starting the relay coil is connected in parallel with the starting winding. When power is applied to the line, the relay does not operate because it is calibrated to operate on a higher voltage. As the motor comes up to speed, the voltage across the starting winding and relay coil increases in proportion to the motor speed. At a definite voltage corresponding to a preselected speed, the relay operates and opens its contacts, thereby opening the starting-winding circuit or disconnecting the starting capacitor. The relay then keeps these contacts open because there is sufficient voltage induced in the starting winding, when the motor is running, to hold the relay in the open contact position.

Ratings established by the compressor manufacturer in cooperation with the motor manufacturer should not be changed, as it may result in improper starting characteristics at low or high field voltage conditions.

Motor Protection

Motor protection is similar to that described in the previous section on Domestic Refrigeration. Most compressors and air-moving motors are equipped with thermal protectors which are either hermetically-sealed for installation within the compressor shell or open for mounting on the outside. Hermetically-sealed protectors provide better protection than open protectors where conditions such as loss of charge, obstructed suction line or low ambient temperature on stalled rotor can be troublesome.

Requirements for maintenance are the same as for motors used in domestic refrigeration.

CENTRAL AIR CONDITIONING SYSTEMS

Refrigeration equipment and fans used in central air conditioning systems are normally driven by electric motors, although compressors may also be driven by steam turbines and internal combustion engines. This chapter deals with motor-drive only.

Motors

Electric motors used in central systems are both single-phase and polyphase, usually single-phase up to 6 hp, and three-phase above 6 hp. Most central systems are in the 2- to 6-hp range. Single-phase motors are usually permanent split capacitor motors. Typical performance data are given in Tables 4 and 5.

Shaded-pole and split-phase motors are used for air moving devices, with split-phase motors being used for higher horsepowers.

Because of their hermetic design, it is neither possible nor necessary to service compressor motors used in central systems. Fan motors are accessible, and should be occasionally serviced in accordance with manufacturer's instructions.

Motor Control

The motor control used in central air conditioning systems is determined by the size and type of motor, the power supply, and the degree of automation. Motor sizes range from approximately 2 hp to several hundred hp. Power supply is usually *single-phase* or *polyphase* a-c.

Control may be manual, but many installations are fully automatic, particularly in 2 to 5 ton capacity. Those installations use motor controllers similar to those used on room air conditioners.

Central system air conditioners are generally located at a distance from the controller, such as room thermostats and other control devices. Therefore, *magnetic contactors* must be used in most installations. Also, all direct-current installations and all large alternating-current installations must be equipped with *current-limiting* controllers which will be discussed. *Synchronous* motors are sometimes used to improve the power factor. *Multispeed* motors provide flexibility for many applications.

Manual control for an alternating- or a direct-current motor is usually located near the motor. When so located an operator must be present to start and stop or change the speed of the motor by operating the control mechanism.

Manual control is the simplest and least expensive control method for small alternating-current motors, both single-phase and polyphase, but it is seldom used with hermetic motors. The manual controller usually consists of a set of main line contacts, provided with thermal overload relays for motor protection.

Manual speed-controllers can be used for large air-conditioning systems using *slip-ring* motors, and then also provide reduced-current starting. Different speed points are used to vary the amount of cooling provided by the compressor.

Across-the-line magnetic starters are widely used in central air-conditioning systems. They are applicable to motors of all sizes, provided power supply and motor are suitable to this type of control. Across-the-line magnetic starters may be used with automatic control devices for starting and stopping. Where push-buttons are used, they may be wired for either low-voltage release or low-voltage protection.

Full-voltage starting for motors is preferable because of its lower first cost and simplicity of control. Except for d-c machines, most motors are mechanically and electrically designed for full-voltage starting. The starting inrush current, however, is limited in many cases by regulations of power companies because of the voltage fluctuations which may be caused by heavy current surges. It is therefore often necessary to reduce the starting current below that obtained by across-the-line starting to meet the limitations of power supply. One of the simplest means of accomplishing this is by the use of *resistors* in the primary circuit. As the motor accelerates, the resistance is cut out of the circuit by use of timing or current relays.

Another method of reducing the starting current for an a-c motor uses an *autotransformer* motor starter. Starting voltage is reduced, and when the motor accelerates, it is disconnected from the transformer and connected across-the-line by means of timing or current relays. Primary resistor starters are generally smaller and less expensive than autotransformer starters for motors of moderate size. However, primary resistor starters require more line current for a given starting torque than autotransformer starters.

Star-delta motor controllers limit current very efficiently, but they require use of special motors designed for this type of starting. They are particularly suited for centrifugal compressor drives starting without load.

Part-winding motor controllers are used to limit line disturbances by connecting only part of the motor winding to the line, and connecting the second motor winding to the line only after a time interval. If the motor is not heavily loaded, it will accelerate when the first part of the winding is connected to the line; if too heavily loaded, it may not start until the second winding is connected to the line. In either case, the voltage *dip* will be less than the dip which would result when using a standard squirrel cage motor with across-the-line starter. Part-winding motors may be either manually or magnetically controlled. The magnetic controller consists of two contactors and a timing device for the second contactor.

Synchronous Motor Controllers. It is sometimes desirable to use synchronous motors for the operation of large refrigeration installations to improve the power factor. Synchronous motors and their starting equipment are much more expensive than squirrel cage motors using across-the-line or reduced-voltage starting equipment. They also require a source of direct current for the rotating field. This may be supplied from a separate source, by means of a rectifier in the a-c power source, or by a separate generator driven by the motor itself. The motor is started as an induction motor, and when it reaches approximately synchronous speed, the direct-current power is applied to the field winding. This direct-current field must be applied at the proper time, in order to avoid a heavy surge of current should the field be out of phase. This function is generally accomplished by a frequency relay.

Multispeed Motor Controllers. Multispeed motors provide flexibility in many types of drives, when variation in capacity is needed. Two types of multispeed motors are used: motors with one reconnectable winding, and motors with two separate windings. Motors with separate windings need a contactor for each winding and only one contactor can be closed at any time. Motors with a reconnectable winding are similar to motors with two windings, but the contactors and motor circuits are different.

Slip-Ring Motor Controllers. Slip ring a-c motors provide variable speed. The *wound* rotor of these motors functions in the same manner as in the squirrel cage motor, except that the rotor windings are connected through slip rings and brushes to external circuits with resistance to vary motor speed. Increasing the resistance in the rotor circuit reduces motor speed, and decreasing the resistance increases motor speed. When the resistance is shorted out, the motor operates with maximum speed, efficiency, and power factor. On some large installations, manual drum controllers are used as speed setting devices. Complete automatic control can be provided with special control devices for selecting motor speeds.

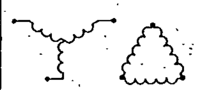
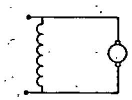
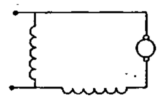
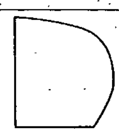
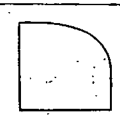
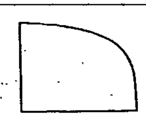
Controllers for Direct-Current Motors. Direct-current motors are not widely used in central systems, because only a few communities have this type of power supply. Furthermore, use of hermetic motors is frequently indicated, and direct-current motors are not suitable for such application. These motors have favorable speed torque characteristics, and their speed is easily controlled. Motor controllers for direct-current motors are more expensive than those for alternating-current motors, except for very small motors. Large direct-current motors are started with resistance in the armature circuit, which is reduced step by step until the motor reaches its base speed. Higher speeds are provided by weakening the motor field.

Motor Protection

Thermal or magnetic overload relays are used for providing running over-current and stalled rotor protection. Additional protection for abnormal running conditions or for automatic reset operation, is provided through the use of thermostats or other thermal devices. They are mounted directly on the stator windings of the motor and connected in series with the control circuit of the starter. Although similar to types used in industrial motor control, specially designed thermal overload relays are required for protection of hermetically-sealed motors. This is necessary in order to obtain a sufficiently short tripping time when the rotor is stalled. In the hermetic units, refrigerant gas normally passes over the motor and cools the windings. With the rotor stalled, there is no refrigerant flow, and the windings heat quickly. So-called *quick-trip* devices, therefore, must be used to prevent damage to the motor.

Thermal protectors may also be used to protect motor wind-

Table 5 .... Characteristics of Polyphase a-c and of d-c Motors

	Polyphase	Direct Current	
Connection diagram			
Speed torque curves			
Starting method	Motor Controller	Motor Controller	Motor Controller
HP ratings	½ HP up	½ HP up	½ HP up
Full load speeds at 60 cycles	3600–1800 1200–900–600	1750–1140 850	1750–1140 850
Torque Locked rotor Breakdown	 Moderate Moderate	 High High	 Very High High
Speed classification	Constant	Constant or adjustable	Constant or adjustable
Full load power factor	Moderate	—	—