Chapter 3

Part 1: ELECTRIC CONTROL FUNDAMENTALS

3-1 Introduction:

Any electrical circuit includes three elements: a power source, a switch, and a load. The switch serves to turn the power on and off. In an **HVAC** control system the load will be an actuator or a relay, and the switch will be the sensor or the controller.
Electrical controls in **HVAC** applications make use **one of the four basic parts*****: the switch, the electromagnetic coil or solenoid, the two-position motor, and the modulating motor***.

Electric energy is commonly used to transmit the measurement of a change in a controlled condition from a controller to other parts of a system and to translate the change into work at the final control element, and, ***electricity offers the following advantages:***

1- It is available wherever power lines can be run.
2- The wiring is usually simple and easy to install.
3- The signals from sensing elements can be used to produce one or a combination of outputs. For example, several actuators can be controlled by one controller.
4- Single controller-actuator combinations are possible without the need for a main-air source as in pneumatic control.

Electric controls consist of valve/damper actuators, temperature/pressure/humidity controllers, relays, motor starters and contactors. They are powered by low or line voltage, depending on the circuit requirements

3-2 DEFINITIONS

Actuator: *A device used to position control dampers or valves*. Electric actuators consist of an electric motor coupled to a gear train and output shaft. Typically, the shaft drives through 90 degrees or 160 degrees of rotation depending on the application.

Actuators designated as line voltage, have line-voltage inputs but commonly have a low-voltage control circuit since the motor is powered by low voltage. A *transformer* is used to supply power to the low voltage motor coils.

Contact arrangement: The electric switch configuration of a controller, relay, contactor, motor starter, limit switch, or other control device. *Contacts which complete circuits when a relay is energized* are called *normally open* (N.O) or “in” contacts. *Contacts which complete electric circuits when a relay is de energized* are called *normally closed (N.C)* or “out” contacts. Many contact arrangements are available depending on the control device. Figure 3-1 illustrates three contact arrangements.

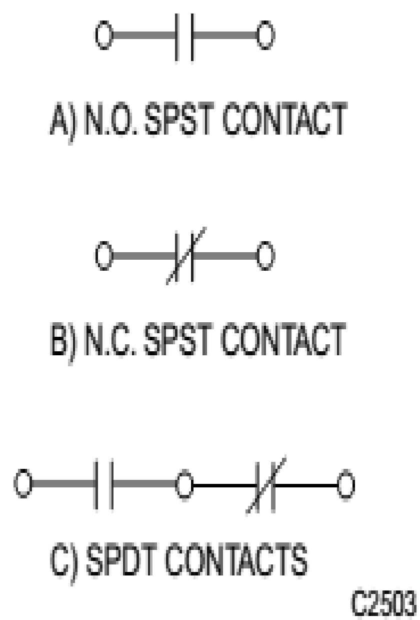


Fig. 3-1 Typical Contact Arrangements.

Controller: A temperature, humidity, or pressure actuated device used to provide two-position, floating, or proportioning control of an actuator or relay. It may contain a mercury switch, snap-acting contacts, or a potentiometer. *Controllers can be two-wire or three wire devices.*

Two-wire controllers are *SPST devices*. The N.O type (Fig. 3-1A) generally opens the circuit on a fall in the controlled variable and closes the circuit on a rise. The N.C type (Fig. 3-1B) generally closes the circuit on a fall in the controlled variable and opens the circuit on a rise. Three-wire controllers are *SPDT*, floating, or potentiometer devices. Generally The *SPDT* controllers (Fig. 3-1C) in the case a fall in the controlled variable and the opposite occurs on a rise.

Figure 3-2 represent the typical controller action in figures 3-2A through 3-2C do not have a true N.O./N.C. contact arrangement but provide a switching action dependent on the condition of the controlled variable. Floating controllers (Fig. 3-2D) are *SPDT* devices with a center-off position. Potentiometer controllers (Fig. 3-2E) move the wiper (R) toward B on a fall and toward W on a rise in the controlled variable. This action varies the resistance in both legs of the potentiometer and is used for proportional control.

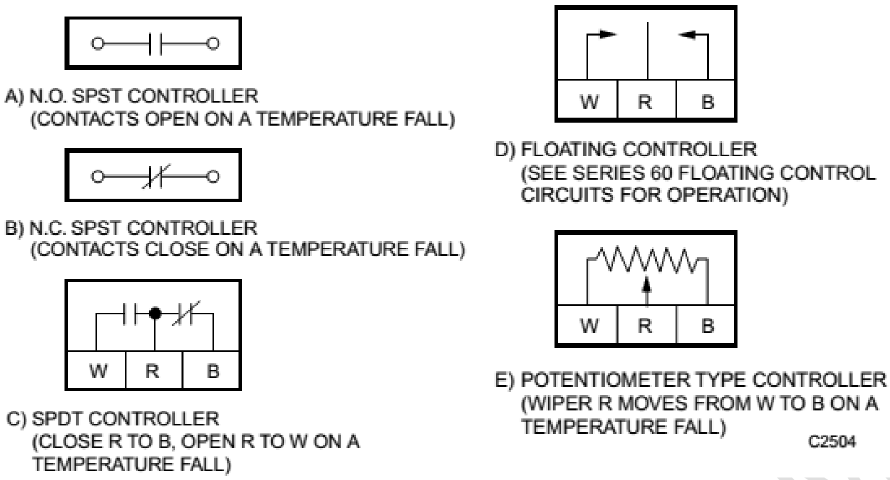


Fig. 3-2 Typical Controller Action

Line voltage: A term which refers to the normal electric supply voltage. Line voltage can be used directly in some control circuits or can be connected to the primary side of a step down *transformer* to provide power for a low-voltage control circuit. Most line-voltage devices function at their rated voltage +10%/–15%.

Low voltage: A term which applies to wiring or other electrical devices using 30 volts or less. Low-voltage control devices usually function on 24V ac +10%/–15%.

Relay: A device consisting of a solenoid coil which operates load-carrying switching contacts when the coil is energized, relays can have single or multiple contacts.

Transformer: A device used to change voltage from one level to another. For control circuits this is usually line voltage to low voltage. Transformers can be used only on AC power.

3-3 ELECTRIC CONTROL DEVICES

3.3.1 Two-Position Controls *Sensors*:

Many types of the sensors described in before, may be used for two-position (on-off) electric control. The *bimetal* is very commonly used in electric thermostats because it can serve to conduct electricity. Figure 3-3 illustrates a simple single pole, single-throw (SPST) bimetal thermostat. *When it is used for heating,* a decrease in room temperature will cause the bimetal to bend toward the contact. When the contact is almost closed, a ***small permanent magnet*** affects the bimetal enough to cause a quick final closure and to lock it in place. This magnet also causes a lag in the release, with resultant quick opening of the contact. *This minimizes arcing and burning of the contacts, and eliminates chattering.*

The bimetal may also be arranged in a spiral, fixed at one end and fastened to a mercury switch at the other (Figure 3-4). *The mercury switch is simply a glass tube partially filled* *with mercury and with wiring connectors at one or both ends*. It is loosely pivoted in the center so that when it turns past center the weight of the mercury running to the low end causes it to pivot farther. The *mercury bubble* acts as a conductor to connect the electrodes. This arrangement is often found in residential thermostats.

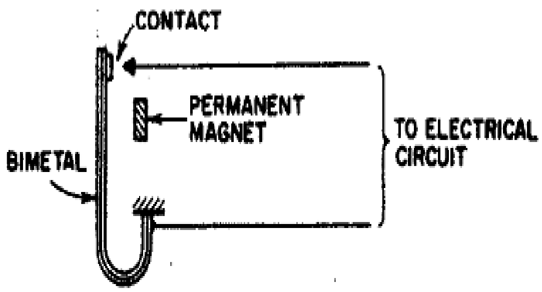


Figure 3-3 Bimetal sensor, electric.

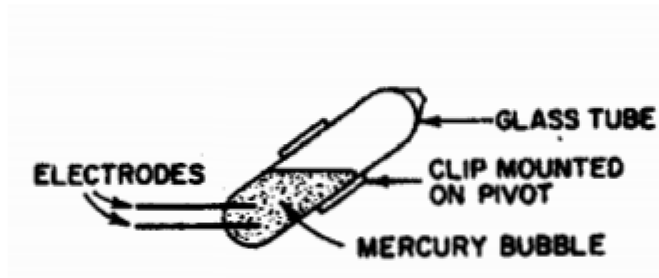


Figure 3-4 Mercury switch.

The diaphragm movement of bulb and capillary sensors can be used to trip an electric switch, and bellows sensors can be used in the same manner. The tripping action can be direct or through a linkage. Humidity sensors also can be used to trip switches, through either bending action or expansion.

Safety Controls: are used in HVAC systems for the detection of abnormally high or low temperatures and for smoke detection. High temperature sensors or smoke detectors are required in most systems by National Fire Protection Association and local codes. Low temperature sensors are used to prevent freeze-up. A low temperature duct sensor should have a long capillary so designed that a freezing temperature at any point will cause the sensor to open the relay contact. This prevents freezing due to stratified air streams. These devices may be automatically or manually reset.

Electromagnetic Devices: sometimes called *electromechanical devices*, this class includes relays, solenoid valves, and motor starters. These elements use the principle of electromagnetism. When an electric current flows through a wire, a magnetic field is set up around the wire. If the wire is formed into a coil then the magnetic field may become very strong, and a soft iron plunger placed in proximity to the end of the coil may be drawn up inside it. *This is the solenoid* that can then be used to operate a valve or a set of contacts.

Solenoid valves are made in many sizes and arrangements, for control of water, steam, refrigerants, and gases. Figure 3-5 shows a typical two-way valve. This valve is held in the normally closed position by fluid pressure. When the coil is energized, the plunger is lifted and opens the valve.

Three-way arrangements are common, and four or more ports are not unusual. The maximum size for a solenoid valve is about a 4 inch pipe size. Large sizes lead to problems of pressure and water hammer due to quick opening and closing.

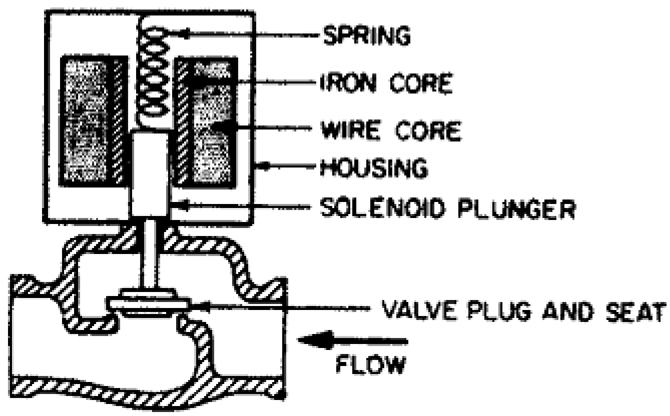


Figure 3-5 Solenoid valve.

Control relays: are designed to carry low-level control voltages and currents, up to about 15 A and 480 V. The contact rating of a control relay will vary with the voltage and with the type of load. The rating will be higher for a resistive load than for an inductive load. A relay can make a circuit with a much higher current than it can break without arcing and burning the contacts. The breaking capacity of the relay should be the criterion.

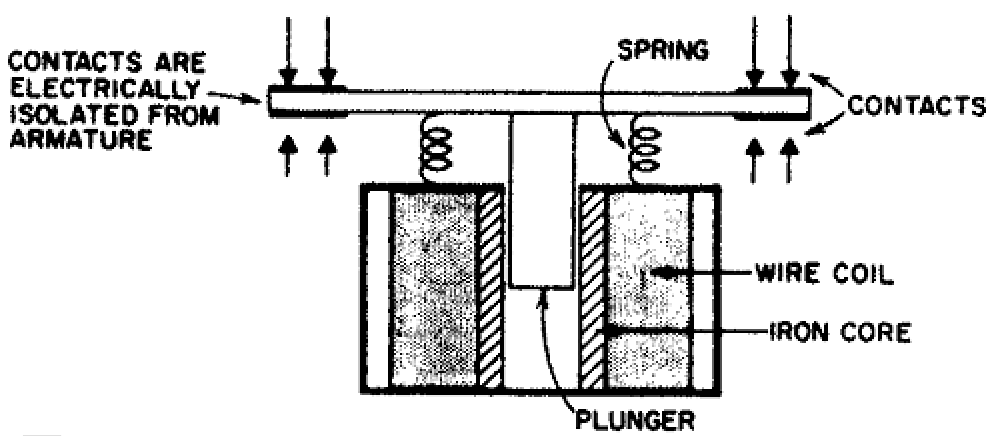


Figure 3-6 Relay coil and solenoid.

One typical control relay configuration is the coil and solenoid shown in Figure 3-6. The figure shows double-pole, double-throw (DPDT) contacts, but many arrangements from single-pole, single-throw to as many as eight poles are available. The armature is spring-loaded so that it will return to the normal position when the power to the coil is turned off. Coils are available for most standard voltages, that is, 24, 48, 120,208/240, and 440/480.

The solenoid-type relay is also available in *latching* arrangements, so that it may be driven to one position by a short-time energization of the coil and will stay in that position until returned by energizing a second coil. One latching system uses weak permanent magnets at each electromagnetic coil. These permanent magnets are not capable of displacing the solenoid, but will hold it in position (Figure 3-7).

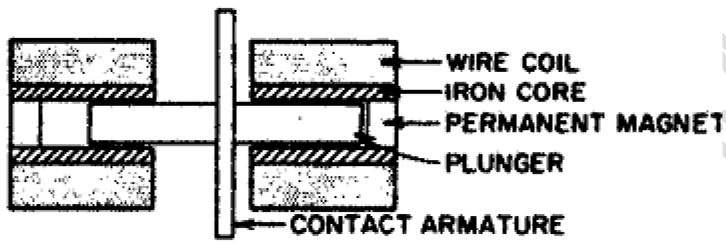


Figure 3-7 Permanent-magnet latching type relay.

Another method uses a mechanical latch or detent, which is tripped when the electromagnetic coil is energized. The advantage of the latching relay is that no power is required to hold it in position. The disadvantage is that it does not "fail safe" when power is removed.

Electromagnetic coils are also used in clapper-type relays (Figure 3-8). The coil is mounted near a soft iron bar that is part of a pivoted, spring-loaded contact armature.

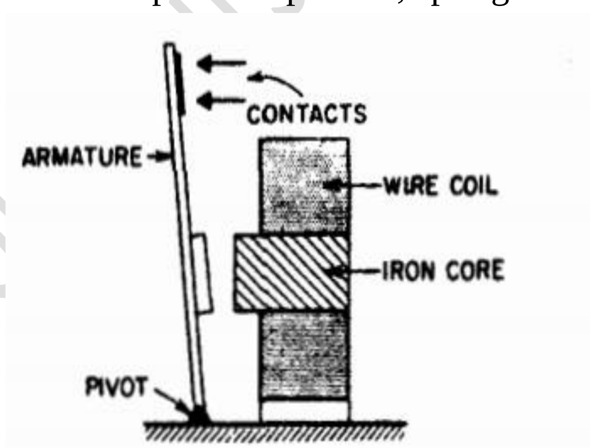


Figure 3-8. Clapper-type relay.

When the coil is energized, the arm is pulled over to close the contact. Several contact circuits may be mounted on a single armature. Double-throw contacts are also supplied. This type of relay usually, but not always, has a lower current and voltage rating than the solenoid type. The units are available as reed relays, and some miniature versions are made for electronics work.

Motor starters also use the solenoid coil actuator, and are similar to relays but with the addition of overload protection devices. These devices sense the heating effect of the current being used by the motor and break the control circuit to the coil if the current exceeds the starter rating. A typical across-the-line starter schematic is in Figure 3-9.

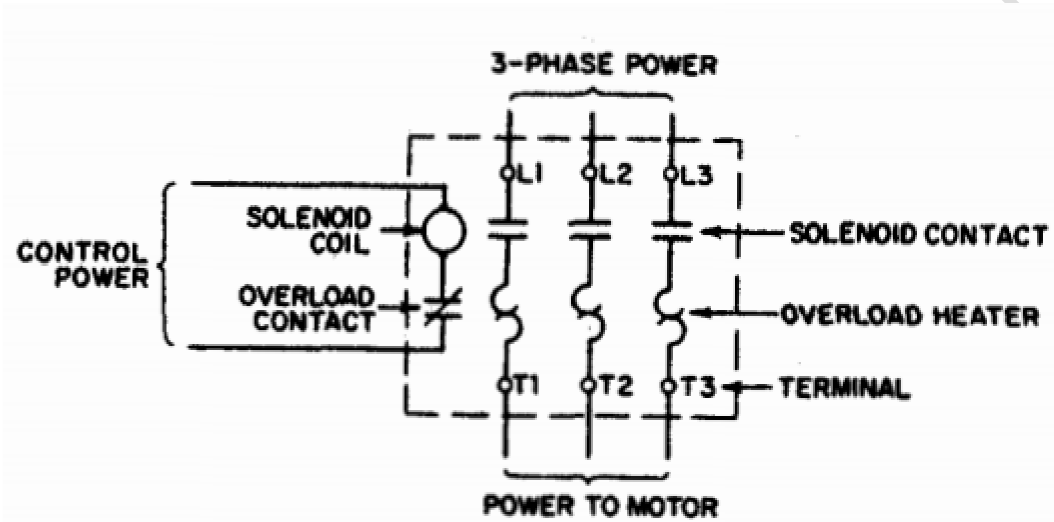


Figure 3-9 Motor starter.

Time-delay relays, as the name implies, provide a delay between the time when the coil is energized (on-delay) or de energized (off-delay) and the time when the contacts open and/or close. This delay may range from a small fraction of a second to several hours. Three general classes of time delay relays are available: solid state, pneumatic, and clock-driven.

Solid-state timers use electronic circuits to provide highly accurate delay periods. Timing ranges vary from **0.05** seconds to **15** minutes or more. Pneumatic timers use the familiar solenoid coil principles, but the movement of the solenoid is delayed by the diaphragm cover of a pneumatic chamber with a very small, adjustable leak port (Figure 3-10).

In the on-delay sequence, when the coil is energized, the solenoid pushes against the diaphragm, forcing the air out of the chamber. The leak port governs the rate of escape, and therefore the time delay. When the coil is de energized, a check valve opens to allow the chamber to refill rapidly. Delays from about **0.1** seconds to **60** minutes are available. Delay on de energizing is also available.

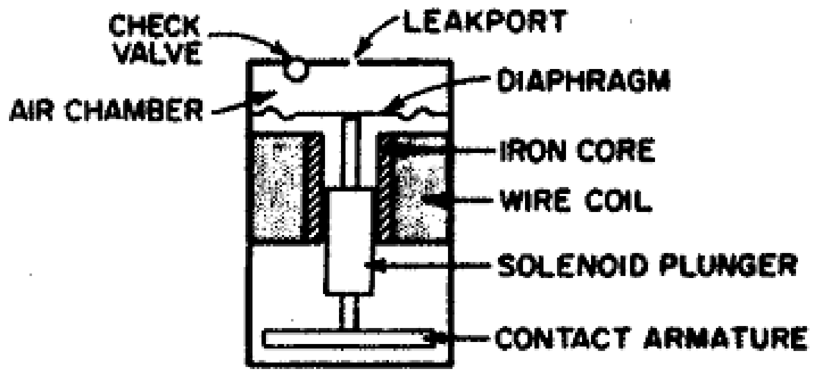


Figure 3-10 Time-delay relay, pneumatic type.

Clock timers use a synchronous clock motor that starts timing when the power is turned on. At the end of the timing period the control circuit contacts are opened or closed. When the power is turned off, the device immediately resets to the initial position. Clock timers are available with ranges from a fraction of a second to about **60** hours.

Many special sequences and capabilities are used in process control. Most of these time-delay relays may be provided with auxiliary contacts that open and/or close without delay, as in an ordinary relay.

3-3-2 Two-Position Motors:

Two-position motors are used for operating dampers or valves that need to open and close more slowly than a solenoid coil will allow.

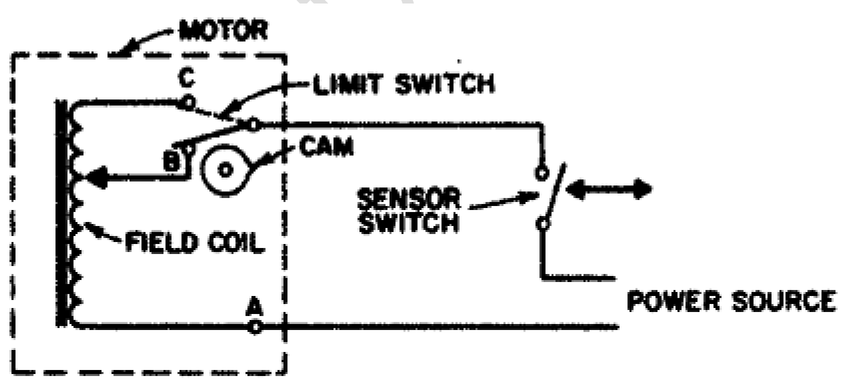


Figure 3-11 Two-position spring-return motor.

Motors may be unidirectional, spring-return or unidirectional, three wire. A spring-return motor is shown in Figure 3-11. When the controller closes its SPST switch, the motor winding is energized from A to B. This starts the motor, and it runs, driving a crankshaft and linkage (through a reduction gear) to open or close a valve or damper. A cam is mounted on the shaft, and at the proper position (usually 180' of rotation but sometimes less) the cam throws the limit switch from B to C. This added coil resistance reduces the current to a holding level, which will hold the motor in this position but will not cause damage. When the controller switch opens, the spring returns the motor to its original position.

Figure 3-12 shows a three-wire motor. For discussion purposes assume that this motor is operating a heating valve and that the valve is closed in the position shown. A double-throw controller is required, and assumes that this is a thermostat that closes contact B on temperature rise and contact A on temperature fall. The controller is shown in the satisfied position. The limit switches (marked SWl, SW2) are operated by a cam of the motor crankshaft. On a fall in room temperature the thermostat closes contact A, establishing a circuit through SW2 to the motor field coil. The motor runs, and almost immediately SW1 closes, establishing a maintaining circuit to the coil. Now the motor will run 180" regardless of what happens at the controller. When a 180" stroke has been completed, SW2 is opened by the cam and breaks the circuit to the coil, stopping the motor. The valve is fully open. On a rise in temperature the controller breaks contact A and makes contact B, establishing a circuit through SW1 to the coil and restarting the motor. As the valve starts to close SW2 closes and makes the maintaining circuit. When the valve is fully closed, the cam opens SW1, stopping the motor.

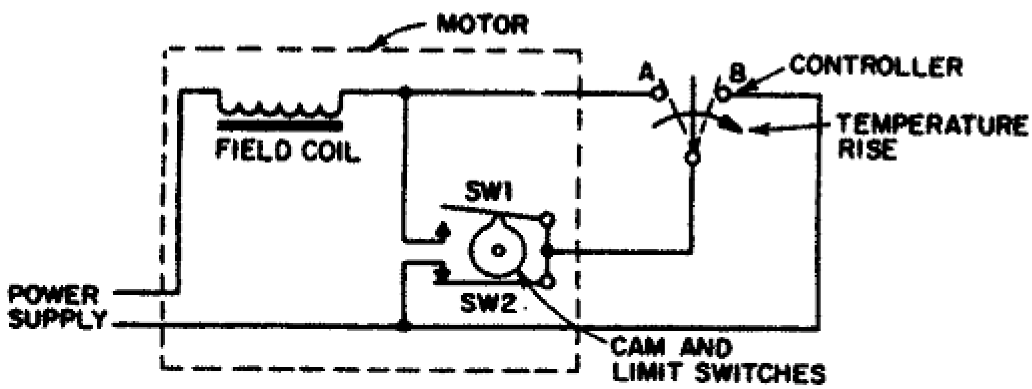


Figure 3-12 Two-position motor, three-wire arrangement.

In case of power failure the three-wire motor will stop and stay wherever it may be. The spring-return motor will return to normal position. These motors may be provided with cam-operated auxiliary contacts that open and/or close at any desired point in the rotation.

3-3-3 Modulating Motors are used for proportional and floating controls. They must, therefore, be reversible and capable of stopping and holding at any point in the cycle. The motors used in these devices will be either reversible two-phase induction motors or reversible shaded-pole motors.

3-3-3-1 Reversible *Induction Motors:*

Schematically, the two-phase induction motor (Figure **3-13)** has two field windings directly connected at one end (C) and connected at the other by a capacitor. Power may be supplied at A or B on either side of the capacitor, with the other power connection at C. If, for example, alternating current power is connected across A and C, then coil 1 is directly powered and coil **2** is indirectly powered through the capacitor. The effect of the capacitor is to introduce a phase shift between coils **1** and 2; thus a rotary motion is imparted to the motor armature. If the power is applied across B and C, the phase is reversed, and the motor runs in a reverse direction.

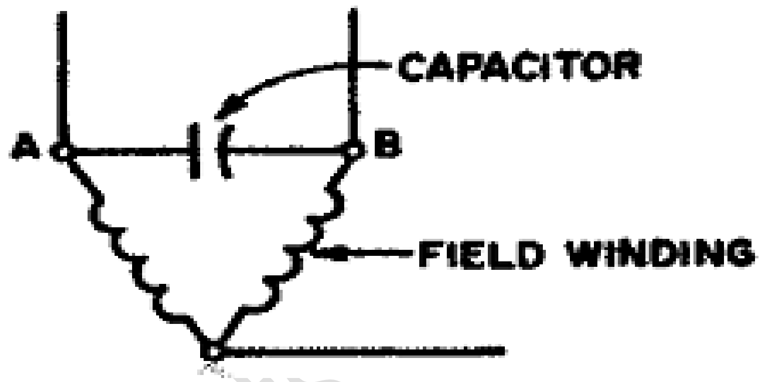


Figure 3-13 Reversible induction motor.

3-3-3-2 Shaded-Pole Motors:

The shaded-pole motor is constructed with a main field coil that is directly energized. However, by itself this will not start the motor. To provide a biasing effect shading coils are added as shown in Figure 3-14. These are powered by transformation effect from the main field coil, and when both ends of the shading coil windings are shorted out, a phase lag is caused in part of the field. This produces a rotating field that starts the motor and improves its efficiency while running. This arrangement is unidirectional. To provide a reversing motor two additional shading coils are added (Figure 3-15) and wired as shown in Figure 3-16. Grounding one pair of shading coils causes the motor to run in one direction, grounding the other pair causes the motor to reverse rotation.

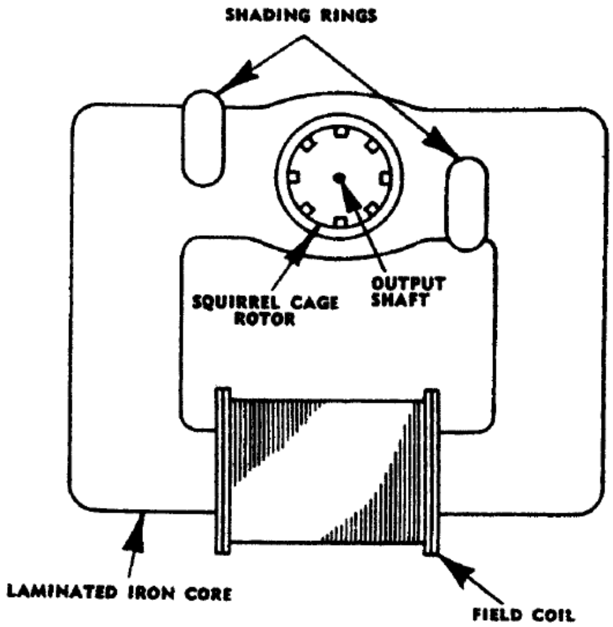


Figure 3-14 Shaded-pole motor.

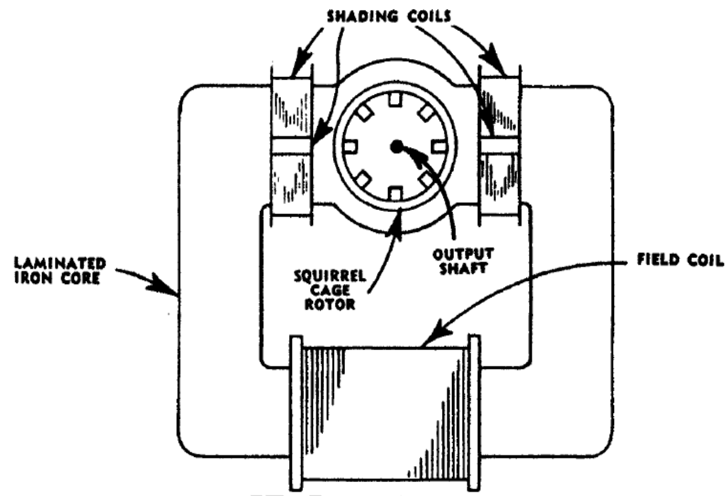


Figure 3-15 Reversible shaded-pole motor.

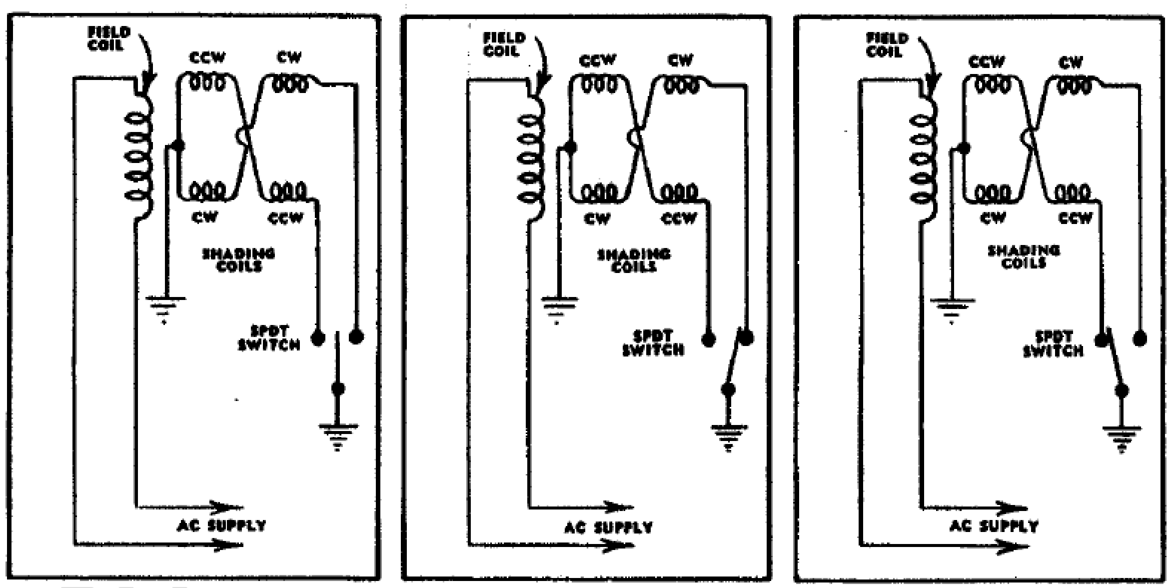


Figure 3-16 Shaded-pole motor wiring diagrams.

3-3-3-3 Modulating Motor Control:

Two general types of control configurations are used with modulating motors. Floating control includes a three-wire controller with a center dead spot and no feedback. The motor is geared down to provide a slow change in the controlled device, so that system response will usually cause the sensor to return the switch to the center-off position before the motor has traveled the full stroke.

Figure 3-17 shows a shaded-pole motor with this type of control. The limit switches are cam-operated at the end of the stroke (as described under two-position motors). The sensor controller is commonly called a floating controller. This same controller may be connected in a similar manner to an induction motor. Fully modulating control requires negative feedback from the motor, as in Figure 3-18. Figure 3-19, which shows only the potentiometers and relay coils, will aid one in understanding the following description. In the balanced condition shown, the wiper arm of the controller potentiometer is centered on its resistance winding, as is that of the feedback potentiometer. Under these conditions the currents through the two coils of the balancing relay are equal, and the relay arm is centered between contacts (Figure 3-19(A)). If the controller responds to temperature (or pressure) change and moves its potentiometer wiper arm, the circuits are unbalanced, and the current differences in the two relay coils cause the relay arm to swing to one contact (Figure 3-19(B)). This starts the motor and causes it to actuate a valve or a damper to offset the variation from set point. The motor operation also moves the feedback potentiometer wiper, which offsets the effect of the controller. When balance is restored (with the motor in a new position), the relay coil currents are again equal, the relay arm is centered, and the motor stops (Figure 3-19(C)). The limit switches are needed to stop the motor at the end of the stroke if the sensed conditions are beyond the throttling range of the controller.

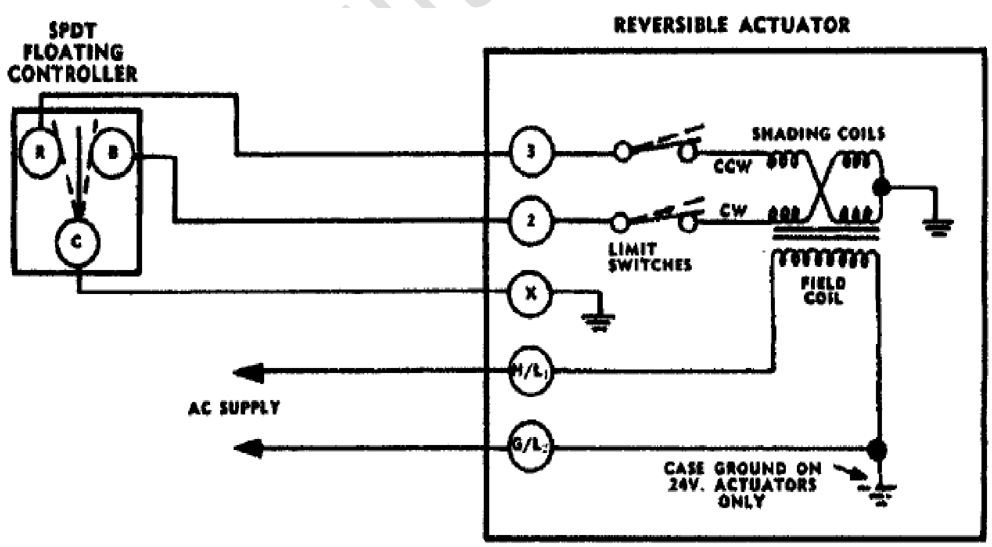


Figure 3-17 Modulating motor control.

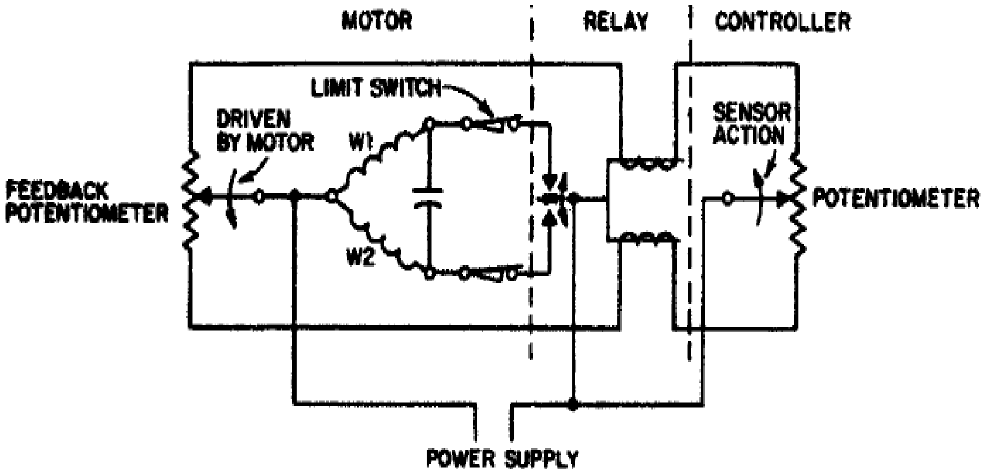


Figure 3-18 Modulating induction motor.

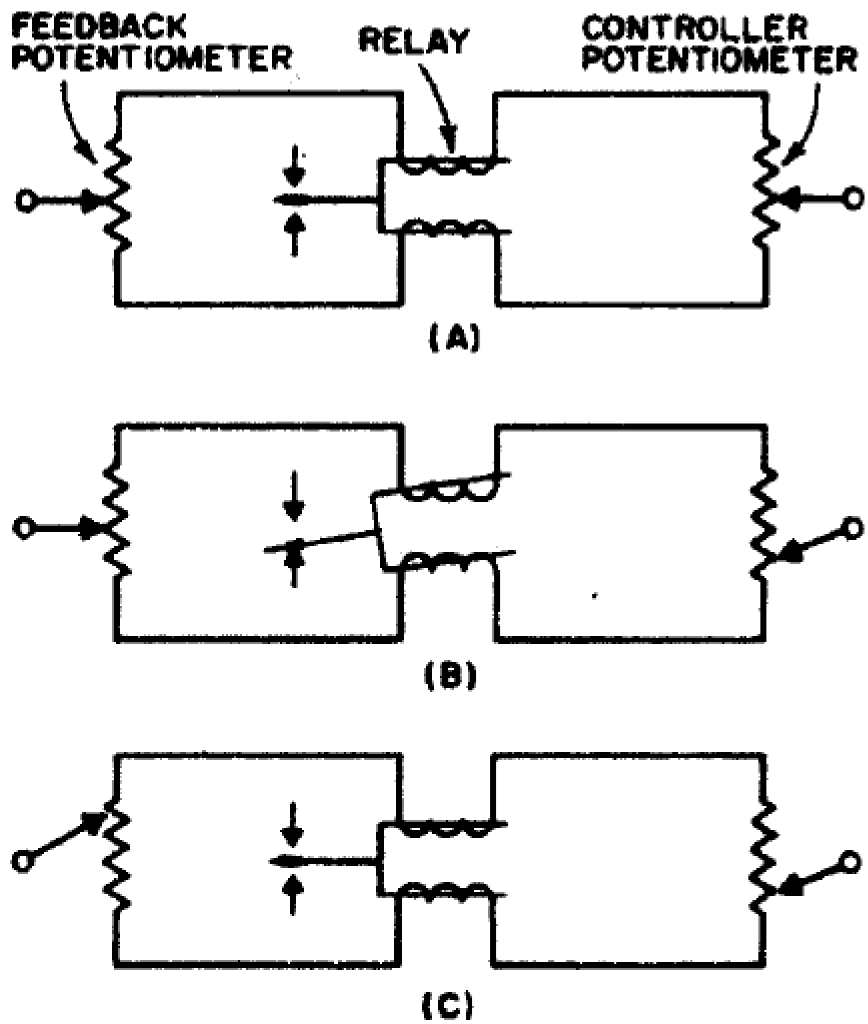


Figure 3-19 (A) Balanced position. (B) Controller unbalanced & (C) Feedback moved, relay balanced.

Part 2: Electric Control Systems

3-4-1 INTRODUCTION

Control of **HVAC** systems includes starting and stopping electric motors for fans, compressors, boilers, pumps, and accessories. All too often the system designer thinks that motor control is the responsibility of the electrical engineer.

The electrical engineer must size and select the wire, conduit, starters, disconnects, and switchgear necessary for supplying power and control to the motor; and this information must appear on the electrical drawings for the benefit of the electrical contractor who is to install it. However, control designers must specify the necessary interlocks to the HVAC control system. So we must learn how to express electrical equipment and wiring diagrammatically using standard electrical symbols and interfacing between the electrical and temperature control systems with proper relays and transducers.

3-4-2 ELECTRIC CONTROL DIAGRAMS

Consider some conventions and symbols used to convey electrical information. Figure 3-20 (A) is a point-to-point or graphic schematic of a motor starter with momentary contact pushbuttons for manual start stop control, in ladder form. The ladder schematic is more frequently used and is easier to follow.

The symbol **1M** over the circle in Figure 3-20 (B) designates the solenoid coil in the starter, which, when energized, actuates the power and auxiliary contacts. The related contacts are identified by the same number, especially when spread out in the ladder schematic. The symbol —| |— shows a normally open contact. That is, when the coil is not energized, the contact is open; when the coil is energized, it closes. The symbol —|/|— shows the opposite or normally closed contact. The symbol -∿- indicates the heater portion of the thermal overload relay in the starter. Next to each in the graphic schematic is a normally closed contact. When excessive current is drawn by the motor, for any reason, the heater heat ups and opens the contact. After the trouble is found and corrected, the contact may be closed (reset) manually. Various types of overload relays are available, depending on the size and the voltage of the motor.

Notice that the auxiliary contact in the starter is wired in parallel with the start pushbutton. In this relation it serves to maintain the circuit after the start button is released, and is therefore called a maintaining or a holding contact. When the motor stops for any reason, the holding circuit opens, and the motor will not restart until the start button is pushed.

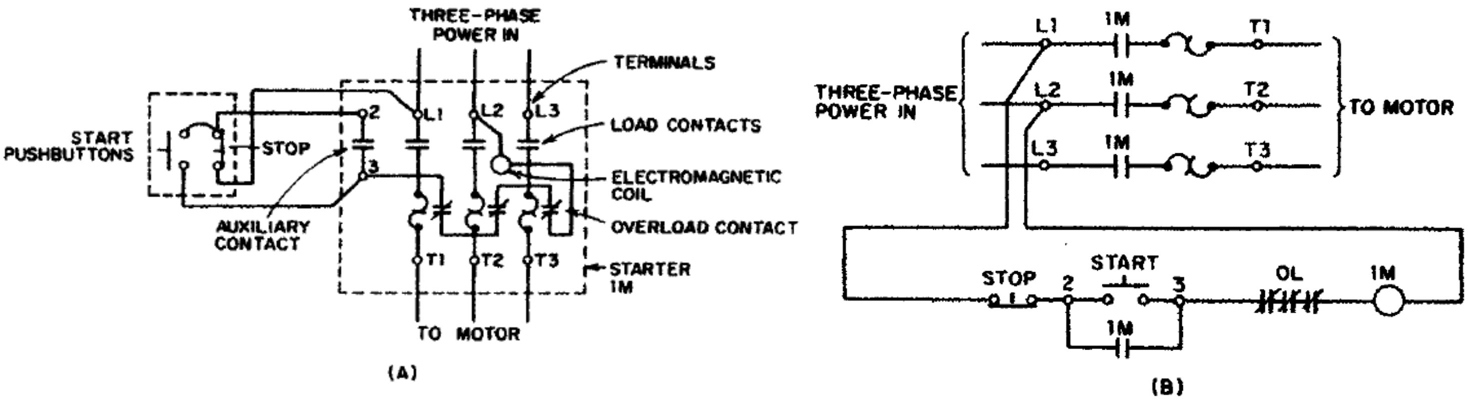


Figure 3-20 Motor starter with pushbuttons. (A) Pictorial diagram. (B)Ladder diagram

Figure 3-21 shows a typical starter with a control transformer for supplying low-voltage control power. This is almost identical with figure 3-20 (B), except that the transformer has been added. The advantage of the control transformer is that opening the disconnect switch interrupts all power, whereas with a separate control power source it is necessary to open two switches to interrupt all power. With complex, interlocking control systems, a separate power source is sometimes necessary.

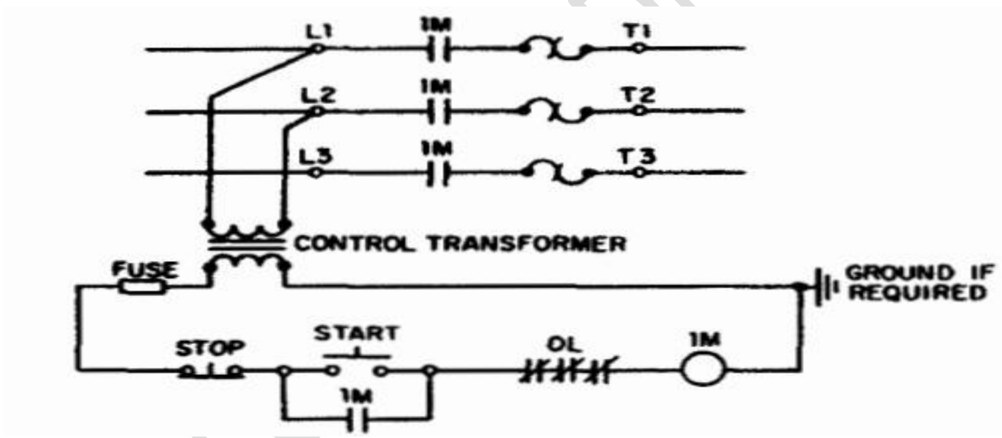


Figure 3-21 Motor starter with low-voltage control circuit.

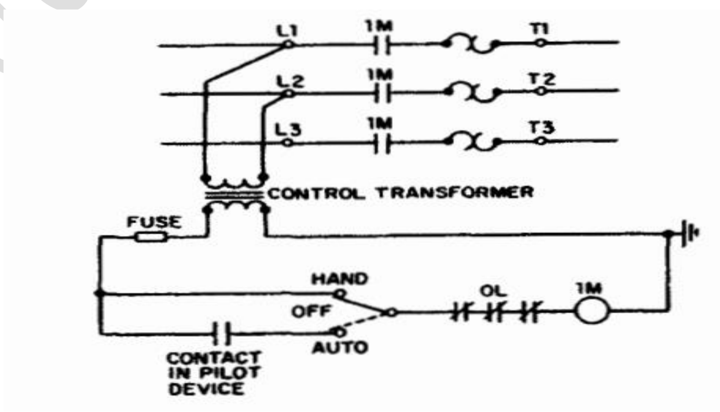


Figure 3-22 Motor starter with hand-off auto switch.

The motor also may be controlled by a hand-off-automatic switch (Figure 3-22). Thus it may be started and stopped manually as needed, but is normally operated by a pilot-device contact in the auto circuit. This arrangement is used where motors are interlocked with other motors, or with temperature, pressure, or flow controls.

Pilot or indicating lights are often used to show the on or off condition of a device. For "on" indication it is desirable to use a flow or a pressure switch in the circuit to give a positive assurance of operation, as the mere fact of power being delivered to the starter does not necessarily prove that the motor is running, or, if running is effectively moving a fluid. Figure 3-23 shows the same control as Figure 3-22 but with the addition of a running pilot light. This figure also shows the fused disconnect switch and the motor.

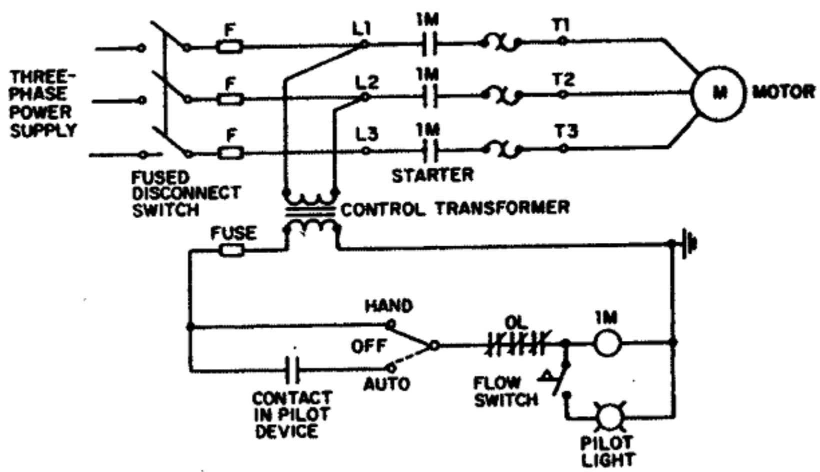


Figure 3-23 Motor starter with pilot light.

3-5 ELECTRICAL CONTROL OF A CHILLER

To illustrate a basic interlock system consider the diagram in Figure 3-24. ***A water chiller, a compressor, a circulating chilled water pump, a condensing water pump, a cooling tower fan, and the necessary relays and safety controls are shown.*** The power for the control circuit is obtained from a control transformer in the compressor starter, as this is the critical piece of apparatus. ***To place the system in operation*** **[1]***the chilled water pump is started manually with a start pushbutton*. As the water flows in the system, its temperature leaving the chiller is measured by a two position thermostat. **[2]***When the water temperature is above the thermostat setting, the thermostat contact closes, opening the solenoid valve in the refrigerant liquid line to the evaporator*. The resulting **[3]***rise in the suction pressure will close the low-pressure switch, starting the condensing water pump*. If water is flowing in both chilled and condensing **[4]***water circuits (flow switches closed) and* *all safety controls are closed, then the compressor motor will start*. The cooling [5]*tower fan is started and stopped by a thermostat in the condensing water supply*, so that the condensing water will not get too hot or too cold.

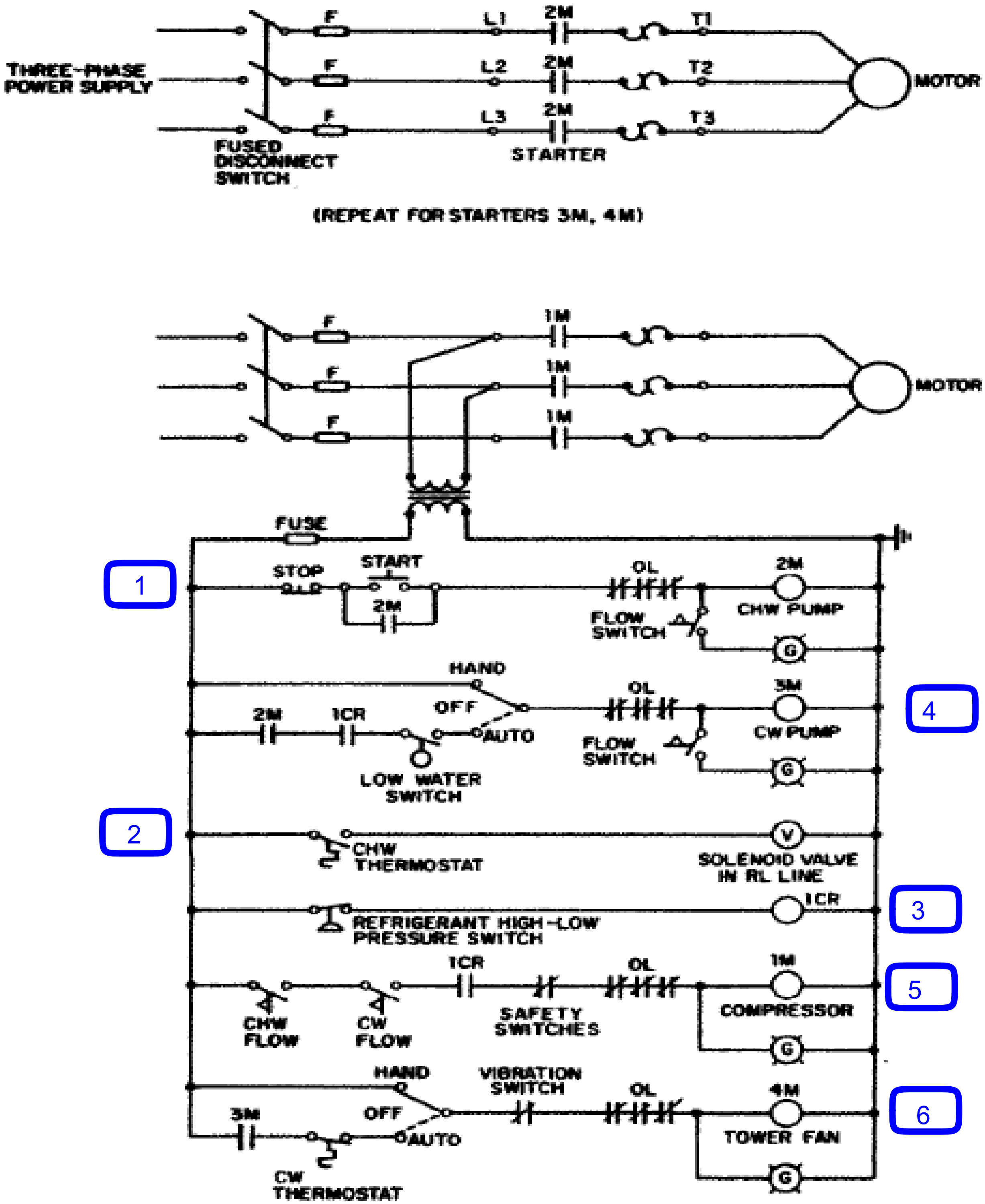


Figure 3-24 Chiller and accessories.

When the chilled water thermostat is satisfied, its contacts will open, closing the solenoid valve, but the condensing pump and compressor will continue to run until the system pumps down, that is, until the decreasing suction pressure opens the low-pressure switch. This pump down cycle is controlled by the pump-down relay **(1CR)**

Many safety controls are provided to protect the equipment against operating under adverse and potentially damaging conditions. ***The oil pressure switch contains a heater that is energized when the compressor starts. It is necessary for increasing oil pressure to open a pressure switch in the heater circuit before the heater opens a thermally delayed contact in the compressor starter circuit***. The compressor also may be stopped by too ***high a condensing pressure, too low a suction pressure, a high refrigerant temperature, a low chilled water temperature, or inadequate flow of chilled or condensing water-or, of course, by the thermal overloads in the motor starter.***

A float switch in the cooling tower sump will stop the condensing water pump if the water makeup system fails and the water level gets too low. A vibration switch will stop the cooling tower fan if the fan blades become damaged or get out of alignment. The control system just described contains several conventional symbols for various types of operating and safety switches. These and many other standard symbols for electrical devices are in common use, but not everyone uses the same standards. It is necessary to define exactly what each symbol means somewhere in the contract documents

3-6 ELECTRICAL CONTROL OF AN AIR HANDLING UNIT

Figure 3-25 shows a simple air handling unit electrical control sequence. Control power is obtained from a control transformer in the supply fan starter. The supply fan is started manually. Interlocks provide for operating the return fan and supplying power to the temperature control system whenever the supply fan is running. The diagram shows an air solenoid for supplying compressed air to appropriate control components (usually damper actuators), but this also could be an electric relay for supplying power to electric or electronic controls.

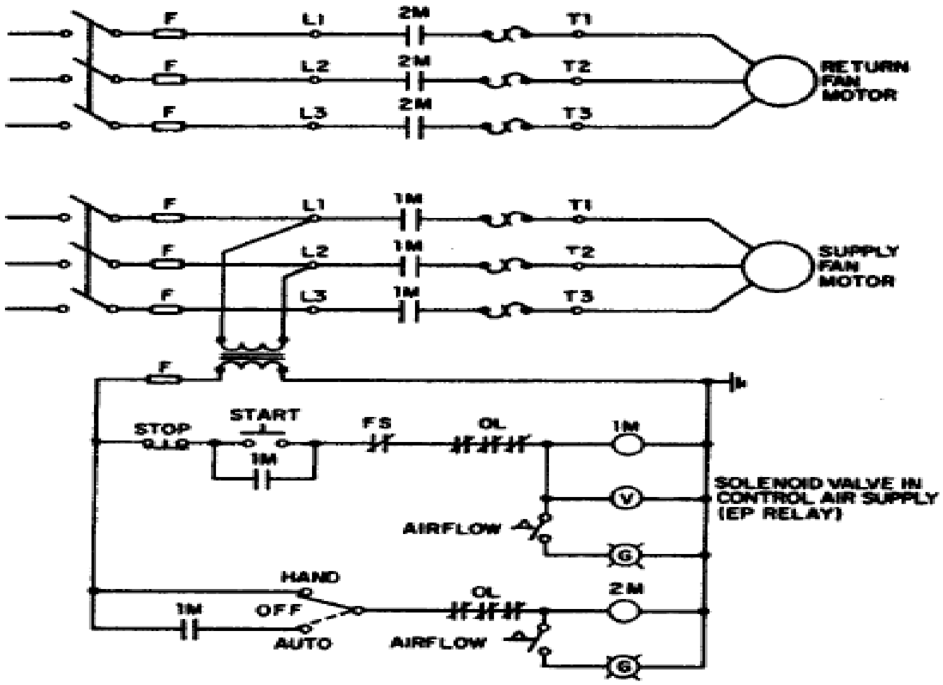
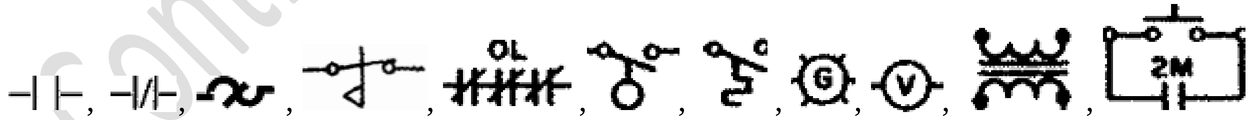


Figure 3-25 Air handling with return fan.

<u>**Questions and Answers**</u>

1- What are the advantages can be offer by electricity control system?
2- Define the following: Proportional gain, Electric actuator, line voltage, low voltage, electrical relay, transformer, mercury switch, electromagnetic Devices , Time-delay relays
3- What are the Rationalization of:
   - Some time the Two-position motors are used instead of solenoid for operating dampers or valves?
   - The *bimetal* is very commonly used in electric thermostats?
   - The use of small permanent magnet in some electric contacts? .
   - The use of modulating motors in HVAC systems?
4- Give the meaning of the following Abbreviations and Symbols:
   SPST, SPDT, DPDT, NO, NC, HVAC, SW, M, ICR, CHW pump, CW pump,



5- Draw showing the main parts of the following: Solenoid valve, Relay coil and solenoid, permanent- magnet latching relay, clapper-type relay, 3 phase motor starter, pneumatic time-delay relay?
6- Draw showing the control circuit of a water cool chiller and its accessories?
7- Draw showing the control circuit of an Air Handling Unit (AHU) with return fan?