# Electrical Equipment - Course PI 30.2

# MOTOR CONTROL

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## OBJECTIVES

On completion of this module the student will be able to:

1. Recall, and list, in writing, four specifications of a contactor.
2. Briefly explain, in writing, the method used to identify contactor components and what normally open/closed contacts are.
3. Recall, and list in writing, five reasons why a motor control circuit is needed.
4. Given a motor control circuit diagram, identify various components and briefly explain their functions and state the sequence of events (i.e. what happens in the circuit) for motor starting and stopping.
5. Briefly explain, in writing, the terms "overload" and "thermal image".
6. Given a list of device numbers, identify the device function.
7. Briefly explain, in writing, when and why the circuit breaker is used for motor control.
8. Recall, that a circuit breaker is a latching type device, and briefly in writing, compare it with a contactor.
9. Given the schematic diagram of a motor control circuit utilizing a circuit breaker, briefly explain, in writing, the operation of the circuit.

## 1. Introduction

This lesson will introduce the reader to:

(a) The basic principle of operation of electromagnetic devices.

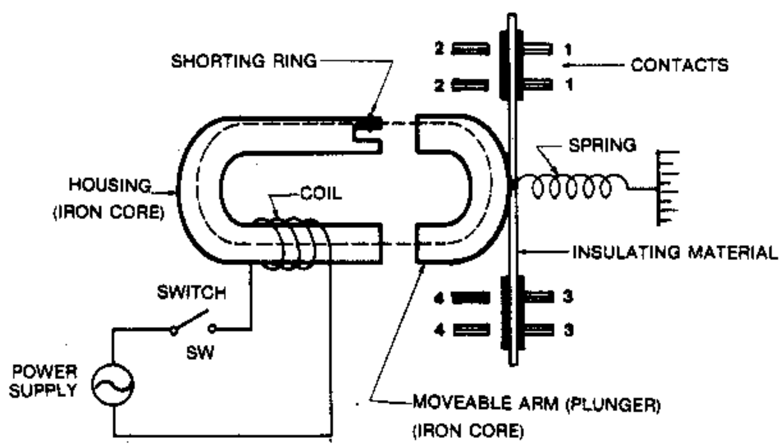
(b) Requirements of motor control.

(c) Operation of a simple motor control circuit.

## 2. Principle of Operation of an Electromagnetic Device

An electromagnetic device utilizes an electromagnet for its operation. The following discussion explains the operation of such a device (solenoid, relay and contactor).

### 2.1 Operation of an Electromagnetic Device




Operation of an Electromagnetic Device

Figure 1

In Figure 1, when switch SW is open, no current flows through the coil. As a result:

- The housing is not magnetized.
- The spring will pull the plunger away, to the right.
- Contacts 1-1 and 3-3 are shorted by the conductive plates. Hence, they are referred to, as being "closed".

- contacts 2-2 and 4-4 are open circuited (not shorted). Hence, they are referred to as being "open".

- When no current is flowing through the coil, the device is referred to as being in its "de-energized" state.

- Contacts shown, in the de-energized state, as closed, are called "normally closed" contacts.

Contacts shown, in the de-energized state, as open, are referred to as "normally open" contacts. In the diagram, contacts 1-1, 3-3 are normally closed and contacts 2-2, 4-4 are normally open.

In Figure 1, when switch SW is closed, current flows through the coil. As a result:

- The electric circuit for the coil will be complete and current will flow through the coil.

- Current flowing through the coil will produce a magnetic field.

- The magnetic field of the coil will cause a magnetic flux to be setup in the housing.

- The magnetized housing will draw the plunger, in, against the spring tension and close the gap.

- The arm attached to the plunger will also move with it. Contacts 1-1 and 3-3 will open. Contacts 2-2 and 4-4 will close.

- This condition is referred to as the energized state. Contacts which were closed in the de-energized state become open in the energized state. Contacts which were open in the deenergized state become closed in the energized state. This change of contact status is important and forms the basis for control circuits.

## 2.2 Contacts

Contacts 1-1, 2-2, 3-3 and 4-4 are independent of each other. While all these contacts are physically operated and located on the same device, they can be electrically connected to operate any equipment in the plant which is in different locations.

These electromagnetic devices are selected to provide the proper number of the contacts for a specific application. Contacts in a schematic diagram are always shown with the coil in its de-energized state.

## 2.3 Example

In Figure 2, when switch SW is open the red bulb will have a complete electrical circuit to the power supply, via the normally closed contact 1-1. The bulb will light. The green bulb will not have a complete circuit to its power supply because the contact 2-2 is open. This bulb will not be lit. When switch SW is closed, the plunger will operate. Contact 1-1 will open and the red light will turn off. Contact 2-2 will close and the green light will turn on. This condition will remain as long as current is flowing through the coil. If the current through the coil is discontinued, the state of the lights will revert to their previously de-energized states. The two bulbs can be located anywhere in the plant.

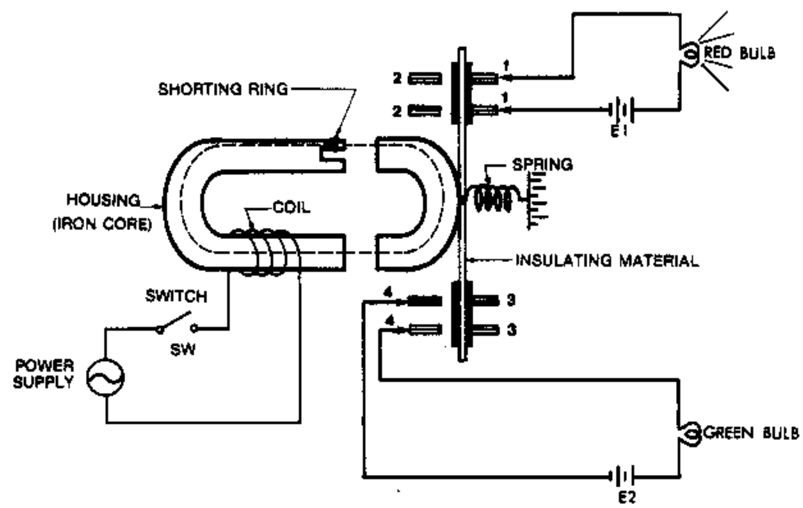



Figure 2(A): De-Energized Circuit

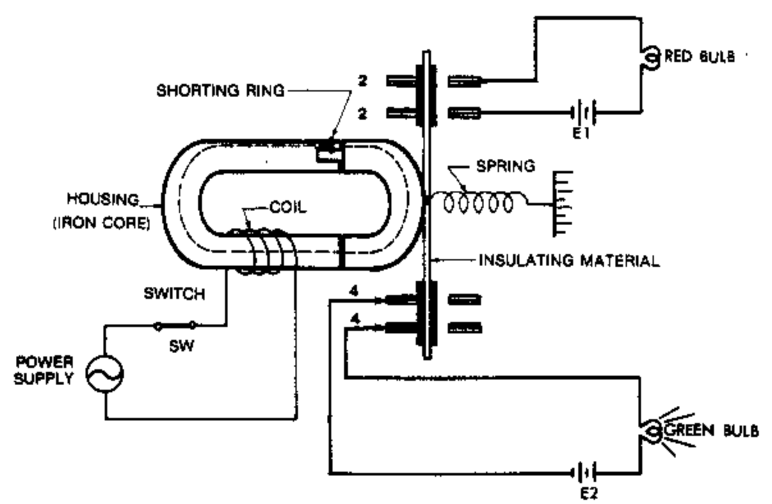



Figure 2(B): Energized Circuit

## 3. Contactor

A contactor is an electromagnetic device which operates as explained earlier. Refer to Figure 3. A contactor is used for the control of motors up to 40 HP. Motors above 75 HP are controlled by circuit breakers. A contactor remains energized only as long as current is flowing through its operating coil.

### 3.1 Contactor Specifications

Some important specifications of a contactor are:

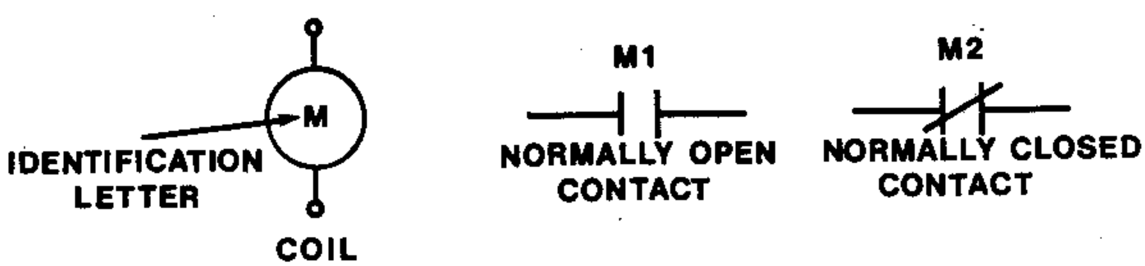
- Operating voltage of the coil.
- Operating frequency of the coil.
- Maximum voltage rating across the open contacts.
- Maximum current rating of the contacts.

### 3.2 Contact Identification

In a given control circuit, more than one electromagnetic device may be used. To facilitate circuit analysis and to maintain ease of wiring, each device coil is assigned a **letter** for its identification. Each set of contacts is assigned a **number** . Contacts belonging to a particular device are further identified by **prefixing the number with a coil letter designation.** For example, if a coil is identified by the letter M and the device has four sets of contacts, then the individual set of contacts would be marked M1, M2, M3 and M4.

### 3.3 Schematic Representation of a Coil and Its Contacts

The following is the schematic representation of a coil and it's contacts when the coil is de-energized;



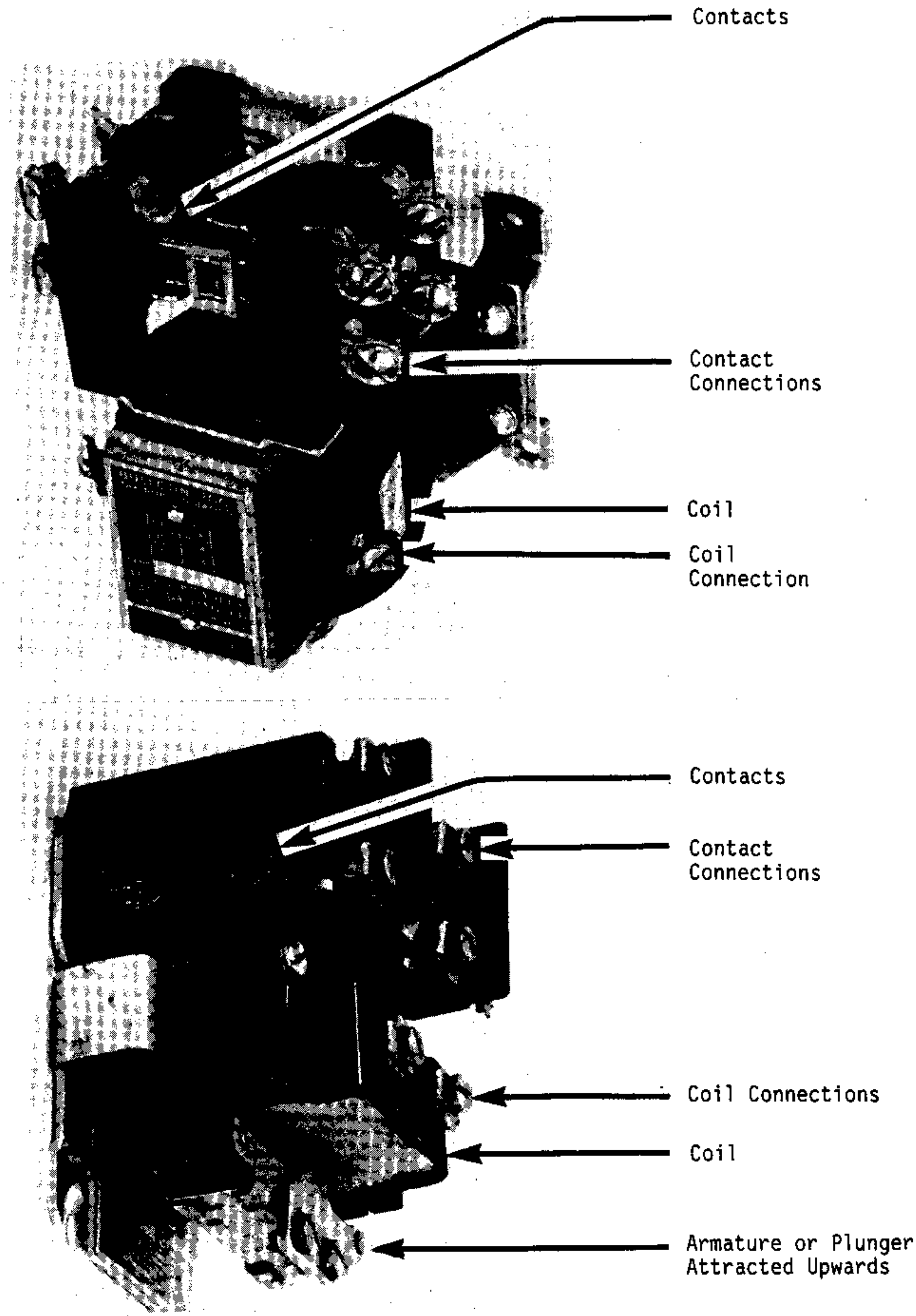



Figure 3: Contactors For 600V, 10 HP Motor

## 4. Motor Control

### 4.1 Why Motor Control Is Needed

Motor control is needed to provide for the following:

(a) A means of starting and stopping the motor. The start/stop control can be located far away from the motor. For example, the control of the heat transport pump motor is in the control room and the motor is far away, in the plant. Remote control allows the operator to start or stop the motor from the control room.

(b) Safety: Most of the motors in the plant operate at 600 V or above. For the safety of operating personnel, voltages on the control devices are reduced, via a transformer, to a a much lower voltage, such as 120 V.

(c) Protection of motor under abnormal operating conditions, such as overload.

(d) Fault protection for power and control circuitry.

(e) Means of isolating the motor from the power circuit, for maintenance purposes.

### 4.2 Development of a Control Circuit

(a) Manual Control: Normally found on household appliances.

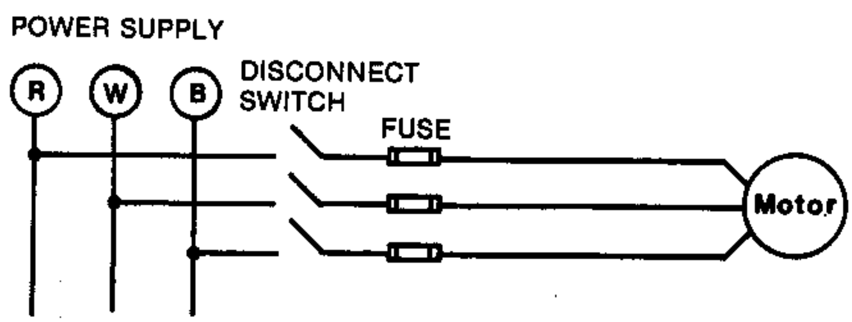



Figure 4(A): A Simple Motor Control

In Figure 4(A) the motor can be started by closing the switch manually and it can be stopped by opening the switch.

Fuses provide protection to the motor, if a fault occurs.

However, this method is manual and it is not safe at voltages of 600 V and greater. To overcome both of these problems, consider the following improvement shown in Figure 4(b).

(b) Contactor Control: The motor can be started or stopped by a local or a remote control station or both.

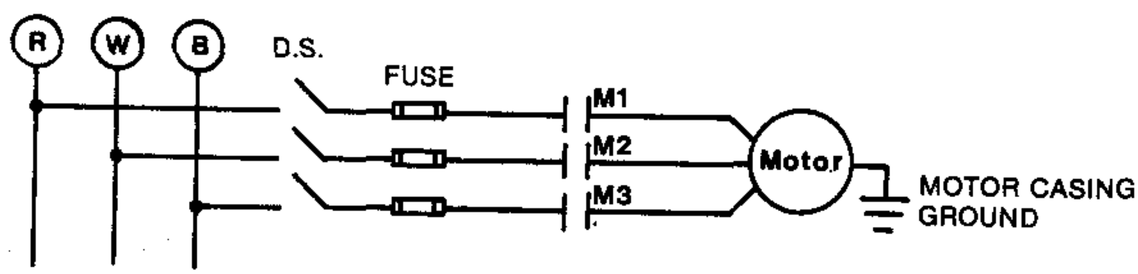



Figure 4(B)

Three normally open contacts of a contactor are placed in series with the motor leads. Now, the only way this motor can be started is, if the disconnect switch is closed, fuses are healthy, and contacts $M_1$, $M_2$ and $M_3$ are closed. To close these contactor contacts, the coil must be energized and this is done as shown in Figure 4(C).

## 4.2 Development of a Control Circuit

### (b) Contactor Control (continued)

In Figure 4(C) two separate circuits can be identified.

- A power circuit, which can be at a high voltage. This circuit involves the power supply, disconnect switches, fuses, normally open contacts $M_1$, $M_2$, $M_3$ and the motor.

- A control circuit, which is powered by a stepdown transformer. This circuit includes the secondary of the control transformer, stop and start push buttons and the coil of the contactor. A fuse is also provided to protect the control circuitry against fault currents.

The operation of this circuit is as follows:

- Press the START push button, and hold this button down. The current path through the control circuit coil, M, will be completed, via the normally closed STOP push button. Coil M will energize. The normally open contacts $M_1$, $M_2$ and $M_3$ will close. This completes the power circuit to the motor, and the motor starts.

- When the spring loaded START push button is released, the electrical circuit to coil, M, is broken and it de-energizes. Contacts $M_1$, $M_2$ and $M_3$ open.

The motor disconnects from the supply and stops running. As can be seen from this discussion, the motor will only run, as long as the START push button is held down. This is not desirable.

On the following page the circuit is modified as shown in Figure 4(D).

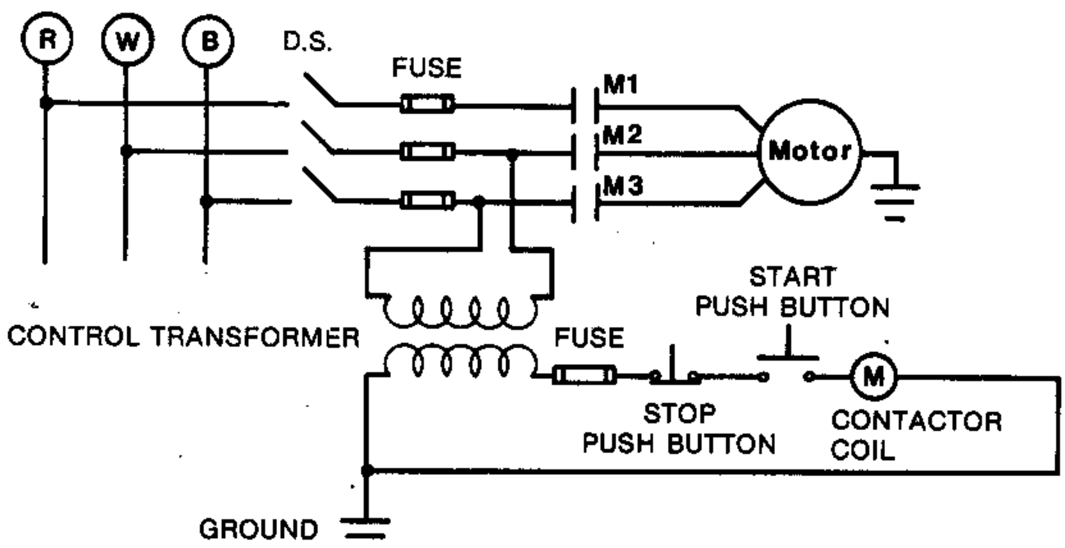

R
W
B
D.S.
FUSE
M1
M2
M3
Motor
CONTROL TRANSFORMER
FUSE
START
PUSH BUTTON
M
STOP
PUSH BUTTON
CONTACTOR
COIL
GROUND

Figure 4(C)

## 4.2 Development of a Control Circuit

Refer to Figure 4(D).

An additional, normally open contact, operated by M, is placed in parallel to the START push button.

Hence, when the START push button is pressed, coil M energizes and contacts $M_1$, $M_2$, $M_3$ and $M_4$ close. When the START push button is released, control current continues to flow via the now closed $M_4$ contact. This keeps coil $M_4$ energized, and the motor keeps running. Contact $M_4$ is normally referred to as the "seal in" or "holding" contact.

To stop the motor, the STOP push button is pressed. This breaks the electrical circuit for coil M and the coil de-energizes. Contacts $M_1$, $M_2$, $M_3$, and $M_4$ open and the motor stops. To restart the motor, the START push button must be pressed again.

So far in this control circuit, we have the following:

- Disconnect switch: which, when opened, provides isolation of the motor, from the power source, for maintenance, etc.
- Fuses: which provide protection for the motor, the main power supply, and the control circuitry in the event of a fault.
- Control Transformer: which provides safety, by reducing the voltage in the control circuit, to a safe, operating level of 120 V.
- START/STOP Buttons: Provide a means for starting and stopping the motor.
- Contactor: Provides for safe, local or remote motor control.
- Ground: Provides safety, by bringing the motor casing to ground potential if the motor casing becomes "live".

The section that follows will discuss OVERLOAD. Figure 4(D) is almost complete, as a contactor control system. However, it lacks motor overload protection.

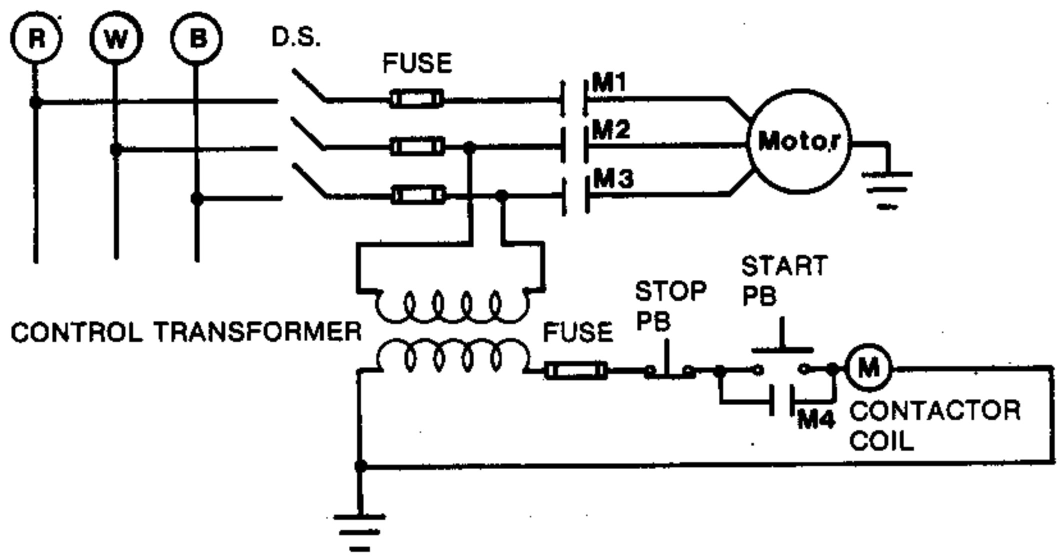

R
W
B
D.S.
FUSE
M1
M2
M3
Motor
CONTROL TRANSFORMER
FUSE
STOP
PB
START
PB
M
M4
CONTACTOR
COIL

Figure 4(D)

## 4.3 Overload

When a motor is operating normally and it is delivering its rated torque, it is drawing 100% of its rated full-load current.

If the motor is required to deliver more torque than it is capable of delivering, it starts to draw current in excess, of the 100% rated current value. This additional current creates additional heat due to increased $I^2R$ loss, in the motor windings. Excessive heat could damage the windings and permanently damage the motor or reduce motor life. **An increase in the motor current above its rated value is referred to as overload.** Motors can only withstand 115% over-load current, for any extended period of time, without permanently damaging the insulation. It is therefore necessary to provide a means of detecting overloading conditions on the motor and automatically stop motor operations, if this condition exists. **Thermal overload relays are commonly used to detect overload currents in a motor circuit.**

## 4.4 Thermal Overload Relay

A thermal overload relay contains a bimetal switch, as shown in Figure 5. It has a heater with a resistance $R_h$, which is connected, in series, with the motor. All the motor current flows through this heater.

A push rod is connected to the bimetal, which can operate a set of contacts. A thermal overload relay works on the **thermal image** principle.

Under normal conditions, the motor current produces a nominal amount of $I^2R_m$ heat in the motor windings. $R_m$ is the motor winding resistance. Also, an $I^2R_h$ heat is produced in the relay heater. Heat produced during this normal operation is not sufficient to bend the bimetal.

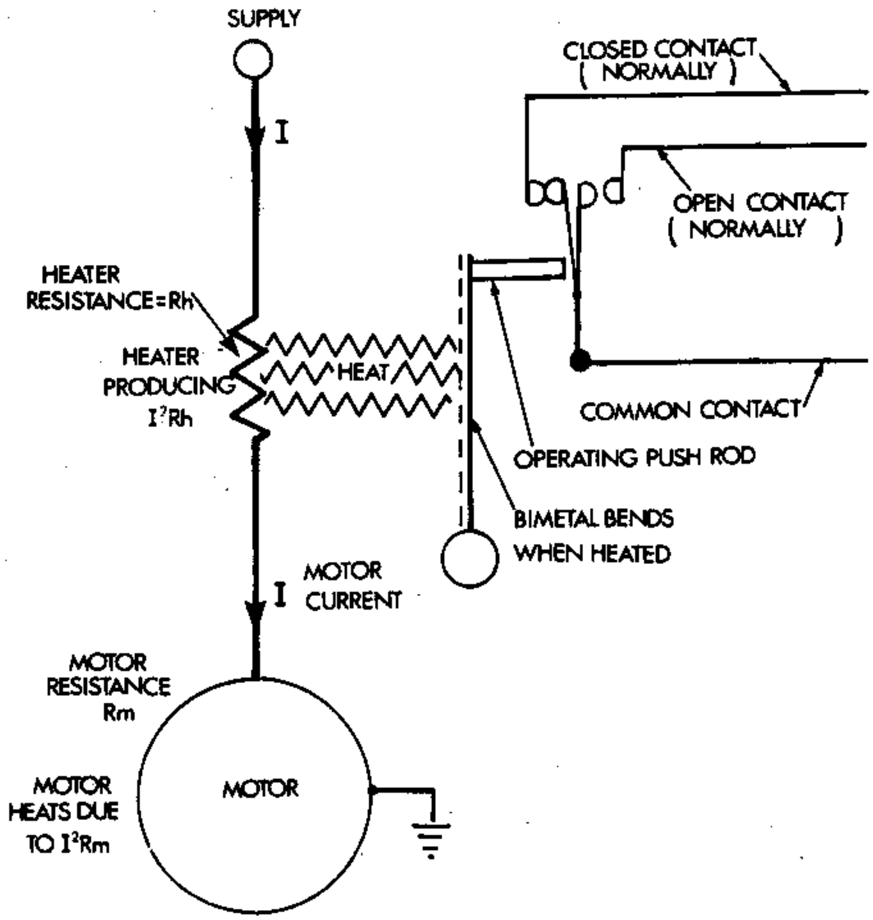



Figure 5: A Thermal Relay

If an overload condition occurs, excessive $I^2R_m$ heat is produced in the motor windings and $I^2R_h$ is also high. This causes the bimetal to bend. The push rod, attached to the bimetal, moves to the right and operates the contacts. Heat produced in the heater of the thermal overload relay is thus a thermal image of the heat produced in the motor.

The heater of the thermal overload relay is shown schematically below.

Contacts of the thermal overload relay can be used to control the motor as illustrated in Figure 6, which follows on the next page.

## 4.5 Thermal Overload Protection

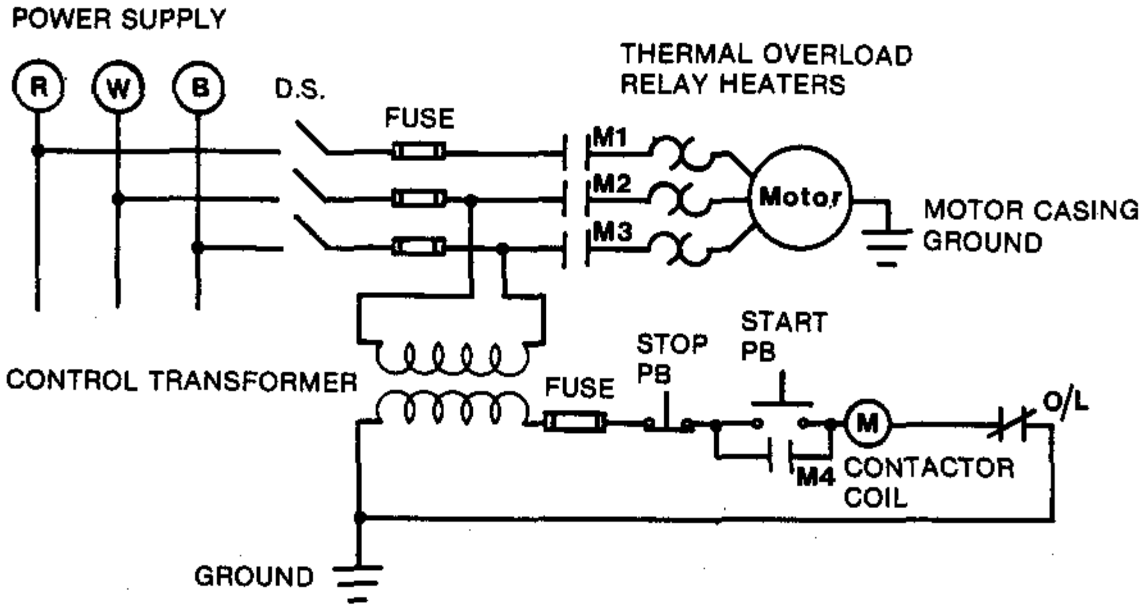



Figure 6: A Simple, but complete Motor Control Circuit

When an overload occurs, the motor current increases. Higher motor current also passes through the heaters of the OL relay and heats the bimetal. The push rod then opens the O/L contacts in the control circuit and de-energizes the contactor coil. This stops the motor.

Important: For large motors, the line current is high. Therefore, the thermal overload relay is connected via current transformers. The turns ratio of these transformers is carefully selected for the specific motor and application. Fuse in the motor circuit is selected to pass the motor starting current which can be as high as 6 times of motor full load current. Fuse therefore will not blow at over currents of 10 to 15%.

## 4.6 Other Types of Protection

Apart from isolation, short circuit, and overload protection, some other types of protection may also be used. However, their application will be determined by the size and the importance of the motor. All of the electrical control devices are given a standard number. A list of some of these devices and their respective numbers is given in Table 1.

**Do not memorize this table.**

TABLE 1

IEEE Device Numbers and Functions for Switchgear Apparatus

| Device Number | Function |
|---|---|
| 3 | Interposing Relay |
| 4 | Master Contractor or Relay |
| 27 | ac Undervoltage Relay |
| 33 | Position Switch |
| 46 | Phase Unbalance Relay |
| 49 | ac Thermal Relay |
| 50 | Short Circuit Selective Relay |
| 51 | ac Overcurrent Relay |
| 52 | ac Circuit Breaker |
| 63 | Fluid - Pressure, Level or Flow Relay |
| 64 | Ground Protection Relay |
| 74 | Alarm Relay |
| 86 | Lock-Out Relay |
| 87 | Differential Current Relay |
| 89 | Line Switch or Disconnect Switch |
| 94 | Tripping Relay |

## 5. Motor Control Using Circuit Breakers

Large motors above 56kW (75HP) draw very high current and are supplied at a high voltage; eg. 600V, 4160V, or 13.8kV. At these high voltages, fault currents can reach very high values. These fault currents must be cleared by the motor controllers. However, contactors are not suitable for handling large fault currents. Hence, the control of the motors, above 56kW (75HP), is achieved by means of circuit breakers.

A circuit breaker simply makes or breaks the current to the motor. In order to start the motor, the circuit breaker must be closed. This can be done either manually or automatically, by energizing the breaker - close coil.

To stop the motor, the circuit breaker must be opened. Again, this can be done manually or automatically, by energizing the breaker-trip coil.

Any type of protection provided to the motor must energize the breaker trip coil, if an abnormal condition exists. It is important to realize that a **circuit breaker is a latching type device.** When the breaker is closed, it latches in the closed state and the current to the close solenoid can be discontinued. Similarly, when the breaker is opened, it latches in the open state, and the current to the breaker trip coil can then be interrupted. A contactor control circuit requires a continuous power supply when the motor is running.

Figures 7(a) and 7(b) must be looked at together in order to understand the operation. These figures are located on a pull-out sheet, at the end of this lesson.

The circuits in Figure 7(a) and 7(b) are discussed on the page that follows.

Complete the following table.

| Device Number | Device Function |
|---|---|
| 52 | |
| 49 | |
| 64 | |

In Figure 7(b):

- 52C is the "close" coil of the circuit breaker. When 52C is energized the circuit breaker will close.
- 52T is the trip coil of the circuit breaker. When 52T is energized, the circuit breaker trips.
- Contacts $L_a$ and $L_b$ are mechanically linked and they change their state when the circuit breaker operates.
- The trip circuit and the close circuit are provided with the seperate fuses for reliability.
- 250 V DC class I supply is used in NGD for control of circuit breakers. Classes of power are discussed in the first chapter.

In Figure 7(a):

- Overload protection is provided via the current transformers (CT's). A contact of 49 is located in Figure 7(b) (simplified breaker control circuit). In the event of an overload on the motor, the thermal overload device will actuate and the contact 49-1 in the trip circuit will close and energize the trip coil. The circuit breaker thus will be opened and the motor will stop.
- An ammeter is connected via a CT to indicate the motor current. This ammeter may be located in the control room.
- Ground fault protection also has a contact in the trip circuit. In the event of a ground fault contact 64-1 will close and trip the breaker, thus de-energizing the motor.

## ASSIGNMENT

1. In your own words, explain the operating principle for an electromagnetic device. Diagrams may be used for clarity. (Sections 2, 2.1)

2. How are the contacts normally shown in a schematic diagram? Select the right answer.

   (a) Coil Energized.
   (b) Coil De-energized.

3. List four specifications (ratings) of a contactor. (Section 3.1)

   (i)

   (ii)

   (iii)

   (iv)

4. Explain in your own words why and how the contactor contacts are identified. (Section 3.2)

5. Describe contacts as being Normally Open or Normally Closed. (Section 3.3)

6. Give five requirements of a motor control circuit. (Section 4.1)

(i)

(ii)

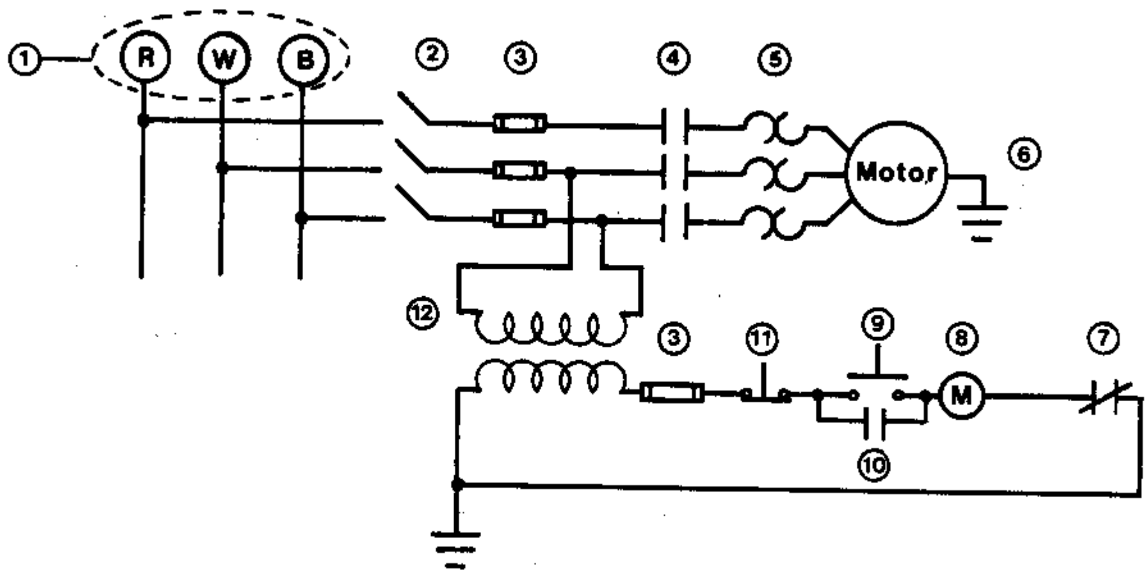
(iii)

(iv)

(v)

7. Explain what is meant by the terms "overload" and "thermal image". (Section 4.3)

8. In the following diagram, identify each component and give its function. (Section 4.2 to 4.5)




| Name | Function |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| 11 | |
| 12 | |

9. When are circuit breakers used for motor control and why? (Section 5)

10. Compare a circuit breaker control system and a contactor control system stating their similarities and their differences. (Section 5)

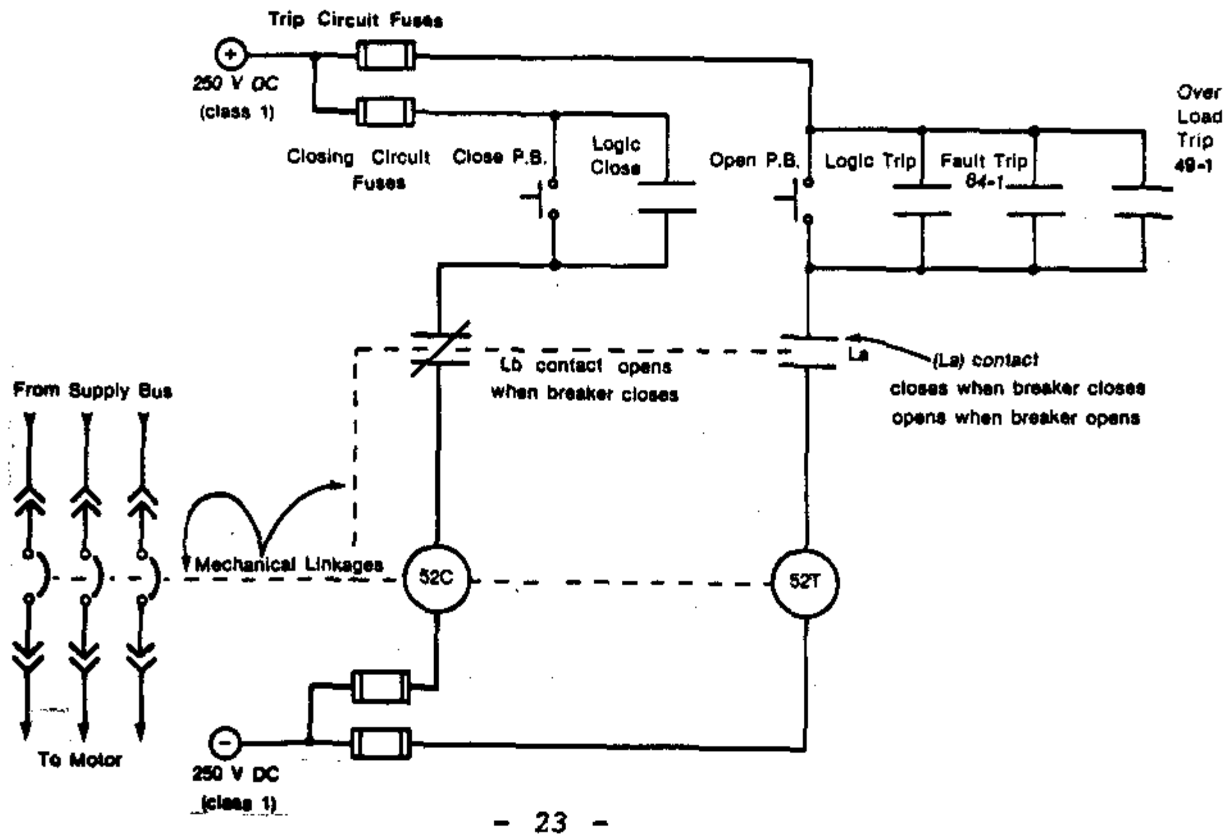
11. (a) In the circuits given below, explain the purpose of: (Section 5.1)

(i) 52C

(ii) 52T

(iii) separate fuses in close and trip circuit.

(iv) Ammeter.



(b) Using the two given diagrams, explain the operation of the circuit for:

(i) 49

(ii) 64

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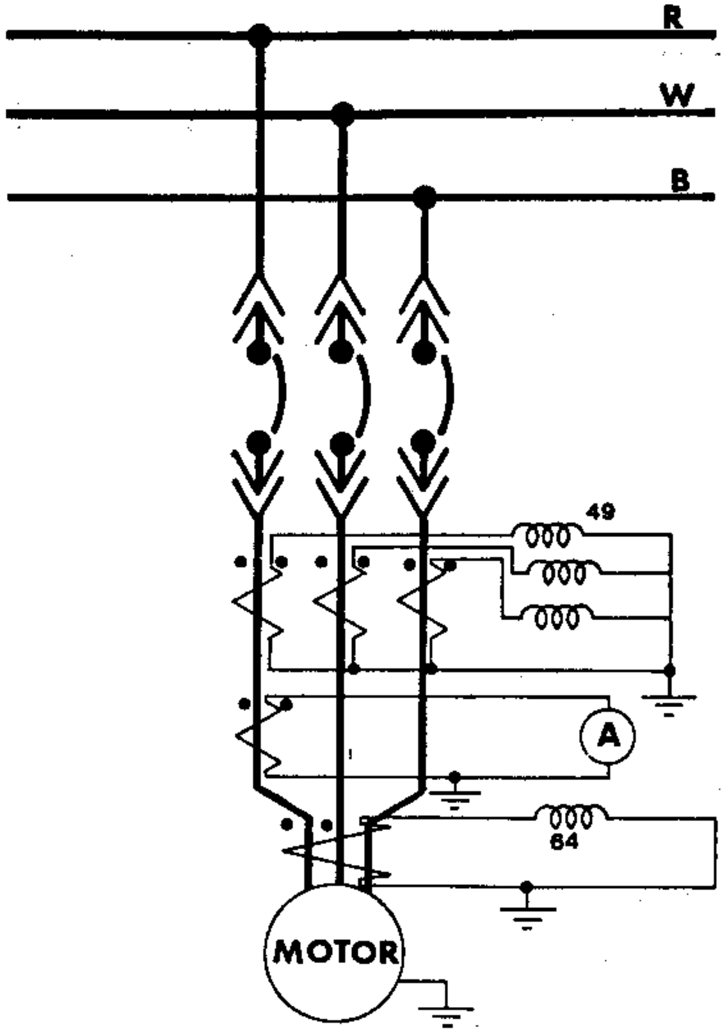


Figure 7(a)

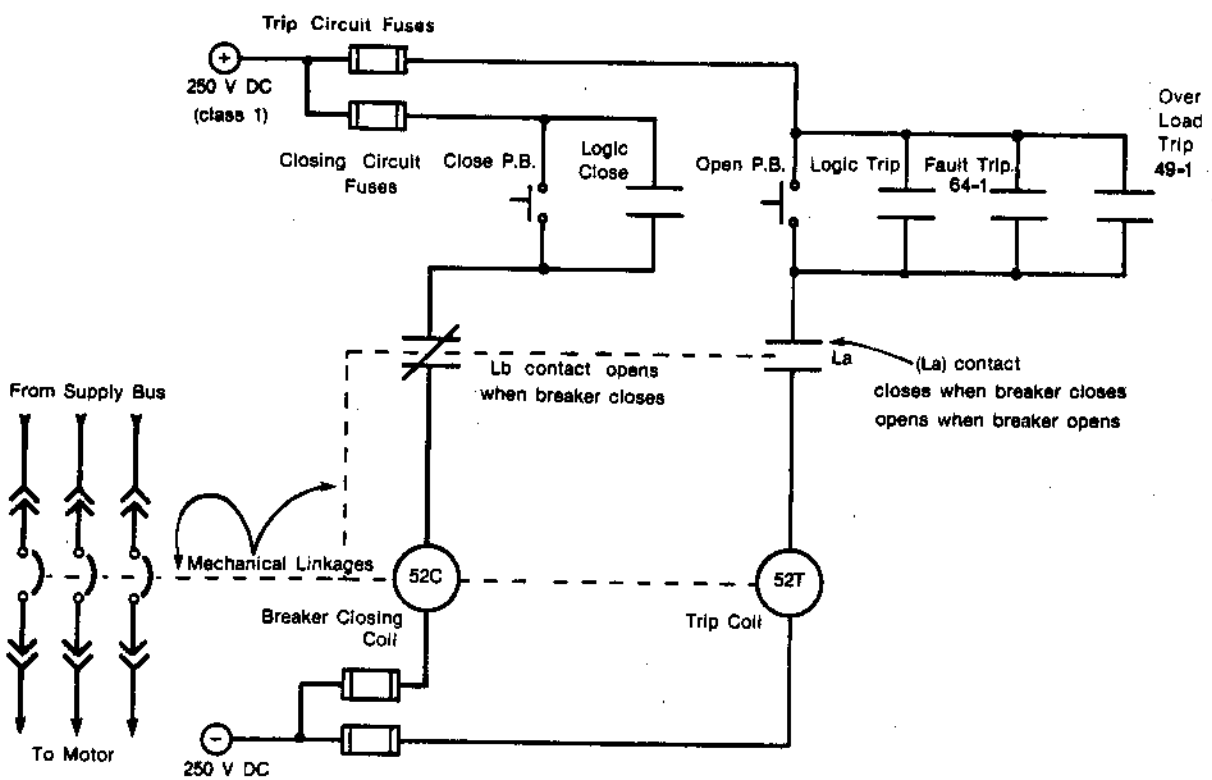


Figure 7(b)