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A smart experimental setup for vibration measurement and imbalance fault detection in rotating machinery

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ABSTRACT

Rotor imbalance is the most common cause of machine vibration. In practice, rotors can never be balanced perfectly owing to manufacturing errors such as porosity in casting, non-uniform density of materials, manufacturing tolerances, and gain or loss of material during operation. Mass imbalance leads to the generation of a centrifugal force, which must be counteracted by bearings and support structures. A full spectrum analysis is presented for vibration signal to reveal the fault specific whirl signatures. The results clearly indicate the potential and feasibility of the discussed approach for the rotor imbalance diagnosis in a rotor shaft system coupled with a three phase induction motor. This paper presents a smart experimental method for vibration measurement and imbalance fault detection in rotating machinery.

1. Introduction

Rotor balancing is required on all types of rotating machinery, including motors, to ensure smooth machine operation. In a factory, this is achieved on a balancing machine at a precision level determined by motor speed, size, and vibration requirements. The highest precision is required for two-pole motors. Two-pole and large four-pole motors should be balanced at their operating speed in the balancing machine. The assembled motors are then tested to confirm that the vibration requirements are met in operation. Although they do not usually directly concern users, a few salient factors affecting factory balancing, mainly pertaining to two-pole motors, will be discussed here. Most medium-to-large motors are used for constant-speed applications, although there has been a recent increase in the number and size of motors used for variable-speed applications with adjustable-speed drives. Constant-speed motors need to be precision-balanced only at one speed, namely, the operating speed. Variable speed applications require that good rotor balance be maintained throughout the operating speed range, which may typically range from 40% to 100% of their synchronous speed [1–3].

Rotor balancing involves the entire rotor structure, which is made up of a multitude of parts, including the shaft, rotor laminations, end heads, rotor bars, end connectors, retaining rings (where required), and fans. The design and manufacture of these components must be controlled for achieving stable precision balance. Specifically, the following must be taken into account: (i) parts must be precision manufactured to ensure close concentricities and to minimize individual imbalance; (ii) loose parts, which can result in shifting during operation, leading to a change in balance, must be avoided or minimized; and (iii) balance correction weights should be added at or near points of imbalance [4,5].

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Rotor imbalance generates reaction force in the coupling, which is often a major cause of vibration in machinery. Szabo [6] first evaluated the unbalanced forces generated in a rotor shaft and showed the presence of first (x1) and second (2x) levels of harmonic vibration responses. Different methodologies based on vibration spectral analysis have been proposed using fast Fourier transform (FFT) [7,8]. Bossio et al. [9] studied angular misalignment and imbalance in induction motors with flexible couplings. Tallam et al. [10] investigated load imbalance and shaft misalignment using stator current in inverter-driven induction motors. Martinez-Morales et al. [14] analyzed imbalance and misalignment by using data fusion for multiple mechanical fault diagnosis in induction motors. Quiao et al. [15] reported that imbalance faults constitute a significant portion of all faults in wind turbine generators (WTGs). Historically, vibration-monitoring techniques have been used widely for diagnosing imbalance faults in induction motors, but as reported by Kucuker et al. [16,17], electrical detection methods have been preferred in recent years [18].

In this work, we develop a smart experimental setup with a field programmable gate array (FPGA)-based signal processor that uses a parallel architecture for multiple-signal processing to combine vibration and FFT analysis.

2. Vibrations of rotating machines

A vibration is the movement of a physical quantity in relation to a reference location in a cyclically increasing and decreasing manner as a function of time. The most important features of machine vibration change according to Equation 1. Fig. 1 shows the behavior of Equation 1 in the time domain [6].

$$x(t) = Asen(wt + \phi) \tag{1}$$

where

A: amplitude (m/s);
w: angular frequency (rad/s);
ϕ: initial phase angle constant.

3. Imbalance and mechanical faults

Imbalance is the most common source of vibration in rotating machinery. It is a very important parameter, and it must be considered carefully in the design of modern machines, especially for machines requiring a high degree of reliability and machines operating at high speeds. Mathematically, imbalance can be expressed as follows [11]:

$$\vec{U}^{\rightarrow} = m \times \vec{r}^{\rightarrow}[\text{gmm}] \tag{2}$$

where

m: unbalanced mass (g);
r: distance of unbalanced mass from the center axis (mm).

The centrifugal force imbalance that generates vibration is expressed as follows:

$$\vec{F}^{\rightarrow} = m \times \vec{r}^{\rightarrow} \times w^2[\text{N}] \tag{3}$$

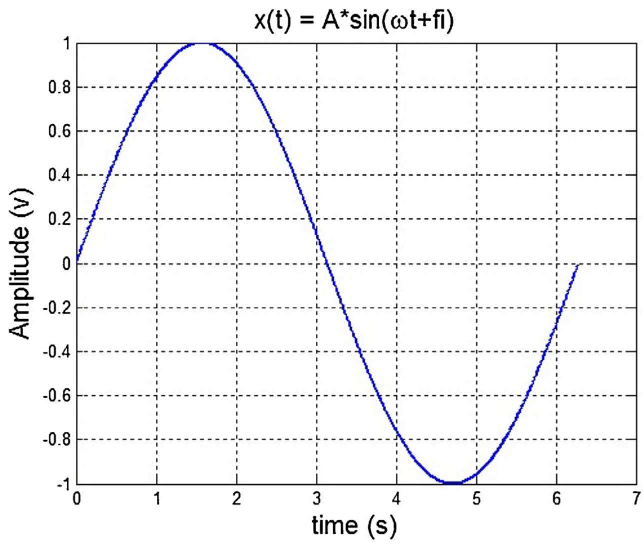

Fig. 1. Vibration signal in the time domain.