Starter for 3-phase induction motor - power control circuits - D.O.L starter

Objectives: At the end of this lesson you shall be able to

- **state the necessity of starters for a 3-phase induction motor and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of the overload relay, different types of overload relays**
- **state the function of a no-volt coil, its rated voltage, position of operation, its common troubles, their causes and remedies.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformer starter

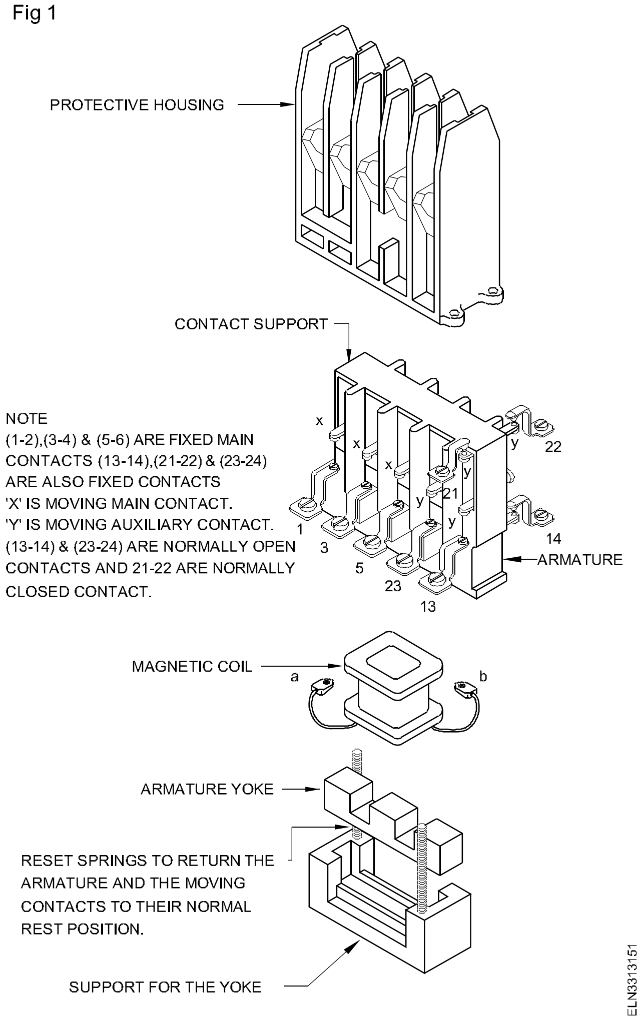
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1

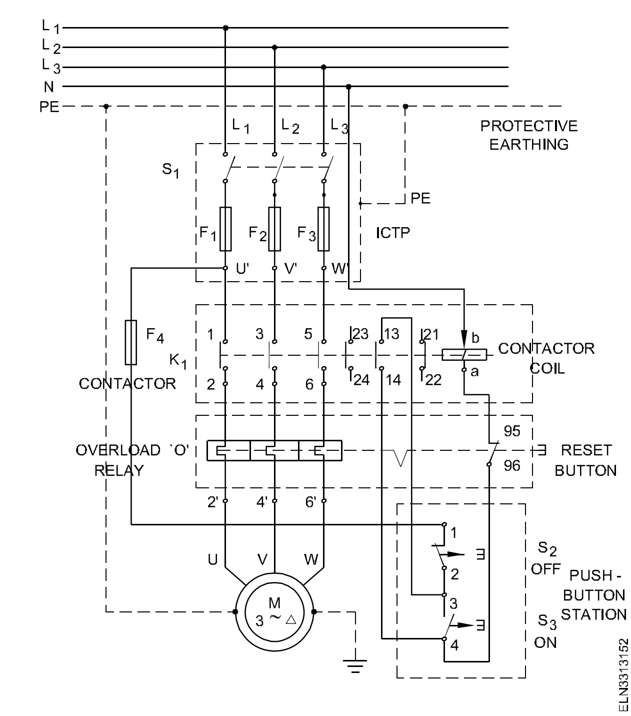


The main parts of a magnetic contactor are shown in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As shown in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2

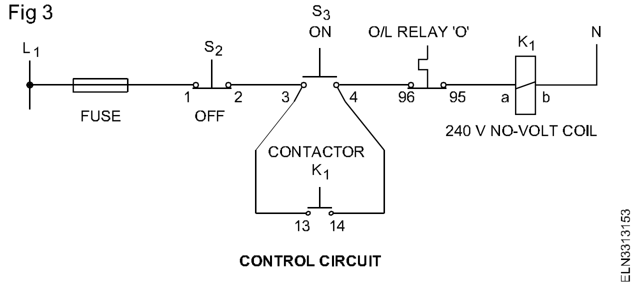


The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

Fig 3



CONTROL CIRCUIT

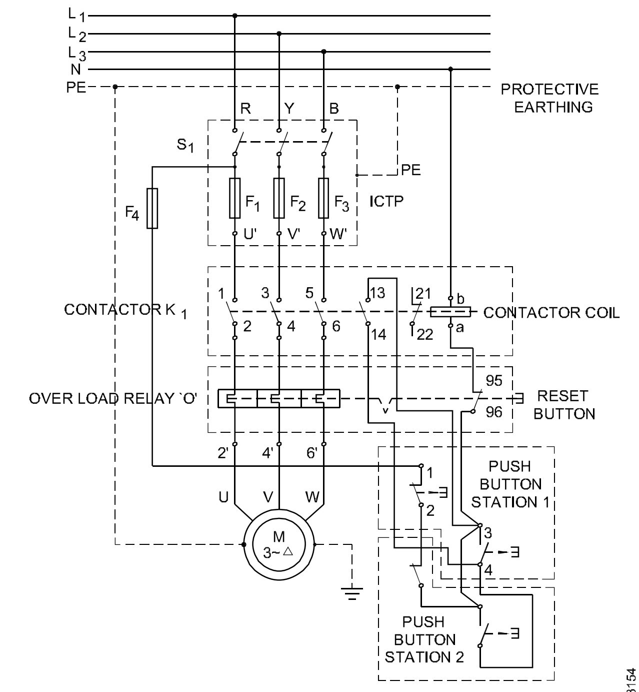
After S_3 is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit. (Fig 3)

Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

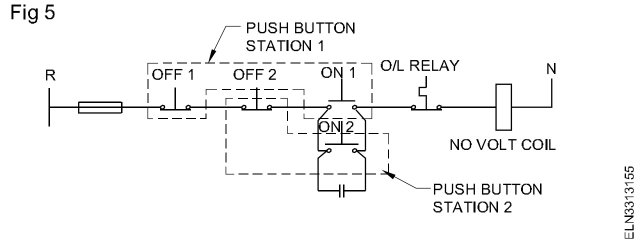
Push-button actuation from two operating locations: If it is desired to switch a contactor off and on from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as shown in the complete diagram Fig 4 and the control diagram Fig 5.

Fig 4



COMPLETE CIRCUIT DIAGRAM OF THE CONTACTOR AND THE 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Fig 5



If either of the two ON push-buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1. If either of the two OFF push -buttons is actuated, the contactor opens.

Purpose of overload relays: The overload relays protect the motor against repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500 percent of the full load current, or in 4 minutes if the current is 150 percent of the full load current.

Types of overload relay

There are two types of overload relays. They are :

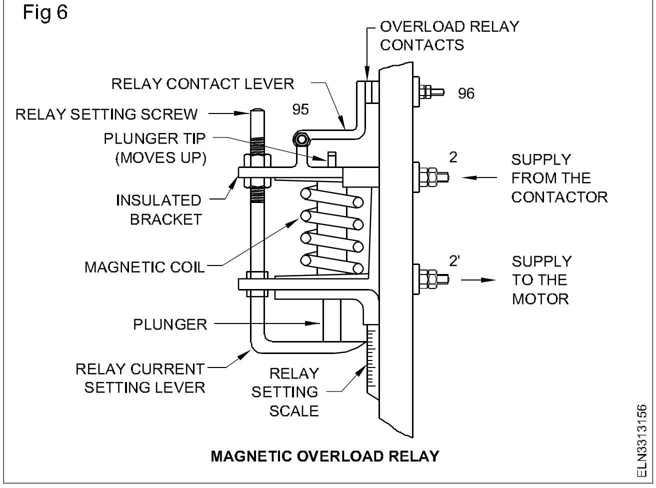
- magnetic overload relay
- thermal (bimetallic) overload relay.

Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing which help in avoiding the burning out of the motor.

Magnetic overload relay: The magnetic overload relay coil is connected in series with the motor circuits as shown in Fig 2. The coil of the magnetic relay must be wound with a wire, large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat, they are faster than bimetal relays.

As shown in Fig 6, the magnetic coil carries the motor current through terminals 2 and 2' which is in series with the power circuit. The relay contacts, 95 and 96, are in series with the control circuit. When a current more than a certain stipulated value, as set by the relay set scale, passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in an upward direction. This upward movement makes the plunger tip to push the relay contact lever, and the contact between terminals 95 and 96 opens. This breaks the no volt coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest-button (not shown in the figure) is pressed.

Fig 6



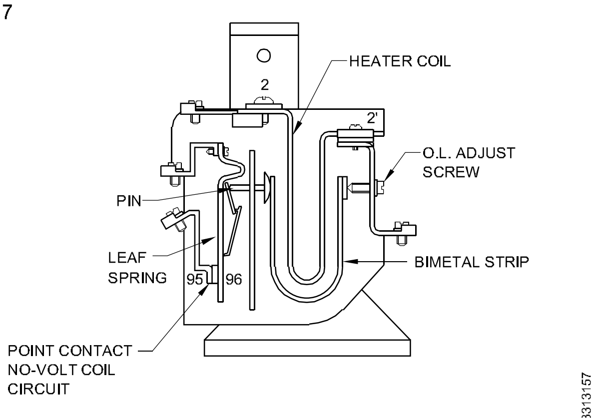
MAGNETIC OVERLOAD RELAY

Bimetallic overload relays: Most bimetallic relays can be adjusted to trip within a range of 85 to 115 per cent of the nominal trip rating of the heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures affect thermally-operated overload relays.

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused together. Movement occurs if one of the metal expands more than the other when subjected to heat. A U-shaped bimetallic strip is used in the relay as shown in Fig 7. The U-shaped strip and a heater element inserted in the centre of the U compartments for avoiding possible uneven heating due to variations in the mounting location of the heater element.

As shown in Fig 7, under normal conditions, the bimetallic strip pushes the pin against the leaf-spring tension, and the point contacts 95 and 96 are in a closed position, and hence the no-volt coil circuit is completed while the motor is running. When a higher current passes through the heater coil connected to terminals 2 and 2', the heat generated in the coil heats up the bimetal strip which bends inward. Hence the pin retracts in the right hand direction and the leaf-spring opens the contact between 95 and 96 to open the contactor. The relay cannot be reset immediately as the heat in the bimetallic strips require some time for cooling.

Fig 7



BIMETALLIC OVERLOAD RELAY

Relay setting: The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

For all direct on-line starters, relays should be set to the actual load current of the motor. This value should be equal to or lower than the full load current indicated on the name-plate of the motor. Described here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase the setting to 85% or more till the relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn by a motor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Tripping of starters: A starter may trip due to the following reasons.

- Low voltage or failure of power supply
- Persistent overload on the motor

In the first instance, the tripping occurs through the coil which opens the contacts when the voltage falls below a certain level. The starter can be restarted as soon as the supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and the load becomes normal.

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V (or) 230/250 V, 380V (or) 400/ 440V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor: Table 1 gives the common symptoms their causes and remedies.

Table 1

Symptoms	Causes	Remedies
Motor does not start when the 'start' button is pressed. However on pressing the armature of the contactor manually, motor starts and runs.	Open in no-volt coil circuit.	Check the main voltage for lower than acceptable value. Rectify the main voltage. Check the control circuit wiring for loose connection. Check the resistance of the no-volt coil winding. If found incorrect replace the coil.
Motor starts when `ON' button is pressed. It however stops immediately when `ON' button is released.	Auxiliary contact in parallel with the start-button is not closing.	Check the parallel connection from `ON' button terminals to the auxiliary contact of the contactor. Rectify the defect. Check the auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective.
Motor does start when the start-button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them. Low voltage supply. Find the cause and rectify the defect. Break in the shading ring in the case of AC magnet.
Failure of contactor due to too much heating of the `No' volt coil.	Higher incoming supply rating. No-volt coil rating is not high.	Higher supply voltage than normal. Reduce the incoming voltage. Voltage rating of the no-volt coil is less. Replace with standard rating, according to the main supply.
Motor does not restart immediately after tripping of OL relay even though OL relay was reset. Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	It takes a little time for the thermal bimetal to cool and reset. Open-circuited NVC. NVC burnt out.	Wait for 2 to 4 minutes before re-starting. Check the nylon strip on relay. Check the nylon button below the start button Replace, if necessary.
Relay coil has been changed. However motor does not start when the start-button is pressed.	Control circuit of relay open.	Check the control circuit for open. Clean the control station contacts. Overload relay not reset.

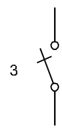
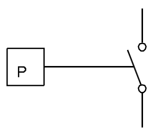
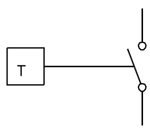
Symptoms	Causes	Remedies
Humming or chattering noise.	Low voltage. Magnetic face between yoke and armature is not clean. Shading ring on iron core missing.	Feed the rated voltage. Clean the surfaces of yoke and armature. Provide shading ring in the iron core

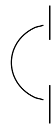
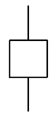
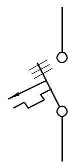
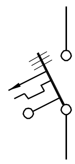
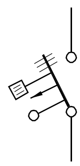
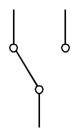
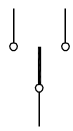
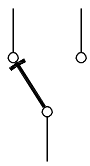
B.I.S. symbols pertaining to contactor and machines

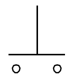
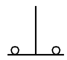
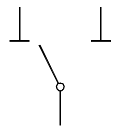
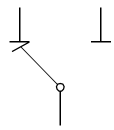
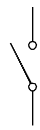
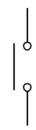
Objective: At the end of this lesson you shall be able to
- **identify B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).**

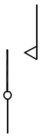
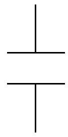
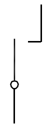
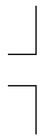
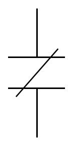
The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.

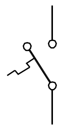
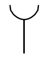
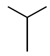
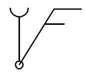
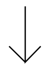
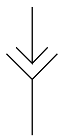
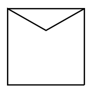
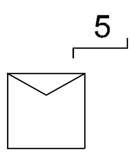
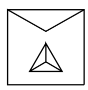
Table

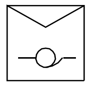
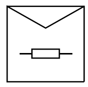
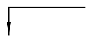
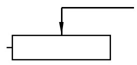
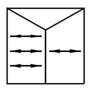
S.No.	BIS Code No.	Description	Symbol	Remarks
	BIS 2032 (Part XXV)-1980			
	9	**Switch gear, accessories**		
1	9.1	Switch, general symbol		
2	9.1.1	Alternate symbol for switch.		
3	9.2	Three-pole switch, single line representation.		
4	9.2.1	Alternate symbol for three-pole switch, single line representation.		
5	9.3	Pressure switch		
6	9.4	Thermostat		
7	9.5	Circuit-breaker		

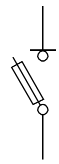
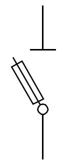
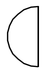
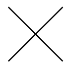
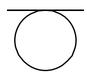
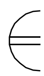
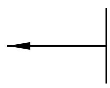
S.No.	BIS Code No.	Description	Symbol	Remarks
8	9.5.1	Alternate symbol of circuit-breaker. **Note : The rectangle of symbol 9.5 should contain some indication that a circuit-breaker is connected.**		
9	9.5.2	Alternate symbol for circuit breaker.		
10	9.5.3	Circuit-breaker with short circuit under voltage and thermal overload releases.		
11	9.5.4	Hand-operated circuit-breaker with short circuit, thermal overload protection and no-volt tripping.		
12	9.5.5	Motor - solenoid operated air circuit-breaker with short circuit and no-volt tripping (triple pole).	E/M 	
13	9.6	Change over contact, break before make. NOTE : The fixed contacts may be placed at any angle except at 60°. In order to facilitate the work of the draughtsman, the contacts may be arranged differently.		
14	9.7	Two-way contact with neutral position		
15	9.8	Make-before-break contact.		
16	9.9	Contactor, normally open.		
17	9.9.1	Contactor, normally closed.		

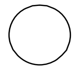
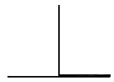
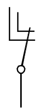
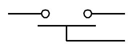
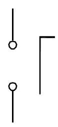
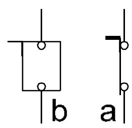
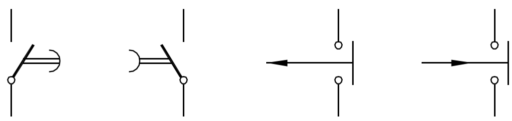
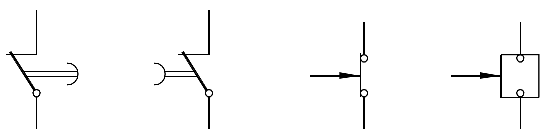
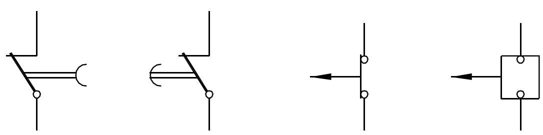
S.No.	BIS Code No.	Description	Symbol	Remarks
18	9.10	Push-button with normally open contact.		
19	9.10.1	Push-button with normally closed contact.		
20	9.11	Isolator.		
21	9.12	Two-way isolator with interruption of circuit.		
22	9.13	Two-way isolator without interruption of circuit.		
23	9.14	Make contact, general symbol.		
24	9.14.1	Alternate symbol for make contact, general symbol.		
25	9.14.2	Alternate symbol for make-contact.		
26	9.14.3	Alternate symbol for make-contact.		
27	9.14.4	Alternate symbol for make-contact.		
28	9.14.5	Alternate symbol for make-contact.		

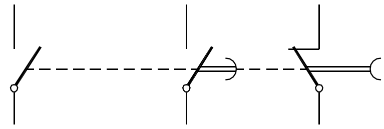
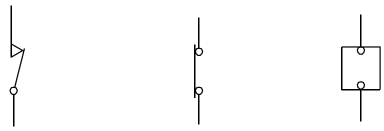
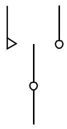
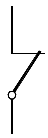
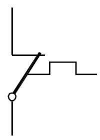
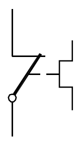
S.No.	BIS Code No.	Description	Symbol	Remarks
29	9.14.6	Alternate symbol for make-contact.		
30	9.14.7	Alternate symbol for make-contact.		
31	9.14.8	Alternate symbol for make-contact.		
32	9.14.9	Alternate symbol for make-contact.		
33	9.15	Break-contact, general symbol.		
34	9.15.1	Alternate symbol for break-contact.		
35	9.15.2	Alternate symbol for break-contact.		
36	9.15.3	Alternate symbol for break-contact.		
37	9.15.4	Alternate symbol for break-contact.		
38	9.15.5	Alternate symbol for break-contact.		

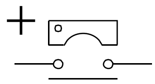
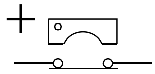
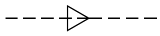
S.No.	BIS Code No.	Description	Symbol	Remarks
39	9.16	Thermal overload contact.		
40	9.17	Socket (female).		
41	9.17.1	Alternate symbol for socket (female).		
42	9.17.2	Socket with switch.		
43	9.18	Plug (male).		
44	9.18.1	Alternate symbol for plug (male).		
45	9.19	Plug and socket (male and female).		
46	9.19.1	Alternate symbol for plug and socket (male and female).		
47	9.20	Starter, general symbol.		
48	9.21	Starter by steps (Example: 5 steps).		
49	9.22	Star-delta starter.		

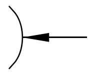
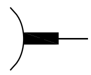
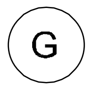
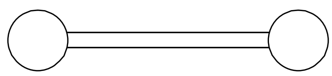
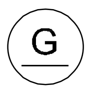
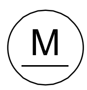
S.No.	BIS Code No.	Description	Symbol	Remarks
50	9.23	Auto-transformer starter.		
51	9.24	Pole-changing starter (Example, 8/4 poles).		
52	9.25	Rheostatic starter.		
53	9.26	Direct on-line starter.		
54	9.27	Sliding contact, general symbol.		
55	9.27.1	Resistor with moving contact, general symbol.		
56	9.28	Combined control panel for two motors (multiple speed and reversible).		
57	9.29	Fuse.		
58	9.29.1	Alternate symbol for fuse.		
59	9.29.2	Alternate symbol for fuse where supply side is indicated by a thick line.		
60	9.29.3	Alternate symbol for fuse where supply side is indicated by a thick line.		

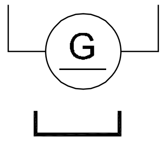
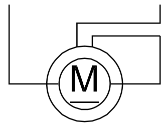
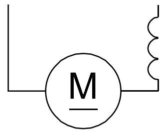
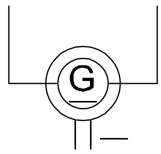
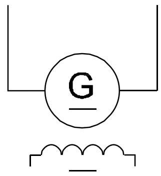
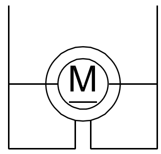
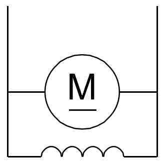
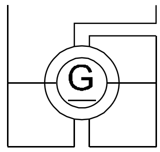
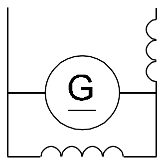
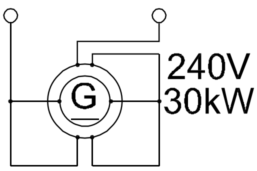
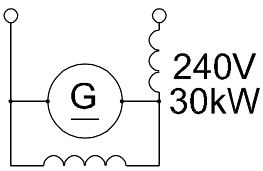
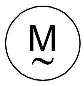
S.No.	BIS Code No.	Description	Symbol	Remarks
61	9.30	Isolating fuse-switch, switching on load.		
62	9.31	Isolating fuse-switch.		
	BIS 2032 Part(XXV11) 1932	**Contactors**		
	3.2	**Qualifying symbols**		
63	3.2.1	Contactor function.		
64	3.2.2	Circuit-breaker function.		
65	3.2.3	Disconnector (isolator) function.		
66	3.2.4	Switch-disconnector (isolator switch) function.		
67	3.2.5	Automatic release function.		
68	3.2.6	Delayed action. Convention - delayed action in direction of movement from the arc towards its centre. **Note: This symbol must be linked by a double line to the symbol of the device, the action of which is delayed.**	 	
69	3.2.6.1	Delayed action convention - delayed action in the direction of movement of the arrow mark.		

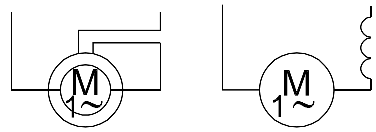
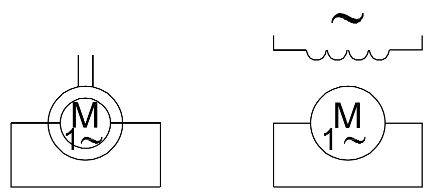
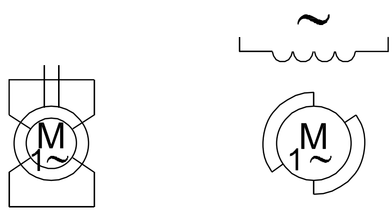
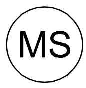
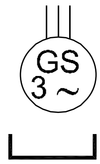
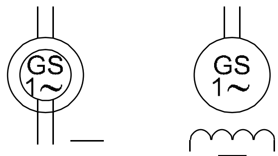
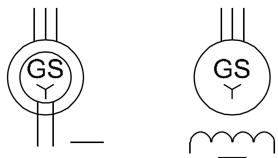
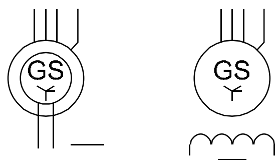
S.No.	BIS Code No.	Description	Symbol	Remarks
70	3.2.7	Non-spring return (stay put) function. NOTE : The symbols shown above may be used to indicate spring-return and stay-put contacts. When this convention is invoked, its use should be appropriately referenced. These symbols should not be used together with the qualifying symbols Nos. 3.1 to 3.4.		
71	3.2.8	Hand reset.		
72	3.3.7	Contact with two makes.		
73	3.3.8	Contact with two breaks.		
74	3.3.9	Three-point contact.		
75	3.3.10	Make contact-hand reset.		IR
76	3.3.11	Break contact-hand reset.		IR
77	3.3.19	Make-contact delayed when operating.		
78	3.3.20	Break-contact delayed when operating.		
79	3.3.21	Break-contact delayed when releasing.		

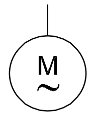
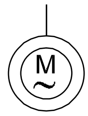
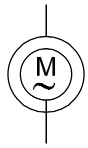
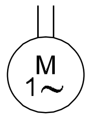
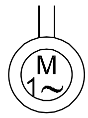
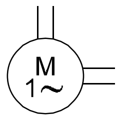
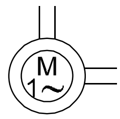
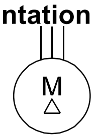
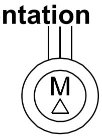
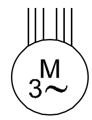
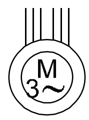
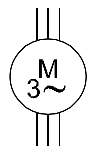
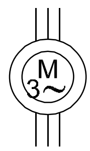
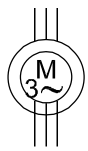
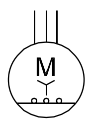
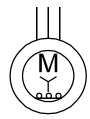
S.No.	BIS Code No.	Description	Symbol	Remarks
80	3.3.22	Make-contact delayed when operating and releasing.		
81	3.3.23	Contact assembly with one make-contact not delayed. One make contact delayed when operating and one break-contact delayed when releasing.		
82	3.3.24	Make-contact with spring return.		
83	3.3.25	Make-contact without spring return (stay-put)		SR
84	3.3.26	Break-contact with spring return.		SR
85	3.3.27	Two-way contact with centre off position with spring. Return from the left-hand position but not from the right hand one (stay-put).		
86	3.3.28	Temperature-sensitive make-contact. **Note: May be replaced by the value of the operating temperature conditions.**		
87	3.3.29	Temperature sensitive break-contact. NOTE : may be replaced by the value of the operating temperature conditons.		
88	3.3.30	Self-operating thermal-break contact. NOTE : It is important to distinguish between a contact as shown and a contact of a thermal relay, which in detached representation is shown in the example below.		
		Example: Break contact of a thermal relay.		

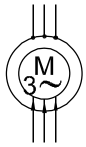
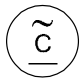
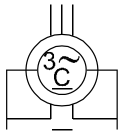
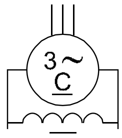
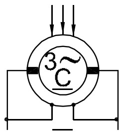
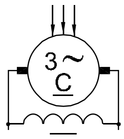
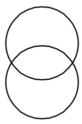
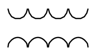
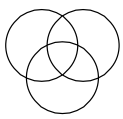
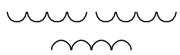
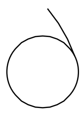
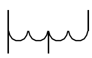
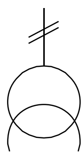
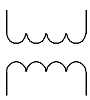
S.No.	BIS Code No.	Description	Symbol	Remarks
89	3.3.32	Blow-out magnetic make-contact.		
90	3.3.33	Blow-out magnetic break-contact.		
	BIS:2032 (PART VII) 1974	**Mechanical controls**		
91	8.4	**Mechanical interlock**		
92	8.5	Reset a Automatic reset b Non-automatic reset **Note : These symbols should be used only if it is essential to indicate the type of reset.**	 	
	BIS:2032 (Part IV) 1964	**Classification** In this standard, more than one symbol have been used to designate the same type of rotating machine or transformer depending on the type and class of drawing involved. For the same type of rotating machines, in simplified as well as in the complete, multi-line symbols have been specified. In the case of transformers, symbols for single line and multi-line representation have been given separately. Wherever single line representation is required for rotating machines, reference may be made to IS:2032(Part II)-1962. Elements of symbols		
93	3.14	Winding Note: The number of half circles is not fixed, but if desired a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4.		
94	3.24	Commutating or compensating winding.		
95	3.34	Series winding.		

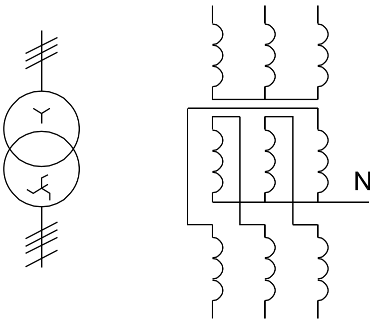
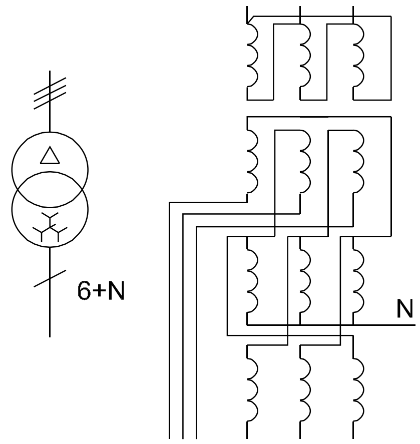
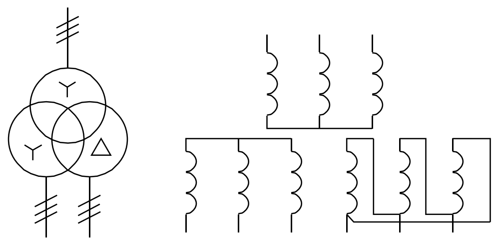
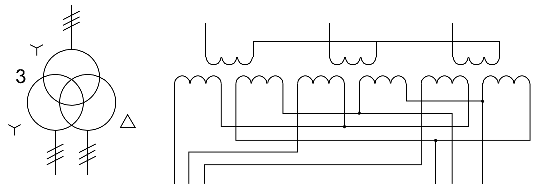
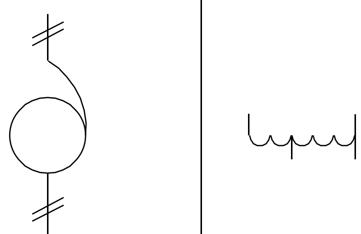
S.No.	BIS Code No.	Description	Symbol	Remarks
96	3.44	Shunt winding or separate winding.		
97	3.54	Brush or slip-ring.		
98	3.64	Brush on commutator.		
99	3.74	**Supplementary indications, numerical data.** **Supplementary indications (method of connecting windings, letter M, G or C and numerical data) are shown only on one symbol for each class of machine, as an example.**		
	4	**Rotating machines**		
	4.1	**General symbols**		
100	4.1.14	Generator		
101	4.1.2	Motor		
102	4.1.3	Machine capable of use as generator or motor.		
103	4.1.4	Mechanically coupled machines. **Note: Other special types of coupling, that is, monobloc construction, shall be suitably indicated wherever necessary.**		
	4.2	**Direct current machine**		
104	4.2.1	Direct current generator, general symbol.		
105	4.2.2	Direct current motor, general symbol.		

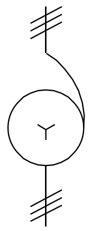
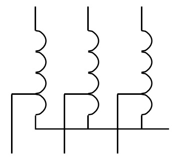
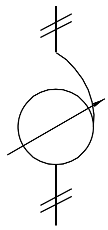
S.No.	BIS Code No.	Description	Symbol	Remarks
106	4.2.3	DC 2-wire permanent magnet generator(G) or motor (M).	 **Simplified multiline representation** **Complete multiline representation**	
107	4.2.4	DC 2-wire series generator (G) or motor (M).	 	
108	4.2.5	DC 2-wire generator (G) or motor (M) separately excited.	 	
109	4.2.6	DC 2-wire shunt generator (G) or motor (M).	 	
110	4.2.7	DC 2-wire generator (G) or motor (M), compound-excited, short shunt.	 	
111	4.2.8	Symbol showing terminals, brushes and numerical data. *Example* : DC 2-wire generator compound excited short shunt, 240 V, 30 KW.	 	
	4.3	**Alternating current machines**		
112	4.3.1	AC generator, general symbol.		
113	4.3.2	AC motor, general symbol.		
	4.4	**Alternating current Commutator machines.**	**Simplified multiline representation** **Complete multiline representation**	

S.No.	BIS Code No.	Description	Symbol	Remarks
114	4.4.1	AC series motor, single phase.		
115	4.4.2	Repulsion motor, single phase.		
116	4.4.3	AC series motor, single phase, Deri type.		
	4.5	**Synchronous machines**		
117	4.5.1	Synchronous generator, general symbol.		
118	4.5.2	Synchronous motor - general symbol.		
119	4.5.3	Permanent magnet synchronous generator (GS) or synchronous motor (MS), three-phase.		
			Simplified multiline representation **Complete multiline representation**	
120	4.5.4	Synchronous generator (GS) or synchronous motor (MS) single-phase.		
121	4.5.5	Synchronous generator (GS) or synchronous motor (MS) three-phase, star-connected, neutral not brought out.		
122	4.5.6	Synchronous generator (GS) or synchronous motor (MS) three-phase star-connected with neutral brought out.		

S.No.	BIS Code No.	Description	Symbol	Remarks
	4.6	**Induction Machines**		
		Note : In symbols 4.6.1 to 4.6.9 groups of conductors may be placed in another manner than generally shown below. For example, symbol 4.6.6.		
123	4.6.1	Induction motor, with short-circuited rotor, general symbol.	 	
124	4.6.2	Induction motor, with wound rotor, general symbol.		
125	4.6.3	Induction motor, single phase, squirrel-cage.	 	
126	4.6.4	Induction motor, single phase, squirrel cage, leads of split-phase brought out.	 	
			Simplified multiline representation **Complete multiline representation**	
127	4.6.5	Induction motor, three-phase, squirrel-cage.	   	
128	4.6.6	Induction motor, three-phase, squirrel cage, both leads of each phase brought out.	 	
129	4.6.7	Induction motor, three-phase, with wound rotor.		
130	4.6.8	Induction motor, three-phase, star-connected, with automatic starter in the rotor.	 	

S.No.	BIS Code No.	Description	Symbol	Remarks
131	4.6.9	Symbol showing terminals, brushes and numerical data. *Example* : Induction motor, three-phase, with wound rotor 415V, 22 kW, 50 c/s.	 415V 22kW 50c/s	
	4.7	**Synchronous converters.**		
132	4.7.1	Synchronous converter, general symbol.		
133	4.7.2	Three-phase synchronous converter, shunt excited. 72	 	
134	4.7.3	Symbol showing terminals, brushes and numerical data. *Example* : Three-phase synchronous converter, shunt excited 600 V, 1000 kW, 50 c/s.	 415V △ 1000kW 50c/s 600V-  415V △ 1000kW 50c/s 600V-	
	5	**Transformers**		
	5.1	**General symbols**		
135	5.1.1	Transformer with two separate windings.	  **Simplified multiline representation** / **Complete multiline representation**	
136	5.1.2	Transformer with three separate windings.	 	
137	5.1.3	Auto-transformers	 	
	5.2	**Transformers with two or three Windings.**		
138	5.2.1	Single-phase transformer with two separate windings.	 11000V 250kVA 50c/s 4%  11000V 250kVA 50c/s 4% 415V	

S.No.	BIS Code No.	Description	Symbol	Remarks
139	5.2.4	Three-phase transformer with two separate windings. Connection: star zig-zag.		
140	5.2.5	Three-phase transformer with two separate windings. Connection: delta 6-phase fork.		
141	5.2.6	Three-phase transformer with three separate windings. Connection: star, star-delta.	 **Simplified multiline representation**	**Complete multiline representation**
142	5.2.7	Three-phase bank of single-phase transformers with three separate windings. Connection : star, star-delta.		
	5.3	**Auto-transformers**		
143	5.3.1	Auto-transformer, single-phase.		

S.No.	BIS Code No.	Description	Symbol	Remarks
144	5.3.2	Auto-transformer, three-phase. Connection:star.		
145	5.3.3	Single-phase auto-transformer with continuous voltage regulation.		

D.O.L. starter

Objectives: At the end of this lesson you shall be able to
- **state the specification of a D.O.L. starter, explain its construction, operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is shown in Fig 1. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 3.1.04 and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as shown in Fig 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own

Specification of D.O.L. starters: While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 240 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

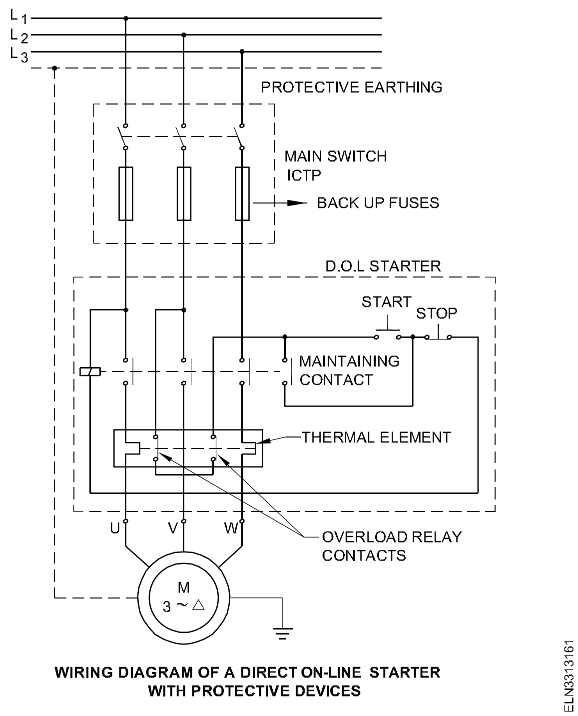
Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

Fig 1



WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

Applications: In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

Necessity of back-up fuses: Motor starters must never be used without back-up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses which, when used in the motor circuit, operate at a faster rate and open the circuit. Hence H.R.C. diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, the back-up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for different motor ratings is given.

It is recommended that the use of semi-enclosed, rewirable, tinned copper fuses may be avoided as for as possible.

The given full load currents apply in the case of single phase, capacitor-start type motors, and in the case of 3-phase, squirrel cage type induction motors at full load having average power factor and efficiency. The motors should have speeds not less than 750 r.p.m.

Fuses upto and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).

Table of relay ranges and back-up fuses for motor protection

Sl. No.	Motor ratings 240V 1-phase			Motor ratings 415V 3-phase			Relay range A	Nominal back-up fuse recommended
	hp	kW	Full load current	hp	kW	Full load current	a	c
1				0.05	0.04	0.175	0.15 - 0.5	1A
2	0.05	0.04		0.1	0.075	0.28	0.25 - 0.4	2A
3				0.25	0.19	0.70	0.6 - 1.0	6A
4	0.125	0.11		0.50	0.37	1.2	1.0 - 1.6	6A
5	0.5	0.18	2.0	1.0	0.75	1.8	1.5 - 2.5	6A
6	0.5	0.4	3.6	1.5	1.1	2.6	2.5 - 4.0	10A
7				2.0	1.5	3.5	2.5 - 4.0	15A
8	0.75	0.55		2.5	1.8	4.8	4.0 - 6.5	15A
9				3.0	2.2	5.0	4.0 - 6.5	15A
10	1.0	0.75	7.5	5.0	3.7	7.5	6.0 - 10	20A
11	2.0	1.5	9.5	7.5	5.5	11.0	9.0 - 14.0	25A
12	3.0	2.25	14	10.0	7.5	14	10.0 - 16.0	35A

Numerical problems in ac 3-phase induction motors

Objective: At the end of this lesson you shall be able to
- **solve the numerical problems in 3 phase induction motor.**

On very many occasions, an electrician may be asked to wire up a workshop well before the proposed machine is installed, having been provided with information only regarding the voltage rating and horsepower of the electrical motor.

While planning the wiring, the cable sizes need to be selected, based upon the full load current of the motor which could be calculated when sufficient data is available. The examples given below illustrate the method of determining the full-load current when other data are provided or vice versa.

To illustrate:

The output of the motor is given in metric horsepower.

Output of the motor = Metric HP x 735.6 watts.

Input of the motor = $\sqrt{3}\, E_L\, I_L \cos\theta$ watts

where E_L is the line voltage

I_L is the line current

$\cos\theta$ is the power factor

Also input = output + losses

= output + copper loss + iron loss + mechanical losses like windage, friction etc.

$$\text{Efficiency of the motor} = \frac{\text{Output}}{\text{Input}} \times 100$$

$$= \frac{\text{Metric horsepower} \times 735.5}{\sqrt{3} E_L I_L \cos\theta}$$

Example 1

A 3-phase, 6000 volts, star-connected induction motor develops 200 HP (Metric). Calculate the full load current per phase if the efficiency of the motor is 85% and the power factor is 0.8.

$$\text{Input} = \frac{\text{Output} \times 100}{\text{Efficiency}}$$

$$= \sqrt{3} E_L I_L \cos\theta$$

$$\text{Line current } I_L = \frac{\text{Output} \times 100}{\text{Efficiency} \times E_L \cos\theta \times \sqrt{3}}$$

$$= \frac{200 \times 735.5}{0.85 \times \sqrt{3} \times 6000 \times 0.8}$$

= 20.81A

In star, as the line current is equal to the phase current, we have the phase current at full load - 20.9 amps.

Example 2

A 3-phase, induction motor takes a current of 100 amps from 400V 50 HZ supply. Determine the power factor if the output of the motor is 70 HP (metric) and the efficiency is 90%.

$$\text{Input} = \frac{\text{Output}}{\text{Efficiency}}$$

$$\sqrt{3} E_L I_L \cos\theta = \frac{70 \times 735.5}{\frac{90}{100}}$$

$$\cos\theta = \frac{70 \times 735.5 \times 100}{90 \times \sqrt{3} \times 400 \times 100}$$

Power factor = 0.82.

Example 3

A 3-phase, 400V, 50 HZ, delta-connected induction motor draws a line current of 150 amps with a P.F. of 0.85 and is delivering an output of 100 (Metric) HP. Calculate the efficiency.

$$\text{\% of efficiency} = \frac{\text{Output} \times 100}{\text{Input}}$$

$$= \frac{100 \times 735.5 \times 100}{\sqrt{3} \times 400 \times 150 \times 0.85}$$

= 83.3 %

Example 4

A 3-phase, 400 V, induction motor takes a line current of 30 amperes with a power factor of 0.9. The efficiency of the motor is 80%. Calculate the output in metric horsepower.

Output in watts = Input x Efficiency

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100}$$

$$\text{Output in metric HP} = \frac{\text{Output in watts}}{735.5}$$

$$= \frac{\sqrt{3} \times 400 \times 30 \times 0.9 \times 80}{100 \times 735.5}$$

= 20.3 HP.

Jogging (inching) control circuits for motors

Objectives: At the end of this lesson you shall be able to

- **define the process of jogging/inching control**
- **state the purpose of jogging/inching control**
- **describe the operation of a jogging control using a selector switch**
- **describe the operation of a jogging control using a push-button station**
- **describe the operation of a jogging control using a control relay.**

Jogging (inching): In some industrial applications, the rotating part of a machine may have to be moved in small increments. This could be done by a control system called jogging (inching). Jogging is defined as the repeated closure of the circuit to start a motor from rest, producing small movements in the driven machine. By pressing the jog push-button the magnetic starter is energised and the motor runs; when the jog push-button is released, the motor stops.

When a jogging circuit is used, the motor can be energised only as long as the jog-button is depressed. This means the operator has instantaneous control of the motor drive.

Purpose of jogging/inching controls: Normally jogging (inching) controls are incorporated in the following machines for operational convenience shown against each.

- Lathe machine controls - for checking the trueness of the job and setting the tool initially.
- Milling machine controls - for checking the concentric running of the cutter at initial setting and also to set the graduated collar for depth of feed of the cutter.
- Grinding machine controls - for checking proper mounting of the wheel.
- Paper cutting machine - for adjusting the cut.

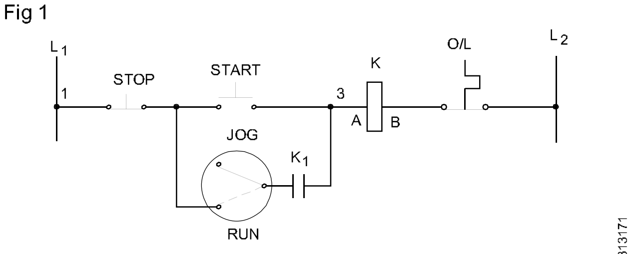
Apart from the above, the inch control is the prime control in cranes, hoists and conveyor belt mechanism so that incremental movements either vertically or horizontally could be achieved in the driven machinery.

Jogging may be accomplished by the following methods.

- Selector switch
- Push-button
- Push-button with a jog relay

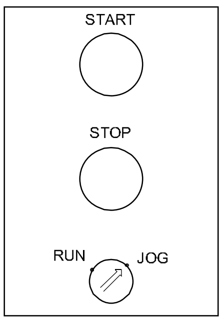
Jogging control using a selector switch: By using a selector switch, the existing start button can be used as a jogging push-button in addition to its function as a starting push-button. The holding contacts of the contactor which are in parallel to the start-button are disconnected and the selector switch is placed in the jog position as shown by the circuit in Fig 1 and the panel layout in Fig 2.

Fig 1



CONTROL CIRCUITS WITH JOG-RUN SELECTOR SWITCH.

Fig 2

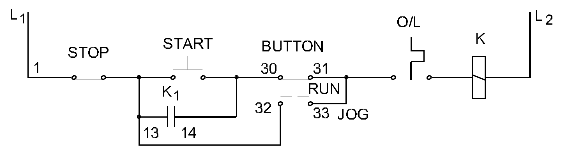


A PANEL OF A STATION IN WHICH THE START BUTTON CAN BE USED FOR INCHING OR JOGGING.

The motor can be started or stopped by jogging/inching the start button. The motor will operate as long as the start-button is held pressed.

Jogging control using a push-button: Fig 3 shows the control circuit of a D.O.L. starter connected to a start-jog-stop push-button station. When the `ON' push-button is pressed, coil K is energised as the no-volt coil circuit is complete through the normally closed `jog' button contacts 30 & 31, thereby closing the main contactor, and the motor runs. The self-holding auxiliary contact K_1 between terminals 13 and 14 gets closed, and keeps the no-volt coil circuit in function though the `ON' button is released. As soon as the jog push-button is pushed, as the circuit of the no-volt coil opens initially, the contactor is de-energised and the motor stops if it is running. Then the jog-button closes the bottom contacts 32 & 33, thereby the no-volt coil circuit closes and the motor runs as long as the jog-button is held pressed. By pushing and releasing the jog-button repeatedly, the motor starts and stops causing the driven machinery to `inch' forward to the desired position. On the other hand, pressing the start-button will make the motor to run normally.

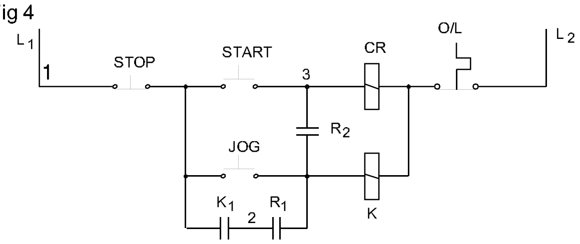
Fig 3



CONTROL CIRCUIT WITH JOG PUSH-BUTTON

Jogging control using a relay: Fig 4 shows the control circuit of a D.O.L. starter connected to a control relay with the other usual components. When the start button is pressed, the control relay coil CR is energised and closes the contacts R_1 and R_2, thereby momentarily completing the no-volt coil `K' circuit through relay contact R_2. This in turn closes the self-holding auxiliary contact K_1 of the no-volt coil relay K, and the motor runs continuously even though the pressure on the start-button is released.

Fig 4



LINE DIAGRAMS USING CONTROL RELAYS IN TYPICAL INSTALLATIONS

When the motor is not running, if the jog-button is pressed the no-volt coil, K circuit, is completed, and the motor runs only as long as the jog-button is held pressed as the holding circuit through R_1 is not completed for the starter coil as the control relay CR is not energised.

For a 3-phase, D.O.L. starter having the jog control through relay, four normally open contacts (3 for main and 1 for auxiliary) are required and the control relay should have two normally open contacts as shown in Fig 4.

Rotary type switches

Objectives: At the end of this lesson you shall be able to
- **explain the type of rotary switches - specifications like voltage rating, current rating, poles, function, position, type of mounting, type of handle, number of operations per hour and special requirement,**
- **explain the schematic diagram of rotary switches along with connection diagram of motors for ON/OFF three-pole switch, forward, stop and reverse three-pole switch, star-delta switch and pole changing switch.**

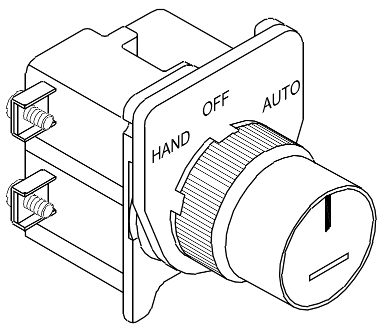
Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs.

These rotary switches are classified according to

- poles
- function
- position
- mounting type
- handle design, and
- frequency of operations.

Poles: According to the number of independent connecting terminals and operation, they are called 2-pole (single phase, refer to Fig 1) or 3-pole (3-phase, refer to Fig 2) switches.

Fig 1

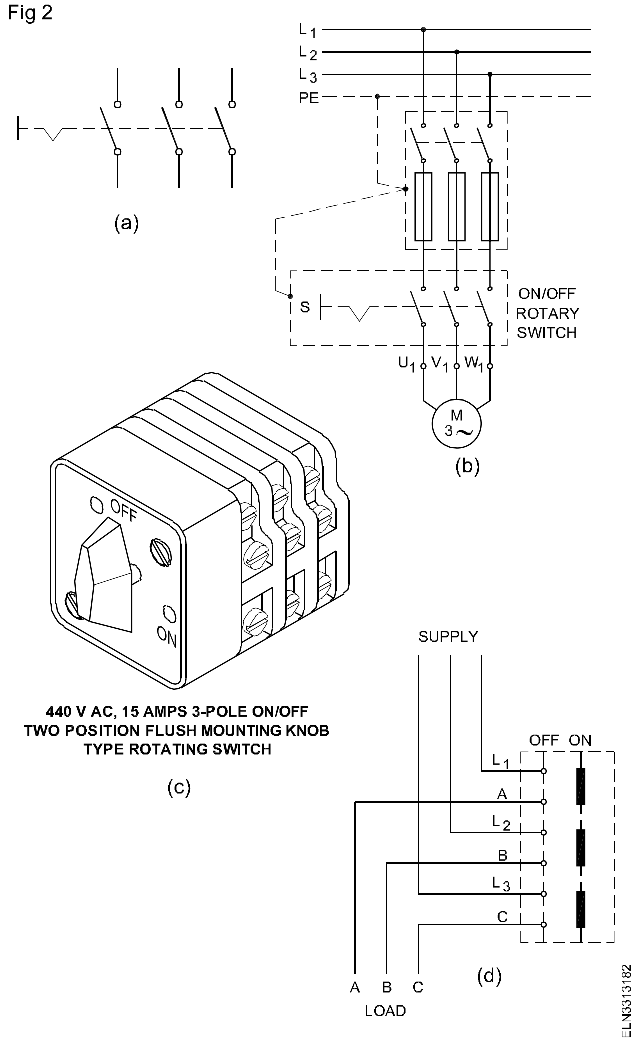


250 V AC 15 AMPS 2-POLE THREE POSITION FLUSH MOUNTING COIN-SLOT OPERATOR

Function: Rotary switches can do a number of functions depending upon the cam and contact block combinations. Accordingly they can be

- ON/OFF switches (Fig 2)
- manual forward/reversing switches (Fig 3)
- manual star-delta switches (Fig 4)
- pole changing switches for speed control. (Fig 5)

Fig 2



440 V AC, 15 AMPS 3-POLE ON/OFF TWO POSITION FLUSH MOUNTING KNOB TYPE ROTATING SWITCH

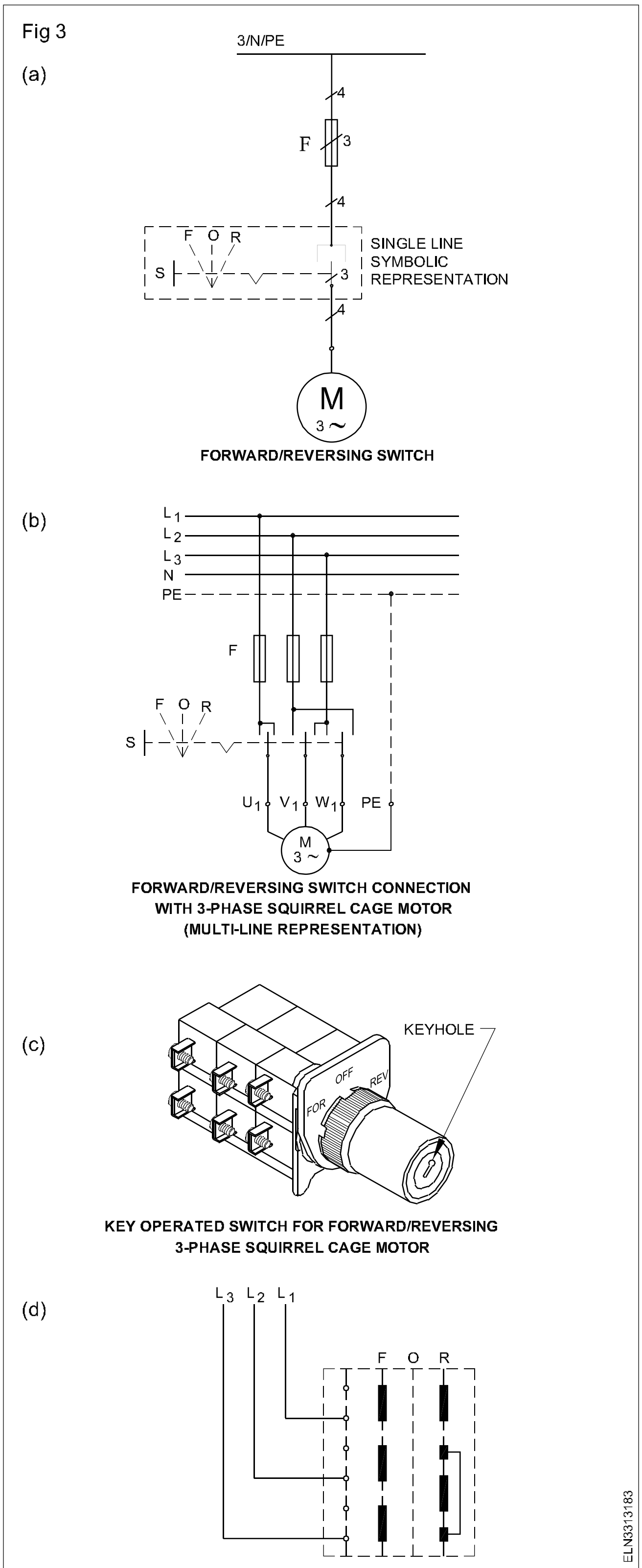
(c)

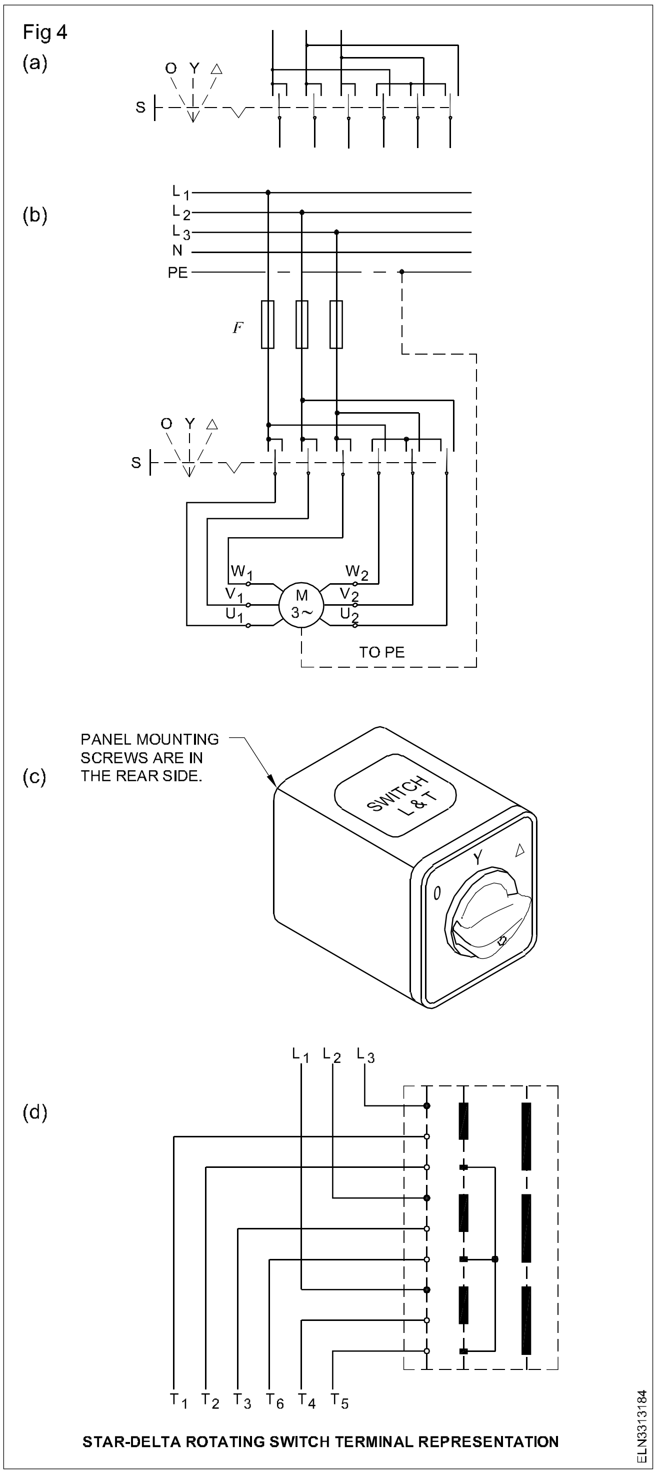
In addition to the above voltmeter/ammeter selector switches, 4-position, air-conditioner switches are also available.

Position: Selector switches of rotary type are available in two (Fig 2), three (Figs 1, 3 and 4) and four positions. They provide maintained or spring-return (momentary) control operation. Two-position and three-position switches can be either maintained or spring-returned whereas four-position switches are maintained in all four positions.

Mounting type: According to requirement, we may select any one of the following types for mounting.

- Surface mounting type
- Flush mounting type (Fig 1)
- Box mounting type (Fig 4)





Handle design: According to the nature of operation it could be done by

- a knob (Fig 2c)
- a lever (Fig 5d)
- a coin slot (Fig 1)
- key operation. (Fig 3c)

Frequency of operation: The number of operations of these switches per hour is specified in B.I.S. 10118 (Part II) 1982. The details given below are taken from the B.I.S. as per the reference cited.

Sl. No.	Description	Operations per hour
1	On-off and system selector switch	Up to 150 times
2	Pole-changing switch	Up to 150 times
3	Manual star-delta switch	Up to 30 times
4	Speed control switch	Up to 150 times

Specification: Specification of rotary switches should contain the following information, for procurement in the market.

- Working voltage and kind of operation - AC or DC
- Load current
- Poles
- Function
- Position of operation
- Type of mounting
- Desired handle type
- Frequency of operation
- Accepted maximum dimensions
- Type of casing

Schematic diagram of rotary switches

ON/OFF switch: These switches are used for a 3-phase squirrel cage motor for direct starting, which is symbolically represented in Fig 2a. The complete connection diagram shown in Fig 2b and Fig 2c shows the normal appearance of such a switch, with a knob type handle, having a box mounting type body.

Fig 2d shows the manufacturer's catalogue representation of an ON/OFF switch.

Manual forward/reversing switch: These switches are used for forward and reverse running operation of the squirrel cage induction motors. A symbolic representation is shown in Fig 3a. The complete diagram is shown in Fig 3b and Fig 3c shows the normal appearance of such a switch with a key operated type switch, having box-type enclosure mounting.

Fig 3d shows the manufacturer's catalogue representation of a forward|reversing rotary switch.

Manual star-delta starter switch: These switches are used for starting a 3-phase squirrel cage induction motor in star position and to run it in delta position.

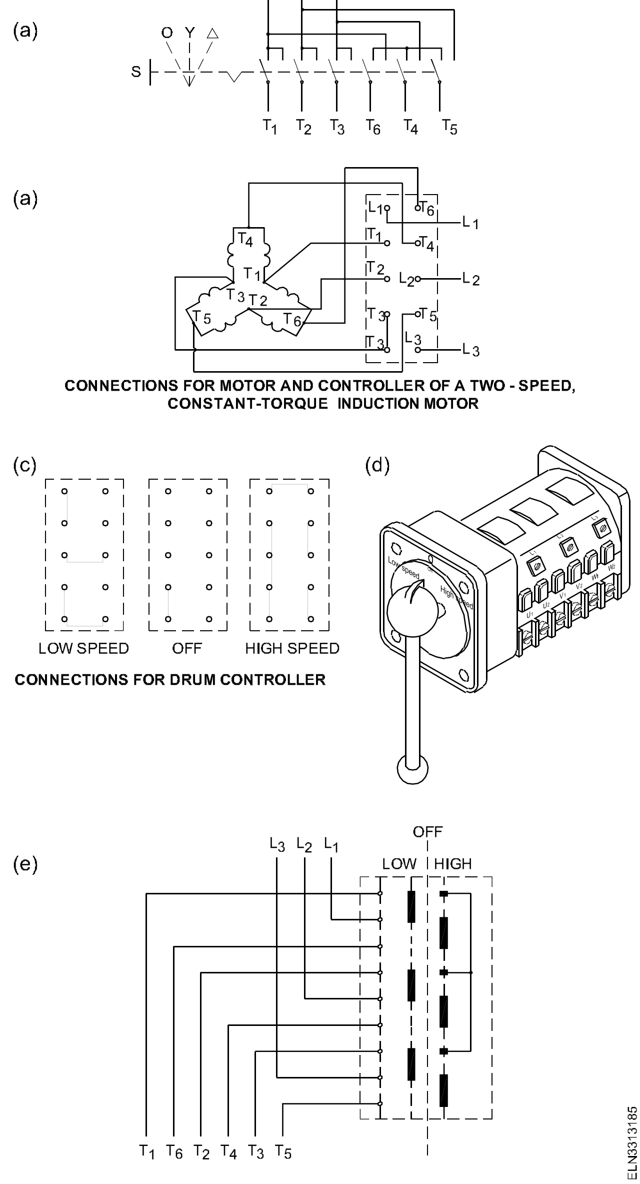
Fig 4a shows the symbolic representation of the star-delta manual switch, the complete diagram of connection to the 3-phase induction motor is shown in Fig 4b, and Fig 4c shows the normal appearance of such a starter switch with knob operation having a box-type body. Fig 4d shows the manufacturer's catalogue representation of a manual star-delta rotary switch.

Pole-changing rotary switch: This is used for changing the speed of a three-phase squirrel cage induction motor from one speed to another with the help of either two separate windings or by six windings arranged for series delta (low speed) or parallel star (high speed) connection. (Fig 5)

Fig 5a shows the symbolic representation of the pole-changing rotary switch, Figs 5b and 5c show the complete connection diagram of the pole-changing switch with motor connection, and Fig 5d shows the normal appearance of such a switch with lever operation.

Fig 5e shows the manufacturer's catalogue representation of the pole-changing rotary switch shown in Figs 5a, b and c.

Fig 5



Manual star-delta starter

Objectives: At the end of this lesson you shall be able to
- **state the necessity of a star-delta starter for a 3-phase squirrel cage induction motor**
- **explain the construction, connection and working of a star-delta switch and starter**
- **specify the back-up rating of the fuse in the motor circuit.**

Necessity of star-delta starter for 3-phase squirrel cage motor: If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

- Star-delta switch or starter
- Auto-transformer starter
- Step-down transformer starter

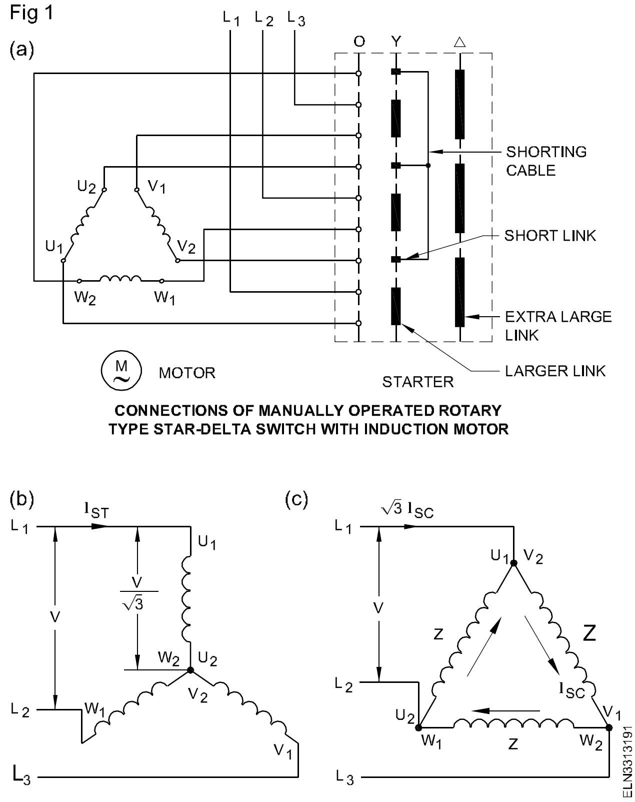
Star-delta starter: A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply L_1, L_2 and L_3 are connected to the beginning of windings U_1, W_1 and V_1 respectively by the larger links, whereas the short links, which connect V_2 U_2 and W_2, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig 1b)

When the switch handle is changed over to delta position, the line supply L_1, L_2 and L_3 are connected to terminals U_1 V_2, W_1 U_2 and V_1 W_2 respectively by the extra large links to form a delta connection. (Fig 1c)

Manual star-delta starter: Fig 2a shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on) coil is energised. When the hold-on coil circuit is closed through the supply taken from U_2 and W_2, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

Fig 1



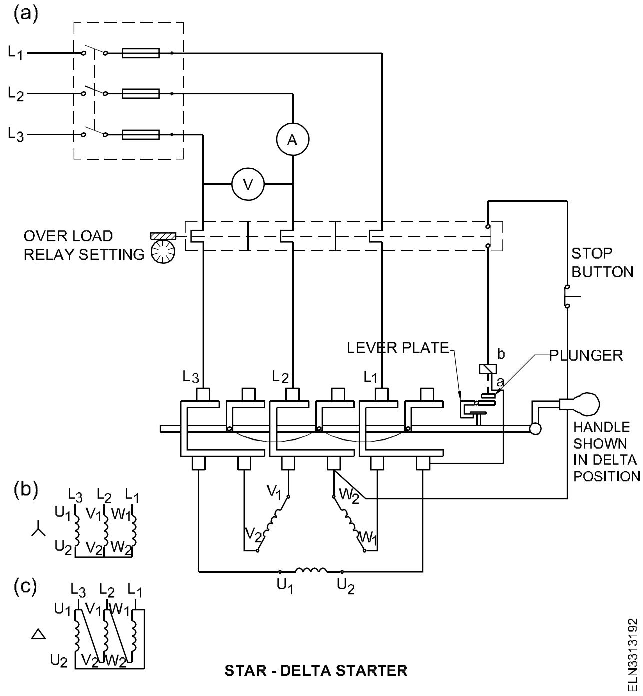
CONNECTIONS OF MANUALLY OPERATED ROTARY TYPE STAR-DELTA SWITCH WITH INDUCTION MOTOR

The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines L_1, L_2 and L_3 to beginning of the 3-phase winding W_1, V_1 and U1 respectively. At the same time the small baffles connect V_2, W_2 and U_2 through the shorting cable to form the star point. (Fig 2b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line L_1, L_2 and L_3 to the winding terminals W_1U_2, V_1W_2 and U_1V_2 respectively to form the delta connection. (Fig 2c)

The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

Fig 2



The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

Back-up fuse protection: Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.

Comparison of impact of star and delta connections on starting current and torque of the induction motor: When the three-phase windings of the squirrel cage motor are connected in star by the starter, the phase voltage across each winding is reduced by a factor of $1/\sqrt{3}$ of the applied line voltage (58%), and hence the starting current reduces to 1/3 of that current which would have been drawn if the motor were directly started in delta. This reduction in starting current also reduces the starting torque to 1/3 of the starting torque which would have been produced in the motor, if it were started directly in delta.

The above statement could be explained through the following example.

Example

Three similar coils of a 3-phase winding of a squirrel cage induction motor, each having a resistance of 20 ohms and inductive reactance of 15 ohms, are connected in (a) star (b) delta through a star-delta starter to a 3-phase 400V 50 Hz supply mains.

Calculate the line current and total power absorbed in each case. Compare the torque developed in each case.

Solution

Impedence per phase

$$Z_{ph} = \sqrt{R^2 + X^2}$$

$$= \sqrt{20^2 + 15^2} \qquad = 25\Omega$$

Star connection

$$E_{Ph} = \frac{E_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ volts}$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{231}{25} = 9.24 \text{amps}$$

$$I_L = I_{sh} = 9.24 \text{amps.}$$

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

$= \sqrt{3}$ x 400 x 9.24 x 1

Assuming PF = 1, we have = 6401 watts.

Delta connection

$$E_{ph} = E_L = 400V$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{400}{25} = 16A$$

$$I_L = \sqrt{3}\, I_{ph} = 1.732 \times 16 = 27.7 \text{ A}$$

Power absorbed = $\sqrt{3}\, E_L I_L \cos\theta$

(assume PF = 1)

$= \sqrt{3}$ x 400 x 27.7 x 1

= 19190 W. (19.19W)

The torque developed is proportional to the square of the voltage across the winding.

In the case of star, the voltage across the winding E_{ph}

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$= \frac{E^2_L}{\sqrt{3}} K \text{ in star}$$

In the case of delta, the voltage across the E_{ph} winding

$E_{ph} = E_L$.

Hence torque

$(E_L)^2 K = E_L^2 K.$

By comparison the torque developed in star connection at the time of starting is 1/3 of the torque developed in a delta connection (running).

As the torque is 3 times less in starting due to the star connection, whenever a motor has to be started with heavy loads, the star-delta starter is not used. Instead an auto-transformer or step-down transformer starter could be used as the voltage tapping can be changed to more than 58% of the line voltage to suit the torque requirement.

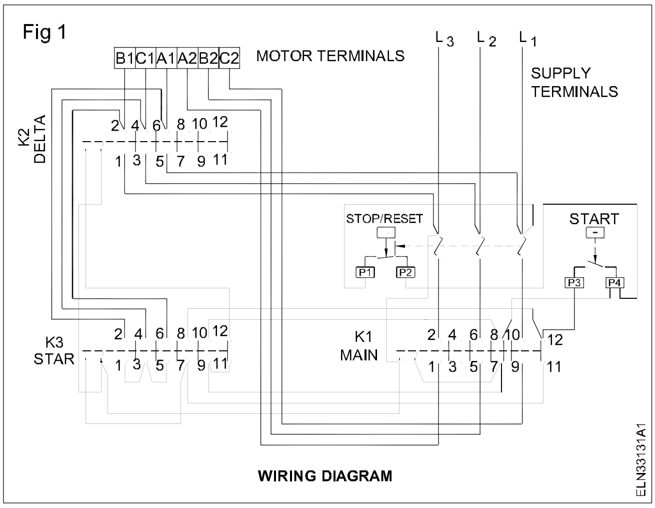
Semi-automatic star-delta starter

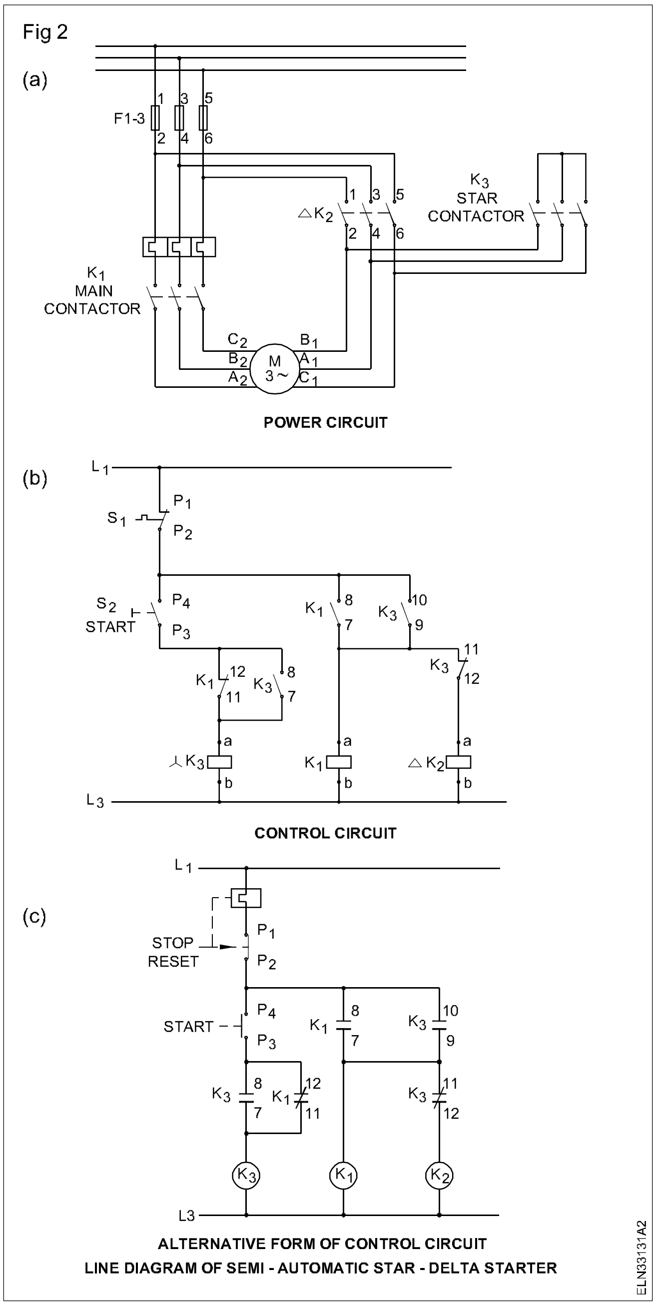
Objectives: At the end of this lesson you shall be able to
- **explain the wiring diagram of semi-automatic star-delta starter**
- **describe the operation of semi-automatic star-delta starter.**

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Fig 1 shows the wiring diagram and Fig 2 shows the line diagram of power circuit and the control circuit.





Operation: Refer to the control circuit and power circuit diagrams shown in Fig 2. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.

When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

The operator has to observe the motor starting and reaching about 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 2c shows the alternative form of drawing control circuit.

Automatic star-delta starter

Objectives: At the end of this lesson you shall be able to

- **state the applications of automatic star-delta and overload relay setting**
- **describe the operations of automatic star-delta starter.**

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Fig 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K_3. (Current flows through K_4T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 1

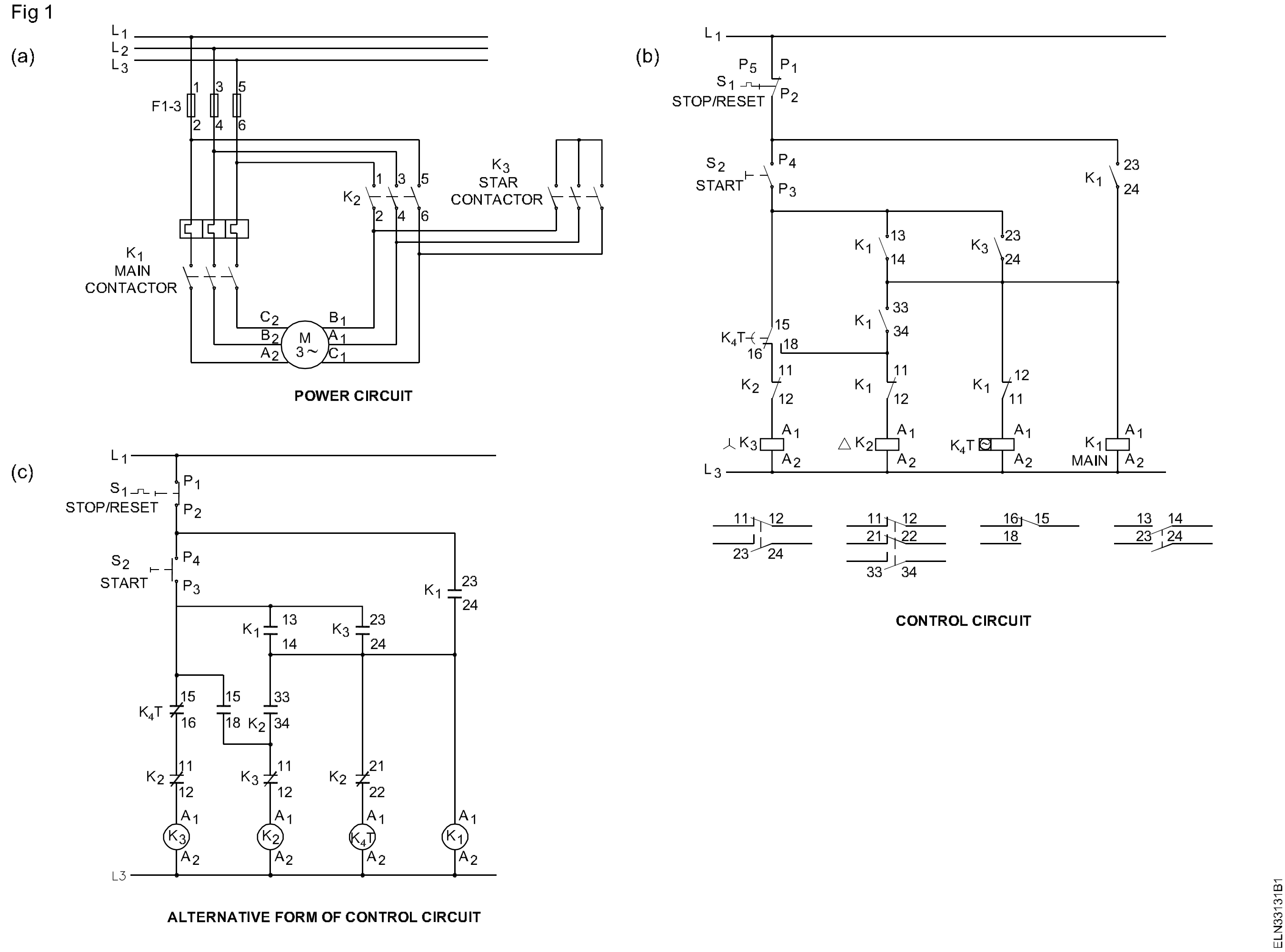
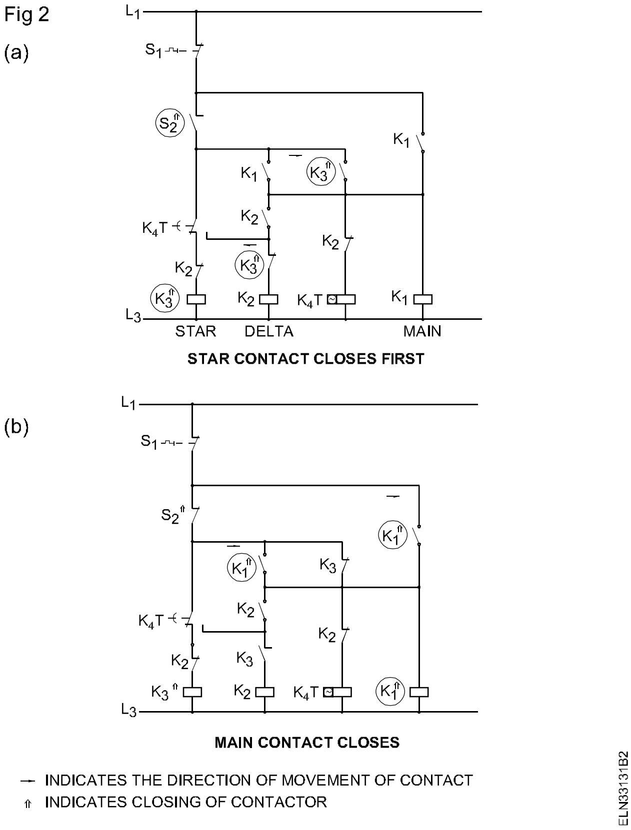


Fig 2 shows the current direction and closing of contacts as explained above.

Fig 2



Similarly Fig 3 shows the action taking place after the timer relay operating the contact K_4T.

Time delay contact changes opening star contact.

Fig 4 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Delta contact closes.

Fig 3

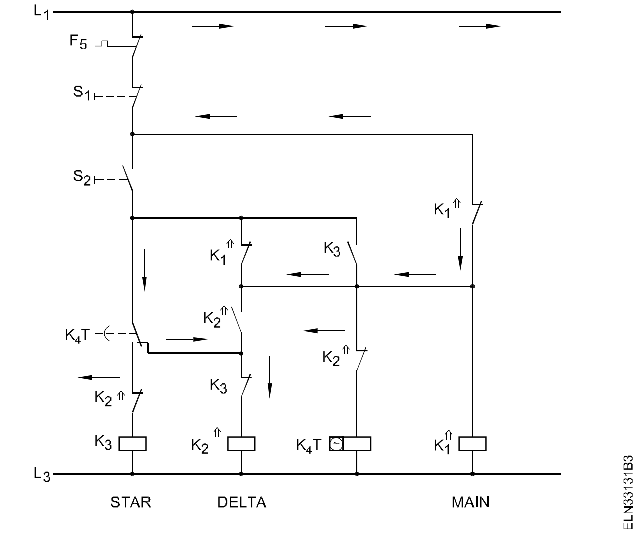
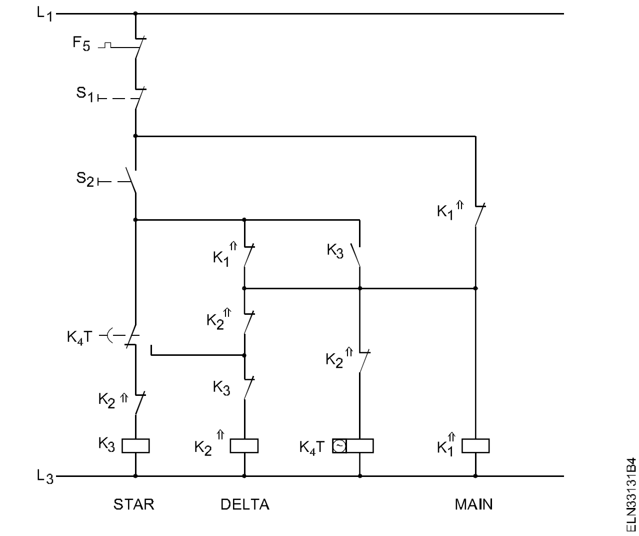


Fig 4

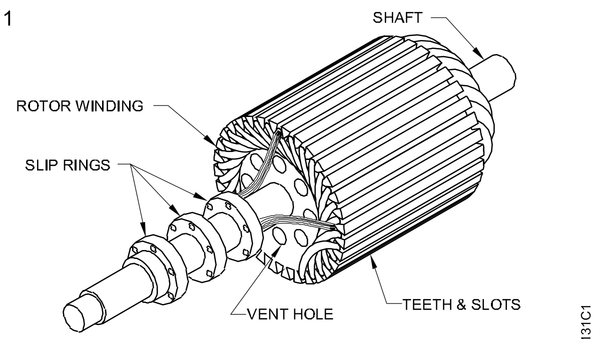


Three-phase, slip-ring induction motor

Objectives: At the end of this lesson you shall be able to
- **explain briefly the construction and working of a three-phase, slip-ring induction motor**
- **explain how the starting torque is high due to insertion of rotor resistance**
- **state the characteristic of the slip-ring induction motor**
- **compare the slip-ring induction motor with the squirrel cage induction motor.**

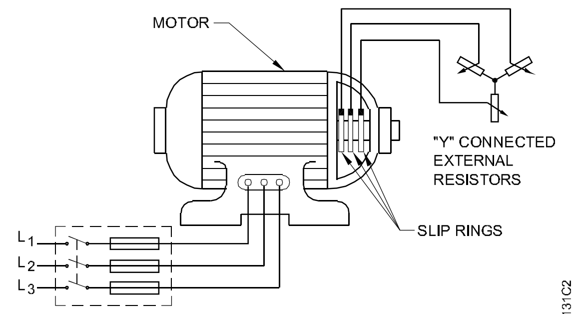
Construction : The slip-ring induction motor could be used for industrial drives where variable speed and high starting torque are prime requirements. The stator of the slip-ring induction motor is very much the same as that for a squirrel cage motor but the construction of its rotor is very much different. Stator windings can be either star or delta connected depending upon the design. The rotor consists of three-phase windings to form the same number of poles as in a stator. The rotor winding is connected in star and the open ends are connected to three slip-rings mounted in the rotor shaft, as shown in Fig 1. The rotor circuit is, in turn, connected to the external star-connected resistances through the brushes, as shown in Fig 2.

Fig 1



WOUND ROTOR FOR SLIP RING INDUCTION MOTOR

Fig 2



CIRCUIT FOR A WOUND - ROTOR INDUCTION MOTOR

Working : When the stator-winding of the slip-ring motor is connected to the 3-phase supply, it produces a rotating magnetic field in the same way as a squirrel cage motor. This rotating magnetic field induces voltages in the rotor windings, and a rotor current will flow through the closed circuit, formed by the rotor winding, the slip-rings, the brushes and the star-connected external resistors.

At the time of starting, the external resistors are set for their maximum value. As such, the rotor resistance is high enabling the starting current to be low. At the same time, the high resistance rotor circuit increases the rotor power factor, and thereby, the torque developed at the start becomes much higher than the torque developed in squirrel cage motors.

As the motor speeds up, the external resistance is slowly reduced, and the rotor winding is made to be short-circuited at the slip-ring ends. Because of the reduced rotor resistance, the motor operates with low slip and high operating efficiency. The motor could be started for heavy loads with higher resistance or vice versa. However at increased rotor resistance, the motor's slip will be greater, the speed regulation poorer and it will have low efficiency. The resistance in the external circuit could be designed and varied to change the speed of the slip-ring motor between 50 to 100 percent of the rated speed. However, the I^2R losses in the rotor due to increased resistance is inevitable.

Starting torque : The torque developed by the motor at the instant of starting is called the starting torque. In some cases it is greater than the normal running torque whereas in some other cases it is somewhat less.

Let E_2 be the rotor emf per phase at standstill

X_2 be the rotor reactance per phase at standstill and R_2 be the rotor resistance per phase.

Therefore $Z_2 = \sqrt{(R_2)^2 + (X_2)^2}$ = rotor impedance per phase at standstill.

Then $I_2 = \frac{E_2}{Z_2}, \cos\theta_2 = \frac{R_2}{Z_2}$

Standstill or starting torque $T_{st} = K_1 E_2 I_2 \cos q_2$ or

$$T_{st} = K_1 E_2 \times \frac{E_2}{\sqrt{(R_2)^2 + (X_2)^2}} \times \frac{R_2}{\sqrt{(R_2)^2 + (X_2)^2}}$$

If the supply voltage V is constant, then the flux, f and hence E_2 is constant.

Therefore $T_{st} = K_2 \frac{R_2}{Z_2}$ where K_2 is another constant.

The starting torque of such a motor is increased by adding external resistance in the rotor circuit. The resistance is progressively cut out as the motor gain speed.

Rotor emf and reactance under running condition : When the starter is stationary i.e. S = 1, the frequency of the rotor emf is the same as that of the stator supply frequency. The value of emf induced in the rotor at standstill is maximum because the relative speed between the rotor and the rotating stator flux is maximum.

When the rotor starts running, the relative speed between the rotor and the rotating stator flux is decreased. Hence the rotor induced emf is also decreased. The rotor emf become zero if the rotor speed become equal to the speed of stator rotating flux.

Hence, for a slip (s), the rotor induced emf will be s times the induced emf at standstill.

Therefore, under running condition $E_r = sE_2$.

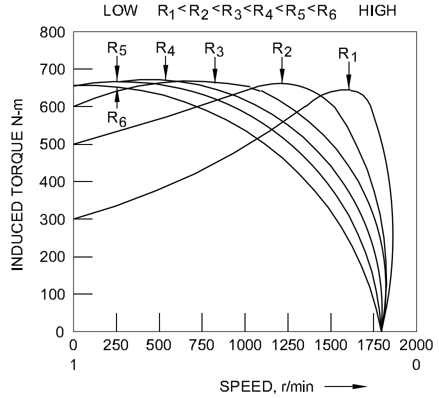
The frequency of induced emf will likewise become $f_r = sf_2$ where f_2 is the rotor current frequency at standstill.

Due to decrease in frequency of the rotor emf, the rotor reactance will also decrease.

Therefore $X_r = sX_2$.

Characteristic and application of slip-ring induction motor: Insertion of higher, external resistance alters the starting torque to a higher value, as shown in Fig 3, by the torque speed characteristic.

Fig 3



THE TORQUE-SPEED CHARACTERISTIC FOR A WOUND - ROTOR INDUCTION MOTOR

By inserting the suitable value rotor resistance, the speed of the slip ring motor could be controlled inspite of power loss in resistance.

As shown in the curve, higher, external resistance improves the starting torque to a higher value. However the maximum torque remains constant for the variation of the rotor resistance.

By these curves, it is clear that the slip-ring motor could be used to start heavy loads by insertion of high resistance in the rotor to facilitate higher starting torque. At the same time the running efficiency of the motor could be achieved by cutting out the external resistance when the motor picks up its speed.

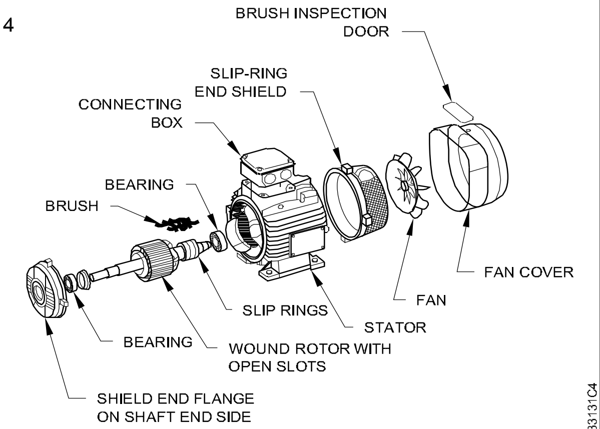
This motor could be used for drive which demands a higher starting torque and also a variable speed control - like compressors, conveyors, cranes, hoists, steel mills and printing presses.

Comparison between squirrel cage and slip-ring induction motors is given below:

Sl. No.	Property	Squirrel cage	Slip-ring motor
1	Rotor construction	Bars are used in rotor. Squirrel cage rotor is very simple, rugged and long lasting. No slip-rings.	Winding wire is used. Wound rotor requires attention Slip-ring and brush gear need frequent maintenance.
2	Starting	Can be started byDOL star-delta, auto-transformer starters.	Rotor resistance starter is required
3	Starting torque	Low	Very high
4	Starting current	High	Low
5	Speed variation	Not easy, but could be varied in larger steps by pole-changing or smaller incre- -mental steps through thyristors or by frequency variation.	Easy to vary speed,but speed change through pole-changing is not possible. Speed change possible by - insertion of rotor resistance - using thyristors - using frequency variation - injecting emf in the rotor circuit - cascading
6	Acceleration on load	Just satisfactory	Very good
7	Maintenance	Almost nil	Requires frequent maintenance
8	Cost	Low	Comparatively high

Fig 4 shows the exploded view of the slip ring induction motor.

Fig 4



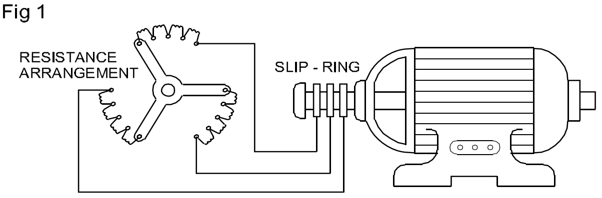
PARTS OF 3 PHASE SLIP RING INDUCTION MOTOR

Resistance starter for 3-phase, slip-ring induction motor

Objective: At the end of this lesson you shall be able to
- **explain the rotor resistance starters used for a 3-phase, slip-ring induction motor.**

Slip-ring induction motors are started with full-line voltage across the stator winding. However, to reduce the heavy rush of the starting current, a star-connected external resistance is added in the rotor circuit as shown in Fig 1. The external resistances are cut out, and the rotor winding ends are shorted once the motor picks up its speed.

Fig 1



SLIP RING INDUCTION MOTOR WITH RESISTANCE STARTER

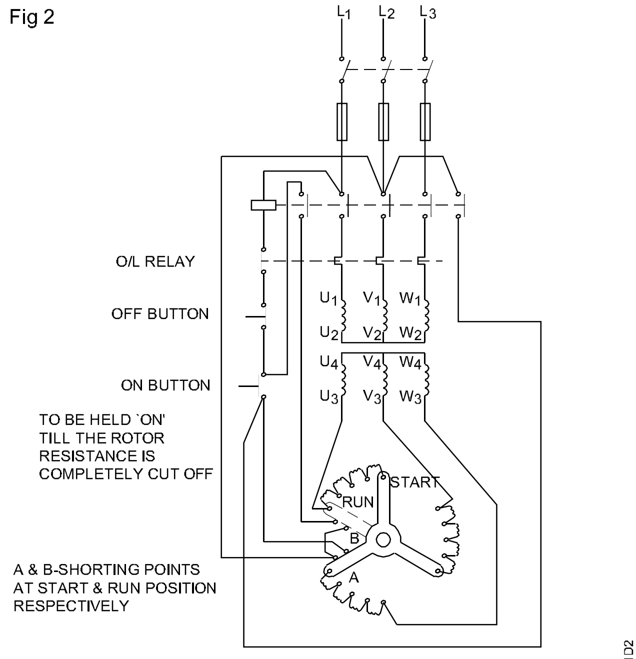
If such a manual starter is used, there is a possibility that someone may apply full voltage to the stator when the rotor resistance is in a completely cut-out position, resulting in heavy rush of the starting current and poor starting torque. This could be eliminated by the use of a protective circuit in the resistance starter; thereby motor cannot be started until and unless all the rotor resistances are included in the rotor winding. Such a semi-automatic starter is shown in Fig 2.

By pressing the 'ON' button, the contactor will close, only when the shorting point 'A' at the rotor resistance is in a closed position. This is possible only when the handle is in the start position. Once the motor starts running, the handle of the rotor resistance should be brought to 'run' position to cutout the rotor resistance.

The position of the handle clearly indicates that at the start position, the contact 'A' is in the closed position, and at the run position, contact 'B' is in the closed position, but both cannot close at the same time. The 'ON' push-button needs to be held in the pushed-position till the handle is brought to the run-position. During the run-position, the handle contact 'B' closes the no-volt coil circuit, and the pressure on the 'ON' button can be released.

In general, for small machines, the rotor resistance is air-cooled to dissipate the heat developed during starting. For larger machines, the rotor resistance is kept in an insulating oil tank for cooling. The starter shown is intended to start the motor only. As speed regulation through the rotor resistance needs intermediate positions, they are specially designed and always oil-cooled.

Fig 2



ROTOR RESISTANCE STARTER FOR SLIP RING INDUCTION MOTOR

Method of measurement of slip in induction motor

Objectives: At the end of this lesson you shall be able to
- **explain the method of measurement of slip by actual motor speed**
- **describe the method of measurement of slip by comparing motor and starter frequencies**
- **explain the method of measurement of slip by stroboscope method.**

Measurement of slip

Following are the methods used for finding the slip of an induction motor

(i) By actual measurement of motor speed: This method requires measurement of actual motor speed N and calculation of synchronous speed N_s. N is measured with the help of a speedometer and N_s calculated from the knowledge of supply frequency and the number of poles of the motor (Since an induction motor does not have salient poles, the number of poles is usually inferred from the no-load speed or from the rated speed of the motor). Then slip can be calculated by using the equation

$S = (N_s - N) \times 100 / N_s$

(ii) By comparing rotor and stator supply frequencies: This method is based on the fact that $s = f_r/f$. Since f is generally known, s can be found if frequency of rotor current can be measured by some method. In the usual case, where f is 50 Hz, f_r is so low that individual cycles can be easily counted. For this purpose, a DC moving coil preferably of centre-zero milli-voltmeter, is employed as described below:

a) In the case of a slip-ring motor, the leads of the centre zero milli-ammeter is connected to adjacent slip-rings as they revolve (Fig 1). Usually, there is sufficient voltage drop in the burshes and their short-circuiting strap to provide an indication on the milli-ammeter. The current in the milli-ammeter follows the variations of the rotor current and hence the pointer oscillates about its mean zero position. The number of complete cycles made by the pointer per second can be easily counted (it is worth remembering that one cycle consists of a movement from zero to a maximum to the right, back to zero and on to a maximum to the left and then back to zero).

   As an example, consider the case of a 4-pole motor fed from a 50-Hz supply and running at 1,425 rpm. Since N_s = 1,500 rpm its slip is 5% or 0.05. The frequency of the rotor current would be $f_r = S_f = 0.05 \times 50 = 2.5$ Hz which (being slow enough) can be easily counted.

b) For squirrel-cage motors (which do not have slip-rings) it is not possible to employ the centre zero milli ammeter.

iii) By Stroboscopic Method: In this method, a circular metallic disc is taken and painted with alternately black and white segments. The number of segments (both black and white) is equal to the number of poles of the motor. For a 6-pole motor, there will be six segments, three black and three white, as shown in Fig 2a.

Fig 1

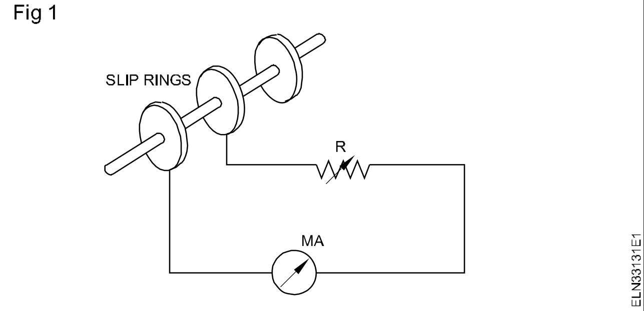
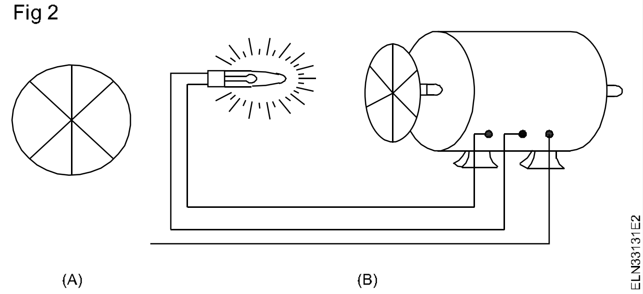


Fig 2

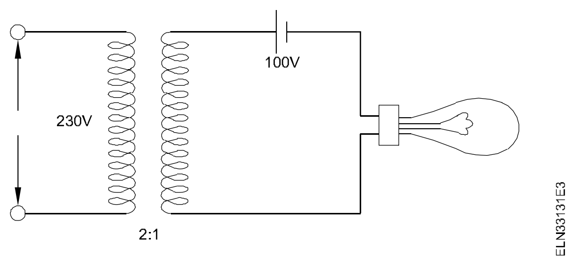


The painted disc is mounted on the end of the shaft and illuminated by means of a neon-filled stroboscopic lamp, which may be supplied preferably with a combined d.c. and a.c. supply although only a.c. supply will do (When combined d.c. and a.c. supply is used, the lamp should be tried both ways in its socket to see which way it gives better light.). The connections for combined supply are shown in Fig 3 whereas Fig 2b shows the connections for single supply only. It must be noted that with combined d.c. and a.c. supply, the lamp will flash once per cycle (It will flash only when the two voltages add and remain extinguished when they oppose). But with a.c. supply, it will flash twice per cycle.

Consider the case when the revolving disc is seen in the flash light of the bulb which is fed by the combined d.c. and a.c. supply.

If the disc were to rotate at synchronous speed, it would appear to be stationary, Since in actual practice, its speed is slightly less than the synchronous speed, it appears to rotate slowly backwards.

Fig 3



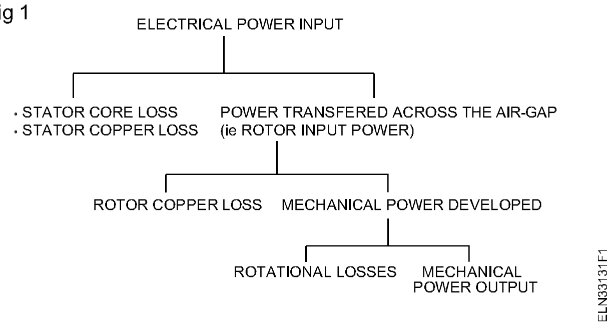
Efficiency - characteristics of induction motor- no load test - blocked rotor test

Objectives: At the end of this lesson you shall be able to
- **state the power flow diagram of an induction motor indicating the losses**
- **calculate the efficiency from the given data.**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes I_2 to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s I_2 \cos \phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig 1. Note that the loss quantities are placed on the left side of the flow point. Fig 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Fig 1



Torque, Mechanical power and Rotor output : Stator input P_i = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input P_g = stator output.

Rotor gross output, P_m = rotor input P_g - rotor cu. losses.