

# **Selection of AC Induction Motors for Cement Plant Applications**

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## **ABSTRACT**

In cement plants, proper specification and supply of AC induction motors is critical to project schedules and providing efficient production. This paper focuses on the selection of AC induction motors for cement mill applications, with reference to fan, kiln and vertical mill applications. The criteria for motor selection includes: operating conditions, driven equipment starting requirements (including the used of adjustable speed drives), electrical specifications, mounting requirements, enclosure and bearing parameters and accessory equipment needs.

## **INTRODUCTION**

Although motors may appear to be the least complicated component in the specification of cement mill equipment, this paper shall begin to demonstrate that cement plant 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 mill operator, driven equipment supplier and motor manufacturer.



## **OPERATING CONDITIONS**

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

Next is the determination of the available power voltage. The cement plant operator, process equipment supplier or engineering consulting firm must determine the most effective power source, taking load hp and amp values of the entire system into consideration.

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

Ambient temperature is often overlooked as a design criteria. Ambient temperatures below  $-30\text{ C}$  can require special bearing lubricant and material requirements. Conversely, ambient temperatures above  $40\text{ C}$  may result in the allowable motor temperature rise to be lowered, which effectively de-rates the motor output.

The altitude at the site can also affect the motor selection when installation elevations exceed 1000 meters. The lower density of air at higher altitudes results in a decreased cooling media for the motor. The derate factor is <sup>1</sup>1% of the specified temperature rise for each 100 meters of altitude in excess of 1000 meters.

## **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 400 hp 1200 rpm motor, which would function well in a low inertia fan application, would also work aptly in a kiln application. However, the load torque requirements of a fan pump during initial starting are typically less than 30% of full load torque, while a full kiln could have load torque requirements of over 100% of full load torque.

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<sup>1</sup> NEMA MG 1-2006 Part 20, Page 5, Paragraph 20.8.4.

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 Manufacturers Association (NEMA) classifies the torque characteristics of motors as follows:

<sup>2</sup>Locked-rotor Torque (LRT) – “the minimum torque which the motor will develop at rest...with rated voltage”, expressed as a 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.

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 cement industry. <sup>3</sup>“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 air-tight”.



Figure 1: Totally Enclosed Air-to-Air Cooled



Figure 2: Totally Enclosed Fin-Cooled

The two major types of TEFC motors are totally enclosed fin cooled and totally enclosed air to air cooled (TEAAC – Figure 1). The fin cooled (Figure 2) 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. <sup>4</sup>“An open machine is one having ventilating openings which permit passage of external cooling air over and around the windings of the machine.”

<sup>2</sup> NEMA MG 1-2006 Section 1 Part 1, Page 19, Paragraph 1.47.

<sup>3</sup> NEMA MG 1-2006 Section 1 Part 1, Page 15, Paragraph 1.26.

<sup>4</sup> NEMA MG 1-2006 Section 1 Part 1, Page 12, Paragraph 1.25

The primary open type enclosures seen in the cement industry is the Weather Protected Type II (WP II – Figure 3). The WP II enclosure includes a minimum of three 90° turns of the inlet and exhaust air to limit the ingress of airborne contaminants. The WP II type motor can also be supplied with filters on the air intake (galvanized steel or stainless steel are most common).

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 or TEAAC enclosure.



Figure 3: WP II Enclosure

The primary limitation/disadvantage of the open enclosures is that airborne dusts that are in the cement environment can build up inside of enclosures and cause the units to overheat. In addition, the airborne contaminants can also tend to “sand blast” the stator winding insulation if filters are not in place.

**TEWAC:** <sup>5</sup>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”.

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. A service factor of 1.0 indicates the motor is specified and designed to not operate above the nameplate hp. 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 motor stator temperature increase over a specified ambient temperature. Temperature rise encompasses a diverse matrix of combinations as evident by the following 1.0 SF table from NEMA MG 1-2006, Part 20, Page 4, which is based on 40C (max) ambient and 1000 meters or less altitude.

HP	Voltage	Method of Determination	Temperature Rise, Degrees C			
			Class of Insulation System			
			A	B	F	H
HP	All	Resistance	60	80	105	125
HP ≤ 1500	All	Detector	70	90	115	140
HP > 1500	V ≤ 7000	Detector	65	85	110	135
HP > 1500	V > 7000	Detector	60	80	105	125

<sup>5</sup> NEMA MG 1-2006, Part 1, Page 16, Paragraph 1.26.7.

Eighty (80) degree Celsius (C) rise by resistance at 1.0 SF over a 40C ambient has become the basic motor industry standard. This represents "Class B" temperature rise. However, the customer has the option to specify alternatives.

**Insulation Class:** Class F is the industry standard temperature endurance rating for AC induction motor insulation.

**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 across the line starting (ACL), 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% (.65 x .65) of the nameplate starting torques.

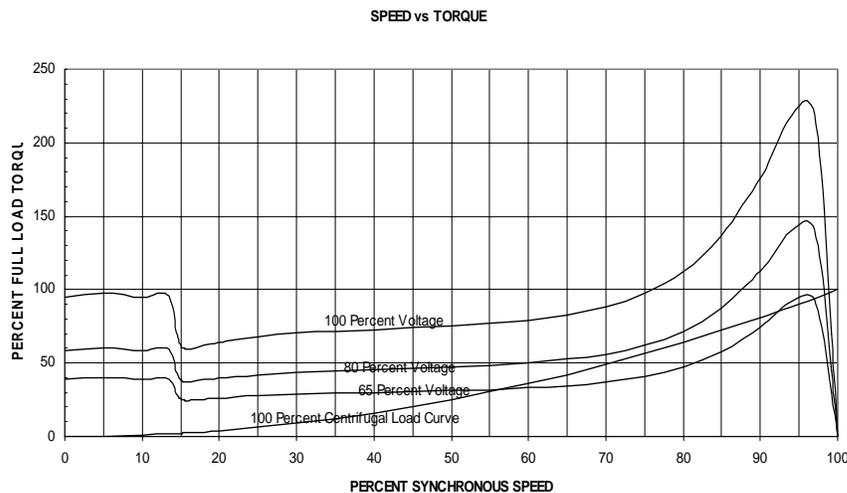
The use of an adjustable speed drive (ASD) is becoming a more frequent application occurrence. ASD application requires specific information about the particular ASD, the load characteristics, and the speed range requirements, for the motor vendor to design the motor appropriately.

The following table details alternate starting methods, with resultant motor torque outputs.

Starting Method	Voltage Applied	Percent of Full Voltage Starting Current ( on Line Side )	Percent of Full Voltage Starting Torque
Across the Line	100	100	100
	90	90	81
	80	80	64
Autotransformer	80	66	64
	65	45	42
	50	27	25
Series Reactor	80	80	64
	65	65	42
	50	50	25
Solid State Soft Start	Adjustable	(Volts Applied / Volts Rated )	(Volts Applied / Volts Rated ) <sup>2</sup>
Variable Frequency Drive	Adjustable	Adjustable	Adjustable
Wye Start - Delta Run	100	33.3	33.3

The following speed torque curves (Figure 4) demonstrate a situation wherein the motor could start successfully at 100, 90 and 80% voltage, but it would stall at approximately 70% speed if only 65% voltage were applied.

Figure 4



**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 is 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 higher resistance that is required in the rotor cage of the motor. Limiting the LRA level can result in larger motor sizes.

Given the load data, the motor vendor can evaluate, and design the motor for reduced voltage starting, and lower inrush; a process most effectively performed during the quotation stage.

**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: Direction connection of the motor shaft to the driven equipment/gear box will be assumed unless a belt drive arrangement is directly specified.

Mounting Orientation: Horizontal mounting on level ground will be assumed by the motor supplier unless otherwise specified. However, in the case of kiln drive motors, it is common for the motors to be oriented on a 3 degree incline, in which case a process equipment supplier specification is helpful.

A particular challenge in motor design can be height restrictions on vertical mill applications. It is common for the motor to be mounted beneath a table or structure surface such that a standard height motor may not fit.

Figure 5 demonstrates such a tight fit



Figure 5

Auxiliary Shafts: Some equipment, including vertical mills, may include the requirement for an inching drive provision on the motor. This necessitates the motor be supplied with a 2<sup>nd</sup> shaft extension on the non drive end (NDE) of the motor to which an inching drive assembly is connected. Figure 6 and 7 show such an arrangement on two vertical mills.

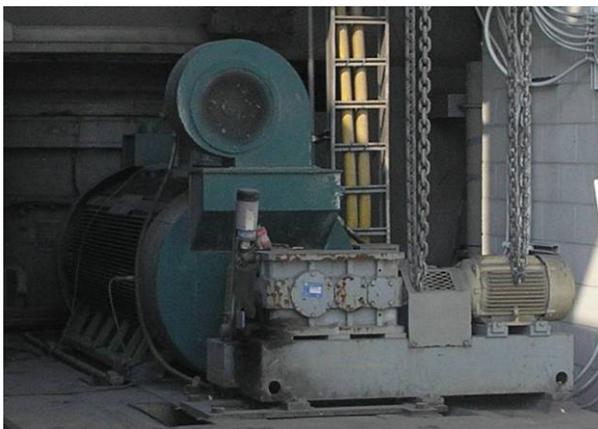


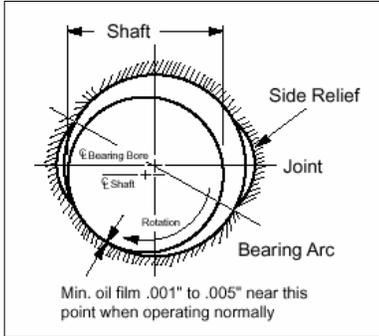
Figure 6: Inching Drive on NDE of Mill Drive Motor



Figure 7: Inching Drive

**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 can 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 can not be applied to belted applications. Also, sleeve bearings can require supplemental oil supply in ambient temperatures higher than 40C and on the larger frame sizes. Sleeve bearings also have minimum speed requirements, something that can be an issue with inching drive situations.

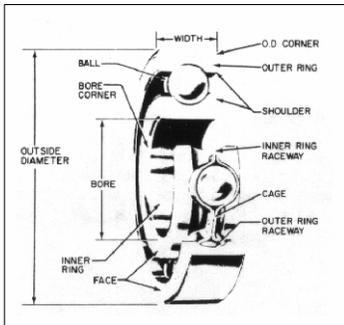


Basic Sleeve Bearing Design

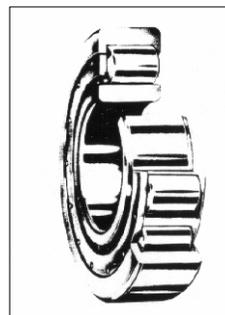


Sleeve Bearings

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 L10. A minimum L10 life of 100,000 hours is typical for direct connection applications. For direct connection applications, deep groove ball bearings are used on both ends of the motor as standard. Roller bearings can also be applied on larger motors. 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 L10 life of 17,500 hours (min) is common for belted applications.



Ball Bearing



Roller Bearing

### **Accessory Equipment**

The specification of the motor accessory equipment is primarily the choice of the motor purchaser. These items represent cost adders, and will 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 (i.e. IP55, "taconite", Inpro®), vibration protective devices, and temperature monitoring devices (RTD's or TC's).

## **CONCLUSIONS AND RECOMMENDATIONS**

In conclusion, for optimum motor performance and customer satisfaction, the application of AC induction motors in cement process equipment must be understood by the cement plant personnel, the process equipment suppliers and the motor manufacturer. This understanding requires a basic understanding of motors by the cement plant operator and process equipment supplier to "spec out" the motors, and specific application knowledge by the motor manufacturer to properly design and manufacture the motors. Transfer of information between all parties is essential due to the vast amount of variables and design factors that exist.