Bearing Faults Condition Monitoring – A Literature Survey

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Abstract – Bearing related faults are one of the most common causes of failure in electrical machines. By means of advanced diagnosis methods it is possible to detect these faults in their incipient phase, before the catastrophic effects of the failures can occur. The aim of this paper is to make a brief survey of the condition monitoring techniques used in the field of bearing fault diagnosis.

Keywords: bearing faults, diagnosis, induction machines, fault detection, condition monitoring.

I. INTRODUCTION

In most industrial processes unplanned stops due to failures have a high economic impact on the cost of the process and it may result in significant process down time. The fault can occur in any part of the machine or even in the drive system. The faults of electrical machine could be electrical or mechanical. The main electrical faults are the stator and rotor windings (or cage) faults [1], [2]. Mechanical faults include bearing faults, air-gap eccentricity, misalignment, gearboxes faults, etc.

The research on fault diagnosis has shown that the most of the failures of induction machines (about 40%) are related to the bearings [3]. The bearing related faults do not cause immediate breakdown, they evolve in time until they produce a critical failure of the machine. Unfortunately these failures results both in costly repair and downtime.

The bearings faults can be caused by material fatigue, overheating, harsh environments, inadequate storage, contamination, corrosion, wrong handling and installation, etc. But the main cause of their failure is due to poor lubrication, which can be easily avoided by a correct maintenance plan.

Vibration based monitoring techniques are usually applied for the diagnosis of the bearings. Unfortunately these methods require vibration sensors and special equipment for the condition monitoring. They also need access to the machine under testing, which is not always possible.

Compared to the methods above, the current monitoring requires only (frequently already existing) simple and cheap current sensors.

The current monitoring based techniques can be used to detect a large number of faults: broken rotor bars [4] [5], shorted windings, air-gap eccentricity [6], bearing faults [7], load faults, etc.

These methods are non-intrusive and can be applied both on-line and in a remotely controlled way.

II. BEARING FAULTS

A rolling-element bearing is generally composed of two rings, between which a set of balls or rollers rotate in raceways. In most cases, bearing failures are the result of material fatigue of the bearing. Under normal operating conditions fatigue failure begins with small cracks, located inside the surfaces of the raceway and rolling elements.

The repetitive impacts between the components of the bearing and the faulted surfaces cause the cracks to gradually propagate and expand, generating an increase in vibrations and noise levels [8].

The repetitive stressing of the damaged area causes the detachment of some small fragments of the material, which produce a phenomenon known as flaking or spalling [9].

The pattern of the vibration signal consists in a succession of oscillations which repeat with each pass of a moving component over the fault [10]. The repetition frequency of the impact depends on the position of the fault. The fault can be on the inner race, the outer race or on the rolling element.

The typical construction and sizes of a ball bearing is shown in Fig. 1. The balls are fixed and held together by a cage which prevents the contact between the balls and ensures a uniform distance between them.

![Figure 1. Main bearing dimensions and characteristic fault frequencies [1]](image)
the location of the fault: inner race, outer race, balls, and cage [7].


A. SINGLE-POINT DEFECTS

A single-point defect can produce different characteristic fault frequencies in the vibration spectrum of the machine. These frequencies are predictable and depend on the surface of the bearing which contains the fault [12].

The single-point defects cause periodic impulses in vibration signals. Amplitude and period of these impulses are determined by shaft rotational speed, fault location and bearing dimensions. Therefore, a specific frequency can be attributed to each component of the bearing [13].

The fundamental cage frequency is given by:

\[ f_c = \frac{f_r}{2} \left( 1 - \frac{d}{D} \cos(\alpha) \right) \]  

(1)

The ball defect, respectively the inner race defect frequencys can be computed by using the following equations:

\[ f_{id} = \frac{D}{d} f_c \left( 1 - \frac{d^2}{D^2} \cos^2(\alpha) \right) \]  

(2)

\[ f_{od} = n(f_r - f_c) = \frac{n f_r}{2} \left( 1 - \frac{d}{D} \cos(\alpha) \right) \]  

(3)

The formula for computing the outer race defect frequencies is the following:

\[ f_{od} = n f_c = \frac{n f_r}{2d} \left( 1 - \frac{d}{D} \cos(\alpha) \right) \]  

(4)

where, \( f_r \) is the rotor speed, \( n \) the number of balls, \( d \) the diameter of the ball, \( D \) the pitch diameter of the bearing and \( \alpha \) the contact angle as shown in Fig. 1. The typical value of the contact angle is 0°.

For most bearings with six to twelve balls, the frequencies given by (3) and (4) can be approximated with [13]:

\[ f_{id} = 0.6 \cdot n \cdot f_r \]  

(5)

\[ f_{od} = 0.4 \cdot n \cdot f_r \]  

(6)

It is known that any air-gap eccentricity produces anomalies in the air-gap flux density, which is reflected on the stator current. In the case of a bearing fault the characteristic fault frequencies are modulated by the electrical supply frequency at a predictable frequency [13].

\[ f_{ses} = [f_s \pm m \cdot f_r] \]  

(7)

where \( f_s \) is the electrical supply frequency, \( f_r \) one of the fault frequencies defined by equations (1)+(4) and \( m = 1, 2, 3... \)

B. GENERALIZED ROUGHNESS FAULT

Generalized roughness fault is the most frequent cause of bearing failure. It usually occurs in the industrial environment due to various causes such as [12]:

- Lack or loss of the lubricant, contamination of lubricant
- Misalignment
- Shaft currents
- Environmental conditions (dust, water, acid and humidity).
- Bearing corrosion, produced by the presence of water and acids.

These causes lead to a faster wear of components of the bearing, especially raceways and balls. They produce generalized roughness fault, as well as single-point defects. A generalized roughness fault of a bearing can be easily determined because it spins roughly or with some difficulty.

III. CONDITION MONITORING OF BEARING FAULTS

A significant part of the papers on the fault diagnosis of induction machines are dealing with on the faults of rolling bearings.

Even though that vibration based condition monitoring techniques are usually applied for the diagnosis of the bearings, many papers use the stator current analysis, due to its advantages.

The methods used for stator current analysis decompose and analyze the signal using various techniques such as Fourier analysis, neural networks, wavelets, statistical analysis, etc.

In [14] the authors analyze two types of bearing faults: a hole drilled into the outer raceway and an indentation produced in the inner and outer surface. Vibration and current analysis is applied to both faulty conditions.

The specific characteristic fault frequencies are highlighted for both faults. The analysis of the first fault shows two components, \( f_{od} \) and \( 2f_{od} \) in the vibration spectrum, and \( |f_s | \pm f_{od} \) and \( |f_s | \pm 2f_{od} \) in the current spectrum. For the second type of fault the highlighted characteristics are \( f_{od} \), \( 2f_{od} \) and \( f_{od} \) for the vibration spectrum, and \( |f_s | \pm f_{od}, |f_s | \pm 2f_{od} \) and \( |f_s | \pm f_{od} \), for the current spectrum.

In [27] the authors introduce a new formulation for the current spectral analysis for the detection of bearing failures in induction motors driven by frequency power converters. The fault is an outer race defect and the authors highlight an increase of the specific fault frequencies components of the current spectrum.

In [15] two inner raceway faults (drilled hole and spalls) are studied using vibration and current analysis. The results show that the fault frequencies are clearly visible only in the vibration spectrum. The authors state that the assembling, disassembling, remounting and
realigning the test motor can alter the vibration and current spectra.

Figure 2. Example of artificially drilled holes in the outer raceway of a bearing [16].

Some authors studied the detection of faults in electrical machines by using the stray flux around the motor [17], [18], [19], [20], [21], [22]. In [20] a small active area sensor was used for the detection of eccentricity and bearing faults. For the bearing fault analysis, a hole was drilled in the inner race of the bearing. Current and stray flux measurements were effectuated under different loading conditions. The spectra of the signals were obtained using Fast Fourier Transform (FFT). The characteristic fault frequencies were almost the same in both spectra, current and flux, but the amplitudes of these components were low in both cases.

In [16] the Park's Vector Approach is used for the detection of broken bearings. The analysis is made on a four bearings with drilled holes in the inner race and outer race. One of the bearings has two drilled holes in the outer race. The authors concluded that the diagnosis of the inner race faults is more difficult because of vibration signal is weak and it is not fully transmitted to the outer race. The results show a good detection of the faulty conditions.

The Park's Vector Approach was also used in [23] for the diagnosis of three bearings with different diameter holes in the outer race. The proposed method showed good results in detecting even an incipient fault can be detected using this method. This paper also presents a new technology for artificially introducing bearing faults such as: pitting, fluting or false brinelling. The method consists in removing the pins of the cage, so all the bearing components can be accessible.

In [24] the Continuous wavelet transform (CWT) is used for the extraction of characteristic features from vibration signals measured for induction machines subjected to bearing fluting. The faults of the bearing were obtained artificially by using an Electrical Discharge Machining (EDM) and thermal ageing. The proposed method was compared with Short-Time Fourier Transform and it was highlighted that the CWT has some advantages. By using the CWT the authors were able extract small amplitudes that cannot be observed along the frequency axis. Also, they found extra amplitudes caused by the damage of the bearing between 2-4 kHz.

In [25, 26] the broken bar and bearing faults (inner race defect) of several inverter-fed induction machines are studied with a new hybrid algorithm that combines the analysis of the signal in time and frequency domain. This new method uses a combination between Independent Component Analysis (ICA) and FFT in order to analyze features of the stator current. ICA is a statistical technique for decomposing a complex dataset into independent subparts. The authors state that proposed method detects and classifies correctly the characteristic fault frequency components. In the case of bearing faults, the detection is more difficult. It is shown that the predominant characteristic fault frequency is given by $f_{sd}$.

For bearing fault diagnosis other authors have used different methods such as: neural networks [28], hidden Markov modeling [29], instantaneous power factor [30], etc.

IV. CONCLUSIONS

The literature reviewed in this paper aims to investigate the possibility of employing the analysis of the stray flux and stator current for bearing fault detection of induction machines in future papers.

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REFERENCES


