UNDERSTANDING ELECTRIC MOTORS FROM A MECHANICAL ENGINEERING PERSPECTIVE

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INTRODUCTION

The purpose of this paper is to present an understanding of the different types of electrical motors and their characteristics with reference to conveyor applications.

ELECTRIC MOTORS

TYPES OF ELECTRIC MOTOR AND THEIR ASSOCIATED CHARACTERISTICS

There are two main types of electrical motors found in industry: AC motors and DC motors. For the purposes of this paper we will deal only with AC motors as DC motors are used very infrequently and will ultimately only be applied in very specialised applications. AC motors are available in three types:

1. Asynchronous AC induction motor
2. Synchronous AC induction motor
3. Slipring AC induction motor

Of these three types only the Asynchronous AC induction motor needs to be considered for conveyor applications. This type of motor is also known as a “squirrel cage” motor or even just as an AC motor.

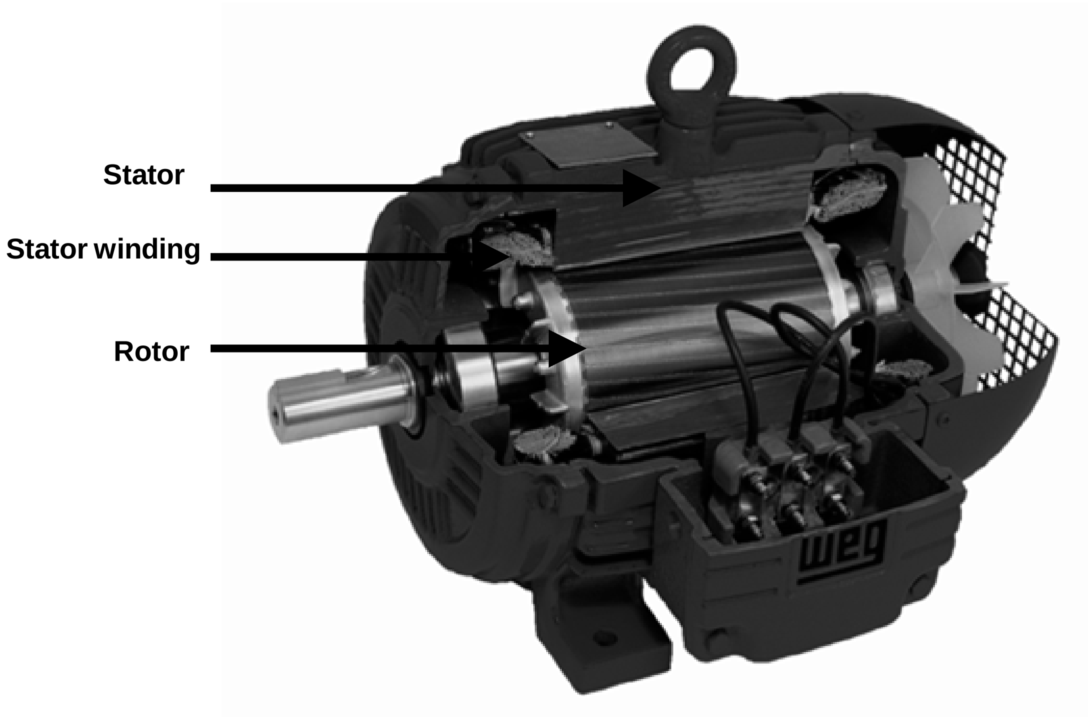


Figure 1: "Squirrel Cage" Motor

Due to its construction and electrical characteristics this motor has become the prime mover in all industries. These motors are simple to operate, very robust and adaptable to most applications. Because there is no physical connection from the rotor to any external electrical power supply the standard AC motor can be designed to an IP55 or even an IP66 degree of protection. Different electrical designs are also possible, for example either a high torque or a low torque at start.

The IP rating of a motor is a specification of it's degree of protection against the ingress of external contaminants. i.e. solids and liquids. "IP" is the abbreviation for "Increased Protection". The higher the IP rating the higher degree of protection. The table below details the meaning of the various IP ratings.

IP Rating Definition			
First Numeral		**Second Numeral**	
Protection against solids		**Protection against liquids**	
0	No Protection	0	No Protection
1	Protection against solid objects > 50 mm (hands)	1	Protected against vertically falling drops of water (condensation)
2	Protection against solid objects > 12 mm (fingers)	2	Protected against sprays of water up to 15º from vertical
3	Protection against solid objects > 2.5 mm (tools / wires)	3	Protected against sprays of water up to 60º from vertical
4	Protection against solid objects > 1.0 mm (small tools / wires)	4	Protected against water sprayed from all directions (outdoor rain) Limited ingress permitted
5	Protection against dust Limited ingress permitted No harmful deposits	5	Protected against low pressure jets of water sprayed from all directions (hosepipe) Limited ingress permitted
6	Totally protected against dust	6	Protected against strong jets of water sprayed from all directions Limited ingress permitted
		7	Protected against immersion between 15cm and 1m
		8	Protected against long periods of immersion under pressure (> 1 m)

Table 1: IP rating definition

It would seem then that the best you can do is to specify that all motors and VSD panels be IP68 or IP66. Unfortunately, there are practical implications to achieving the above protections. The higher the degree of protection the more robust (heavy and large) the item must be. Due to the simplicity of construction an AC motor can easily and practically be manufactured to a high degree of protection. Guidelines for IP ratings are given below.

Standard AC motors as per Figure 1 on previous page (cast iron totally enclosed) – IP66
Large AC motor of fabricated steel construction – IP55
Large AC motor terminal box – IP65
VSD panel for indoor use – IP42
VSD panel for outdoor use – IP54

The principle of operation of an electrical motor is illustratedin Figure 2.l

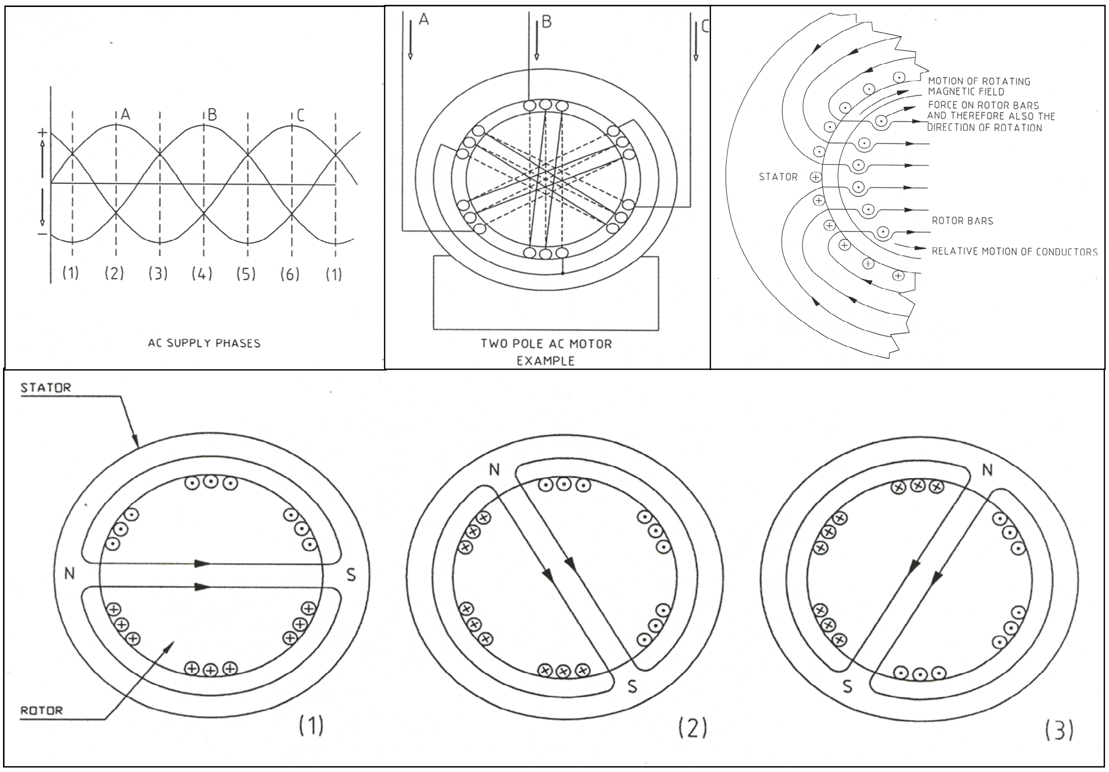


Figure 2: The principle of operation of an electrical motor

A three phase alternating current (AC) voltage is applied to such a motor. Each phase is connected to a winding which is wound around a part of the stator core. Each phase produces a magnetic field. As the AC voltage fluctuates, the magnetic field changes and rotates. The movement of the magnetic field in the stator magnetically induces a voltage and current in the rotor. (Hence the term induction motor). The current flowing in the rotor also produces a magnetic field. The stator and rotor magnetic field interact. The stator field attracts the rotor field causing the rotor to rotate following the stator field. Except in VSD applications, the stator field always rotates at a speed that corresponds exactly with the frequency of the supply. In South Africa this is 50Hz. When a motor has 2 poles the speed of rotation is 3000 RPM, 4 poles is 1500 RPM and 6 poles is 1000 RPM. This can be calculated as follows:

$$N = \frac{60 \times f}{p} = \frac{60 \times \textit{frequency}}{\textit{number of pole pairs}}$$

This is known as “synchronous speed”. It is synchronized with the mains supply frequency.
The rotor and hence the motor shaft never turns at the same speed as the stator field. The difference in rotational speed is termed the motor “slip”. Typical slip values are between 0.3% and 4% of stator speed. The actual value of the slip differs from motor to motor and is dependant on many design factors. A 4 pole motor can thus run at 1450 RPM or perhaps 1460 RPM or even 1490 RPM. This is the motor nominal speed and is always quoted at 100% rated load. If the mechanical load is reduced the motor will run faster. For example, a 1460 RPM motor will run at 1480 RPM at 50% load. AC motors have common features or specifications but there is a possible range of values for these.

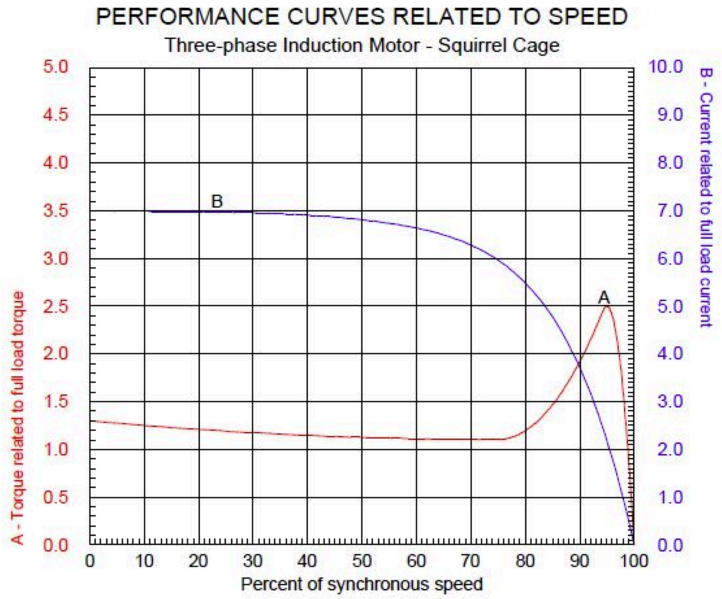
Before considering different motor characteristics let us understand these different characteristics. The main characteristics are shown in Table 2.

Item	Description
Nominal Power	The mechanical power that the motor is rated to deliver on its shaft
Nominal Voltage	The nominal voltage at which the motor is designed to be used
Full Load Current	The current drawn from the supply at 100% of motor power
Nominal Speed	The speed at which the shaft will rotate when the motor supplies 100% load
Locked Rotor Torque	The torque that the motor will supply at starting when started direct on line
Breakdown Torque	The maximum torque that motor can deliver before stalling
Nominal Torque	The design or nominal torque
Locked Rotor Current	The current the motor will draw from the supply at starting when started direct on line
Locked Rotor Time	The duration of time for which a motor can endure locked rotor current without exceeding its thermal limit

Table 2: Different motor characteristics

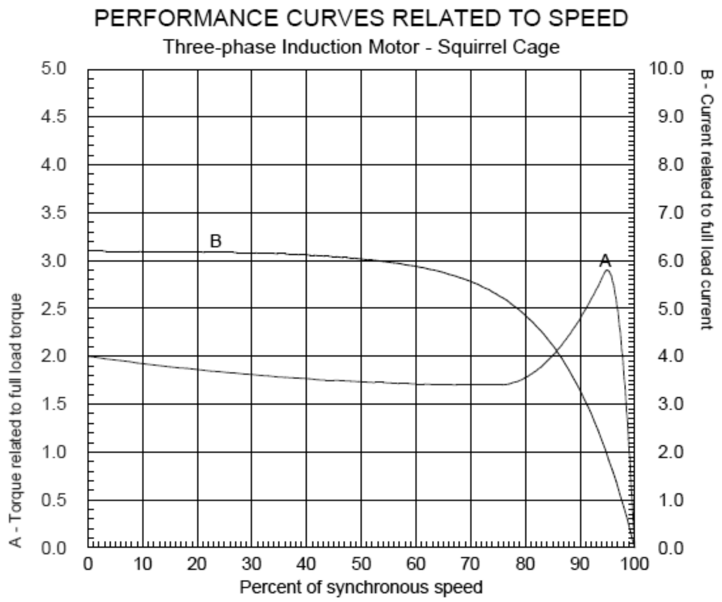
There is no specification that gives exact values for these characteristics. There is an acceptable and normal variance. Each motor has a data sheet applicable to that motor only. The data sheet for a motor of the exact same rating but from a different manufacturer or even from a different range by the same manufacturer will have a different data sheet. For example two motors each rated as 525 V 250 kW 4 pole will have differing starting torque, current etc. One may have a starting torque of 130%, another may have 200%. One may have a nominal current of 334 A, another of 348 A. One may have a nominal speed of 1485 RPM, another of 1490 RPM. One design is not necessarily better than the other; there are just always slight differences.

Graph 1 shows two motor data sheets and characteristic curves with an example of these differences.



Customer	:		
Product line	: Low and High Voltage Machines - H Line - HGF - Low Voltage - TEFC		

Output	: 250 kW	Il/In	: 7.0
Frame	: 315C/D/E	Duty cycle	: S1
Rated speed	: 1485	Service factor	: 1.00
Frequency	: 50 Hz	Design	: N
Rated voltage	: 525 V	Locked rotor torque	: 130%
Insulation class	: F	Breakdown torque	: 250%
Rated current	: 334 A		

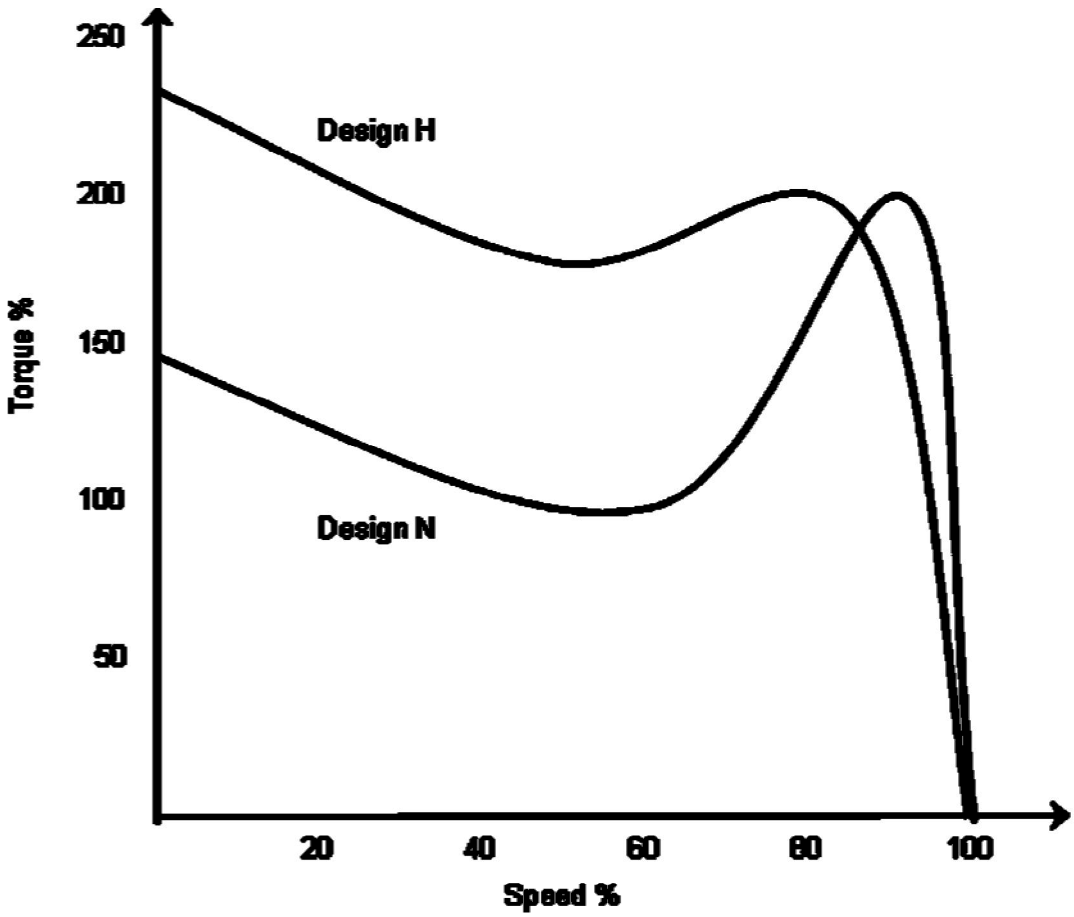


Customer	:		
Product line	: Low Voltage Motors - IEC General Purpose - IP55 - Cast Iron Frame - Improved Efficiency - Multivoltage		

Output	: 250 kW	Il/In	: 6.2
Frame	: 315B	Duty cycle	: S1
Rated speed	: 1485	Service factor	: 1.00
Frequency	: 50 Hz	Design	: N
Rated voltage	: 525 V	Locked rotor torque	: 200%
Insulation class	: H	Breakdown torque	: 290%
Rated current	: 348 A		

Graph 1: Motor Data Sheets and Characteristic Curves

In terms of torque characteristics there are two types of motors:
Normal torque – IEC34 Design N or Nema MG.1 Design B
High torque – IEC34 Design H or Nema MG.1 Design C
High starting torque motors – Design D uncommon and not considered here.
Normal torque motors have a starting torque that varies from 1.9 for a small motor to 0.9 for a large motor. Breakdown torque varies from 2.0 to 1.7. These values are per unit of nominal torque.
High torque motors have a starting torque that varies from 3.0 for a small motor to 2.0 for a large motor. Breakdown torque varies from 2.1 to 1.9.



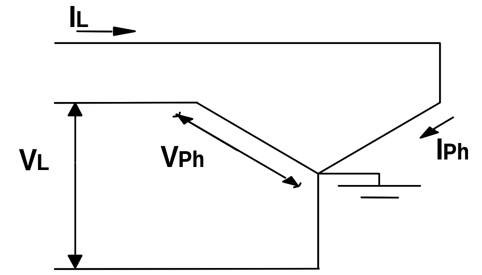
Graph 2

Selecting a motor as either a Design N or H is not a guarantee of correct performance. It is always better to check the exact motor characteristics from its data sheet. There is also no definite industry standard stating that motors normally kept in stock are to be of a certain design. This should always be checked.

An AC motor has three windings. One is connected to each phase of the supply voltage. In order for current to flow the ends of the windings must be connected to one another. They can be connected in star or in delta. As illustrated below:

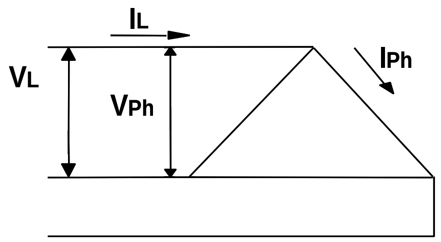
Connections for three - Phase Systems:

Star



$$I_L = I_{Ph}$$
$$V_{Ph} = \frac{V_L}{\sqrt{3}}$$

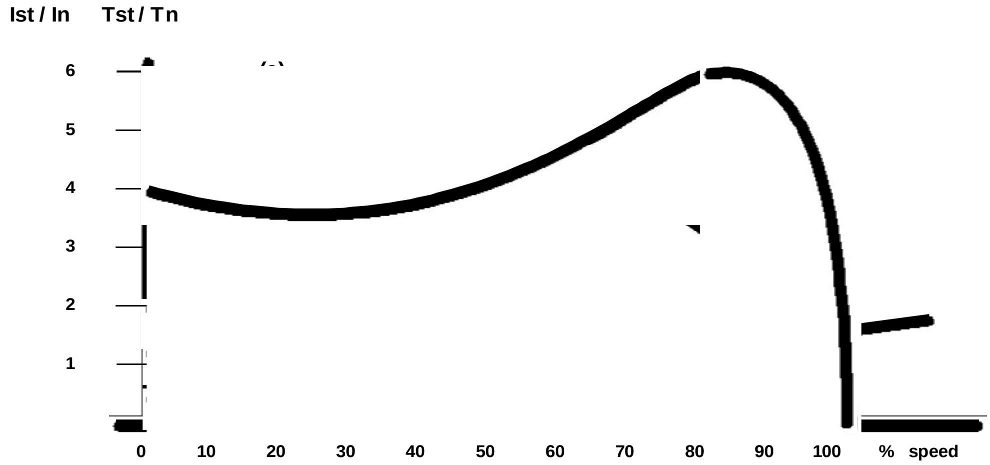
Delta



$$V_L = V_{Ph}$$
$$I_{Ph} = \frac{I_L}{\sqrt{3}}$$

Figure 3: Connections for three-phase systems

The individual motor windings are designed to operate at a certain voltage, e.g. 400 V. When a motor is connected in delta the line voltage is connected directly to the two ends of the winding, therefore the voltage on the winding is the same as the supply voltage. When a motor is connected in star the line voltage is connected to one end of the winding and the three windings are connected to each other at the other end. When connected like this the voltage across the winding is only 58% of the line voltage. For example, 400 V line voltage will result in 230 V across the motor phase voltage. The effect of this is like connecting the motor to a low voltage. It has a low starting current, low torque and slow acceleration. This is what is done when motors are started star/delta. It is a simple method of “soft start”.



(a) Current at delta

(b) Torque at delta

(c) Current at star

(d) Torque at star

(e) Example of load torque on a pump

CORRECT MOTOR SELECTION

From an electromechanical perspective there are four main considerations when selecting a motor:

1. Nominal power – This defines the rated output power of the motor. This must exceed, but be closely matched with the absorbed power requirement of the mechanical load. When a motor runs at a load between 70% - 100% of nominal power it is at its best efficiency. The safety margins in the design should then aim to not exceed this. Therefore, for example, if the load absorbed power is 100 kW, the installed motor should not be greater than 100 / 0.7 = 143 kW. The two nearest standard motor sizes are a 132 kW or a 150 kW.
2. Nominal RPM – This defines the motor speed of rotation at full load. Generally 4 pole motors, e.g. 1460 RPM are most commonly used. However, certain loads may require 2 pole, 6 pole or another nominal speed. The number of poles affects the motor nominal speed and torque. A 4 pole motor runs at 50% the speed of a 2 pole motor and at 200% the torque of a 2 pole motor of the same power rating.

$$p = 2\pi nT \; and \; T = \frac{p}{2\pi n}$$

3. Starting torque – This defines the torque that the motor will deliver at the moment of starting DOL. For high inertia loads such as a large fan, one would want a low starting torque to avoid undue mechanical stress at startup. Conveyors require a relatively high starting torque. For this reason a motor with high or sufficient starting torque must be selected. The nominal starting torque also affects the acceleration time. The higher the starting torque, the quicker the acceleration.
4. Locked rotor time – This defines the length of time for which a motor can draw starting current without overheating. Starting current is drawn during acceleration; therefore the motor locked rotor time must exceed the time required for acceleration. Motor manufacturers may provide either a hot or cold locked rotor time. The locked rotor time considered should be the hot locked rotor time so that the load can be started without undue delay after a trip. A high inertia load such as a fan will require a long locked rotor time. Conveyors have a low inertia and do not require a long locked rotor time. It is desirable for a conveyor to have a very gradual acceleration over a fairly lengthy period. This is normally achieved by using an electronic variable speed drive or a mechanical fluid drive coupling. In both cases the motor is not subjected to starting current during the acceleration time.

These are not the only considerations. A complete design would consider the mechanical mounting arrangement, type of bearings, type of coupling, ambient and altitude de-rating, etc.

SPECIFIC MOTOR FEATURES FOR CONVEYOR APPLICATIONS

From a motor electrical design perspective, conveyor applications do not require any specific features. Selection should be as described in the previous section. Often conveyors are in locations where the ambient conditions and mounting arrangement must be taken into account.

DIFFERENT TYPES OF MOTOR INSULATION

In terms of motor insulation the main consideration is thermal characteristics. This really defines the maximum temperature that the motor can reach before the insulation material is damaged. For practical purposes there are three temperature classes to consider: Class B, Class F and Class H. The temperature class is determined as follows:

Total maximum temperature = Ambient + heat rise + hot spot allowance

Ambient is 40°C

Heat rise is the motor rise in temperature when it supplies nominal power. Hot spot allowance makes allowance for the reality of a non-uniform heat rise resulting in certain points within the motor being hotter than others.

The table below gives a summary of the thermal class values.

Motor insulation Thermal Classes in °C			
Insulation Class:	**B**	**F**	**H**
Ambient	40	40	40
Heat rise	80	100	125
Hot spot allowance	10	15	15
Total maximum temperature	130	155	180

Table 3: Summary of thermal class values

Until recently almost all motors were designed and specified with a Class B heat rise and a Class F insulation system. This meant that when operated at 100% full load in an ambient temperature of 40°C the hottest spot in the motor would reach 130°C, while the motor insulation system is capable of operating at 155°C. This gave a margin of safety of 25°C. In recent times and especially in the 525 V mining industry this has changed so that the motors have a Class H insulation system. This then gives a safety safety margin of 50°C. In addition, it is seldom that motors are run at 100% of nominal power.

These temperature classes have nothing to do with dielectric strength or voltage insulating strength or capability to withstand peak voltage capability.

The second consideration in terms of motor insulation is dielectric strength or peak voltage rating of the motor insulation. When a motor is used on 525 V, it does not have 525 V insulation because the peak values of the sine wave and other voltage peaks present are much higher. When used in DOL applications the voltage rating is not really a major concern. This is because most insulation systems can cater for voltage peak values >1000 V. This far exceeds any voltage peak that occurs on a DOL system. In the last number of years the percentage of motors used on AC variable speed drives has increased greatly. On VSD applications the motor insulation dielectric strength is very important. The requirements for VSD applications are dealt with later in this document.

MOTOR TECHNOLOGY DEVELOPMENTS ON THE WORLD MARKET

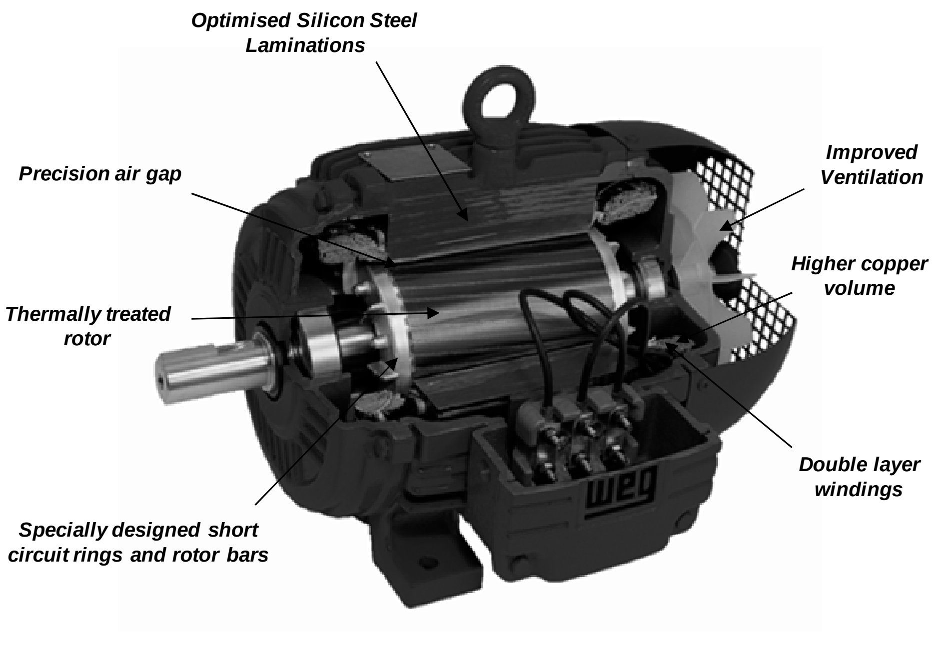
One of the major benefits of an AC motor is its basic simplicity of concept and construction. As a result of this developments happen in small incremental steps rather than quantum leaps. There are several trends or areas of development. These are listed as follows:

1. Premium efficiency motors and motors of even higher efficiency are being developed.
2. Improved insulation is being developed. This results in insulation that is thinner, thereby allowing more conductors to be fitted into a given area. The benefit of this is to achieve a higher power output from a given motor size. At present, the motor frame size and corresponding power rating are specified in IEC60034. This means that even though it is technically possible to deliver a higher power output from a given frame size it may not be done within the IEC specification requirements. In future this may change. At present this benefit is passed on to the user by having a service factor greater than 1.00. So, for example, an IEC standard 250 kW motor in a 355 frame can be rated for a 1.15 service factor. This means that the motor can be loaded to 287.5 kW without damaging or stalling the motor.
3. Permanent magnet motors have been developed by several suppliers. These motors do not depend on a magnetic field that is induced into the rotor. The rotor is fitted with several high power magnets. These motors have the capability to produce at high torque at low speeds when VSD driven. Their efficiency is also much higher than the conventional AC motor. At this stage these motors can not be started DOL. They are only suitable for VSD control. Local repair is also not yet possible. For these reasons permanent magnet motors are not yet practical for general industrial use on a worldwide basis.

PREMIUM OR HIGH EFFICIENCY MOTORS

The subject of premium or high efficiency motors is unclear. There is not a clear understanding as to which efficiency level is correct or applicable: high efficiency, energy efficient or premium efficiency? There is not a clear understanding of which standards that are applicable both internationally and in South Africa. There is also not clarity regarding the possible need for special considerations for selection and use of these motors.

Premium efficiency motors are designed and manufactured according to the same concepts as standard AC motors. There selection, installation and application follows the same engineering principles. The improved efficiency levels are the result of certain refinements or improvements. These are illustrated below.



Motor losses are comprised of three components:

1. Joule effect losses which result from motor current – 80%
2. Iron losses which result from magnetic and flux losses – 12%
3. Mechanical losses which result from friction and windage – 8%

The percentages given above approximate the percentage of losses that can be linked to each component. This will vary between different motors but the order of magnitude will remain the same. The losses are reduced in the following ways:

1. Joule effect losses:
    a. By using more copper, the resistance I of the windings is reduced. Because losses are proportional to $I^2 \times R$, a reduction in R reduces losses.
    b. The winding is composed of two separate windings as opposed to the normal single winding. This results in each individual winding having a smaller overall diameter and thereby a lower heat rise. A lower heat rise results in lower resistance.
    c. The rotor and rotor bars are thermally treated to reduce resistance.
    d. The rotor short circuit rings are designed to reduce their resistance.
2. Iron losses:
    a. The grade of steel used for the motor stator core is a silicone steel that has better magnetic properties than the previous types of core steel. This results in lower magnetic losses and lower magnetizing current.
    b. The smaller the air gap of a motor the less magnetic loss results between stator and rotor. The air gap is thus precision machined to be smaller than previously.
3. Mechanical losses:
    a. The main development here has been to improve the design of the motor cooling fan and fan cowl so that improved air flow is achieved with lower windage losses.

Until recently there were three international standards:
Europe: Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP)
Australia and New Zealand: Minimum Energy Performance Standards (MEPS).
USA: Nema (Nema Premium and Nema EPACT).
The Nema standard was not considered locally due to frame sizes and other technical issues that make the Nema motor standard incompatible with South African standards.
IEC and SANS did not have a standard ready for use at the time that the market in South Africa started focusing in high efficiency motors. Subsequently IEC have issued IEC60034-30. SANS are in the process of adopting and subsequently publishing this standard. Table 4 summarises the standards and their range of specification.

Country	Standard	Power range covered
Europe	CEMEP	1.1 – 90kW
Australia & New Zealand	MEPS	0.75 – 185kW
International	IEC	0.75 – 375kW

Table 4: Summary of standards and their range of specification

The IEC standard is the most comprehensive standard currently on the market presently. Unfortunately IEC have specified efficiency standards that are not in line with the aforegoing established efficiency levels as established by the CEMEP and MEPS standards. The efficiency standards are tabulated in Table 5 in sequence of efficiency from lowest to highest.

Comparison of efficiency standard levels from lowest to highest			
Description	**IEC 60034**	**CEMEP**	**MEPS**
IEC Standard motor	IE1		
CEMEP Improved efficiency		EFF2	B1
IEC High efficiency	IE2		
CEMEP Premium efficiency		EFF1	B2
IEC Premium efficiency	IE3		
MEPS Top Premium efficiency			B3
Super-Premium	IE4		

Table 5: Efficiency standards in sequence of efficiency from lowest to highest

COMPARISON OF EFFECIENCY LEVELS						
4 Pole Motor		**IEC IE1**	**CEMEP EFF 2**	**IEC IE 2**	**CEMEP EFF 1**	**IEC IE 3**
100% Load		**Standard Efficiency**	**Improved Efficiency**	**High Efficiency**	**Premium Efficiency**	**Premium Efficiency**
Motor	Frame					
0.75	90S	72.10	74.40	79.60	82.20	82.50
1.1	90S	75.00	76.20	81.40	83.80	84.10
1.5	90L	77.20	78.50	82.80	85.00	85.30
2.2	100L	79.70	81.00	84.30	86.40	86.70
3	100L	81.50	82.60	85.50	87.40	87.70
4	112M	83.10	84.20	86.60	88.30	88.60
5.5	132S	84.70	85.70	87.70	89.20	89.60
7.5	132M	86.00	87.00	88.70	90.10	90.40
11	160M	87.60	88.40	89.80	91.00	91.40
15	160L	88.70	89.40	90.60	91.80	92.10
18.5	180M	89.30	90.00	91.20	92.20	92.60
22	180L	89.90	90.50	91.60	92.60	93.00
30	200L	90.70	91.40	92.30	93.20	93.60
37	225S/M	91.20	92.00	92.70	93.60	93.90
45	225S/M	91.70	92.50	93.10	93.90	94.20
55	250S/M	92.10	93.00	93.50	94.20	94.60
75	250S/M	92.70	93.60	94.00	94.70	95.00
90	280S/M	93.00	93.90	94.20	95.00	95.20
Average		**85.90**	**86.91**	**88.87**	**90.26**	**90.58**
Difference			**1.01**	**1.96**	**1.39**	**0.33**

Table 6: Comparison of efficiency levels

It is the view of the author that the IEC and SANS efficiency levels should have been chosen according to the already established EFF2 and EFF1 levels. Unfortunately the IEC committee chose to specify efficiency levels that do not correspond with the aforegoing CEMEP and MEPS standards. Each IEC efficiency level is "pegged" in between the other previously established efficiency levels. In addition to this, the IEC IE3 Premium efficiency levels are only marginally above EFF1. Many of the leading motor manufacturers have invested huge amounts to develop and set up manufacturing for Premium Efficiency motors in accordance with EFF1. Much of this may now be changed by IEC's changed levels. This also makes it more difficult for end users to establish a clear policy regarding their choice of motor efficiency levels. If these efficiency levels were a clear progression from EFF2 to EFF1 this would make sense. There is so little difference that either EFF1 or IE3 can be considered as Premium

Efficiency. The IE4 levels of efficiency are not established yet, nor are there motors ready for this. Future developments such as permanent magnet motors may fulfill these efficiency levels.

A “High Efficiency” motor may thus be defined as a motor that meets the efficiency level as defined by IEC60034-30 IE2.
A “Premium Efficiency” motor may thus be defined as a motor that meets the efficiency level as defined by IEC60034-30 IE3. For practical purposes and because of the aforegoing history of EFF1, a motor that meets the efficiency levels as defined by CEMEP EFF1 may also be considered to be a “Premium Efficiency” motor.
It is important to note that the efficiency levels as stipulated by the standards all correspond with 100% of motor nominal power. Most motors do not operate at 100% load. It is therefore important to consider the motor efficiency at 75% load. This should only differ marginally from the efficiency at 100% load. There is no standard for this, however the author suggests a value of 0 – 0.2% as being acceptable. For example a 55 kW motor having an efficiency of 94.6% at 100% load should have an efficiency of ≥ 94.4% at 75% load.

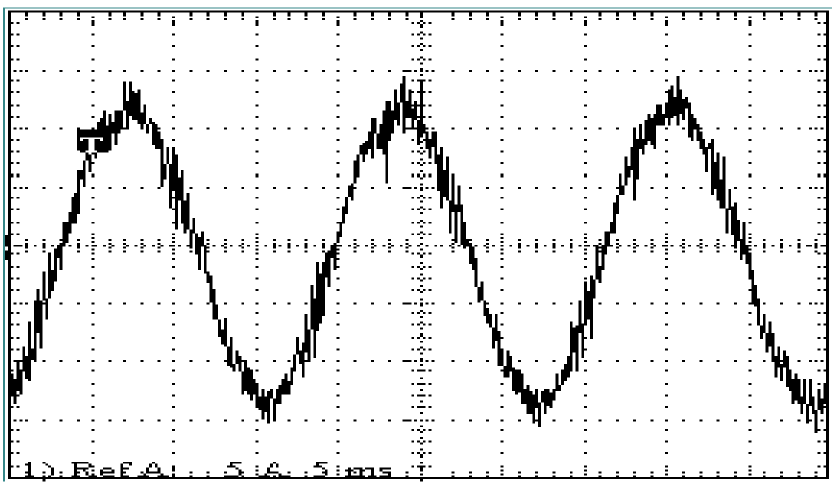
VSD MOTOR APPLICATIONS

There are many benefits to using VSD driven motors on conveyor applications:
1. The conveyor start-up can be controlled optimally and thereby the stress in the belt and structure is minimised
2. The conveyor speed can be varied to cater for differing product or process delivery requirements
3. At times when full production is not required, the conveyor can be slowed down resulting in reduced electrical power consumption and also reduced mechanical wear

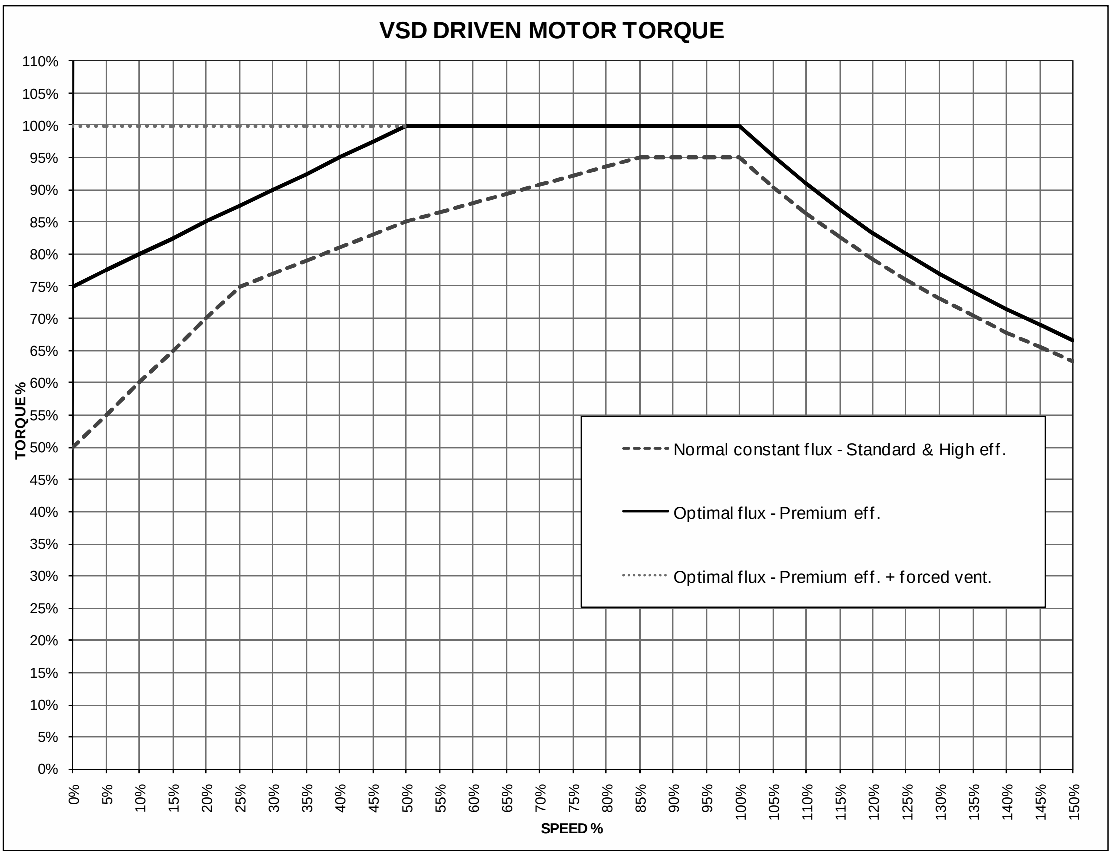
There are many concerns as to AC motor compatibility for VSD applications. In principle any normal AC motor can be used in conjunction with any AC VSD. The VSD will start and speed control the motor. The issue of compatibility affects medium and long term durability and reliability. So, while any AC motor can be driven by any AC VSD this does not necessarily guarantee compatibility. Fortunately this is not difficult to achieve. Compatibility can be considered from four perspectives:

1. The motor thermal capability
2. The motor insulation suitability
3. Mechanical adaptations required on the motor
4. Mechanical speed limitations

The voltage and current that an AC VSD supplies to a motor is not a pure smooth sine wave such as Eskom supplies. The distortion is known as harmonic distortion. This distortion creates additional heat losses of 1 – 5% in the motor. The motor thermal capability and hence it’s torque delivery is reduced by this amount. An AC VSD driven motor current is illustrated below.



An AC motor is dependant on the shaft mounted cooling fan on the non-drive end for cooling air flow. When a VSD is used to slow the motor down this air flow is reduced. As a result the motor thermal capability is reduced. This means that at speeds below 100% the motor can no longer run at 100% nominal current. To compensate for the loss of cooling, the permissible current at which the motor can run is reduced. Current and torque are roughly proportional, therefore the motor capability to deliver torque on its output shaft is reduced. The relationship between speed and torque is illustrated on Graph 4.



Graph 3: The relationship between speed and torque

For example, a motor may be rated at 100 A and 200 Nm. When used in a VSD application this motor can only deliver 95 A and 190 Nm for an extended period of time. If this same motor runs at 25% speed it can only deliver 75 A and 150 Nm at that speed. This is a purely thermal consideration and this limitation only applies to constant operation. The motor may be overloaded for short periods. For example the motor may deliver 150 A and 300 Nm for 60 seconds once every 10 minutes.

Above 100% speed the motor magnetic flux weakens. This is known as “field weakening”. Motor torque is proportional to motor flux therefore in this area the motor torque capability is reduced proportionally to the inverse of the speed.

$$T \alpha \frac{k}{N}$$

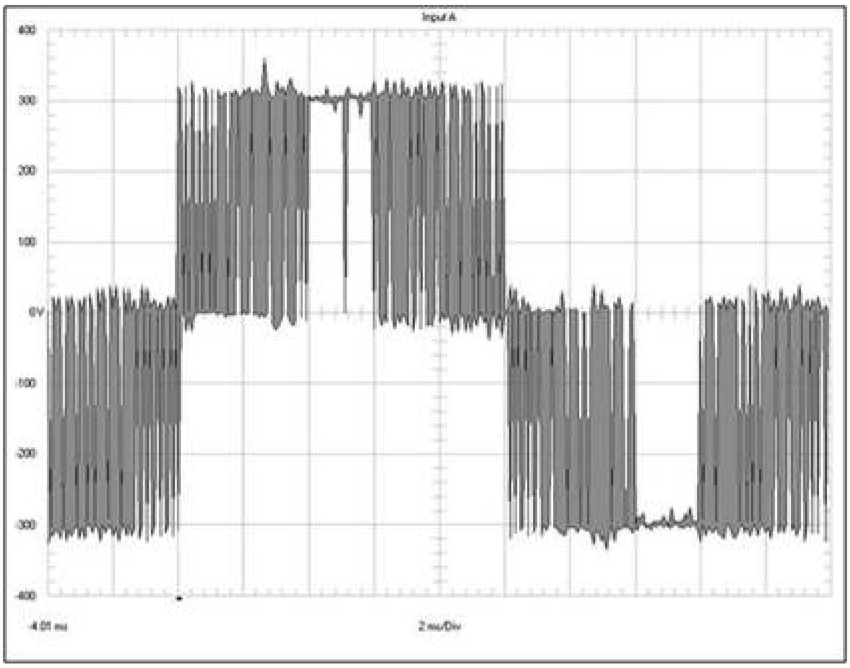
The theory behind this does not need to be known and considered in depth for correct motor selection. The curve as provided in graphs makes this easy. On the curve there are two torque rating curves. The bottom or lower curve is for standard EFF2 WEG motors and the top curve is for EFF1 WEG motors when used in conjunction with a WEG VSD.

The second consideration in terms of motor selection is dielectric strength or peak voltage rating of the motor insulation. IEC60034 Part 17 defines motor insulation requirements for VSD use. The requirements are not however given in a manner that is practically very easy to apply. This standard deals with ≤500 V and then ≥600 V. This leaves a gap exactly for the South African 525 V market. Furthermore the IEC standard links the voltage rating requirement to the rise time of the VSD pulses. This value is very seldom known and therefore not a practical and useful specification. The American Nema MG1 Part 31 has a more practical specification. Nema requires insulation that is ≥ 3.1 x the supply voltage and inverter output rise time > 0.1 µsec. This rise time requirement is generally met and therefore not of concern. Both Nema and IEC refer to “General Purpose” motors and “Definite Purpose” or VSD motors.

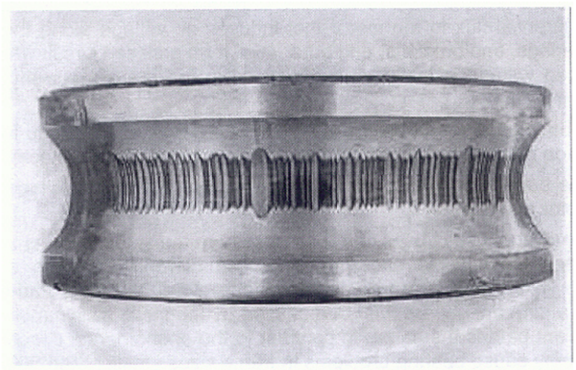
How does the user differentiate between a general purpose and a VSD purpose motor? Which of these motors are stocked and supplied by the motor suppliers? While this may seem problematic, the situation is really simple. In South Africa nobody stocks and supplies “VSD Purpose” motors as a standard. These motors are always specially labeled and identified. There are however, local suppliers that stock and supply “General Purpose” motors that are also designed and manufactured to be suitable for VSD use. These motors have an insulation rating that is ≥3.1 VAC supply in accordance with the Nema MG1 Part 31 mentioned above. So for 525V systems the motor insulation must be ≥ 525 x 3.1 = 1627 V and on 400 V systems the motor insulation must be ≥ 400 x 3.1 = 1240 V.

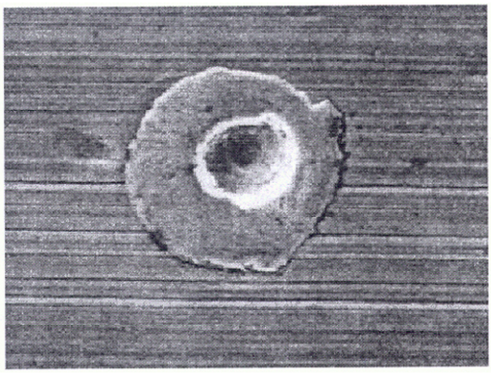
If motors of this standard are used then the user does not have to be concerned regarding the suitability of either new or spare motors for either DOL or VSD use. This means that motor selection on this basis is easy and that these motors are readily available.

The normal 3 phase voltage that a DOL motor would be connected to when started DOL is a balanced sinusoidal waveform. At any point in time the three phases are balanced and their vector sum is zero. In reality the balance is not perfect but the differences are so small that they are negligible. When supplied from a VSD the motor voltage consists of many individual pulses that add to produce a near sinusoidal voltage waveform. (See picture below) The three voltages are not balanced.



This results in voltage being induced into the metal frame of the motor and in the motor rotor. This voltage will cause a current to flow from the motor down to earth. The current flowing from the rotor can only pass through the bearings to go down to earth. The result is pitting which damages the bearing and leads to failure, as illustrated below.





It is a rather complex phenomenon. The solution however is simple. This phenomenon can only build up sufficient electrical field in motors with a frame size greater than a 280 frame. On all VSD application motors of frame size >280 the vendor must be informed. The vendor will then fit an insulated non-drive end bearing and a shaft grounding device on the drive end.

The final consideration is the mechanical speed limitation. The motor bearings are limited to a certain maximum speed. On small motors this is in the region of 6000 RPM but on larger machines the limit is lower.

MOTOR STANDARDS

There are three motor standards for general industrial use AC motors.
SANS / IEC 60034
SANS / IEC 60072
SABS 1804
These standards cover all the specifications and requirements. They are well known and applied by the South African motor industry.

MAINTENANCE

One of the benefits of standard AC motors is that they require very little maintenance. The requirements are listed below:

1. Visual inspection – weekly.
2. Bearing vibration check – monthly.
3. Greasing of bearings – according to the motor greasing plate requirements. This is normally every 2 – 4 months.
4. Check and clean terminal box – annually.
5. Complete overhaul, i.e. dismantle, clean, re-paint, replace bearings, replace any parts that are damaged, re-assemble and re-grease – 3 year intervals.

The above proposed maintenance schedule may be varied according to individual end user or site requirements. Some motors are small and drive unimportant items. The user may elect to do no maintenance and simply replace them as and when required. Some motors drive very critical applications and should be inspected on a daily basis.

If a motor has been inspected regularly, the bearings have received grease according to the stipulated intervals and vibration monitoring does not indicate any problem, then the suggested complete overhaul may be ignored.

In terms of maintenance, the single most important consideration is alignment. The majority of motor failures can be attributed to misalignment. The initial installation must ensure correct alignment. Once in operation the ongoing bearing vibration analysis will show if there is any problem with alignment.

CONCLUSION

Some of the issues related to motors are complicated at a design level; however the solutions and application thereof for the user are simple and clearly defined. This paper has aimed to present this. When the various issues as dealt with in this paper are properly considered the user or designer can have confidence of a successful installation that will operate correctly and efficiently for many years

AUTHOR'S CV

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Johan van Niekerk has worked in the drives industry for 20 years, first gaining practical experience as a technician involved hands on with installations and applications. Thereafter he has been a project engineer, business development manager and drives manager. He is drives and automation manager for Zest Electric Motors & Drives.