Detecting Faults in Rotating Machines

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Maintenance and repair tasks that follow established procedures reduce the chances of unexpected failure and the consequent losses in production, time, and money. In some critical cases, failure in a process can cause serious damage or even endanger human lives. We have developed a fuzzy logic system to diagnose the operation of rotating machines and help improve maintenance and repair procedures.

Vibration Analysis for Monitoring Machines

Machines can have complex mechanical structures with articulated elements. The parts can oscillate, and coupled elements can transmit these oscillations. The result is a complex frequency spectrum that characterizes the system [6]. A frequency component in the system will change when a mechanical part either wears or cracks. A change in the coupling between parts also affects the frequency spectrum of the system.

Vibration measurements have been taken on bearings [6], which see vibrations from such forces as centrifugal, alternating, and friction. These measurements reveal stress on components, potentially leading to functional abnormalities. Gaps, failures, or misalignments of bearings or an unbalanced rotor can alter the spectrum of frequencies in rotating machines. Table 1 shows some of the diagnostic parameters.

According to Ya'Cubsohn, failures can be divided into two generic classes: low-frequency faults (e.g., unbalancing, misalignment) and high-frequency faults (e.g., ball bearing defects, lack of lubrication) [6]. However, measuring the frequency of each one of the vibration components is not sufficient to identify the fault. Frequency must be related to the rotating speed of the axle. Therefore, we must know the rotating speed of the axle in order to diagnose faults.

Imbalance, misalignment, excessive gap, insufficient rigidity, bad coupling, belt wear, or bent axles will change the amplitude of vibration at the rotational frequency [4], [6]. These faults can be classified as a cluster of low-frequency faults and are called nonadjustments.

One of the difficulties with fault detection is the high dimensionality in the motor [1]. Many variables can affect the process of fault detection, including load, saturation, unpredictable operating conditions, electrical noise, and temperature. These can result in dozens of possible combinations for different patterns that will mask the vibration measurement [2].

A fundamental premise of this vibration analysis is: "Each component or each kind of mechanical deficiency of a machine in operation produces one vibration of specific frequency which, in normal conditions of operation, can reach a maximum known amplitude" [6]. The basic methodology recommends measuring:

- The frequency to identify the origin of vibration, which may be either a machine component or a fault and
- The amplitude of the vibration level to evaluate normal or abnormal operation and the magnitude of the detected fault.

Spectral Analysis

Accelerometers can detect and measure the vibration within a system. Analysis then plots the frequency spectrum of the

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Table 1. Parameters to be Measured in Predictive Maintenance.	
Parameter	***Fault or Defect***
Amplitude of vibration displacement	Imbalance, misalignment, excessive gap, insufficient rigidity, bad coupling, worn belts, a bent axle
Amplitude of vibration velocity	Bearing or damaged gear
Amplitude of vibration acceleration	Worn bearings, excessive friction between components, lack of lubrication
Vibration frequency	Data to complement the measurement of any characteristic of vibration, essential to the determination of any detected problem

vibration through the Fourier theorem, which establishes that any periodic function is based on a series of sinusoids at multiple harmonics of the fundamental frequency. We can diagnose the state of operation or the evolution of faults within the system by observing the amplitudes of the peaks in some frequencies and relating them to the amplitude of the fundamental frequency of the system.

Forces that excite vibrations exist in different places within the machine. Each exciting force will generate a harmonic of the vibration that is characteristic of displacement, velocity, and acceleration. The sum of all harmonics to each variable will result in a unique spectrum at the bearings. The harmonic components of vibration may be classified into two groups [6]:

- Low-frequency components with frequencies up to five times the axle rpm and
- High-frequency components with frequencies greater than five times the axle rpm.

The Rotating System

We developed an experimental setup, called the rotating system, so that we could insert faults and measure the results. The rotating system comprises an ac motor with a nominal rotation of 1800 rpm and an axle with a wheel disc (Fig. 1). The motor drives the axle, which is doubly supported by a belt. It rotates at 2270 rpm. The main rotating mass of the axle subsystem is a metallic disc that is 15 cm in diameter and has a mass of 1012 g. An L20 Microtest tachometer measures the rotational speed.

The accelerometer is an Analog Devices ADXL202, a solid-state, biaxial, low-power device. The ADXL202 can measure dynamic acceleration and vibrations over a range of ±2 g and null out gravity. This electronic circuit has two digital outputs, x and y, that give information about the accelerations in two orthogonal directions by modulating the duty cycle of each signal. The two signals can input directly to a digital circuit that computes the duration of the "on" periods of each signal without using an A/D converter.

We measured the vibration signals from the rotating system with a development system designed for digital signal processing and based on a TMS320C25 microprocessor (the Psi25). The Psi25 system acquires signals above 18 Hz. It connects to a microprocessor-based counter inside a personal computer. A program in the C language commands the acquisition of acceleration data and records them in *.dat files [3].

Experimental Results

We obtained the spectral signature of the rotating system by acquiring ten *.dat files and computing the average spectrum. Then, we considered changes in the status of the rotating system by inserting faults. We examined faults by inserting weights that unbalanced the wheel, which has a hole to receive the weights. The ratio of mass between the wheel (1012 g) and the smallest weight (0.6 g) is 1:1666 [4], [5]. Fig. 2 presents spectrograms of three different data sets, one for each test condition: normal operation (blue, 0 g), incipient fault (red, 0.6 g), and maintenance (cyan, 5.1 g).

The experimental process follows these steps and runs in Matlab (Fig. 3):

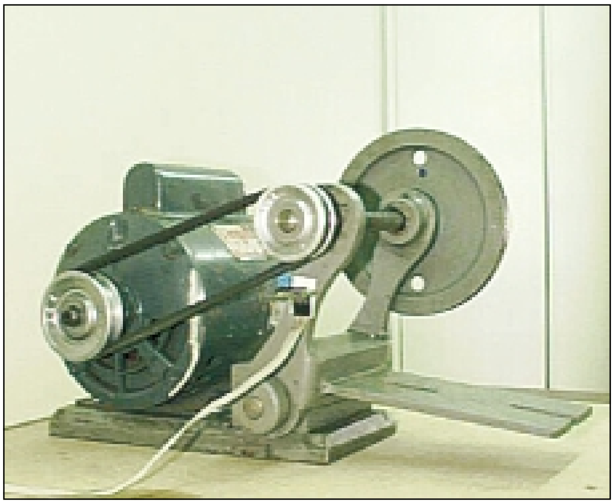

Fig. 1. The rotating system.

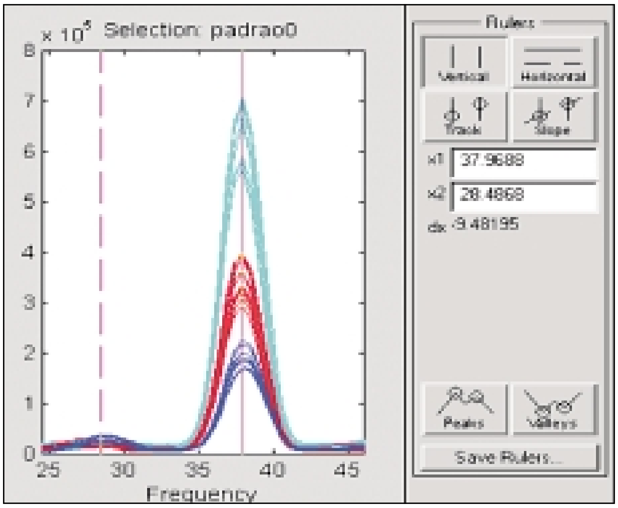

Fig. 2. Spectrogram with the cluster of ten acquisitions.

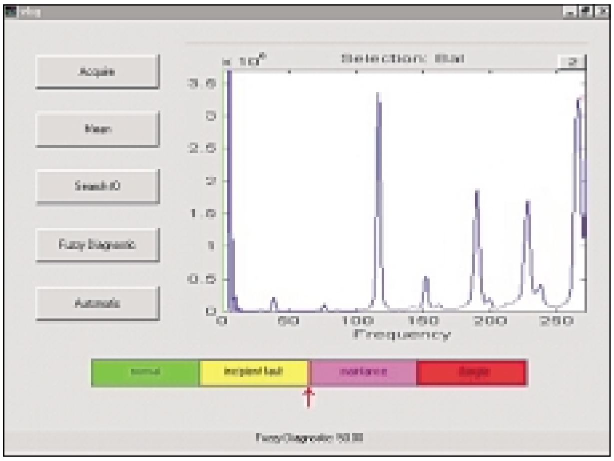

Fig. 3. The fuzzy diagnostic.

- Acquire data (*.dat),
- Compute the mean of the data acquisition (*.mat),
- Evaluate and plot the spectral signature,
- Search for amplitude values at the frequency of wheel rotation, and
- Perform analysis and fuzzy diagnostic.

It automatically executes all steps via command; adjusts the acquisition time, number of acquisitions, and range of frequency; and sets the fuzzy logic system. The *.dat files are computed and analyzed in the frequency domain with the signal processing tool (SPTOOL) in the Matlab5 package.

Fig. 3 shows the result of the fuzzy analysis that determined the condition of the actual system. The fuzzy system returns the result in a qualitative form by placing the cursor at the correct position.

Fuzzy Diagnostic

This method allows the diagnosis of the rotating system's operational status with a fuzzy logic system. It uses a collection of logical rules in the form of IF-THEN statements. The antecedent statements are the rotational frequency of the wheel and the vibration amplitude at this frequency (Fig. 2). The resulting statement is the diagnostic of the system (Fig. 3).

The ease of altering rules and updating variables makes this method versatile. It can accommodate the desired performance range of the system, the quality of the construction, risk factors, and tolerance.

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