CONDITION MONITORING OF INDUSTRIAL FANS

S.H.Ghafari

Quality Assurance, Mechworks Systems Inc.

ABSTRACT

Industrial fans are integral components of any industrial plants, particularly automotive, air conditioning, printing, and coating, where fan failure can cause expensive unscheduled plant shutdowns. Early detection of faults in these systems allows the user to initiate repairs to prevent costly maintenance. Fan problems result from such conditions as impeller imbalance, shaft misalignment, cracks, resonance, and bearing problems. In this paper, fault detection techniques for industrial fans, which are based on vibration signals that are acquired from accelerometers, are proposed. In addition, bearing fault detection is conducted by signal processing methods, based on the vibration signature of the rolling elements of bearings. It is demonstrated that the Beta Kurtosis and wavelet transform are reliable techniques for detecting bearing faults.

1. INTRODUCTION

Any device that produces the air current by the movement of a surface can be called a fan. The focus of this paper is on those types of fans that are classified as turbo-machines, and have a rotating impeller that is encased in a stationary housing. A fan impeller consists of a number of blades that are welded or riveted to the impeller's shroud and are mounted on a shaft. Typically, the shaft is supported by two bearings and is driven by a motor, directly or indirectly.

Regardless, the power source (motor) or energy transfer components (belts, pulley, or gearbox), faults fall into four categories: *imbalance*, *bearing defects*, *shaft faults*, and *resonance*. Impeller imbalance that can be created during the manufacturing process or during operation produce a high level of vibration that can damage bearings or the other components. Defects in bearings usually result from the wear out and shaft faults are due to misalignments or cracks. Operating a fan within the range of its components' natural frequencies can cause a high level of vibration in the impellers, causing serious damages.

The vibration signature, measured externally on a fan's bearings contains information about the machine operating condition. The signature that includes the health characteristics of the system can be changed in a well-defined way, when a fault occurs. Fan vibration is measured in two ways: measuring the relative displacement of the shaft in its bearing by means of proximity probes, or the absolute vibration of the bearing housing by an accelerometer. Usually, proximity probes are installed on high-speed, large, and expensive fans, and are utilized for monitoring simple parameters such as the displacement amplitude or shaft orbit. In the event of an extreme change of these parameters, the fan is shut down and repaired to avoid a major damage. Since most early

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faults can be detected only at high frequencies, accelerometers are more reliable for condition monitoring applications.

Once a significant change in the vibration signature of a fan is detected, to diagnose the fault, a series of signal processing techniques must be applied. The type of a signal analysis depends on the characteristic of the fault. Therefore, studying different types of fan problems and their sources leads to a better utilization of the signal processing techniques and results in a more reliable condition monitoring system.

2. FAN FAULTS

Fan defects can be classified in four categories: imbalance, shaft faults, bearing defects, and resonance that are described as follows.

2.1. Imbalance

Although manufacturers apply different techniques to ensure the symmetry of the impeller during fabrication, the weight center of the rotor (it contains all the rotating components) usually does not coincide with the center of the rotation. This results in a centrifugal force during fan operation, causing imbalance. Even a balanced fan can become unbalanced during field operation due to the adherence of sticky particles to the surface of the blades, particularly in spray booths and wet scrubbers. The deposition of dirt or fluid inside the hollow airfoil blades is another source of imbalance usually in HVAC fans.

Fans that operate at high temperatures are more sensitive to unbalance. Temperature variations between the top and bottom of the fan, the dissimilarity between the shaft and the impeller thermal expansion, and underestimating the thermal radiation are common sources of imbalance. The other reasons for fan imbalance during field operation are broken or cracked blades, loose hubs or bolts, fallen balance weights, corrosion, and deformation.

A standard for the tolerable level of a fan’s imbalance vibration is ANSI/AMCA Standard 204-96, "Balance Quality and Vibration Levels for Fans" [1]. This standard shows different categories of fan applications and the acceptable grades of vibration. The balance quality grade defines the RMS of the vibration velocity in the free space measured in mm/s. Two principal characteristics of the vibration signature are as follows.

- In all types of fans, imbalance has a sinusoidal vibration with a frequency of one per revolution. However, this sinusoidal signal can be accompanied by low-level harmonics. In general, when the signal has high harmonics above one per revolution the existing fault does not denote imbalance.
- The unbalanced force (detected by an accelerometer) is a rotating vector with increasing amplitude that is proportional to speed ($F = mr\omega^2$).

Since the imbalance force is a rotating vector, the vibration phase follows the location of the accelerometer. As shown in Figure 1, by changing the location of the sensor, the phase of signal changes, while the amplitude of the vibration is relatively same. Therefore, dual axis accelerometers are very useful for fan imbalance detection.

Fans with journal bearings are usually monitored by orthogonally mounted Eddy probes or proximity sensors. The diagnosis of an imbalance condition is performed by concentrating on the size and the shape of the orbit, which related to the location of the shaft inside the bearing.

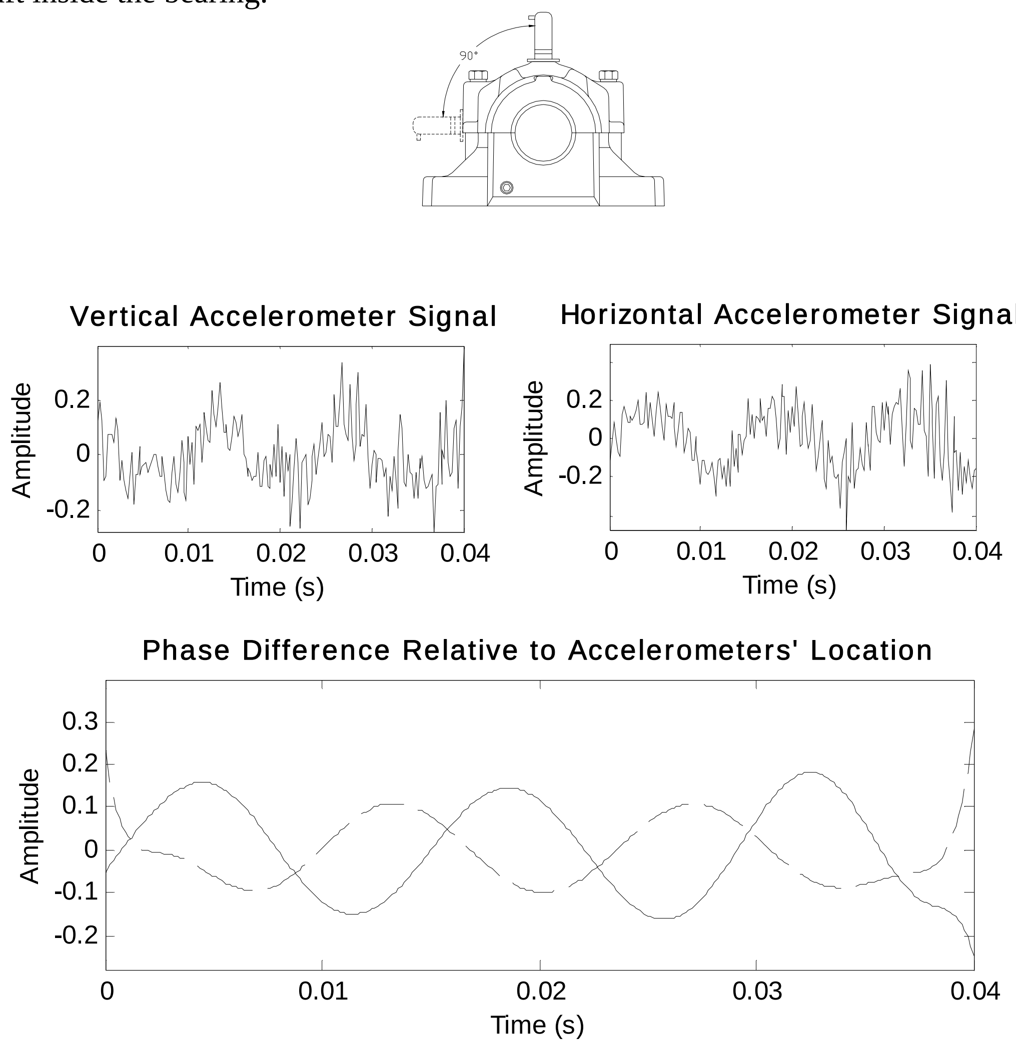

Figure 1: Changing the location of the sensor results in a 90º change in the vibration phase

2.2. Shaft Faults

Of the various problems of shafts, misalignment and the cracked shaft occur frequently. Typically, misalignment failure affects the second harmony of the shaft speed, and creates a high level of axial vibration [2]. An alignment problem occurs from a bent shaft, angular deviation, improper mounting, or the offset of a shaft center. The vibration spectrum of misalignment contains a number of harmonics, but the key factor in recognizing this failure is a high amplitude in the second harmonic. In addition, since machines are more flexible along the axial direction, the vibration component in this direction, caused by misalignment, is more detectable. Moreover, the axial components of the misalignment force, regarding the dynamics of the shaft have a 180º phase shift. This factor is useful to determine the misalignment from the imbalance of the impeller.

When a crack is shaped in the shaft, the symmetry disturbance reflects in the mass distribution and results in imbalance, which can be distinguished in the first harmonic of the shaft speed. Since the initial cracks create a low amplitude vibration, the phase analysis is more accurate for fault diagnosis. Misalignment tends to excite the second harmonic of the shaft speed, but a cracked shaft is more evident in the first harmonic, which is difficult to detect in an unbalanced impeller.

2.3. Bearing Defects

Rolling element bearings are the most common source of fan failure, and early detection is crucial to reveal their fault in the early stage. Such faults are categorized as distributed or localized defects. Distributed defects such as surface roughness, waviness, and misaligned races can be caused by a low manufacturing quality or poor installation. The major source of localized defects such as cracks, pits, and wear out is fatigue, which is generated on the surface of the race or the rolling element after a certain running time. Regardless of the type of bearing faults, the defect can occur on the outer race, inner race, ball, or train [3]. It has been shown that these vibration frequencies reflect themselves in the current spectrum as $f = \left| f_1 \pm m f_c \right|$, where $m = 1,2,3,...$ and f_c is one of the characteristic vibration frequencies and f_1 is shaft frequency [4].

Two important factors should be considered in the analysis of the characteristics of the bearing frequencies. They are usually modulated by residual imbalance, looseness, and misalignment that produce sidebands at the shaft frequency. In addition, as bearing wear continues and defects appear around the entire surface of the race, the vibration resembles random noise, and the significant peaks disappear. This is misleading in bearing fault diagnosis, but in this case, the defect energy is increased and the fault signature can be identified in the higher harmonics of the characteristic frequencies.

Due to the complexity of fault detection by means of bearing characteristic frequencies, other types of signal processing methods are currently being adopted for bearing condition monitoring; each has its merits and limitations. Of these techniques, Beta Kurtosis and continuous wavelet transform are more common for bearing fault diagnosis purposes. Beta Kurtosis is the fourth moment of Beta function, and is usually used as an indicator of the impulsive contents in the vibration signature [5]. A large Kurtosis value (>3) is an indication of a potential failure; however, an advanced damage has the same level of Kurtosis as a healthy bearing.

The wavelet transform represents a signal in the time-frequency domain for detecting structural periodic force impulses that are generated from the passing of the rolling element over the defect. This technique, which is based on the Morlet wavelet, usually detects the damage in the early stage, but is not sensitive to advanced damages. In recent years, the wavelet transform has been widely developed for early fault diagnosis purposes. Figure 2 presents a comparison of the preceding techniques for an early damage on the inner case. This comparison shows the simplicity of the Beta Kurtosis method for detecting the bearing defect, and robustness of wavelet transform in a starting defect, which is often difficult to identify by other techniques.

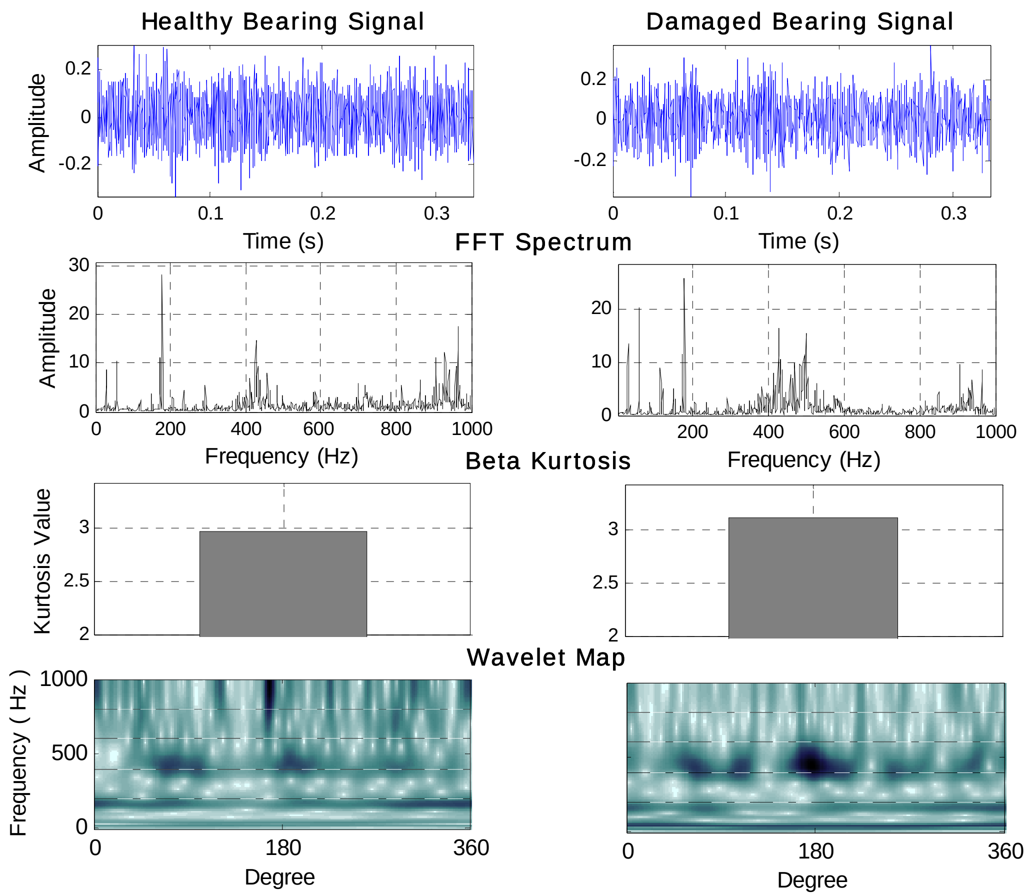

Figure 2: Various signal-processing techniques for roller bearing fault detection

2.4. Resonance

Since various parts of the impeller are typically made of thin sheet metal, their natural frequencies are relatively small values that can be excited during operation. This type of vibration that is related to the "critical speed" of the shaft can be confused with imbalance or other fan defects. It is obvious that when a component such as the blade, shroud, or even center disk of the impeller vibrates with its natural frequency, the resonance of that part due to the high amplitude of vibration can damage the entire impeller. Therefore, a modal analysis of the fan components is essential in fan designing.

The critical speed of the impeller or blade passage frequency plays an important role in the resonance effect and can be determined by $f_c = f_s \times N$, where f_c is the critical speed or blade passage frequency, f_s is the shaft frequency and N is the number of blades [6]. The most sensitive part of a fan to resonance failure is the blade. The blade resonance often occurs when the critical speed of the fan is within one of the first three harmonics of the blade. The defect can be identified as cracks in the welding joints initially then the impeller can lose one or more blades. Due to the complexity of the impeller geometry, the impulse excitation technique can be utilized for impeller modal analysis. The resonance effect is important in a blade's defect, but most of the other components of the fan have natural frequencies well above the shaft and blade passage frequency.

3. CONCLUSION

The vibration sources that are described in this paper are the common faults of fans. Applying vibration analysis techniques for monitoring the condition of industrial fans are convenient, inexpensive, and reliable in determining the faults in their early stages and can avoid unscheduled shutdowns and expensive repair costs.

4. REFERENCES

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