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Selection of ac induction motors for mining applications

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Abstract

Misapplication of ac induction motors for mine crusher and mill applications has long been a frustration for the driven equipment supplier and the mine operator. Proper selection of ac induction motors is critical to providing efficient production. This paper focuses on the selection of ac induction motors for gyratory crusher, cone-crusher and grinding mill applications. The criteria for motor selection includes: proper enclosure, driven equipment torque requirements, bearing life, temperature rise, starting requirements, ambient temperature, altitude and accessory requirements.

Introduction

Although motors may appear to be the least complicated component in the specification of mining equipment, this paper begins to demonstrate that mining applications present an immense matrix of application criteria to properly specify, design and build motors.

To obtain the correct motor for the specific job, communication, expectations and knowledge must be exchanged between the mine operator, driven equipment manufacturer and motor supplier.

Operating conditions

Basic motor specifications begin with determining the motor nameplate horsepower and rpm. These are determined by the driven equipment supplier and are based upon a steady state equipment operation.

Next is the determination of the available power voltage. The mine operator or engineering consulting firm must determine the most effective power source, taking horsepower and ampere values of the entire system into consideration.

The frequency (Hz) rating is determined by the power system available at the site. Because the mining market is global with many frequency and voltage combinations, the frequency value cannot be assumed. It is important to the motor manufacturer in the proper design of a motor, which is different for Chile (50 Hz) than Argentina (60 Hz).

Ambient temperature is often overlooked as a design criterion. Ambient temperatures below -30° C (-22° F) can require special bearing lubricant and material requirements. Conversely, ambient temperatures above 40° C (104° F) cause the allowable motor temperature rise to be lower, which effectively derates the motor design.

The altitude at the site can also affect the motor selection when installation elevations exceed 1,000 m (3,281 ft). The lower density of air at higher altitudes results in a decreased cooling media for the motor. The derate factor is 1% of the specified temperature rise for each 100 m (328 ft) of altitude in excess of 1,000 m (3,281 ft).[1]

Driven equipment torque requirements

To properly select ac induction motors for any application, the speed vs. torque requirements of the driven equipment must be understood. It is an easy mistake to believe that a 298-kW (400-hp), 1,200-rpm motor, with a full load torque rating of 245 kg-m (1,773 ft-lb.), which would function well in a centrifugal pump application, would also work aptly in a crusher application. However, the load torque requirements of a centrifugal pump during starting are typically less than 30% of full load torque, while a full gyratory crusher would have load torque requirements at start-up of more than 100% of the motor's full load rated torque.

The distinction must be understood between the running condition of the driven equipment, which dictate the hp and rpm of the motor, and the starting load condition of the driven equipment, which dictates the motor starting characteristics. The National Electrical Manufactures Association (NEMA) classifies the torque characteristics of motors as follows:

- *Locked-rotor torque (LRT):* the percentage of rated full load torque the motor generates at initial rotation of motor shaft.
- *Pull-up torque (PUT):* the lowest percentage of rated full load torque the motor generates during starting.
- *Breakdown torque (BDT):* the highest percentage of rated full load torque the motor generates prior to reaching full load speed.[2]

Table 1 shows the typical start-

[1]NEMA MG 1-1993 Rev. 4 Part 20, Page 3, Paragraph 20.40.

[2]NEMA MG 1-1993 Rev. 4 Part 20, Page 4, Paragraph 20.41.

TABLE 1

Starting torque requirements.

Driven equipment	Torque requirement, (% Min.) LRT	BDT
Gyratory crusher	180-200	250
Cone crusher	125	200
Grinding mill	40-230	230-250
Centrifugal pump	*60*	*175*

ing torque requirements specified by the original equipment manufacturers (OEM) for gyratory crushers, cone crushers and grinding mills. To show the contrast, the torque requirements of a centrifugal pump are also shown.

Figure 1 displays a series of speed torque curves for three motors with identical hp and rpm ratings designed for a centrifugal pump (A), cone crusher (B) and gyratory crusher (C).

Motors that do not have sufficient starting torque for the driven equipment will stall during starting. A stall condition requires the mine operator to lower the starting load before attempting to restart the equipment. In the case of crushers or mills, this means the removal of aggregate from the machine. Excessive stall conditions also damage the motor due to excessive current flow in the stator and rotor.

Design specifications

Motor enclosure. The motor enclosure defines the degree of protection for the motor windings. The selection of the motor enclosure is typically left to the discretion of parties other than the motor manufacturer. However, the motor manufacturer can choose to provide an enclosure that exceeds the requirements of that specified by the purchaser.

TEFC. Totally enclosed fan cooled is the most common enclosure for the mining industry. "A totally enclosed machine is one so enclosed as to prevent the free exchange of air between the inside and the outside of the case but not sufficiently enclosed to be termed airtight."[3]

The two major types of TEFC motors are totally enclosed fin cooled and totally enclosed air to air cooled (TEAAC). The fin cooled variant is defined by the cooling fins that cover the main structure of the enclosure. Typically, this frame is constructed of cast iron, although welded steel fin and aluminum cast construction is occasionally offered. TEAAC motors are equipped with an air to air heat exchanger on the top of the motor stator. In a TEAAC enclosure, the hot air from the stator is forced around the tubes that channel the cooling air. Available tube materials on TEAAC motors include aluminum, copper and stainless steel, as appropriate for the environmental conditions.

Open enclosures. Open type enclosures present a lower cost option to the mining industry, although as the NEMA definition implies, the degree of protection for the motor windings is diminished. "An open machine is one having ventilating openings that permit passage of external cooling air over and around the (stator) windings of the machine."[4]

The two primary open type enclosures seen in the mining industry are drip proof (ODP) and weather protected Type II (WPII). The ODP is intended only for indoor duty, where as the WPII enclosure is designed to be suitable for outdoor duty. The WPII enclosure includes a minimum of three 90° turns of the inlet and exhaust air to limit the ingression of airborne contaminants.

The advantages to the open type enclosure include a greater hp/stator weight ratio and lower cost. By allowing the ambient air to pass directly through the motor rotor and stator, the open enclosures cool the motor better allowing for more hp output than with a TEFC enclosure.

The primary limitation of the open enclosures is that airborne dusts that are in the mining environment can build up inside of enclosures and cause the units to overheat. In addition, the airborne contaminants will also tend to "sand blast" the stator winding insulation leading to stator failure.

TEWAC. "A totally enclosed water-air-cooled machine is a totally enclosed machine which is cooled by circulating air which, in turn, is cooled by circulating water. It is provided with a water-cooled heat exchanger for cooling the internal air and a fan or fans, integral with the rotor shaft or separate, for circulating the internal air."[5]

The TEWAC enclosure provides the advantage of the greater hp/stator weight of an open type motor with the protection of the stator via its "totally enclosed" characteristics. This enclosure will provide the highest hp ratings of all enclosed motors, ratings unachievable or cost prohibitive on TEFC motors.

The obvious drawback of the TEWAC enclosure is its water requirements. The supply water must be pumped, cooled and retain a high level of cleanliness.

Electrical specifications

The electrical design criteria of a motor are often assumed by the motor vendor at the time of quotation, unless a specification is submitted by the customer or consulting engineer.

Service factor. The service factor (SF) of the motor is the level of overload the motor is capable of maintaining above the nameplate power rating. A service factor of 1.0 or 1.15 is most common, although 1.05, 1.1 and 1.25 are occasionally used.

A service factor of 1.0 indicates the motor is specified and designed to not operate above the nameplate horsepower. Service factors above 1.0 indicate the motor is suitable for continuous operation at the nameplate hp multiplied by the SF.

Temperature rise. The temperature rise of a motor is the specified maximum level of stator temperature increase over a specified ambient temperature.

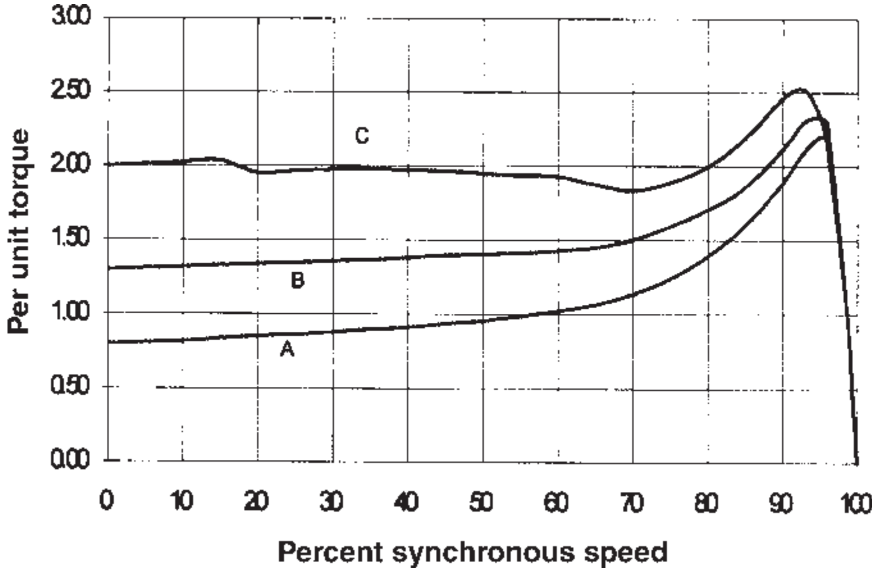
An 80° C (144° F) rise by resistance at 1.0 SF at 40° C (104° F) ambient at a maximum elevation of 1,000 m (3,281 ft) has become the basic motor industry standard.

[3] NEMA MG 1-1993 Rev. 1 Part 1, Page 10, Paragraph 1.26.
[4] NEMA MG 1-1993 Rev. 1 Part 1, Page 8, Paragraph 1.25.
[5] NEMA MG 1-1993 Rev. 3 Part 1, Page 11, Paragraph 1.26.8.

However, temperature rise encompasses a diverse matrix of combinations as evident by the detail of the previous statement. NEMA MG 1-1993, Revision 4, Part 20, Page 3 devotes an entire page to the complexity of temperature rise. The page features two tables of temperature rise, one based upon measurement at 1.0 SF and one based upon measurement at 1.15 SF. Within each table are criteria for motor insulation classes, method of temperature rise measurement and machine rating. Below the tables are additional instructions on how to modify the table values for ambient temperatures above 40° C (144° F) and altitudes above 1,000 m (3,281 ft).

FIGURE 1

Motor speed vs. torque curves.



Starting method. This is a subject that is frequently overlooked until a motor will not start at the job site. When a motor has been sold on the assumption of full nameplate voltage (across the line) starting, and the customer intends to use an auto transformer or some other type of reduced voltage starter, the potential exists for starting problems.

Motor torque performance is based upon 100% nameplate voltage. Motor torque output varies as the square of the voltage change. Therefore, with an auto transformer starter with a 65% tap setting, the 65% voltage (assuming no line drop) results in only 42.25% (0.65 x 0.65) of the nameplate starting torques.

The motor vendor can evaluate, and design the motor for reduced voltage starting, with the submittal of starting voltage, load inertia value and load speed vs. torque curve.

The use of an adjustable speed drive (ASD) is becoming a more frequent application occurrence. Fan and pump motors are being installed with ASDs for the purpose of energy savings via speed variation instead of the use of valves and dampers. ASDs are also being applied with motors for crushers and conveyors for more precise process control.

ASDs can also be used with motor applications that require high starting torques (crushers) or high load inertias (fans) to allow for the installation of a more efficient motor design. Ultimately, for motor applications on ASDs, details about the specific ASD, the driven equipment load characteristics and the speed range requirements are required for the motor to be specified and designed properly.

Inrush amps. Evaluation of the power distribution system of a processing area can result in inrush amp limitations placed upon the motors. Inrush amps are the amp draw of the motor during starting. Locked rotor amps (LRA) is the common designation. The units for LRA are typically a percent of the full load amp value.

Motors designed for high starting torques have the inherent characteristic of higher LRA values than standard torque motors. This is due to the higher flux density and/or the higher resistance that are required in the rotor cage of the motor. Limiting the LRA level can result in larger motor sizes.

Efficiency. Specifying a minimum motor efficiency is occasionally seen in the mining market. Similar to temperature rise, discussion of efficiency represents an opportunity for a paper itself. When specifying a motor, if efficiency is to be a criterion, it must be defined in terms of method of acquisition and in the interpretation of the value (guaranteed minimum, nominal, calculated or typical).

Mechanical specifications

The mechanical design criteria includes some items that must be specified by the driven equipment manufacturer, some that can be assumed and some that must be dictated by the motor manufacturer.

Connection to load. Crusher motors are typically connected to the crushers via belts, gear boxes or direct connection. The connection type should be specified by the purchaser when requesting a motor quotation.

Mill motors can have the same connection modes as the crusher motors, but they frequently include an air clutch. Besides the change of minimum torque that comes with an air clutch, the purchaser must also specify how the air clutch is to be installed. Air clutches can be installed on an intermediate gear box shaft, wherein the motor mechanical design is not effected. Or, the air clutch can be installed directly to the motor drive shaft, which requires that the motor shaft be gun drilled and both ends of the shaft be modified to accommodate the special clutch components.

Bearing type. Although both sleeve and anti-friction bearings are available on most motors larger than 440 frames, the connection of the load and the speed of the motor will usually dictate the choice.

The advantage of sleeve bearings is that, theoretically, they will provide an infinite life. However, they do have their limitations. Sleeve bearings cannot be applied to belted applications. Also, sleeve bearing can require supplemental oil supply in ambient temperatures higher that 40°C (104° F) and on the larger frame sizes.

Anti-friction bearings provide the greatest flexibility in application, but they do have a finite life. Anti-friction bearing life is specified in terms of rating life or L_{10}. "The rating life of a group of identical ball or roller bearings is defined as the number of revolutions, or hours at some given constant speed, that 90% of a group of bearings will complete or exceed before the failure criterion develops." [6] A minimum L_{10} life of 100,000 hours is typical for direct connection applications. For direct connection applications, deep groove ball bearings are installed on both ends of the motor as standard. Belted duty dictates the use of a roller bearing on the drive end of the motor to provide higher levels of side loading capacity and longer bearing life. A minimum L_{10} life of 17,500 hours is common for belted applications without the use of a jack shaft.

Accessory equipment

The specification of the motor accessory equipment is primarily the choice of the motor purchaser. These items represent additional cost and will typically not be included by the motor vendor unless required by the operating conditions.

Stator winding protection. The available accessories for protecting the stator windings include space heaters, abrasion resistant treatment on the end turns, anti-fungus treatment, surge protection (lightning arrestors and surge capacitors), metering current transformer (CT) and differential CT's.

Stator temperature protection. Overheating is a primary mode of decreasing motor life. The available accessories for monitoring the stator for temperature include resistance temperature detectors (RTD's), thermocouples (TC's) and thermostats. The specific type of RTD or TC is required for final motor design.

Bearing protection. Protection of the motor bearings includes the diverse options of special shaft seals, vibration protective devices and temperature monitoring devices (RTD's or TC's).

Mill motor specific. Mill applications require two unique accessory requirements on motors. One is the inclusion of an air clutch provision, alluded to in the "Connection to load" previous section. The second accessory requirement unique to mill motors is the requirement for an inching drive provision on the motor. This provision requires a second shaft extension on the opposite drive end (ODE) of the motor. This second shaft extension is fairly easy to do on an open-type motor, but is more complex on a TEFC motors because of their external cooling fans that are mounted on the ODE. Both an inching drive provision and an air clutch provision cannot be specified on the same motor.

Conclusions and recommendations

For optimum motor performance and customer satisfaction, the application of AC induction motors to mining process equipment must be understood by the mine personnel, the consulting engineer(s), the driven equipment suppliers and the motor manufacturer. This understanding requires a transfer of critical information between all parties. ■

[6] Shigley and Mitchell, *Mechanical Engineering Design*, Fourth Edition, 1983, Page 488.