a resistance wire wound heater coil. The passage of current through the coil causes the bi-metallic strip to deflect and thereby close the relay contacts. A system of levers is arranged to obtain the closure compensation for ambient temperature arranged is usually provided by another bimetal strip, shielded from heater coil and arranged to oppose the bending of main bi-metallic strip.

The bimetal strip consists of two metal strips having different coefficient of (thermal) expansions joined together. As the combined strip is heated, one strip expands more than the other. One support is fixed and uneven expansion causes bending of the strip. This effect can be used to obtain closure of relay contacts.

Temperature Indicators and controllers employing thermocouples are becoming extremely popular in various temperature indicating and controlling devices for higher (above 60°C) temperature range. They are finding their way in protective relaying too. A thermocouple consists of a junction of two selected materials, the junction is connected in electric circuit. The difference in temperature between the hot junction and cold junction induces e.m.f. This e.m.f. is measured by a sensitive moving coil element.

Resistance temperature measuring devices employ the principle that the resistance of conductors increases with the temperature. The change in resistance is used for measuring the temperature. In large generators resistance temperature detectors are provided to measure temperature of stator winding.

In case of 3-phase motor, triple-pole bimetal relays are used. The bending of bimetal strip causes the movement of a common lever, which in turn operates the trip contact or trip lever in case of over load. The bimetal strip is heated directly by the current flowing in through it or by spacing heating coil. In case of bigger motors they are connected *via* current transformers.

Eutectic Alloy Relays operate on a different principle. In such relays a special alloy "Eutectic Alloy" is used. It is filled in a tube. When heated to a certain temperature, the alloy melts. A heater coil, which is in series with motor circuit encircles the above mentioned tube filled with Eutectic Alloy. When the current supplied to motor increases, the alloy melts and thereby the ratchet is released, thereby the contacts open by spring mechanism. Under normal conditions the Eutectic Alloy is solid and the control circuit is not closed. As soon as the Eutectic relay operates the coil is disconnected and the alloy cools and solidifies. Control circuit can be reset manually.

Winding thermostat usually comprises a tube containing a bimetal operated snap switch. The thermostat can be embedded in a motor winding. The snap switch can have normally open (NO) or normally closed (NC) contacts, and is to trip motor contactor or circuit breaker. Further details are given in the chapter "protection of Motors". (Acknowledgements to : Mr. V.S. Bhatia, Siemens Paper : Over-load protection of motors, *Courtesy* : Siemens India Ltd.).

26.16. DIRECTIONAL RELAYS

26.16.1. Principle of Measurements

Active-power flowing through a part of an electric circuit is given by

$$P = VI \cos \phi$$

where ϕ is a phase angle between I and V

The reactive power is given by $VI \sin \phi$

Referring to Fig. 26.21 (a).

For $270° < \phi < +90°$, $\cos \phi$ is positive, hence real power P is positive.

For $\phi = 90°$ and $180°$, real power P is zero.

For $+90° < \phi < +270°$ real power P is negative. Therefore the power flow can be sensed by sensing the magnitude and sign of $VI \cos \phi$. The voltage coil of the directional relay is supplied from secondary of voltage-transformer. The current coil is supplied from the secondary of current transformer. [Ref. Fig. 26.21 (b)].

The directional relay senses the power and responds if the power is positive. (For further details Ref. Sec. 26.16.4).

26.16.2. Directional Relays

Directional protection responds to flow of power in a definite direction with reference to the location of CT's and PT's Directional relays respond to the magnitude and sign

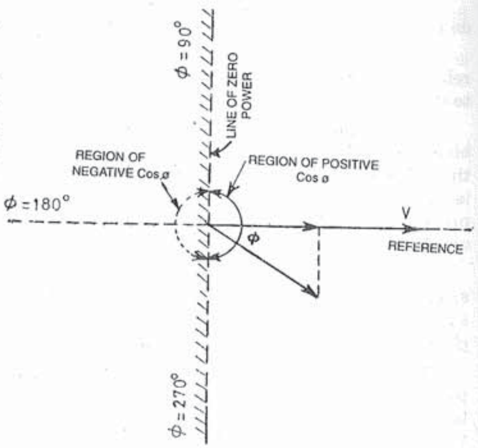
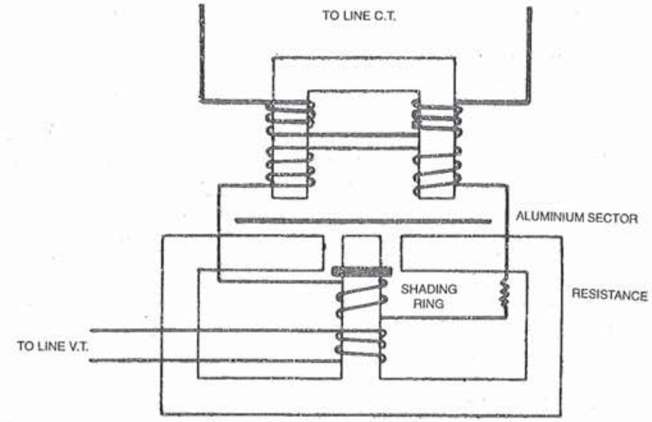


Fig. 26.21. (a). Vector diagram of Power.



Directional Element: Electro-magnetic System.

Fig. 26.21 (b). Directional relay induction disc type.

(direction) of power applied at their terminals. 'Directional relays" are used in protective system as elements which judge the direction of power flow.

Both Direction Power Relays and Directional Over-current, Directional Earth fault relays come under the group "Directional Relays". inductional disc type-watthour meter type constructional can be modified to obtained directional feature. When directional feature is desired, the relay is provided with two actuating coils called 'Current Coil' and 'Voltage Coil'. Fig. 26.21 illustrates the construction of an a.c. directional relay. Applications of directional relays have been discussed in Sec. 27.5.

Induction cup relays having 4, 6, 8 pole construction are also used as directional relays. The current coils of the relays are connected to the secondary of CT's (1 A, 5 A or 0.5 A). Voltage coils of directional relay are connected to the secondary of PT's. (110V). The method of connections is important. Depending upon the phase angle between current and voltage in the relay coils, the connection is called 90°, 60°, 30° connection. The values of angles refer to the phase angle between current of the current coil and voltage of the voltage coil. Fig. 26.22 explains the phase relationship of a 90° connected directional relay.

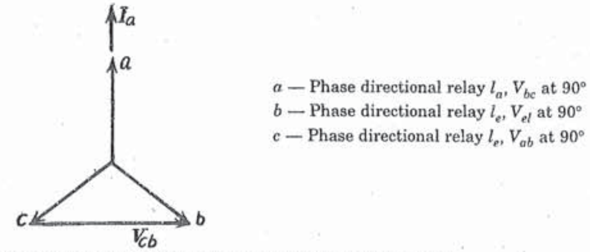


Fig. 26.22. 90° connection of directional relay : phase relationship.

Maximum torque angle of directional relay is the angle between current in the current coil and voltage applied to voltage coil to obtain maximum torque. Maximum torque angle has typical values such as 0°, 30°, lead 45° etc.

26.16.3. Principle of Operation of Directional Element

The moving system of induction disc type directional relay comprises an aluminium sector and a contact which are fixed to a vertical spindle fitted with hardened steel pivots. The hair spring, which is attached to the spindle at one end and to the main frame at the other, is equipped with a torsion setting device and serves two purposes ; (*a*) as control spring and (*b*) as the electrical connection from the moving contact to the main frame.

Under healthy system conditions or, under fault conditions where the current flow is in the normal directional, eddy currents induced in the sector produce a torque the direction of which restrains relay operation. Should current reversal occur, then the direction of the torque reverse causing the moving system to rotate and thus close the contacts, the latter being so connected that they complete the I.D.M.T. element operating coil circuit.

The maximum torque exerted on the movement occurs when the voltage and current in the coils are in phase. However, as the system power factor may be considerably removed from unity under fault conditions, depending on both the nature of the fault and system conditions, the element can be supplied with a phase-angle suited to the particular application, *i.e.* the relay is arranged to develop maximum torque at the probable phase-angle introduced by fault conditions. This is achieved by employing a suitable shading ring, the requisite value of resistance and the appropriate connection.

26.17. POLARIZED MOVING IRON RELAYS

These are moving iron relays with an additional polarising feature. Polarising quantity is one that produces flux in addition to the main flux. A moving iron relay can be polarised by providing a permanent magnet in its magnetic circuit. Fig. 26.24 shows a polarized relay.

Polarization increases the sensitivity of the relay, the other features of the relay as combinations of speed, sensitivity, characteristics etc. can be modified by means of polarization.

26.18. FREQUENCY RELAYS*

The frequency of induced e.m.f. of synchronous generators is maintained constant by constant speed. In case of overspeeding due to loss of load, underspeeding due to increase in load etc. the frequency varies from normal value. Frequency relays are used in generator protection and for Load-frequency control. (Ref. Sec. 45.7)

Frequency relays are either electromagnetic or static. They can be under-frequency relays or over-frequency relays.

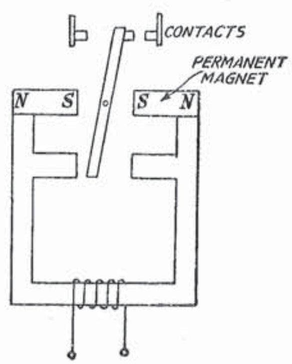


Fig. 26.23. Polarized Relay.

Frequency relays are generally connected to the secondary of voltage transformer. The frequency relay monitors the frequency continuously. It has two pairs of coils, constituting Ferraris Measuring System. The two pairs of coils are connected in parallel to the supply voltage through impedances. The impedances vary with frequency of supply. The impedances are tuned such that no torque is exerted on the cup-rotor at rated frequency. The torque exerted on the cup-rotor be clockwise or anticlockwise depending upon the frequency is higher or lower than the rated frequency.

The frequency setting can be varied by varying the position of sliding resistor. The pick-up sensitivity can be varied by adjusting the restraining spring.

The relay can operate on under-frequency or over-frequency. The under voltage relay is generallay provided in conjunction with under frequency relay.

* Ref. Sec. 45.8 for static frequency relay, load-frequency control.

Technical Data of a Frequency Relay

— Rated voltage	100/110 V, ± 20%
— Scale	46 — 54 Hz
— Accuracy of set value	± 0.4%
— Setting range for time lag	0.1 — 0.3 sec. 0.1 — 0.5 sec. 0.25 — 1 sec. 1 — 5 sec.
— Consumption	12 VA

26.19. UNDER-VOLTAGE RELAYS

Under voltage protection is provided for A.C. Circuits, bus-bars, motors, rectifiers, transformers etc. such protection is given by means of Under-voltage relays. Under-voltage relays are necessary for voltage control and reactive power control of network buses and load buses. Undervoltage relays can have instantaneous characteristic or inverse characteristic depending upon the construction and design. Inverse time undervoltage relays have inverse characteristic, their operating time reduces with reduction in voltage. Induction disc type construction is used for Inverse undervoltage relay. The relay coil is energized by voltage to be measured either directly or *via* a voltage transformer.

The construction of instantaneous under-voltage relays is similar to usual induction relay or attached armature relay. But the directions of torque/forces on the movable element of relay are different. For normal voltage, the restraining torque/force reduces and the relay operates due to operating torque/force given by the spring.

Typical setting-range of an Inverse Undervoltage Relays :

— 50 to 90%, Adjustable in equal steps of 10%.
— For 240 V or 400
— Disc resets completely at 10% or lest of voltage setting.
— Inverse characteristic.
— Consumption 5 VA at setting voltage.

26.20. D.C. RELAYS

Induction disc type and Induction cup type constructions are not suitable for d.c. Moving iron type, permanent magnet moving coil type, thermal type constructions are employed for d.c. relays. Permanent magnet moving coil relays have relatively high accuracy. Low consumption and are, therefore, widely used for d.c. circuits. Static relays are being increasingly preferred for d.c. use. (Ref. Sec. 26.13).

Applications of D.C. Relays. D.C. relays are used in d.c. trolley-bus systems, motor control, electroplating works, chemical and metallurgical processes, auxiliary and control circuits.

D.C. current relays are developed for controlling direct current, *i.e.* either rise in current, or fall in current or reverse current. D.C. relays are also developed for current regulating, summation or differential operations.

D.C. voltage relays are generally suitable for control of d.c. voltage *i.e.* either rise in voltage or fall in voltage or reversal of voltage, special designs are available for regulating the voltage.

D.C. relays are used for a.c. applications in conjunction with rectifiers. These are called Rectifier Relays.

26.21. ALL-OR-NOTHING RELAYS

In 'All-or-nothing relays', the pick-up value is not critical. The relay does not perform precise measurement, but it does not operate and changes its state (open contacts, close contacts). All-or-nothing relays include tripping relays, repeat contactors, time-lag relays, trip circuit supervision relays, auxiliary relays, indicator relays, etc. Such relays assist the measuring relays and they take over the various duties such as time lag, tripping indication etc. from the protective relay. Thereby, the protective relay can be designed for less burden and more sensitivity.

Repeat contactors are important components of relay contact systems. They repeat the operation of the measuring relay and relieve the latter of the duties such carrying current for a longer period. Thus the contacts of the measuring relay are relieved of other tasks and they can be made of light weight, delicate resulting in higher sensitivity of relay and less burden.

Alarm relays initiate alarm. In many abnormal conditions such as overload, the tripping of essential service motors or equipment may not be desirable. In such cases alarm is provided. So that the operator is alerted and can take corrective action. Alarm : visual (lamps) and audible (bell).

Tripping relays are fast, instantaneous relays and are generally attracted armature type. They are either hand or electrically reset type. Their operating time is of the order of 10 ms. Tripping relays have a few pairs of robust contacts. Tripping relays are used for high speed tripping duties where a number of simultaneous switching operations are desired.

Flag indicator relays are used for obtained indications of the operation of a remote protective device. The operation of a relay indicates operation of the corresponding measuring relay and circuit-breaker.

26.22. PLUG SETTING (Ref. Sec. 26.11.1. and 26.11.2)

It should be possible to use the same relay for a certain range of current/voltage. Hence a plug setting bridge is provided with electromagnetic relays. The plug setting refers to the reference value of operating quantity at which the relay starts operating. If by inserting the plug, setting of 2.5 is selected, the relay will start operating when the current in relay coil (secondary current of (CT) is about 2.5 A or more. Fig. 26.12 illustrates the principle of plug setting. Plug setting determines the number of turns tapped from the relay coil. The current-time characteristic for various plug setting, is generally same, provided time setting remains unchanged. Such performance is achieved by matching the plug-setting and corresponding number of turns tapped from the coil such that the Ampere-turns remains same for various plug-settings.

26.23. TIME SETTING (Refer Fig. 26.14)

In induction disc relays, the starting position of the moving contact is adjusted by means of back-stop. The time taken by relay to close is decided by the length of arc through which the moving contact travels, before touching the fixed contacts.

By increasing the length of travel of moving contacts, the relay time is increased. By reducing the length of travel, the relay time is minimised. The time setting dial is marked from 1 to 0.1.

26.24. TEST FACILITY

It should be possible to test the relay by injection test without actually tripping the circuit breaker, *i.e.* without closing the trip circuit, or without disturbing the panel wiring. In flush mounted, withdrawable relays, the relay is mounted on a carriage which can be completely pulled

(*a*) Normal position of finger contacts. (*b*) During testing of relay.
Fig. 26.24. Arrangement for testing the relay without disturbing circuit.

out the case for the purpose of testing keeping the connections undistributed. The terminals of current transformers are automatically short circuited. Such relays can be tested by inserting test plugs between finger contacts between the case and the carriage.

QUESTIONS

1. Define the following terms : Pick-up, reset.
2. With a neat sketch, describe the difference between definite characteristic and inverse characteristic of relays.
3. Describe the various types of constructions of attracted armature type relay. Why can they operate with a.c. and d.c.? State its salient features.
4. Describe the construction of an induction disc relay. State its principle of operation.
   What are the advantages to induction relays. How is the current setting and time setting obtained?
5. State the advantages and disadvantages of a moving coil permanent magnet relay. Can it be used for a.c. circuits ? How?
6. State the application of thermal relays. Describe the principle of operations. Give a schematic diagram of automatic temperature control of a furnace.
7. Explain the principle of Directional Element. Where is it applicable?
8. What are Rectifier Relays? Explain the components.
9. Explain the principle, types and applications of thermal relay.