# Chapter 14
# Motors

## 14-1. General

*a. Motor types.* Constant-speed motors of either the squirrel-cage induction or synchronous type are the preferred drives for pumps installed in flood-protection pumping stations. Both squirrel-cage and synchronous motors are available in speed ranges and sizes that embrace most requirements.

*b. Vertical-type motor construction.* Usually, the vertical-type motor construction is preferred since it requires a minimum of floor space, which contributes significantly to an economical pumping station layout. The simplicity of the vertical motor construction also contributes to station reliability. Horizontal motors with gear drives have been used in some applications, but any first cost advantages must be weighed against increased operation and maintenance costs as well as decreased reliability over the life of the project. The gear reducer and its associated auxiliary equipment are additional components that are subject to failure. Comparative costs should include installation and maintenance costs for gear lubricating pumps, cooling water pumps, associated piping, monitoring equipment, etc.

*c. Full-voltage starting.* All motors should be designed for full-voltage starting, even if incoming power limitations indicate that some form of reduced-voltage starting is required. For installations having siphonic discharge lines, the power required to establish prime should not exceed the motor rating plus any additional service factors. This is necessary to assure successful operation in case siphon action is not established.

*d. Contractual requirements.* The contractual requirements for the majority of induction and synchronous motors used in flood-control pumping stations are described in Guide Specifications CW 15170, Electric Motors 3-Phase Vertical Induction Type (for Flood-Control Pumping Stations) and CW 15171, Electric Motors 3-Phase Vertical Synchronous Type 1500 Horsepower and Above (for Flood-Control Pumping Stations).

## 14-2. Induction Motors

*a. Squirrel-cage.* The squirrel-cage induction motor has a stator winding which produces a rotating magnetic field that induces currents in a squirrel-cage rotor. The squirrel-cage consists of a number of metal bars connected at each end to supporting metal rings. Current flow within the squirrel-cage winding produces the torque necessary for rotor rotation. Squirrel-cage induction motors have very simple construction, with no electrical connections to the rotor, and hence they possess a very high degree of reliability. However, the squirrel-cage rotor does not rotate as fast as the revolving magnetic field setup by the stator winding. This difference in speed is called "slip." Because of this inherent feature, squirrel-cage motors are not as efficient as synchronous motors, whose rotors rotate in synchronization with the magnetic field. There are three basic variables that classify motor performance types. These are:

(1) Starting torque.

(2) Starting current.

(3) Slip.

Motors can have high or low starting torques, starting currents, and slip. However, these six variables are not produced in every combination. For example, high resistance rotors produce higher values of starting torque than low resistance rotors. But high resistance in the rotor also produces a "high slip" motor. A high slip motor, by definition, has higher slip losses, hence lower efficiency, than an equivalent low slip motor.

*b. Wound-rotor.* The wound-rotor induction motor has coils instead of conducting bars in the rotor circuit. These coils are insulated and grouped into poles of the same number as the stator poles. The coil winding leads are attached to slip-rings. The brushes that travel along the slip-rings are connected to variable external resistances. High starting torques with relatively low starting current can be obtained by adding external resistance to the rotor circuit. As the motor comes up to speed, the resistance is gradually reduced until, at full speed, the rotor is short-circuited. Within certain limits, the motor speed can be regulated by varying resistance in the rotor circuit. It is not commonly used in flood-control pumping stations.

## 14-3. Synchronous Motors

*a. Operating principle.* The synchronous motor starts and accelerates its load utilizing the induction principles common to a squirrel-cage motor. However, as the rotor approaches synchronous speed (approximately 95 to 97 percent of synchronous speed), a second set of windings located on the rotor is energized with direct current. These field coil windings are responsible for providing the additional torque necessary to "pull" the rotor into synchronism with the revolving magnetic field established by the stator windings. The time at which direct current is applied to the field coil windings is critical and usually takes place when the rotor is revolving at approximately 95 to 97 percent of synchronous speed.

*b. Field coil winding excitation.* There are several methods commonly employed to achieve field coil winding excitation. Generally, brushless field control is the preferred method of field application. In a brushless motor, solid state technology permits the field control and field excitation systems to be mounted on the rotor. The motor, its exciter, and field control system are a self-contained package. Application and removal of field excitation are automatic and without moving parts. The brushes, commutator collector rings, electromagnetic relay, and field contactor are eliminated. Thus, the extra maintenance and reliability problems usually associated with older brush-type synchronous motors are greatly reduced.

*c. Load commutated inverter.* A recent development that may have limited application in pumping station design is the load commutated inverter (LCI). It is a promising adjustable-frequency drive for variable-speed high-voltage, high-power applications utilizing synchronous motors. Because of the internal counter electromotive force generated in a synchronous motor, the design of inverter circuits is greatly simplified. This device provides continuously variable speed regulation of from 10 to 100 percent of synchronous speed. It also limits inrush currents to approximately rated full-load current. Being a solid state device, however, the LCI may cause harmonic currents in the neutral conductors. Neutrals should be sized to 1.732 times the phase current. Further guidance can be found in CEGS 16415, Electric Work Interior.

*d. Flow- or propeller-type pumps.* Synchronous motors find their application as pump drives in the large capacity, low rpm mixed flow- or propeller-type pumps. In general, their usage should be limited to pumps of at least 375 kW (500 HP) and above, and at speeds of 500 rpm and below. Careful attention must be given to available pull-in torque to "pull" the rotor into synchronism with the revolving magnetic field. At this point, the motor must momentarily overspeed the pump past the moving column of water. Knowledge of the pump speed torque curve, voltage drop at the motor terminals, and the ability of the motor field application control to provide the best electrical angle for synchronism must all be considered.

## 14-4. Submersible Motors

Submersible motors have been used very effectively in smaller stations where economy of design is paramount. Where the possibility exists that combustible gases or flammable liquids may be present, the motor should be rated for explosion-proof duty. Thermal sensors should be provided to monitor the winding temperature for each stator phase winding. A leakage sensor should be provided to detect the presence of water in the stator chamber. If the possibility exists that rodents may enter the sump, special protection should be provided to protect the pump cable(s).

## 14-5. Common Features

Guide Specifications CW 15170 and CW 15171 give detailed requirements for common motor features such as enclosures, winding insulation, overspeed design, or anti-reversing device and core construction.

## 14-6. Shaft Type

Motors can be furnished with either a hollow or solid shaft. Commonly, however, hollow shaft motors are available only up to about 750 kW (1,000 HP). The hollow shaft motor provides a convenient means to adjust the impeller height. Other factors such as station ceiling height and the ability of the crane to remove the longer pump column must be considered in the decision of the type of shaft to employ.

## 14-7. Starting Current Limitations

Guide Specifications CW 15170 and CW 15171 limit the locked rotor current to 600 percent of rated (full-load) current. However, when utility requirements necessitate, lower inrush current induction motors may be specified not to exceed 500 percent of the rated full-load current. (Note: Starting inrush varies with efficiency; therefore, specifying reduced inrush will result in a somewhat lower efficiency.) The motor manufacturer should be contacted before specifying a reduction of inrush current for a synchronous motor. If 500 percent is not acceptable, reduced-voltage starting of the closed-transition autotransformer type should generally be used. Autotransformer starters provide three taps giving 50, 65, and 80 percent of full-line voltage. Caution must be exercised in the application of reduced voltage starting, however, since the motor torque is reduced as the square of the impressed voltage, i.e., the 50-percent tap will provide 25-percent starting torque. Connections should be made at the lowest tap that will give the required starting torque. Reactor-type starters should also be given consideration for medium voltage motors. Solid state motor starters employing phase-controlled thyristors are an option to reduce inrush currents for 460-volt motor applications. However, the reliability, price, availability of qualified maintenance personnel, and space considerations should all be studied carefully before electing to use solid state starters.

## 14-8. Duty Cycle

Care should be taken in the selection of the number and size of pumps to avoid excessive duty cycles. Mechanical stresses to the motor bracing and rotor configuration as well as rotor heating are problems with frequently started motors. The number of starts permissible for an induction motor should conform to the limitations given in MG-1-20.43 and MG-1-12.50 of NEMA MG-1, as applicable. Synchronous motors should conform to MG-1-21.43 of NEMA MG-1. The motor manufacturer should be consulted concerning the frequency of starting requirements if other than those prescribed above. Economic comparisons of different pumping configurations should include the reduction in motor life as a function of increased motor starting frequency.

## 14-9. Starting Torque

*a. General*. Most stations use medium or high specific speed propeller-type pumps with starting torques in the range of 20 to 40 percent of full-load torque. The motor must be designed with sufficient torque to start the pump to which it is connected under the maximum conditions specified, but in no case should the starting torque of the motor be less than 60 percent of full load. For a more detailed discussion of torque values, see the particular motor type below.

*b. Squirrel-cage induction motors*. Normally, motors specified in CW 15170 will have normal or low starting torque, low starting current. Each application should be checked to ensure that the motor has sufficient starting torque to accelerate the load over the complete starting cycle. CW 15170 requires a minimum starting torque of 60 percent of full load. Breakdown torque should not be less than 200 percent of full load unless inrush is reduced to 500 percent of full load. If 500 percent is specified, the breakdown torque must be reduced to 150 percent of full load.

*c. Synchronous motors*. Synchronous motors must usually be specially designed for pumping applications. The load torques and $WK^3$, so called "normal" values, on which NEMA MG-1 requirements are based are generally for unloaded starts and are therefore relatively low. Starting and accelerating torque shall be sufficient to start the pump and accelerate it against all torque experienced in passing to the pull-in speed under maximum head conditions and with a terminal voltage equal to 90 percent of rated. The minimum design for a loaded pump starting cycle should be: 60-percent starting torque, 100-percent pull-in torque, and 150-percent pull-out torque for 1 minute minimum with a terminal voltage equal to 90 percent of rated. This would produce inrush currents of 550 to 600 percent of full load.

*d. Amortisseur windings.* Double-cage amortisseur windings may be required to generate the uniformly high torque from starting to pull-in that is required by loaded pump starting. They consist of one set of shallow high-resistance bars and one set of deeper low-resistance bars.

## 14-10. Selection

*a. General.* The choice between a squirrel-cage induction and synchronous motor is usually determined by first cost, including controls, and wiring. In general, the seasonal operation of flood-control pump stations results in a fairly low annual load factor, which, in turn, diminishes the advantage of the increased efficiency of synchronous motors. A life-cycle cost analysis should be performed that includes first costs, energy costs, and maintenance costs. Another factor that should be considered is the quality of maintenance available since the synchronous motor and controls are more complex than the induction motor. The additional cost of providing power factor correction capacitors to squirrel-cage induction motors, when required, should be included in cost comparisons with synchronous motors. Also, the extra cost to provide torque and load $WK^2$ values higher than normal for a synchronous motor because of loaded pump starting characteristics must be taken into account.

*b. Annual Load Factor (ALF):* The ALF can be estimated from data obtained from a period-of-record routing (PORR) study or from the electric billing history of a similar pumping station. If a PORR or billing history is used, ALF would be defined as

$$ALF = We/(Pd \times 8{,}760) \qquad (14\text{-}1)$$

where

We = total amount of energy consumed during year

Pd = maximum of 12 peak demands occurring during year

8,760 = number of hours in a year

## 14-11. Power Factor Correction

*a. General.* Power factor is the ratio of total watts to the total root-mean-square (rms) volt-amperes. Utility companies may meter the reactive or out-of-phase component (kvar) of apparent power (kva) as well as total energy (kwh). They may charge additionally for higher capacity requirements driven by peak loads and low power factor. A rule of thumb is that about 12 to 14 percent of line loss can be saved by improving the power factor 10 percent.

*b. Flood-control pumping stations.* In flood-control pumping stations, the power factor for induction motors will vary according to size and rpm. The power factor should be corrected to 92 to 95 percent at full load through the addition of power factor correction capacitors. The power factor correction capacitors are usually located either within or on top of the motor control center. The capacitors should be switched in and out of the circuit with the motor.

## 14-12. Noise Level

The Department of Defense considers hazardous noise exposure of personnel as equivalent to 85 decibels or greater A-weighted sound pressure level for 8 hours in any one 24-hour period. The guide specifications provide requirements to obtain motors that meet this limitation. The designer, however, should evaluate the advantages and disadvantages of providing either the more expensive motors that meet these requirements or a room to isolate the operating personnel from the noise exposure. American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) Standard No. 85, Test Procedures for Airborne Sound Measurements on Rotating Machinery, and NEMA MG-1 provide more information on the subject.

## 14-13. Variable Speed Drives

*a. General.* Variable speed pump drives are not normally required in flood-control pump stations. Normally, if base flows are anticipated, a smaller constant speed vertical or submersible pump is furnished to avoid excessive cycling of larger stormwater pump motors. Variable speed drives are more frequently employed in sewage stations where the ability to match flow is more critical. If it has been determined, however, that a variable speed drive is necessary, the designer should determine the most efficient and economical method that meets the needs of the application. Two common methods of speed control are discussed below:

*b. Variable frequency.* Adjustable speed is obtained by converting the fixed-frequency alternating current (AC) line voltage into an adjustable voltage and frequency output that controls the speed of a squirrel-cage motor. A rectifier converts power from 60-Hz AC to direct current (DC). An inverter, then, reconverts the DC power back to AC power, which is adjustable in frequency and voltage. Drives are available in sizes up to 600 kW (800 HP) with variable frequency operation from 2 to 120 Hz. Inrush currents can be reduced to 50 to 150 percent of rated. Variable frequency drives are very efficient and provide a wide range of speed adjustment.

*c. Wound-rotor motors.* The speed of a wound-rotor motor is varied by removing power from the rotor windings. This is usually accomplished by switching resistance into the rotor circuit via the use of slip-rings and brushes. As resistance is added, the speed of the motor decreases. This method is not efficient, however, because of the loss in the resistors. Starting torques of the wound-rotor induction motor can be varied from a fraction of rated full-load torque to breakdown torque by proper selection of the external resistance value. The motor is capable of producing rated full-load torque at standstill with rated full-load current. The motor has low starting current, high starting torque, and smooth acceleration. In general, however, speed stability below 50 percent of rated is unsatisfactory. Additional maintenance is required because of the slip-rings and brushes required to access the rotor windings.