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Mechanical Systems and Signal Processing 20 (2006) 1572–1589

Mechanical Systems and Signal Processing

www.elsevier.com/locate/jnlabr/ymssp

A validated model for the prediction of rotor bar failure in squirrel-cage motors using instantaneous angular speed

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Received 14 September 2004; received in revised form 12 September 2005; accepted 15 September 2005
Available online 25 October 2005

Abstract

Instantaneous angular speed (IAS)-based condition monitoring is an area in which significant progress has been achieved over the recent years. This condition monitoring technique is less known compared to the existing conventional methods. This paper presents model-predicted simulation and experimental results of broken rotor bar faults in a three-phase induction motor using IAS variations. The simulation was performed under normal, and a broken rotor bar fault. The present paper evaluates through simulating and measuring the IAS of an induction motor at broken rotor bar faults in both time and frequency domains. Experimental results show a good agreement with the model-predicted simulation results. Three vital key features were extracted from the angular speed variations. One feature is the modulating contour of pole pass frequency periods in time domain. The other two features are in frequency domain. The primary feature is the presence of the pole pass frequency component at the low-frequency region of the IAS spectrum. The secondary feature which are the multiple of pole pass frequency sideband components around the rotor speed frequency component. Experimental results confirm the validity of the simulation results for the proposed method. The IAS has demonstrated more sensitivity than current signature analysis in detecting the fault. This research also shows the power of angular speed features as a useful tool to detect broken rotor bar deteriorations using any economical transducer such as low-resolution rotary shaft encoders; which may well be already installed for process control purposes.

Keywords: Instantaneous angular speed (IAS); Condition monitoring; Induction motor; Broken rotor bar fault; Pole pass frequency; Modulation

1. Introduction

Three-phase induction motors are by far the most common type of industrial drive, and although they are relatively reliable, they do inevitably breakdown, and hence need to be condition monitored. Condition monitoring of these machines is notoriously difficult because of the complex combination of mechanical and magnetic effects that occurs within them. Motors driven by solid-state inverters normally experience severe

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0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2005.09.010

voltage stresses due to rapid switching on and off. Moreover, induction motors are required to operate in highly corrosive and dusty environments. Such requirements have lead to improvements in insulation material and treatment processes used. However, cage rotors design and manufacturing have received little development. As a result, broken rotor bar faults now account for a large percentage of total induction motor faults [1,2]. In general, modelling and simulation of machine operation will provide economical and useful information for fault prediction and identification. Computer simulation of motor operation can be especially useful in attaining a close insight into the dynamic behaviour of machines. Modelling the performance of three-phase induction motors with broken rotor bar faults has a substantial history of published literature [1–5]. Current signature analysis approach has been the main focus to monitor the health of induction motors with respect to modelling broken rotor bar faults. Of course, over the years other less appealing methods of detecting faults have already been explored, such as measuring harmonics in motor torque and axial flux [6,7]. To date, broken rotor bar faults condition assessment and fault diagnosis has been based upon conventional current signature analysis [8–12]. Similar indications were suggested using vibration spectra [13–16].

A possible way for induction motor fault diagnosis is the instantaneous rotor speed analysis since the pulsating torque due to rotor faults will alter or modulate rotor speed. This paper addresses the use of the model-prediction to simulate a squirrel-cage induction motor operation under healthy rotor and broken rotor bar faults using instantaneous angular speed (IAS) analysis. A Runge–Kutta integration algorithm was used to solve simultaneous differential equations governing motors behaviour. The purpose of this model is to foresee and examine the effects of a rotor with broken rotor bar faults on IAS. Simulation results represent the contribution to the correct evaluation of the measured data. For that reason, the IAS model-predicted simulation results will be confirmed using experimental measurements. Both IAS simulated and experimental results will be compared with stator currents spectra method under similar operating conditions.

2. IAS-based condition monitoring

In practice many mechanical systems in engineering applications rotate with varying speed, in spite of the assumption they rotate at constant speed. Gear-based power transmission system exhibits speed fluctuations due to a combination of effects, including geometric errors and transmission errors [17]. The Monitoring and Diagnostics Research Group at the University of Manchester has adopted the term IAS to refer to the variations of angular speed that occur within a single shaft revolution. The use of the IAS of an engine was investigated by Gu et al. [18] and Ben Sasi et al. [19] for fault detection and diagnosis. The variation of IAS was explored for the monitoring of electric motors. These investigations show that IAS is useful for the condition monitoring of a wide variety machines [20,21].

Cheap devices such as shaft encoders, magnetic pickup sensors and gears, etc., are used for IAS measurement. These devices produce signals in the form of an electrical pulse train. The time interval between successive pulses is inversely proportional to the speed of the rotor. There are a number of methods to extract IAS that has proven useful in a variety of machinery control and condition monitoring applications. However, these methods can be generally classified into two categories: pulse interval-based methods and fast Fourier transform (FFT)-based methods [19].

3. Broken rotor bar faults

Broken rotor bar faults can be a serious problem, although they do not initially cause an induction motor to fail. Therefore, there can be serious secondary effects. The fault mechanism may result in broken parts of the bar hitting the end windings or stator core of high voltage motor at high speed. This can cause serious mechanical damage to the insulation and a consequential winding failure may follow, resulting in a costly repair and lost production. Several authors have addressed the typical causes behind broken rotor bar faults as follows [1,22–24]:

- Direct-on-line starting duty cycles for which the rotor cage winding was not designed to withstand. This causes high thermal and mechanical stresses.