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Revision Memo

12/01 References updated. Full-Load Torque, Service Factor and Temperature Rise definitions revised. Space Heaters definition added. Noise section added. Formula for Torque updated. Motor Details Required in Design Specifications section revised to include requirement for space heater.

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SCOPE

This section provides an introduction to the application of electric motors for pump and compressor drive services for process designers. Plant power system design is not covered. The information provided will not be sufficient to cover the selection of unusual drive requirements, e.g., variable speed drives, or services over 1500 HP without ELECTRICAL SPECIALIST consultation.

REFERENCES

DESIGN PRACTICES (BESIDES OTHER SECTIONS OF SECTION XI)

Section X-I Pump Drivers and Utility Requirements

GLOBAL PRACTICES

GP 10-11-1	Sizing of Drivers and Transmissions for Compressors, Fans and Pumps
GP 16-2-1	Power System Design
GP 16-7-1	Motor Application
GP 16-9-1	Low Voltage A-C Motors up to 200 HP (150 kW)
GP 16-9-2	A-C Motors: Medium Voltage and Low Voltage over 200 HP (150 kW)
GP 16-14-1	Standard LV Variable Frequency Drives
GP 16-14-2	Engineered Variable Frequency Drive Systems

OTHER LITERATURE

National Electrical Manufacturers Assn. (NEMA), MG 1, *Motors and Generators*
 NEMA MG 2, *Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators*
 International Electrotechnical Commission (IEC) IEC 60034 - 1, *Rotating Electrical Machines - Part 1, Rating and Performance*
 IEC 34 - 17 *Rotating Electrical Machines - Part 17: Guide for the Application of Cage Induction Motors when Fed from Converters*
 IEC 60038 - 1983 *IEC Standard Voltages*
 American Petroleum Institute (API), API Standard 541 - *Form Wound Squirrel Cage Induction Motors - 250 HP and Larger*
 American Petroleum Institute (API), API Standard 546 - *Brushless Synchronous Machines - 500 kVA and Larger*
 Bose, Bimal K., *Power Electronics and Variable Frequency Drives*, IEEE Press, 1996 ISBN 0-471-58408-8
 Smeaton, R. W., *Motor Application and Maintenance Handbook*, McGraw-Hill Book Company, 1969
 OSHA Regulations (Standards - 29 CFR): Standard Number 1910.95 - *Occupational Noise Exposure*

BACKGROUND

Electric motors are the most frequently used drivers for refinery compressor, blowers, fans and pumps. Motors up to 22,000 HP have been applied to compressors in ExxonMobil refineries. Other manufacturers, like air liquids refiners, have applied motors in the 60,000 HP range. Gas pipeline compressors have used motors to 50,000 HP with variable frequency drives.

Advancements in electrical variable frequency drives (VFD)¹ permit electric motors to power loads at super-synchronous as well as sub-synchronous speeds. Compressors can, therefore, be motor driven without gears, thereby decreasing maintenance, and improving train efficiency. One recent (non-ExxonMobil) application involved replacing an existing steam turbine with a two pole induction motor, supplied by a VFD, and designed to operate at 11,000 rev/min. It is rated at 3500 HP.

¹ The terms variable frequency drive (VFD), adjustable speed drive (ASD), and variable speed drive (VSD) are used interchangeably in the literature. VFD is preferred here to distinguish the electrical drives from other mechanical-type drives, e.g., fluid drives.

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BACKGROUND (Cont)

Electronic soft-starting units are now available to start large motors connected to power systems which cannot start them directly across the line due to severe voltage drop. Before electronic soft-start equipment was available, the alternative was to use reduced voltage starting. Reduced voltage starting effectively limits system voltage dips to acceptable levels, but the accelerating torque of the motor is reduced by the square of the available voltage. For example, if the motor voltage is reduced to 60%, the available torque is only 36% of the torque available at 100% volts. This limits reduced voltage starting to trains which can be accelerated at these low torque levels. Electronic soft-starting units can keep high torque levels, and reduce system voltage dips, by controlling both the voltage and the frequency being supplied to the motor. Note that the use of a soft-starting electronic package, or a VFD will increase the cost of the driver by up to 100%, so these units should only be used where required.

The majority of electric motors used in refineries are less than 2000 HP. Motors offered in manufacturers frame sizes are highly standardized and need little engineering attention. Motors larger than frame size will need some engineering attention in the procurement, testing and commissioning stages. Frame size motors complying with the NEMA MG-1 standard have the maximum continuous horsepower rating as shown below for various speeds.

SYNCHRONOUS SPEED	RATED HORSEPOWER
3600	500
1800	500
1200	350
900	250
720	200
600	150
514	125

Motors 450 rpm and slower are not considered standard regardless of the horsepower.

DEFINITIONS

Ambient Temperature

Ambient temperature is the temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the apparatus. (Note: Ambient temperature is commonly known as "room temperature" in connection with air-cooled apparatus not provided with artificial ventilation.)

Breakaway Torque

Breakaway torque is the maximum torque required to accelerate the load (e.g., a compressor train) from zero speed.

Breakdown Torque

The breakdown torque of a motor is the maximum sustained torque which it will develop with rated voltage applied at rated frequency, without an abrupt drop in speed.

Efficiency

The efficiency of a motor is the ratio of the power output at the shaft to the total electrical power input. It is expressed in percent.

Full-Load Torque

The full-load torque of a motor is the torque necessary to produce its rated horsepower at full load speed. In pounds at a 1-foot radius, it is equal to the horsepower times 5252 divided by the full-load speed in rpm.

Locked-Rotor Current

The locked-rotor current of a motor is the steady-state current taken from the line with the rotor locked and with rated voltage (and rated frequency in the case of alternating-current motors) applied to the motor.

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DEFINITIONS (Cont)

Locked-Rotor Torque (Static Torque)

The locked-rotor torque of a motor is the minimum torque which it will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency. This condition must be allowed to persist only momentarily, to prevent damage to the rotor or stator windings. The locked-rotor torque must exceed the breakaway torque, for the motor to be able to accelerate the load from zero speed. Locked-rotor torque is often called starting torque.

Overload Capability

See *Service Factor*.

Power Factor

The power factor of an alternating current motor is the ratio of the kilowatt input to the kVA input and is usually expressed as a percentage. See also the discussion of power factor under **BASIC DESIGN CONSIDERATIONS**.

Pull-In Torque

The pull-in torque of a synchronous motor is the maximum constant torque under which the motor will pull its connected load into synchronism with the power system when its field excitation is applied, and the power line is at rated voltage and frequency, and the motor is near to operating speed.

The motor torque required to accelerate the train when attempting synchronism depends on the torque required by the load (mass flow, head, etc.) and the accelerating torque required to provide kinetic energy to bring the train inertia up to that speed. Whether the motor can pull the load into step from this speed depends on the inertia of the revolving parts. Therefore, the pull-in torque depends not only on the torque of the load, but also on the inertia of the entire system.

Pull-Out Torque

The pull-out torque of a synchronous motor is the maximum sustained torque which the motor will develop at synchronous speed with rated voltage applied at rated frequency and with normal excitation. Pull-out torque is similar to breakdown torque, except that pull-out torque applies to *synchronous* motors only.

Pull-Up Torque

The pull-up torque of an alternating-current motor is the minimum torque developed by the motor during the period of acceleration from rest to the speed at which breakdown torque occurs. For motors which do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to rated speed.

♦ Service Factor

The service factor of an alternating-current motor is a multiplier which, when applied to the *rated* horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the service factor. These conditions usually include the requirement that the actual temperature rise must not exceed the rated temperature rise by more than 10°C, if valid voltage and frequency are maintained. Also called *Motor Continuous Overload Capability / Service Factor*.

Slip

Slip is the difference between the actual running speed of an induction motor and synchronous speed, expressed as a percent of synchronous speed. See the discussion under *Speed and Slip*.

♦ Space Heaters

Space heaters are installed inside motor enclosures to prevent moisture from condensing inside the motor when it is not in operation. Space heaters are of low power density, one or three phase, with a frequency of 50 or 60 Hz and a voltage of 115, 230 or 460 volts. The available voltage and frequency for these shall be specified on the motor data sheets. See **GP 16-2-1** and **GP 16-9-2** for general requirements and applications.

Starter

A switching device which turns the motor on and off. It contains high power contacts for connecting the motor cable to the power mains, sensors to determine the current flow to the motor, and protective devices to shut the motor off for overloads and internal insulation breakdowns (faults).

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DEFINITIONS (Cont)

◆ Temperature Rise

Rated temperature rise of an electric motor is the difference between ambient temperature and the temperature of the motor in continuous service at its rated load, as measured under conditions specified in **IEC 60034-1**.

Temperature Tests

Temperature tests are tests taken to determine the temperature rise of certain parts of the machine above the ambient temperature when running at full load.

Variable Frequency Drive

An electronic package which separates the motor from the power system and adjusts the frequency and voltage of the power supplied to the motor. In the most common form of VFD, power from the mains is rectified to d-c. A converter section, containing electronic switching devices, converts the d-c to a-c power for the motor. This device is also sometimes called a variable speed drive.

MOTOR TYPES AND APPLICATIONS

ADVANTAGES AND DISADVANTAGES

Electric motors have been selected over other mechanical drivers due to these advantages:

- Lower annual maintenance cost. About 25% of gas turbines or steam turbines.
- Reduced noise emissions when compared with mechanical drivers.
- No combustion emissions on site.
- Energy costs can be lower, especially where power is available from co-generator, or independent power producer. Retail wheeling will provide lower negotiated rates.
- High efficiency, between 0.89 and 0.97, depending on HP rating and type.
- Easy installation, no pressure piping or fuel conditioning equipment.
- Long run times with little performance deterioration.
- Output little affected by changes in ambient temperature.
- Quick startup. No thermal growth conditions requiring warm-up.
- Simple operation with minimum monitoring. No speed governing systems.
- Higher machine reliability than other drivers.

Some disadvantages using motors are:

- Requires a reliable plant electrical system.
- Can be affected by power outages on systems outside of the plant.
- Space required for substations and cables.
- Cost of power not fixed if purchased outside.

MOTOR TYPES APPLIED TO REFINERY SERVICES (SEE **FIGURE 1**)

General

Two types of motors are used for nearly all refinery and chemical plant pump and compressor services. Both types use alternating current. Direct current motors are not used for these services. These types are:

1. Polyphase squirrel cage induction motors.
2. Polyphase salient pole synchronous (single speed) motors.

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MOTOR TYPES AND APPLICATIONS (Cont)

Of the two, the squirrel cage induction motor is the most commonly used motor drive for pumps and compressors. The synchronous motor is mainly used to drive low speed reciprocating machines.

Squirrel Cage Induction Motors

The polyphase squirrel cage motor is characterized by a rugged and simple design and is the workhorse of industry. Far more squirrel cage motors are used than all other driver types combined.

The motor has two main parts: the stator and the rotor. The stator is a cylindrical iron core having insulated windings and mounted within an enclosure. The windings are arranged around the inner periphery of the core. When excited by a 3-phase power system, the windings produce a magnetic wave which travels around the circumference of the stator. This traveling wave crosses the rotor cage inducing power into the rotor. Hence, the name induction motor.

The rotor is a cylindrical iron core mounted on a shaft and fitted inside the stator. The rotor windings consist of a number of copper or aluminum bars fitted lengthwise in the core and connected at each end to a ring: thus the term squirrel cage. There is no direct electrical connection to the rotor winding. All the rotor excitation comes from the stator traveling magnetic wave.

The source of 3-phase voltage is connected to the stator winding through a motor starter. Most squirrel cage motors are single speed (speed varies slightly with load), but two-speed and three-speed motors are commercially available.

Squirrel cage motors use bearing construction similar to that of other types of medium speed rotating machines. Grease-lubricated ball bearings are most common in motors 200 HP and smaller. Oil lubricated sleeve bearings are normally applied in large size motors. Oil mist lubrication has also been applied to motors above about 400 HP.

Salient Pole Synchronous Motors

Salient pole synchronous motors are similar to squirrel cage motors except for their rotors. The rotor, or field, consists of a number of individual iron core pole pieces arranged around a central hub on the shaft. Each pole has an insulated winding. All pole windings are connected together and then connected to a direct current source. Also mounted on the poles is a squirrel cage-like structure called an amortisseur winding.

The motor starts like a squirrel cage motor on its amortisseur winding. After accelerating to near-synchronous speed, the d-c field winding is energized pulling the rotor into synchronism with the stator traveling wave. The motor then runs at a constant speed, equal to synchronous speed, regardless of load variations, provided that the load does not exceed the capability of the motor.

The direct current source used to excite the rotor winding can come from outside the motor through brushes and slip rings, or from a generator hung on the end of the motor shaft. The latter is termed a brushless synchronous motor. The brushless machine has the advantage that it has no arc producing brush system and can be located in a **Class I, Division 2** hazardous areas without a continuous purging arrangement for brushes. An added advantage is it will be less susceptible to falling out of synchronism for voltage dips on the power system.

One disadvantage of synchronous motors is that they must be allowed to roll to nearly a stop before reaccelerating following a short duration outage of the power system.

Synchronous motors can be economically built to operate at high efficiency at lower speeds than can squirrel cage induction motors.

Special Purpose Variable and Multiple-Speed Motors

1. Multiple-speed motors are available which change the number of poles by use of multiple windings or winding reconnection. Such motors can provide two or more different speeds. While there is no technical horsepower limitation on this type of motor, it becomes too expensive at sizes above 1500 to 2000 HP.
2. A motor type known as a "pole amplitude modulation" (PAM) motor can provide two-speed operation with a single winding by reconnecting the winding in a way which splits the poles into a greater number to get a low speed, or joins the pole windings to reduce the number of poles to get a higher speed.
3. Wound rotor motors can provide variable speed operation over a limited range. They can also provide high starting torque with relatively low inrush current. Refinery applications for these motors are nominally limited to cranes, hoists, conveyors, etc., which have high starting torque requirements. The installed cost of wound rotor motors is relatively high.
4. Direct current motors can provide variable speed operation, but their installed cost is very high; therefore, they are rarely, if ever, used in refinery applications.
5. Variable frequency drives are available for motors up to about 50,000 HP. They can be used to run a motor at any steady speed, including super-synchronous, or on a continuously ranging basis according to process needs. VFDs are electronic packages and can be applied to either induction or synchronous motors.