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Time-frequency vibration analysis for the detection of motor damages caused by bearing currents

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ABSTRACT

Motor failure due to bearing currents is an issue that has drawn an increasing industrial interest over recent years. Bearing currents usually appear in motors operated by variable frequency drives (VFD); these drives may lead to common voltage modes which cause currents induced in the motor shaft that are discharged through the bearings. The presence of these currents may lead to the motor bearing failure only few months after system startup. Vibration monitoring is one of the most common ways for detecting bearing damages caused by circulating currents; the evaluation of the amplitudes of well-known characteristic components in the vibration Fourier spectrum that are associated with race, ball or cage defects enables to evaluate the bearing condition and, hence, to identify an eventual damage due to bearing currents. However, the inherent constraints of the Fourier transform may complicate the detection of the progressive bearing degradation; for instance, in some cases, other frequency components may mask or be confused with bearing defect-related while, in other cases, the analysis may not be suitable due to the eventual non-stationary nature of the captured vibration signals. Moreover, the fact that this analysis implies to lose the time-dimension limits the amount of information obtained from this technique. This work proposes the use of time-frequency (T-F) transforms to analyse vibration data in motors affected by bearing currents. The experimental results obtained in real machines show that the vibration analysis via T-F tools may provide significant advantages for the detection of bearing current damages; among other, these techniques enable to visualise the progressive degradation of the bearing while providing an effective discrimination versus other components that are not related with the fault. Moreover, their application is valid regardless of the operation regime of the machine. Both factors confirm the robustness and reliability of these tools that may be an interesting alternative for detecting this type of failure in induction motors.

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1. Introduction

Over recent years, many industrial users have reported bearing damages in motors operated with variable frequency drives (VFD). After intensive research in the area, most of these failures have been attributed to the appearance of bearing currents caused by the VFD operation [1]. More specifically, these currents are due to the existence of a common mode voltage in the drive system; as pointed out in [2], while a typical three phase sinusoidal power supply is balanced and symmetrical under normal operation conditions (hence, the neutral is at zero level), in a PWM switched three phase power supply, perfect balance between phases is not achieved instantaneously; this causes a potential between the inverter output and earth which will force currents through stray impedances in the motor cables and motor windings (this is known as common mode current [2]).

More concretely, different studies have revealed that bearing currents can be classified into several categories, each of them having different origin [3]. Depending on aspects as motor size, one or other type of current will prevail. In small motors (rated less than 30 kW), the common mode voltage will cause a voltage drop between the inner and outer race of the bearing. This will create high frequency bearing current pulses that will flow through the capacitive coupling of both races. This can happen in installations where the shaft is not grounded via the driven machinery [2,4–5]. On the other hand, in large motors (with rated powers above 100 kW and frame sizes above IEC 315 [2]) high frequency bearing currents are induced in the motor shaft due to asymmetrical flux distribution in the motor. Voltage pulses fed by the inverter contain such high frequencies, that the capacitances between the motor windings and its frame provide paths for currents to leak to earth. This will induce a voltage difference between the ends of the shaft. If this voltage difference is high enough to reach the breakdown voltage of the bearing oil film, a current will flow through the bearing [2,5]. A third type of bearing current may circulate when the VFD common voltage mode saturates the stator winding capacitance and it discharges via the grounding system. The leakage current returns to the inverter via the grounding circuit, seeking the lowest impedance paths. If the motor shaft is grounded via the load and impedance path to the load is low, a part of the leakage current can flow through the bearings, shaft and driven machinery back to the inverter. This third type of bearing current is known as shaft grounding current; it is caused by poor stator grounding and only appears if the coupling motor-load is conductive [2]. It can appear for any motor size.

The circulation of these currents may lead to shorten the life of the bearings: although failure rates may vary widely depending on many factors, evidence suggests that a significant portion of failures occur only 3 to 12 months after the system starts its operation [4,6]. Bearing currents may damage the contact surface on the bearing balls as well as the bearing rings. The metal is progressively heated and small craters may appear on the surface of the material (arcing, pitting and fluting of the bearing race). This effect is often accompanied by a discoloration in the balls. Fig. 1 shows the picture of a real bearing that was damaged due to the circulation of bearing currents: note the damaged inner ring with a characteristic washboard pattern caused by fluting effect [1,4] (Fig. 1(a)). Note also the characteristic matt grey colour of the balls (Fig. 2).

To mitigate the effects of shaft currents, two main strategies have been proposed [4,6]. These are based on diverting the induced shaft current from the bearings by: 1) insulating the bearings and/or 2) providing an alternative path to ground. Based on these strategies there are a number of technologies nowadays available in the market: Faraday shields, insulated bearings, ceramic bearings, conductive grease, grounding brush, bearing protection rings, etc.. However, as [6] points out, few of them meet all the criteria of effectiveness, low cost, and application versatility. Due to these facts, the real implantation of these technologies to prevent bearing currents is still scarce in many industrial sites.

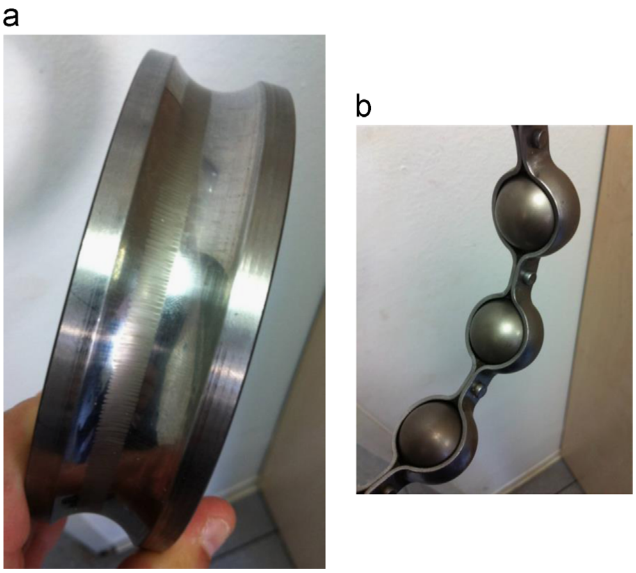

Fig. 1. Effects of bearing currents on a real bearing: (a) surface roughness of a bearing race caused by fluting effect, (b) Matt-grey colour of bearing balls. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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