The conduit or terminal box should be of cast construction and should have a hub threaded for rigid conduit. For larger horsepower sizes, only sheet steel boxes may be available (see IEEE Std 841), particularly where auxiliary devices such as surge capacitors, lightning arresters, or differential current transformers are used.

Vertical motors should have a drip shield over the fan.

6.13 MOTORS FOR CLASS I LOCATIONS

6.13.1 Division 1 or Zone 1

6.13.1.1 Suitable Types

Motors for use in Class I, Division 1, locations, as defined in NFPA 70, should be the explosionproof type and must be suitable for use under the specific conditions to be encountered in service. Depending on the specific conditions, a motor may have to be suitable for Class I, Groups A, B, C, or D. If a motor size is not available as explosionproof for Groups A and B, then totally enclosed pipe-ventilated motors, totally enclosed inert-gas-filled motors, or submersible-type motors must be used. For more complete details, NFPA 70 may be referenced.

An increased safety type “Ex e” motor is suitable for areas classified as Zone 1, but not for Division 1 areas. Motors are not recommended for installation in Zone 0 areas. This type of motor is designed to have excellent winding integrity; limits on internal and external temperatures during starting, operation, and stalled conditions; defined clearances between the rotating and stationary parts; and power terminals that have provisions against loosening. It is generally a TEFC motor, but can be of any totally enclosed type. An integral part of the increased safety type “Ex e” motor application is the use of a specific overload relay with the motor to limit temperatures during a stall or overload.

6.13.1.2 Nationally Recognized Testing Laboratory (NRTL) Approval

When available, motors should bear an NRTL label of approval for the gas or vapor involved. The label shall include temperature limits or other items as required by NFPA 70 for approved equipment.

Most laboratories cannot test larger motors, particularly those with voltage ratings exceeding 600 V. Where third-party approval is desired, the manufacturer can generally perform the tests required for conformance at the manufacturing site and submit the results to the third party for approval. Site approval may also be required and the user should work with the local “authority having jurisdiction” (see the NFPA 70) to determine the approval or labeling requirements.

6.13.1.3 Care in Inspection

The hazardous approval label becomes void when the motor enclosure is opened unless the work is performed by a repair facility which is duly authorized (generally by the original NRTL).

6.13.2 Division 2 or Zone 2

6.13.2.1 Motors Having Arc-Making Devices

Motors for use in Class I, Division 2, locations, or in Zone 2 locations, as defined in NFPA 70, shall be the totally enclosed, explosionproof-type approved for Class I, Division 1, locations when the following devices are used in the motors:

a. Sliding contacts.
b. Centrifugal or other types of switching mechanisms, including motor overcurrent devices.
c. Integral resistance devices, used while the motors are either starting or running.

If these devices, however, are provided with separate explosionproof enclosures approved for Class I locations, then motor enclosures complying with 6.13.2.2 may be utilized.

6.13.2.2 Motors Having No Arc-Making Devices

In Class I, Division 2, locations, or in Zone 2 locations, NFPA 70 permits the installation of squirrel-cage induction motors in enclosures other than explosionproof-type. This is permitted because it is not probable that a motor will fail electrically during those rare periods when gases or vapors are present in ignitable quantities.

A motor intended for use in Class I, Division 2 or Zone 2 service should be constructed so that induced currents will not produce arcing, nor produce surface temperatures capable of causing ignition of the flammable vapor.

6.13.3 General

6.13.3.1 Mechanical Requirements

Motors for use in a Class I area, either Division 1 or Division 2, should be nonsparking mechanically as well as electrically. For example, the fan or fans of a fan-cooled motor should be made of nonsparking material.

6.13.3.2 Other Factors

Even when other considerations may not dictate the use of totally enclosed motors, factors like dust, dirt, drifting snow, and corrosive fumes may influence the type of enclosure to be used.

6.13.4 Totally Enclosed Forced-Ventilated (TEFV) Motors (also known as Totally Enclosed Pipe Ventilated [TEPV])

If an application for a classified location requires a synchronous or wound-rotor induction motor, a motor with a Totally Enclosed Forced-Ventilated (or TEPV) enclosure may be used to meet the requirements of the classified location. In some cases, the design will permit a pressurized enclosure around the collector or slip rings only; an example of this type of motor is one built with a gasketed steel metal housing.

If a motor has brushes or slip rings, it is recommended that its enclosure be provided with pressure-tight windows which permit observation of the brush or slip-ring operation. A separate source of ventilating air is provided for this type of motor, usually by a separate motor-driven blower, and the ventilating air must be drawn from a unclassified location. The air passage should also have filters to minimize the airborne dust. A common arrangement is to interlock the blower with the main motor controller so that the blower must be started and must remain in operation for some fixed period to assure that at least ten air changes have occurred before the main motor can be started. If air ventilation is lost, interlocks are often provided to shut down the main motor.

Other interlocks are as follows:

a. An auxiliary contact to detect the opening of the ventilation motor controller.

b. An air flow switch installed in the duct near the main motor to detect actual flow. The switch enclosure shall be suitable for the location classification.

6.13.5 Totally Enclosed Inert Gas-Filled Pressurized (TEIGF) Motors

For applications requiring a large induction or synchronous motor in a Class I, Division 1 location, a totally enclosed motor, pressurized internally with inert gas and arranged for water cooling or surface-air cooling, may be used (see NEMA MG 1 and NFPA 496). TEIGF-type of motors are rare and not readily available. In this type of application, the motor housing must be specially designed to be airtight and to provide tight closure around the shaft to prevent excessive loss of the pressurizing medium. In the event of a pressure failure, it is required to disconnect the motor from its power source. An alarm should be provided to signal an alarm if there is any increase in temperature of the motor beyond design limits.

Nitrogen is the preferred pressurizing medium. When a motor uses nitrogen as its pressurizing medium, the oil seals should be of a type that will prevent oil from being drawn into the motor when the motor is shut down. Where a water-cooled motor is used in this application, the cooling water should continue to flow through the motor heat exchanger when the motor is shut down.

The following accessories should be considered:

a. Indicators to show whether cooling water is flowing in the proper amount.

b. Warning alarms or automatic shut-off devices to operate as desired in the event of loss of pressure inside the motor, loss of the cooling water supply, water leakage from the cooler, and overheating of the stator windings or bearings.

c. Other devices required to give the degree of protection warranted for the particular application.

6.13.6 Totally Enclosed Water-to-Air Cooled Motors

Totally Enclosed Water-to-Air Cooled motors use water-to-air heat exchangers. A source of cooling water or glycol-water mixture is piped to the motor heat exchanger, and the internal air is circulated over the exchanger tubes. This cooled air is then passed through the stator and rotor cores to cool the motor. The majority of the heat generated in the motor is taken up by the water supplied to it with a small portion being radiated from the frame.

Totally enclosed water-to-air-cooled motors have an advantage when medium- and large-size motors are required, and where there is an environment that is hostile to motor windings and that might otherwise require the use of NEMA Type I or Type II weather-protected motors. Totally enclosed water-to-air cooled motors, however, require protection from the possibilities of loss of cooling water or low flow. Embedded winding temperature detectors are usually used in this type of motor. In many cases, the motor enclosure may have a "make-up" air inlet to provide an air inlet for bearing seals. Even though the air flow rate is relatively small, this air inlet should be provided with adequate filtration.

6.14 MOTORS FOR CLASS II LOCATIONS

6.14.1 Suitable Types

Motors for use in Class II locations, as defined in NFPA 70, shall be suitable for use in locations that are hazardous because of the presence of combustible dust.

6.14.2 Division 1

Motors should bear a third-party label of approval for Class II, Division 1, locations or be totally enclosed pipe-ventilated, meeting the temperature limitations for the specific dust on them or in their vicinity. Some explosionproof motors approved for Class I, Division 1 locations are also dust ignitionproof and are approved for Class II, Division 1 locations.

6.14.3 Division 2

For Class II, Division 2 locations, motors should be totally enclosed nonventilated, totally enclosed pipe-ventilated, totally enclosed fan-cooled, or totally enclosed dust-ignitionproof. The maximum full-load external temperature for these motors shall not exceed 120°C (248°F) for operation in free air (not dust blanketed). Certain exceptions are permitted by NFPA 70.

6.15 MOTOR SERVICE FACTOR

To apply a motor properly and economically, its service factor must be taken into account. A standard, integral-horsepower NEMA-frame open motor; or a high-efficiency, totally enclosed fan-cooled motor will generally have a service factor of 1.15 and will carry its rated nameplate load continuously without exceeding its rated temperature rise. It will continuously carry 115% of its rated full load without attaining excessive temperature, although its insulation temperature limit will be approached, thus reducing winding insulation life. The bearings will also operate at a higher temperature, affecting bearing lubrication and bearing life. It is recommended that the service factor rating be reserved for contingency use. Consideration should also be given to the speed and torque characteristics of the motor, which are based on a 1.0 service factor.

For the above NEMA-frame and other non-NEMA-frame motors the service factor is generally 1.0 with no margin for exceeding the nameplate rating. It is not good practice to impose continuous loads in excess of the nameplate rating on such motors; therefore, it is advisable to determine definitive load requirements and to size motors conservatively.

As an example, a certified copy of the characteristic curve of a centrifugal pump should be examined over its entire range to determine the maximum load the curve can impose on its driver. Regardless of service, motors with a service factor of 1.0 should not be operated continuously nor for extended periods at loads exceeding the nameplate rating. When heavier loading is permitted, it should be done only with the understanding that the reliability and motor life expectancy will be reduced. Additionally, other specifications may effect motor sizing, such as API Std 610.

6.16 FREQUENCY OF STARTING

NEMA-frame motors are capable of multiple starts per hour. The number of which is defined by NEMA Std MG 1, paragraph 12.54.1, and NEMA Std MG-10 paragraph 2.8.1.

Medium voltage motors are limited in their starting capability, usually to two starts from cold (or ambient) condition and one start from hot (or running temperature) condition. This is on the basis of a) the load inertia is within NEMA limits, b) the load start curve is a "square-of-speed" type curve, and c) the voltage at the motor terminals is greater than 90% (see 6.20). In between starts (while the motor is at rest), these units must be cooled (generally by convection) to a lower stator and rotor temperature prior to another attempted start. Motors that comply with API Std 541 or Std 546 usually have greater starting capabilities. This time between starts must be coordinated with the manufacturer for automatic-restart or frequentstart duty conditions.

Note: Time between hot starts may exceed 1 hour. Motors driving high inertia loads, or operating under high power system voltage drops should receive special consideration.

6.17 TEMPERATURE, VIBRATION, AND CURRENT INDICATORS

Motors larger than 1,000 HP and special-purpose motors frequently require temperature, current, vibration, air flow, water flow, or differential pressure monitoring. (See API Std 541 and 546 for proper application.)

6.18 CONDUIT OR TERMINAL BOX

Attention should be given to the size and direction of conduit entrances to motor terminal boxes. Sizing requirements of the local electrical code should be observed. Medium and high voltage main terminal boxes may also require special construction if ANSI/NEMA Type II design, space for stress cone-type cable termination, or auxiliary protection devices are used.

6.19 SPACE HEATERS

6.19.1 Application

In locations where motor windings are likely to be subjected to accumulations of excessive moisture during extended periods of idleness, consideration should be given to the installation of space heaters or direct winding heating control modules (which apply low power directly to the stator winding) to maintain the winding above the dew point. This applies, especially, to motors operating at greater than or equal to 2,300 V. Space heaters are particularly applicable to large totally enclosed motors installed outdoors and operated intermittently, and to vertical weather-protected motors, such as those used for water well service. Space heaters are also used in many large motors located indoors, particularly those that operate intermittently. Some designs of totally enclosed fan-cooled motors are adaptable to space heater installations while others are not. Space heaters are also recommended for terminal boxes that enclose surge protection components or instrument transformers.

6.19.2 Installation Precautions

Space heaters should be selected and applied in a manner that prevents unsafe surface temperatures, and they should possess the correct heater rating and element temperature as well as materials that are necessary for obtaining satisfactory operation and long life. Generally, sheaths made of Monel or other normally corrosion-resistant materials should be used. The maximum sheath temperature of space heaters must be limited to 80% of the ignition temperature of the gases or vapors expected within the area unless there are special reasons for a lower limit. It is common practice to operate space heaters at half the rated voltage (or other reduced voltages), or to specify low-surface temperature [e.g., 200°C (392°F)] to prevent excessive temperatures and to increase heater life. Space heater leads are often wired out to a separate terminal box.

6.19.3 Ratings

Space heaters usually have an operating voltage rating of 115 V or 230 V, single phase. Heating capacity should be sized to maintain the winding temperature 5°C to 10°C (10°F to 20°F) above ambient temperature.

6.19.4 Operation

When auxiliary contacts are used in the motor starter, the supply circuit to the motor heater is normally arranged to be de-energized automatically when the motor is started, and energized when the motor is stopped. If used, terminal box heaters are normally continuously energized or controlled by differential temperature thermostats. A local nameplate at or near the space heater auxiliary terminal box or connection point should indicate when a separately derived power source is employed.

6.19.5 Low-Voltage Winding Heating

Low-voltage winding heating is a method for heating a motor winding while the motor is shut down. This heating is accomplished by applying low voltage directly to one phase of the motor winding. The amount of heating voltage necessary to circulate the proper current in the winding and keep the internal temperature 5°C to 10°C (10°F to 20°F) above ambient must be selected. Approximately 5% voltage is normally sufficient to maintain this temperature. A low-voltage contactor must be interlocked with the main contactor to keep the two sources of power electrically separated. Low-voltage winding heating is normally used for small motors because it is usually more economical to use space heaters for motors over 100 HP.

6.20 BEARINGS AND LUBRICATION

6.20.1 Horizontal Motors

Motors are available with either antifriction (ball or roller) or hydrodynamic radial (sleeve) bearings. The type of bearing lubrication, whether oil, oil mist, or grease, should be chosen when the bearings are selected. Most NEMA-frame and IEEE-841 motors will have grease-lubricated antifriction bearings. Motors above NEMA standard sizes should be designed according to API Stds 541 and 546.

Most sleeve bearings for horizontal motors are oil-lubricated using oil rings. Except where a forced-oil lubrication system is used, the bearings should be equipped with constant-visible-level automatic oilers. Wick or yarn oilers are not satisfactory except for the smallest fractional horsepower motor sizes.

An opening should be provided to permit observation of the oil rings if the motor is in operation. Suitable slingers, pressure equalizers, and vents are required to prevent loss of lubricant and to maintain the proper level.

For large (1,000 HP), sleeve-bearing motors, particularly those used to drive equipment that requires forced-oil lubrication, consideration should also be given to using forced-oil lubrication for the motors. API Std 614 covers lubrication systems for special drive trains.

Sleeve-bearing motors, usually in the larger sizes, require the use of limited-end-float couplings to keep the motor rotors centered. When the couplings are properly installed, the motors will operate at or near their magnetic center.

Ball bearings for horizontal motors are usually grease-lubricated, except in the larger sizes and in horizontal motors that operate at higher speeds. Horizontal motors operating at higher speeds often use oil-lubricated ball or roller bearings.

Some manufacturers provide grease-lubricated ball-bearing motors with sealed bearings that permit several years of operation without regreasing. At the end of these periods, the bearings are either repacked or replaced. Because many bearing failures are the result of too-frequent greasing, overgreasing, or mixing of incompatible greases, motors which permit long periods between regreasings are the most desirable, particularly in plants that lack suitable maintenance personnel and control over their regreasing programs.

When oil mist lubrication is used, internal and noncontacting external shaft seals should be used. The seal and main lead insulation material shall be compatible with the oil.

6.20.2 Vertical Motors

The thrust bearings in vertical motors include antifriction (ball or roller) and plate-type thrust bearings. When oil is used as the lubricant for either thrust or guide bearings, the oil reservoir should be deep enough to serve as a settling chamber for foreign matter; should be provided with drain plugs accessible from outside the motor housings; and, except where a forced-oil type of lubrication system is used, should be equipped with constant-visible-level automatic oilers. In vertical motors, it is generally preferred that all bearings use the same type of lubricant. The magnitude and direction of external thrust, operating speed, and required bearing life will determine the type of bearing used.

Where required, it is common practice to supply motors that are subject to high thrust, equipped with bearings that are capable of carrying thrusts from driven equipment. The motors on vertical pumps are examples of motors equipped with bearings capable of carrying the high thrusts from the pump. When high-thrust driven equipment is being used, it is essential to specify the maximum thrust loads in both directions. (For vertical motor bearing requirements, see API Std 610.)

6.21 TORQUE REQUIREMENTS

6.21.1 Torque Considerations

Most motors used in petroleum processing and associated operations drive centrifugal or rotary pumps, centrifugal blowers, centrifugal compressors, and other equipment that do not impose unusually difficult torque requirements. Normal-torque motors are well-adapted to such equipment and usually will have sufficient torque to meet the normal conditions of service, provided the supply voltages are satisfactory. The net torque delivered by the motors to the driven equipment is less than the rated torque of the motors when the voltages at the terminals of the motors are less than the rated voltages of the motors. Table 2 shows characteristic torque variations of large squirrel-cage induction motors and synchronous motors, with respect to applied voltage.

For example, a motor capable of exerting a locked-rotor (or starting) torque of 100% (with respect to full-load running torque) with its nameplate voltage at its terminals may be found to have only 90% of its nameplate voltage at its terminals at the instant it is started across the line, due to a 10% voltage drop during this period of high current in-rush. The output torque developed by the motor is proportional to the terminal voltage squared times the full voltage locked-rotor torque; or, under a 10% voltage-drop condition, this is calculated to be: 0.9 x 0.9 x 100, or 81%.

Similarly, the entire starting torque curve is reduced by the same value. From NEMA MG 1 paragraph 20.41, a medium voltage induction motor minimum torque curve is 60% locked rotor; 60% pull-up; and 175% breakdown torque (under full voltage condition). Under a 20% voltage drop, this curve then becomes 38% / 38% / 112%. (See Figure 14.) Additionally, any further reductions in voltage due to line loss or auto-transformers will be added to the system drop. This figure also includes the typical "square-of-speed" type curve for centrifugal loads. The top line is for open valve or damper- type starting, while the lower line is for throttled-type starting (this example is for a 50% closed valve/damper start). It can be seen from this example that the effect of reducing the voltage at the motor terminals may prevent start-up unless the load-starting curve can be reduced.

6.21.2 Torque Analysis

The maximum torque that can be developed by a motor is proportional to the square of the voltage, resulting in acceleration torque reduction for reduced-system voltage. Power system, motor, and load characteristics should be evaluated to assure adequate torque during starting and acceleration. It should also be evaluated during re-acceleration and re-synchronizing following voltage sags and disturbances.

However, if the inspection of the available data does not yield a clear result, it is recommended that a detailed engineering analysis be performed to resolve marginal cases and to avoid any delays or inconveniences that may be caused by the failure of motor-driven equipment to start satisfactorily.

Table 2—Characteristic Torques

Squirrel-Cage Induction Motors		Synchronous Motors	
Locked-rotor torque[a]	60%	Locked-rotor torque[a]	40%
Pull-up torque[a]	60%	Pull-in torque[a]	30%
Breakdown torque[a]	175%	Pull-out torque[b,c]	150%

[a]The output torque varies approximately as the square of applied voltage.
[b]The output torque varies directly as the applied voltage.
[c]With excitation constant.

If reduced-voltage reactor or resistor starting is used, a substantial amount of impedance is introduced into the supply circuit of the motor when the controller is in the starting position. This impedance as well as the other impedance between the motor and its supply source must be taken into account. All reduced-voltage starting applications should evaluate the starting torque available versus that required by the load (acceleration torque) to determine that adequate torque margin is available for starting the load.

A torsional analysis should be undertaken for high-speed synchronous motors to determine the effects of torsional pulsations during across-the-line start acceleration of the motor and driven equipment.

6.21.3 Low-Voltage Considerations

Voltage that is lower than normal may exist, particularly during starting, because of the system's design or characteristics. Some causes for this lower-than-normal voltage are as follows:

a. The motor being started is large in relation to the capacity of the electrical supply system.

b. The supply circuit's length and design cause an unduly high voltage drop between the power source and motor.

Where it is questionable whether the voltage received at the terminals of the motor will be satisfactory, the voltage at that point should be calculated under the most unfavorable conditions likely to exist in actual service. In most cases, this will be at the instant of starting, when the current inrush is several times the rated full-load current and the power factor is low, usually in the 0.2 to 0.4 range. If the circuit under consideration will be used to carry other loads, the effect of these other loads on voltage should be taken into account at the same time.

When a synchronous motor is to be used, voltage conditions at the instant of pull-in should be checked. It must be determined that correct torque will be developed at the pull-in point with net voltage available at the motor terminals.

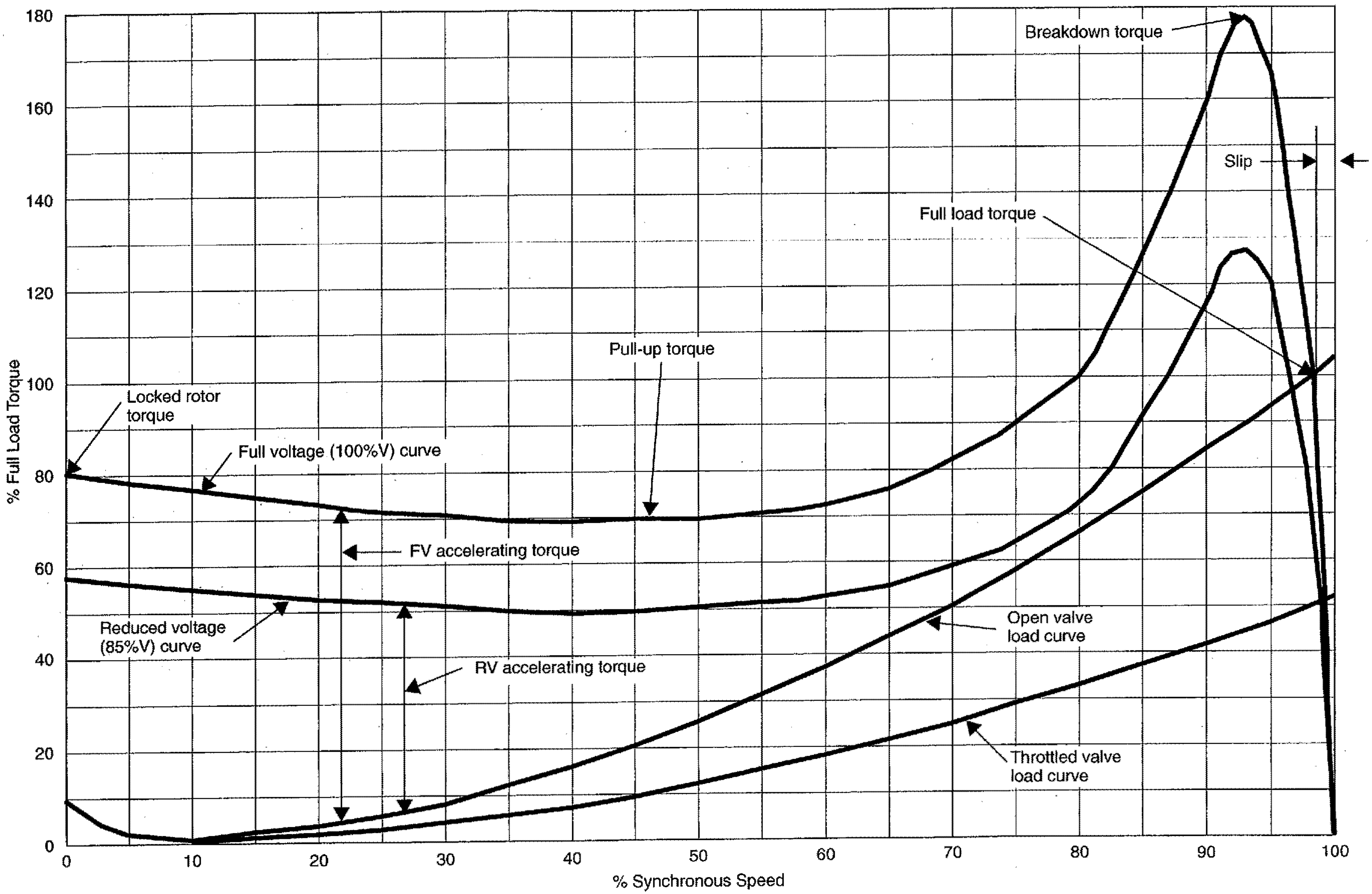

Figure 14—Combined Motor and Load Speed-Torque Curve

6.21.4 Minimum Torque Specifications

Occasionally, the normal starting torque characteristic of the motor will not be sufficient to accelerate the driven equipment. In these marginal cases, it is advisable to establish the minimum motor torque characteristic that is acceptable. For borderline cases, the motor torque characteristic (including any voltage drop considerations) should be specified to be 10% greater than the driven equipment starting-speed-torque curve throughout its entire range.

If the application requires more than normal torque, it will be appropriate to determine which will be more economical: to obtain a motor with higher than normal torque, within available limits, or to improve voltage at the point of utilization. In an extreme case, it may be correct to do both. In most instances, satisfactory results can be obtained most economically by determining torque requirements and specifying these requirements to suit the predetermined voltage conditions at the terminals of the motor.

In some cases, increased torque designs require higher in-rush current, increasing the voltage drop, which in turn, lowers the net output torque.

6.21.5 High Torque

For motors used to drive machines that require extra-high starting torque (e.g., most conventional pulverizers, shredders, crushers, and some air blowers or fans), it is advisable to predetermine the voltage conditions and to stipulate the torque requirements on the basis of anticipated voltage conditions, as net torque requirements may be high, even when the machine is started unloaded. High-torque motors are available for a variety of applications requiring higher-than-normal torque.

6.21.6 High-Inertia Loads

For high-inertia loads and other loads where the motor is subjected to heavy loading during acceleration (0% to 100% speed), calculations should be made to ensure it will have sufficient torque and thermal capacity to bring the driven equipment up to rated speed under actual operating conditions within the allowable length of time. A motor that drives equipment that may be subject to occasional sudden, heavy loads while running at rated speed should be checked to determine if it will have sufficient breakdown (induction motor) or pull-out (synchronous motor) torque under this condition to keep it from stalling or from abruptly losing speed. The use of high-slip motors, as well as the possible need for additional flywheel effect, should be considered for such conditions of service. This type of problem is not encountered often, but does call for detailed consideration of equipment and load characteristics.

Following a shutdown of a motor driving a high-inertia load, the restarting of the motor should be delayed sufficiently until the motor-generated voltage has decayed to a value of 25% or less of the rated voltage. Otherwise, high transient torques can be produced that exceed the mechanical limit of the motor shaft, coupling, or driven equipment.

6.21.7 Additional Torque Requirements.

Recognition should be given to the requirement for greater torque under certain conditions of operation. For example, in the case of a centrifugal blower or centrifugal pump, more torque is required to bring the machine up to rated speed with the discharge valve open than with it closed. If, for some reason, it is not practical to follow the customary practice of starting a centrifugal blower or pump with the discharge valve closed, sufficient torque should be made available to start it with the discharge valve open.

6.22 METHOD OF STARTING

6.22.1 Starting Control

Starting control for all motors is essentially the same. In the larger motor sizes, which represent a considerable investment of capital and upon which a higher degree of dependability is placed, the complexity of starting control increases. Larger motors can require power distribution systems with high system capacity to prevent undesirable voltage drops when the motors are started at full voltage under load. If these undesirable effects are produced, reduced-voltage starting should be considered. With reduced-voltage starting, the motor characteristics must be checked to ensure that there is sufficient torque to accelerate the load at the reduced voltage.

It is also important to consider the current in-rush to various motors following a voltage dip. The in-rush during reacceleration often will nearly equal the starting in-rush; so if motors are to operate satisfactorily through a voltage dip, the system must be stiff enough to handle the subsequent in-rush.

Control circuits which provide for the reacceleration of motors are complex and require additional considerations. Reduced-voltage controllers reduce the net torque exerted by the motors and, in some cases, may complicate the starting problem, especially for synchronous motors.

6.22.2 Full-Voltage Starting

In general, the full-voltage magnetic controllers supplied with air-break, vacuum-break, or oil-immersed contactors offer the simplest and most economical method for starting induction motors. See Figure 15 for an example of a simplified, full-voltage nonreversing starter using an air-break contactor. This method is based on acceptable motor-loading conditions and the ability of the power distribution system to function without undue voltage disturbance during motor start-up. Most motors, particularly the small and medium horsepower motors, are designed for full-voltage starting. Synchronous and large induction motors, usually at the higher voltages, require more control selectivity because their size may represent an exceptionally large portion of the available power system capacity. In this connection, circuit breakers operating at a normal breaker duty cycle may provide the dual service of controller and disconnecting means.

6.22.3 Reduced-Voltage Starting

The autotransformer, reactor, and resistor types of reduced-voltage controllers provide methods for decreasing the starting in-rush current of squirrel-cage and synchronous motors. See Figure 16 for an example of reduced-voltage starting using an autotransformer. Though more costly than the full-voltage controller method, these reduced-voltage controller methods may be required where specific high-inertia loads or system limitations are encountered

6.22.4 Wye-Delta Starting

A motor that normally has its windings connected in delta may be started by connecting its windings in wye. This reduces the current in-rush and starting torque to one-third of the full-voltage starting values. This method should only be used if moderate starting torque is satisfactory. This starting method usually requires an "open transition" where the motor is disconnected for a couple of seconds when changing from the wye to the delta configuration. When the motor is reconnected to the delta (run) configuration, the power system will be subjected to a severe current in-rush (approaching the full-voltage, locked rotor current) unless the transition time is made very short (less than 0.1 second). A short transition time is not recommended for most applications because of the risk of mechanical coupling or motor winding damage that could result from out-of-phase closure between the power system voltage and the residual motor voltage.

6.22.5 Solid-state Control

Soft-start controllers (reduced starting-current in-rush) using solid-state devices may also be used with or without a standard contactor to bypass the solid-state starter. Starting times for high inertia or high torque loads should be reviewed with the soft-start supplier.

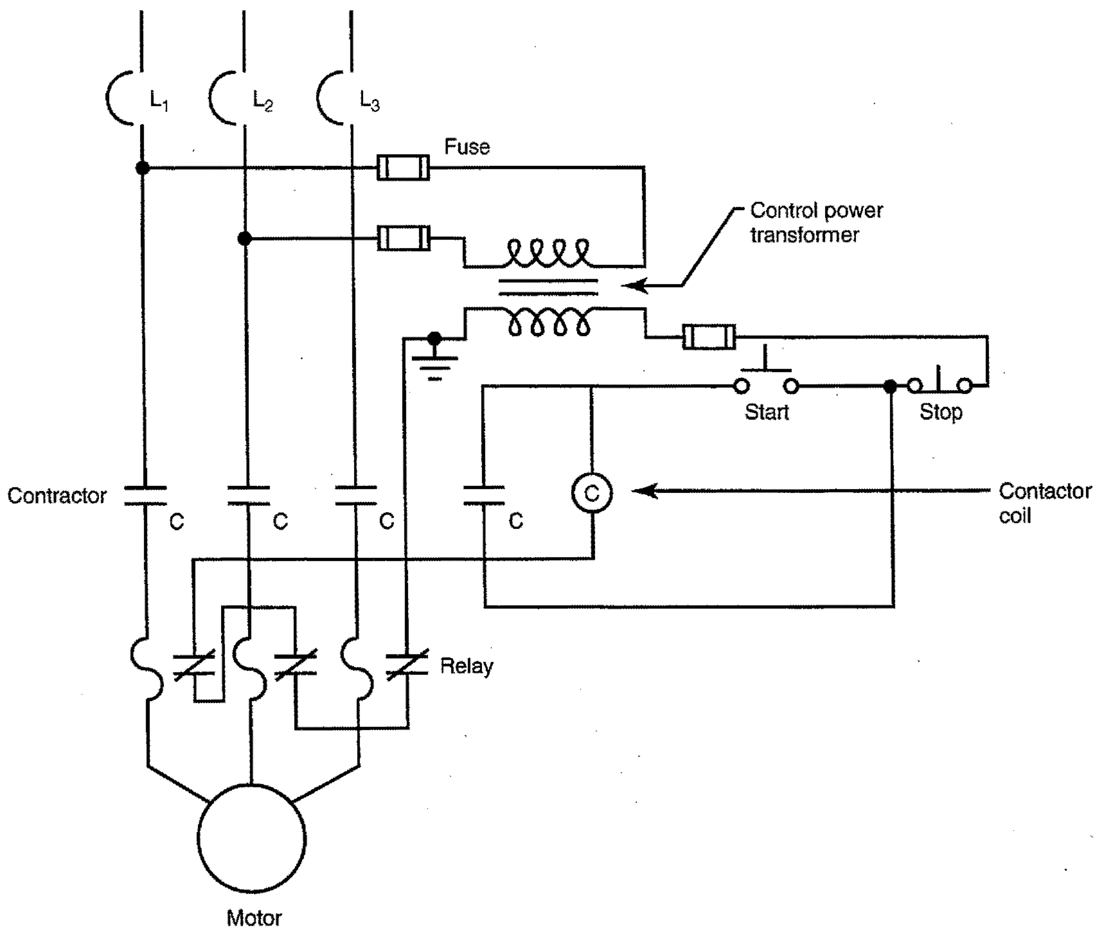

Figure 15—Typical Wiring Diagram for Full-Voltage Starting

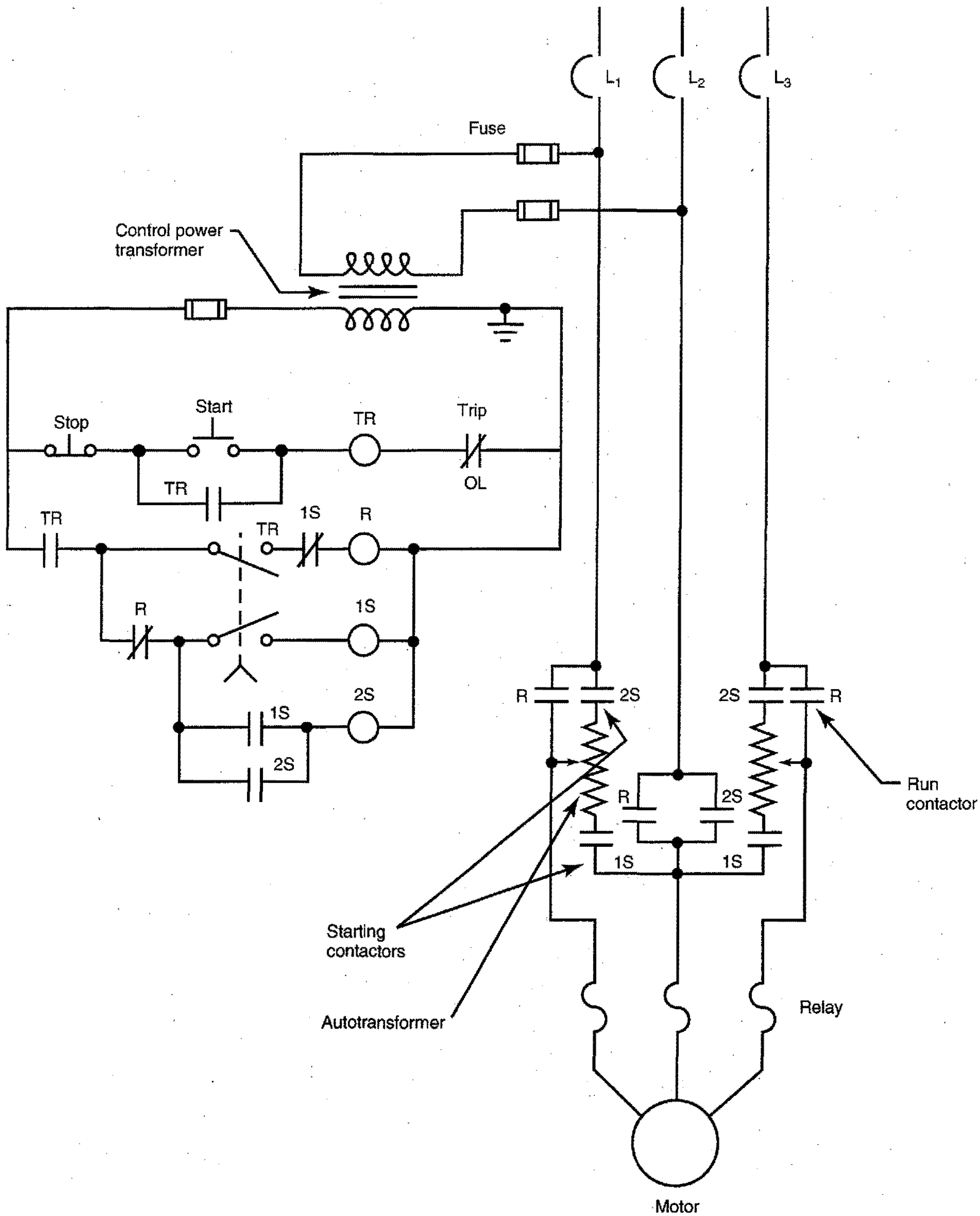

Figure 16—Typical Wiring Diagram for Autotransformer Method of Reduced-Voltage Starting

6.22.6 Capacitor Assisted Starting

Motors to be started on "weak" power systems can use a technique where a relatively large capacitor bank is switched onto the same bus as the motor an instant before the motor is connected. The capacitors provide most of the reactive requirements of the motor during the motor acceleration, minimizing the system voltage drop. As the motor accelerates to rated speed and the bus voltage recovers, the capacitor bank is disconnected. Surge arresters and surge capacitors, applied at the motor terminals, are recommended for this application to protect the motor from switching surges.

6.22.7 Wound Rotor Control

The typical wiring diagram for a wound rotor motor (Figure 17) begins with the basic control system for a full-voltage type motor (see Figure 15). Rpm adjustment is obtained through the addition of a speed control rheostat external to the motor enclosure, and near the motor control center, in a safe area. This variable resistance is typically implemented through sets of fixed contactors and resistors, or a stepless liquid rheostat. See 6.10.4.3 for concerns regarding the installation of wound rotor-type motors.

6.23 MOTOR CONTROLLERS

Motor controllers provide the means to start, regulate speed, and stop electric motors. In addition, controllers afford protection against abnormal operating conditions that may result in production losses, equipment damage, and exposure of personnel to unsafe conditions.

6.23.1 Selection of Control Equipment

When selecting control equipment, the power supply system, the type and size of the connected motor, and operational and service conditions should be taken into account. Affecting these conditions and requiring careful appraisal are the power supply, the controller size and rating, and the frequency of starting.

6.23.1.1 Power Supply

The ability of the power distribution system to satisfactorily handle motor starting loads is of major importance and in

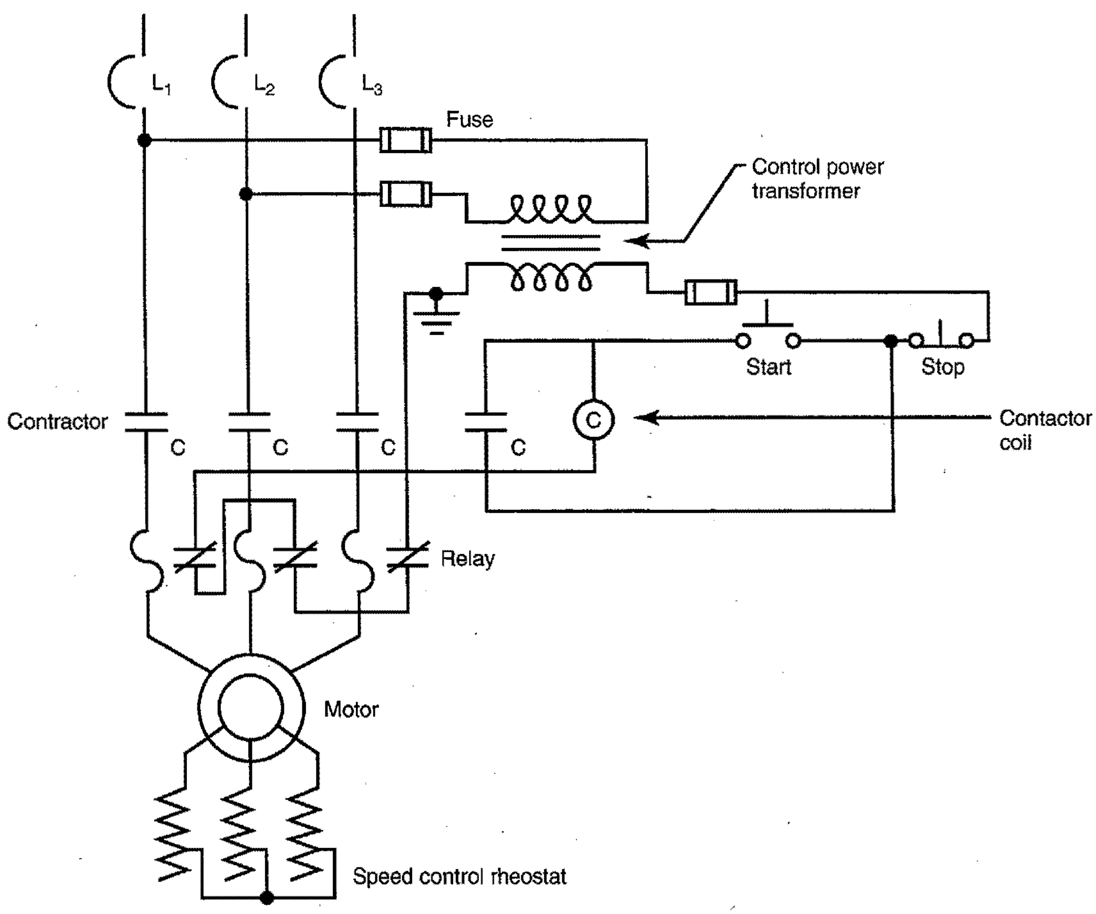

Figure 17—Typical Wiring Diagram for Wound-Rotor Motor Control

large measure determines the selection of control. This is true, particularly where objectionable voltage disturbances are produced by the starting of a few large motors representing the bulk of the system capacity. The full-voltage starting current of squirrel-cage induction motors and synchronous motors is several times full-load current (350% to 700%), so the system capacity must be able to supply the increased kilovolt-amperes without objectionable system disturbance. If this is not practical, an alternative starting method must be employed to confine the current in-rush and voltage drop to satisfactory levels.

6.23.1.2 Controller Size and Rating

Motor controllers are rated in horsepower or current-carrying capacity and must be capable of interrupting the motor locked-rotor current at the voltage specified. Industrial motor controllers bear the manufacturer's nameplate specifying their size, horsepower rating, and voltage. Controllers are supplied in several duty classifications and include the following types:

a. The continuous-duty type, which is capable of indefinitely carrying full-load motor current without exceeding a specified temperature rise of current-carrying parts.
b. The intermittent-duty type, which is used on cranes, machine tools, or other equipment requiring less sustained duty.

It is recommended that the user consult with the manufacturer to select adequate equipment for the operating conditions.

6.23.2 Manual Operation

Manual control has limited use, which is customarily for the starting of fractional horsepower, single-phase motors in the 120-V to 240-V range. Within the 240-V range, on-off control as well as motor overload protection is provided within the control enclosure. The overload protection is provided by trip-free thermal devices located in at least one side of single-phase units and in all three phases of three-phase units. Fused switches or circuit breakers providing a line-disconnect feature and short-circuit protection can be obtained in combination units (combined with the control in a common enclosure) or can be separately mounted. Low-voltage release may not be available; consequently, the control contacts remain closed during periods of power failure, thereby causing automatic restarts of the motor upon resumption of power. Manual control is not recommended for motors greater than 1 HP or for motors greater than 240 V because of increased risk to personnel.

6.23.3 Contactor Operation

The application of magnetic contactor control is the standard throughout the petroleum industry. Magnetic contactor control utilizes a magnetic contactor and a pushbutton, or automatic control device(s), to start and stop the motor. In general, the control voltage is at a level lower than the equipment utilization voltage.

The equipment is applied at standard voltage levels matching the motor requirements. Fuses, circuit breakers, or motor circuit protectors, separately or integrally mounted within the starter enclosure, provide the required disconnect and short-circuit protection. Thermal elements or current-sensitive devices, connected in all three phases of the control equipment, provide the overload protection. Three-wire control provides the undervoltage protection against automatic restart of motors after the restoration of failed voltage. Starters controlled by automatic devices are wired for undervoltage release (two-wire control permitting automatic restart after voltage restoration). The selection of the pushbutton or control location may be made to comply with desired operational requirements.

Where continuity of service or operating conditions demand, time-delay relaying is available to permit motors to ride through momentary voltage dips. The delay interval is critical because full voltage, particularly in the larger sizes, should not be applied to de-energized motors having residual voltages above 25% to 35% rated voltage, unless the motors have been designed for such applications.

The time-current characteristics of associated protective device and relaying equipment should be coordinated to ensure selective protection. Overload, locked-rotor, and short-circuit protection should be provided by the protection characteristics.

Medium-voltage circuit breakers, along with protective relays, are sometimes used with large motors to serve not only as controllers but also as the means for disconnection. These breakers will be electrically operated and can provide automatic control comparable to that of magnetically operated contactors; however, for frequent operation, magnetically operated contactors are more reliable because circuit breakers are not designed for such service.

6.23.4 Protective Relaying and Automatic Control

As a rule, the function of protective relaying is to disconnect the faulty equipment from the source of the electrical supply as quickly and with as little system disturbance as possible. In a comprehensive installation, each circuit or piece of equipment should operate independently under distress, and the protective relaying should be so selective that only the affected units are de-energized. In more detail, protective relaying must distinguish between abnormal equipment operation and system failures.

6.23.4.1 Overload Protection

Overload protection is applied to de-energize overloaded motors automatically before winding or conductor damage has been caused by excessive operating temperature. The