OPTIMAL LUBRICATION TECHNIQUES TO IMPROVE RELIABILITY AND MOTOR LIFE EXPECTANCY

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Flaviano Carvalho
WEG Euro – Indústria Eléctrica S.A.
R. Eng. Frederico Ulrich, Z.I. Maia,
Sector V, 4471-908 Maia
Portugal

Pedro Maia
WEG Euro – Indústria Eléctrica S.A.
R. Eng. Frederico Ulrich, Z.I. Maia,
Sector V, 4471-908 Maia
Portugal

Abstract - Oil & Gas operators are in constant search for more reliability and downtime reduction as ways to improve productivity and reduce cost. Electric motors are the core driving force of many processes in the Oil and Gas industry, which implies that an unpredicted or premature failure of a motor may represent significant downtime and cost. This paper focuses on one of the most common sources of early failure in electric motors: bearings. More specifically, it details electric motor bearings lubrication processes and techniques that can contribute to a long and reliable operating life. Different bearing types are analyzed and their specific lubrication criteria for initial operation as well as maintenance procedures. The use of different lubricants other than the one originally supplied with the motor is also addressed. Finally a set of good lubrication practices, including the use of control systems and automatic lubricators, is presented as a way to extend the operating life of electric motors in a wide range of applications.

Index Terms — lubrication, electric motors, reliability, maintenance.

I. INTRODUCTION

Electric motors are running the world, being responsible for consuming more than 40% of the electricity produced globally. [1]

They are present in the simple tools used in daily life and in the most demanding processes in the oil and gas industry, being the effective force that put in motion gas refineries, vessels, mines and many other.

A fail in motor bearings can conduce to catastrophic failures that may include the need for new motor parts or even to motor replacement.

This may increase production costs as it can shut down entire processes.

Avoiding these failures will improve the reliability of the whole production process, allowing to reduce the costs by means of predictive and preventive maintenance procedures.

This paper focus in the best practices and lubrication procedures in order to assure a continuous operation of electric motors minimizing the risk of potential failures.

This work starts by explaining some basic principles of the motor bearing dimensioning during project design by the manufacturer. A brief description of different types of lubrication is presented, followed by best practices in the maintenance of the bearings of electric motors, including long term storage procedures.

Finally, some case studies of failures that occurred due to wrong lubrication procedures are shown and discussed.

II. MOTORS' BEARING DIMENSIONING

Bearings are responsible to allow the rotation of mechanical elements, they can be of different types depending on the application and grouped in: rolling bearings and journal bearings. [2]

One of the most critical step in designing an electric motor is the dimensioning of the bearing and associated components.

A brief description of how the bearings for an electric motor are chosen and dimensioned is enunciated in this chapter.

A. Dimensioning the Bearing System

Being responsible for the majority of failures in electric motors, bearings need to be dimensioned to operate continuously under the applicable conditions.

Several factors may impact the predicted life of these components, some closely associated to design issues and others associated with operational issues.

The dimensioning of a bearing system consists in analyzing the loads of what the bearing will be subjected. In electric motors this load includes the weight of the rotor and any external loads applied at the shaft ends.

Other design factor is the rotational speed of the motor. The combination of these two factors and the respective calculated life will define the type of bearing and its lubrication.

Regarding the bearing related components, some elements can be defined as critical for the correct behavior of the motor [3]:

- Bearing seat and housing fits, allowing an even distribution of loads in the bearing;
- Axial displacement of one end of the shaft to allow for thermal growth of the rotor;
- Preload of the bearings, maintaining a smooth and constant contact between balls and races;

In Fig. 1 and Fig. 2 two examples of shaft expansion are shown.

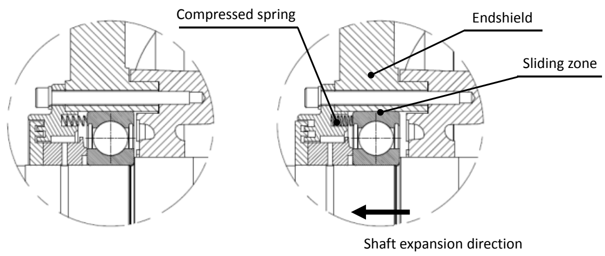


Fig. 1 – Shaft expansion with ball bearings

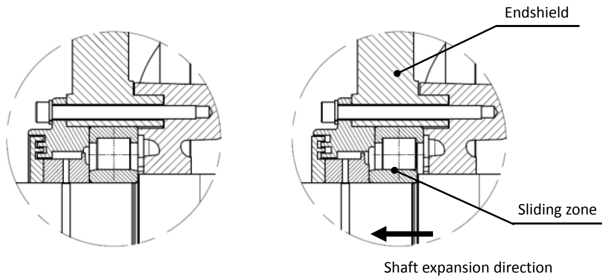


Fig. 2 - Shaft expansion with roller bearings

B. Loads and Speeds

Choosing the correct bearing size and type for a specific application of the electrical motor is essential to allow the machine to be reliable and achieve its estimated life without failures.

The first dimensioning step is to define which should be the shaft end to sustain the load in both fatigue and static criteria. This will define the minimum size of the drive end bearing.

The second step is to select a bearing arrangement that can sustain the weight of the rotor at operation speed with the desired life expectancy (L10h).

As the bearing size increases for motors of higher power, their speed limit decreases.

Journal bearings allow to break this limitation, allowing to support a much higher load with higher speeds. [2]

In Fig. 3 a schematic drawing of a rotor is shown with reference to the internal and external loads on the bearings.

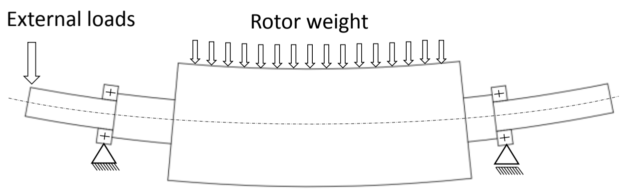


Fig. 3 – Schematic drawing of rotor of electric motor

C. Influence on Motor Behavior

The rotor dynamics of an electric motor, especially two and four pole motors, are of major importance to guarantee low vibration and noise in the motor and is even critical to maintain its integrity.

The rotor behavior is mainly influenced by its own mass and the stiffness and damping of the bearings.

The aim of these analyses is to obtain the rotor natural frequencies and to keep them far from any excitation frequency.

Rolling bearings have a nearly constant stiffness for a determined load. In the opposite, journal bearing stiffness and damping are highly dependent of operation conditions.

The oil film thickness will change with load, temperature and speed, and consequently change the rotor natural frequencies.

Thus, journal bearing machines operating with variable speed drives must be detailed studied to guarantee that it does not operate on any natural frequency of the rotor.

Fig. 4 shows an example of a Campbell diagram where several natural frequencies are identified. The thin lines in the near horizontal position represent each vibration mode changing with speed due to the variation of bearing stiffness and damping coefficients.

Fig. 5 represents the amplitude response of the same rotor, where the amplification of an imbalance is plotted.

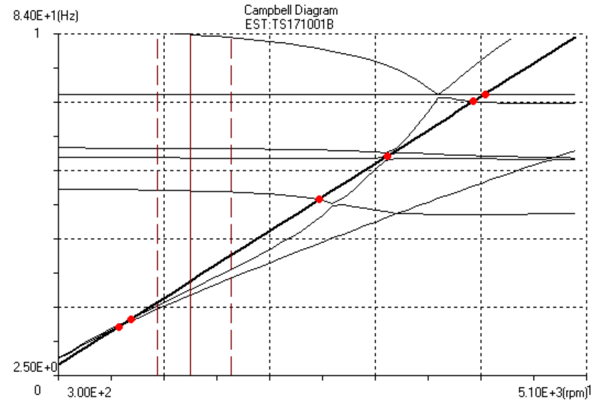


Fig. 4 – Example of Campbell diagram for journal bearing motor

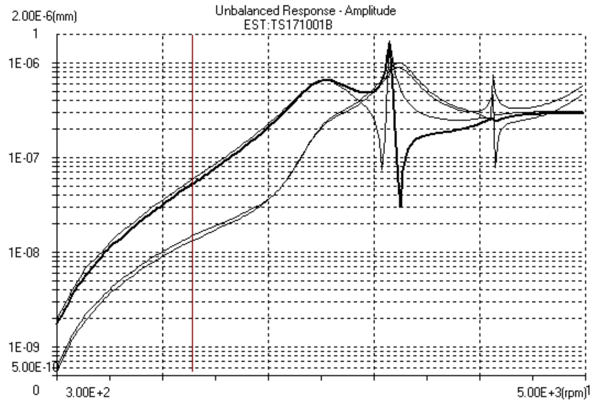


Fig. 5 – Example of amplitude response to imbalance

III. TYPES OF LUBRICATION

Lubrication is the mean to prevent or reduce the contact between rotating parts. Maintaining low friction between parts and consequently reducing the wear. [4]

A. Grease Lubrication

Grease is the most common lubricant in electric motors, used for wide ranges of temperatures and operating conditions.

The use of grease lubrication allows the use of a simple construction of the housing and its related components. As a downside, grease higher viscosity limits the speed of the bearings when compared with oil lubrication. [2]

B. Types of Greases and Their Application

The grease used in roller bearings is composed of a base oil, a thickener and additives. Its working principle relies on the bleeding process, the release of oil from the thickener to the bearing. [5] This process is mainly influenced by the viscosity of the grease, as a high viscous grease will tend to release less oil.

Schaeffler [4] refers that according to failure statistics the three principal causes of bearing failures are:

- Unsuitable lubricants;
- Aged lubricants;
- Lubricant starvation.

Thus, the selection of the correct grease is decisive to make to guarantee the reliability of the motor.

The most common oils are:

- Mineral;
- Polyglycol;
- Ester;
- Silicone oil;
- Alkoxyfluoro oil.

The most common thickeners are:

- Lithium;
- Lithium complex;
- Barium complex;
- Calcium complex;
- Bentonite.

Several combinations of oils and thickeners can be found in the literature with a description of their optimal operating conditions such as the range of temperatures and resistance to contaminants. [4]

C. Oil Film Lubrication

Oil lubrication may be used in both rolling bearings and journal bearings.

In the particular case of the journal bearings, its working principle consists in the creation of a thin film of oil (some microns) that sustain the rotor of the motor and avoid rubbing and wear between parts.

The oil film height influences greatly the life of the motor, as a very low oil film will eventually conduce to punctual rubbing between shaft and bearing and considerably reduce the life expectancy of the bearing.

In the design process the size of the journal bearing and the oil viscosity is chosen so it is able to sustain the weight of the rotor, any external loads informed by customer and the speed range of the motor.

Reinforcing that the variation of the speed of the motor changes the dynamic behavior of the rotor and needs to be thoroughly analyzed.

IV. MAINTENANCE OF MOTOR BEARINGS

A. Storage

Oil and gas projects extend normally during long periods of time. The engineering teams select and acquire electric motor for the application in the early stage of the project, but the final installation and commissioning of the project may take months or even years.

Electric motors exposed to long periods of storage need to be subjected to periodic maintenance procedures to guarantee the optimum condition of their components.

One of the most important aspects is the lubricant of the bearings. An incorrect maintenance of the motor bearings and lubricant may conduce to premature failures in start-up and consequently heavy costs due to delays in the production schedule.

B. Short-Term Storage

For storage periods of up to two months care must be taken to verify the overall conditions of the motor. [6]

To start-up the motor it is recommended to lubricate the bearings with the grease type and quantity defined by the motor manufacturer or with an equivalent one.

If the motor is supplied with automatic lubrication devices they need to be turned on when the motor is put in operation. [7]

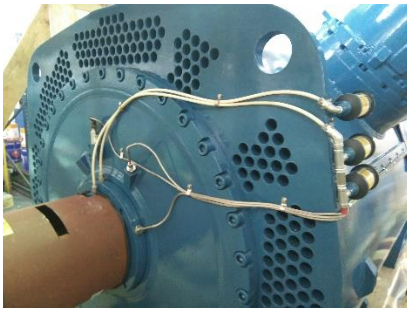


Fig. 6 – Medium voltage flameproof motor fitted with automatic lubricators

C. Long-Term Storage

For longer periods of storage, or when storage conditions are considered harsh for the equipment, it is recommended to proceed with the complete verification of the motor condition. [6]

Every two months the motor shaft must be rotated while in storage to have the grease homogenized.

Cleaning of the lubrication circuit and the bearings of old grease is vital to guarantee the correct operation of the electric motor.

Leaving hard old grease stuck inside the bearing and bearing caps will impede the entry of new grease to the bearing even if lubrication attempts are made.

This old grease will conduce to poor lubrication of the bearing and consequently to very high temperatures mainly in the inner race and thus cause heavy damage not only to the bearing but also to the overall motor.

In electric motors that may be equipped with automatic lubrication devices the end user must clean all the grease path before turning on the lubricator. [7]

D. Bearing Condition Monitoring

Following the correct lubrication procedures it is possible to extend considerably the expected life of the bearing. Nevertheless, anti-friction bearings have a limited life, defined by statistical analysis of bearing manufactures (ex: L10h).

Monitoring the bearings temperatures and vibrations, are vital to access their behavior and to obtain information about their current state and predictable life.

Zhang et al. [8] divide the bearing failures in three groups:

- Thermal stresses;
- Mechanical stresses;
- Electrical stresses

Both of them may cause bearing failures in electric motors, and contribute to deteriorate the lubricant of the bearings and conducing to a quicker fail.

E. Temperature Monitoring

Monitoring the bearing temperature and setting the alarm and trip values informed by the motor manufacturer may eliminate the occurrence of catastrophic failures.

In addition to this, the bearing operating temperature and consequently the lubrication optimum performance must be controlled to guarantee that the lubricant properties are maintained and the lubrication intervals set according to these temperature values.

Zhou et al. [9] considers the temperature monitoring as a useful mean to access the information about the electric motor health. Nevertheless, the authors also state the limitations of this type of condition monitoring, including the impossibility to completely determine the cause of the bearing overheating without additional data from other methods.

F. Vibration Monitoring

Vibration monitoring is an effective method not only to detect bearing faults, but also identify them with regard to which bearing component is responsible for the potential damage.

Fig. 7 and Fig. 8 represent two different vibration spectrums that can be obtained in bearing analysis.

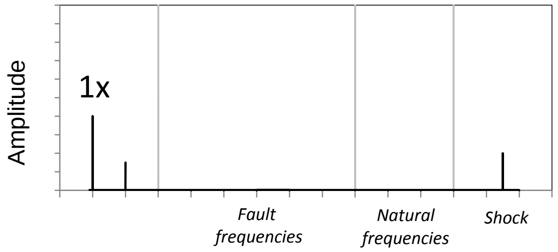
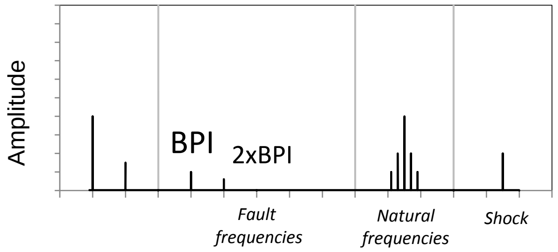


Fig. 7 - Bearing early life vibration spectrum



BPI - bearing fault frequency

Fig. 8 – Bearing advanced failure vibration spectrum

The limits for trip and alarm of vibration are defined for example, in ISO 10816 [10], consisting in two different approaches:

- Vibration limit values – defining the limit values considering the typology of the electric motor and its application;
- Vibration limit change – considering not only the value but also abrupt changes in value even if the value is within allowable limits.

G. Particular Cares in Explosion Proof Motors

Explosion proof motors are present in multiple applications throughout refineries, platforms and other oil and gas installations.

Bearings operation temperature is influenced by changes in load, changes in ambient temperature, lubrication conditions and multiple other variables that may affect their operating temperature.

Monitoring of the motors' bearing temperature is then critical to assure the efficient protection against the risk of explosion.

A bearing subjected to poor lubrication procedures may reach temperatures clearly above the gas auto-ignition temperature and be responsible for the high risk of explosion if left unmonitored.

H. Lubrication Procedures and Good Practices

Conducing adequate maintenance procedures is vital to keep the bearings in good condition and extend their life and the life of the motor. Keeping the motor running with old or without grease may heavily damage the bearings. Cann et al. [11] performed multiple tests with rolling bearings to study the distribution and degradation of the grease.

I. Good Practices in Rolling Bearings

The lubrication of the bearings must be made using the correct quantity and a grease compatible to the one supplied with the motor.

Using excessive quantities of grease may cause bearing overheating and consequently reduce the grease quality.

As a best practice it is recommended to have a grease quantity meter (see Fig. 9) to supply the exact quantity of grease to the bearings.

Fig. 9 – Example of grease flow meter

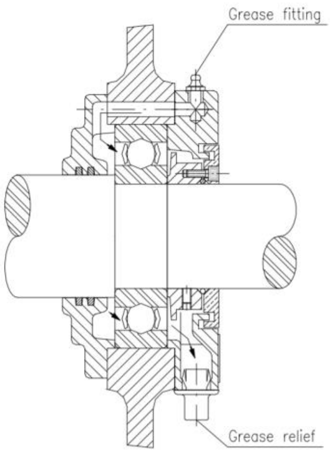


Fig. 10 – Grease circuit in bearing assembly

The grease fittings and surrounding areas must be cleaned before lubrication to avoid dust to enter the grease flow and damage the bearings.

During the lubrication it is possible to notice a slight increase of bearing temperature. This rise is temporary and should disappear after one hour of operation.

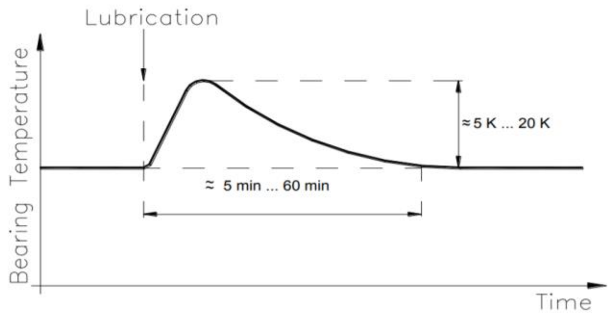


Fig. 11 – Bearing temperature after lubrication

J. Good Practices in Sleeve Bearings

Sleeve bearings can theoretically have infinite life [2], nevertheless this can only be achieved with correct operation conditions (temperature, lubrication, loads, etc.).

This kind of bearings may be self-lubricated or work with forced lubrication.

In self-lubricated bearings the oil should be changed according to motors' nameplate quantities and intervals.

In forced lubricated bearings the respect for oil supply temperature and flow are critical no only to the long life of the bearing but also to the stability of the motor behavior.

If the supply of oil is too high or too low the oil film thickness and consequently the support stiffness will change. This change will eventually affect the rotor dynamics of the motor and possibly conduce to instable operation.

The oil used must be of the same viscosity grade as indicated in motor's nameplate in order to keep its desired properties.

K. Bearings Replacement

Even with best practices in maintenance and lubrication the bearings will eventually reach their expected lifetime.

The correct replacement of the bearings and grease is therefore of vital importance to guarantee the operation of the motor after maintenance. Any bad procedure in these works may lead to considerable loss of motor expected life and reliability.

1) *Removing Old Bearing*: Removing correctly the old bearings avoid damage in the shaft. This damage, if it occurs, may oblige to disassemble to rotor and perform machining operations to recover the parts. For flameproof motors, where tight flame paths are found, any recover by machining of the shaft is critical and must follow the IEC 60079-19 [12].

2) *Heating the Bearing*: The heating up of the bearing must be performed using appropriate equipment, granting and uniform controlled temperature to avoid any overheating of the bearing.

The use of direct flame is not recommended as it may overheat the bearing in some areas.

Fig. 12 – Induction heating machine for bearings

3) *Bearing Grease*: Filling the grease with the recommended amount of grease will conduce to a smooth bearing operation without overheating due to lack or excess of grease.

Too much grease will block the bearing thermal dissipation and conduce to overheating.

Fig. 13 – Bearing assembled with grease

V. CASE STUDIES

Field experience shows that the lubrication has a huge impact on motor reliability. Bad procedures will in most cases reduce the expected life of the bearings that left uncontrolled may conduce to catastrophic failures that may end the life of the motor.

In this chapter several field cases are shown with different failure causes.

A. Start-Up after Long Storage Period without Bearing Cleaning

Data of application: motor stored for more than two years without lubrication procedures. Start-up of the motor realized without cleaning and lubricating the bearings. (Old and crystallized grease in bearing - Fig. 14).

Fail: motor bearings overheating, causing the motor was being removed from application to conduce bearing and grease replacement.

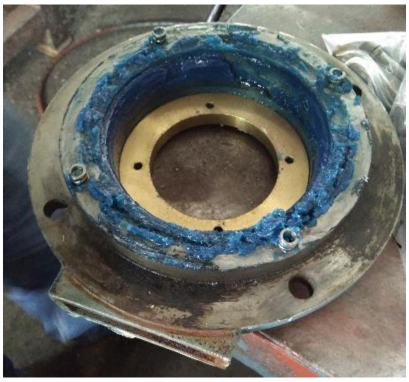


Fig. 14 – Old hardened grease in bearing cap

B. Non-Compatible Grease

Data of application: motor operated lubricated with grease not compatible with originally supplied grease.

Fail: Grease incompatibility caused a reaction that invalidated the properties of both greases. (Fig. 15) the bearings started to overheat due to lack of lubricant.

Fig. 15 – Non-compatible grease mixture in bearing housing

C. Stray Currents

Data of application: motor operated with high stray currents imposed by application. The motor was not installed with insulated bearings.

Fail: Grease was burned due to the constant sparks that occurred in the bearings. (Fig. 16) Increase in bearing noise and temperature due to bad lubrication.

Fig. 16 – Burnt grease due to stray currents in bearing

D. Lack of Lubrication Oil

Data of application: motor with high thrust bearings operated with oil leak in the bearings.

Fail: Oil film thickness was reduced until bearing and rotor started to rub. (Fig. 17) Increase in bearing noise and temperature.

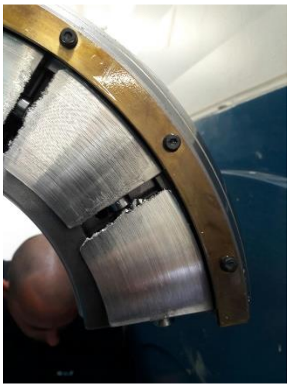


Fig. 17 – Rubbing of bearing thrust pads

VI. CONCLUSIONS

The lubrication may be considered a turning point when evaluating the life of a motor. It influences considerably the operation behavior of bearings that in turn condition the reliability of the motor.

Good installation and maintenance procedures are the first step to avoid critical failures in electric motors, increasing the expected life of both bearings and motors.

The referred procedures should be supported with additional data from sensor installed in the motor, to allow the monitoring of temperature and vibrations.

In the new age of industry, the Internet of Things allows the live acquisition and treatment of large volumes of data which allow the end users to perform a detailed analysis of complete installations in one control room.

These capabilities will certainly allow a better understanding of fault mechanisms and allow the preventive actions needed to increase the life expectancy of the motor.

Finally, the monitoring of temperatures and care with lubrication procedures is even more critical in hazardous areas electric motors in order to avoid the overheating of parts that may be subjected to a dangerous atmosphere.

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VIII. VITA

Flaviano Santia´ de Carvalho graduated from the University of Santa Catarina State in 2001 with an honors degree from CREA-SC. He has been the Manager for the Department of Service at WEGeuro and Regional Europe Service since 2014 and a total of 15 years with Service Experience in Electrical motor. Authored a paper in PCIC Middle East 2017.
flaviano@weg.net

Pedro Maia graduated from the University of Porto in 2013 with a Master in Mechanical Engineering. He participated in research works in biomechanics at INEGI Porto and composite materials at ILK Dresden. He has been a research and development engineer for WEGeuro since 2013. In 2016 he joined the national technical committee 70 and authored a paper in PCIC Europe 2016 and PCIC Middle East 2017.
pmiguel@weg.net