Cooling Fan Fault Diagnostics Using Vibrational and Acoustical Analyses

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Abstract

Machine condition monitoring and fault diagnosis are strategies commonly employed by processing and manufacturing facilities to monitor the reliability, availability, and performance of machines. This set of standards is used in an effort to detect any faults before they cause serious problems or lead to a machine failure. Most industrial machines comprise rotors, disks, blades, fines, or other similar components that are subject to machine vibration, an operation condition parameter that is monitored and analyzed during machine condition monitoring and fault diagnosis. Cooling fans, which are particularly vulnerable to machine vibration, are widely used by processing and manufacturing facilities for cooling electronic systems and to generate renewable energy. The effective monitoring of these fans to predict, prevent, and address faults is paramount to the successful operation of industries that use these instruments. This study aims to identify the typical faults in a cooling fan by measuring the vibration and noise produced by the fan. I used a simple cooling fan with different types of faults to measure the vibrational and acoustical system response associated with different types of system faults.

Keywords: *Fault Diagnosis, Vibration Monitoring, Noise Measurements, Cooling Fans*

1. Introduction

Fans are used in industrial and manufacturing facilities for technical air applications and ventilation services. Critical systems often rely on the proper and reliable functioning of fans for ventilation and air flow. Because the critical role fans play in industrial settings, it is important to be able to predict, prevent, and address fan failure. Cooling fans, one of the most important parts in most electrical products, contain electronic and mechanical parts in their assemblies, including bearings, lubrication, shafts, fan blades, and fan housings [6]. The failure of just one of these components can lead to significant damages to the larger system.

Cooling fans are subject to vibration-related problems. For example, cooling fans with mass variations among fan rotors are unbalanced and will experience vibration. Vibration, in turn, can lead more complex issues of bearing fatigue, shaft misalignment, or system resonance. In many cases, extreme fan vibration levels require unintended forces to maintain the proper functioning of the fan. Cooling fan break downs can be avoided by conducting fault diagnoses. A fault analysis is a simple and operative process for signal analysis and is extensively used to examine faults in rotating machinery [1], [5]; this analysis effectively and continually monitors system faults to avoid downtime, thereby decreasing maintenance costs and improving the overall operations of systems. Without fault analyses, cooling fans could experience expensive failures due to vibration that damages fan blades, bearings, or shafts [8].

The research presented here measured the vibrational and acoustical effects of experimentally manipulated cooling fans with four different fault types. The results of this

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research could be used to more accurately and easily predict and prevent system failures due to cooling fan faults.

2. Literature Review

Zhongjun Yin, Tian Han, and Jianfeng Wang [2] examined a fault diagnosis system where they monitored a simulated fan system. Their simulation involved a three-dimensional model within a virtual environment. They simulated typical mechanical fan faults including unbalanced and misaligned fans. Their results provided the framework for a new "low consumption and high efficiency" method of equipment maintenance.

Qiang Miao et al. [3] examined cooling fan bearing faults to identify a method to detect the faults using vibration measurements. They aimed to use the vibration measurements to identify the type of cooling fan bearing failure. They used wavelet and the Hilbert transforms to develop a method that could classify the fault-related characteristic frequencies of fan bearings. They argued that this method could be used to avoid serious failures of cooling systems. Dekys [4] also examined the use of vibration measurements to detect cooling fan failures. This author discussed the detection of vibration sources with chosen signal processing techniques. These techniques were adapted from the field of machine monitoring, where measurements of base vibrations are often used to reduce or correct noise and vibrations. Both these studies present solutions for the reduction of vibration and noise in cooling fan systems that rely on detecting the source of vibrations and involving tuning outside the machine structure.

Vishwakarmaa et al. [5] reviewed the methods used to extract vibration features with different types of rotating machines. They examined fast Fourier transformation (FFT), a method that is generally used in diagnosis techniques to recognize the frequency features of vibration signals, continuous wavelet transform (CWT), a method that is useful for gear fault analysis, and discrete wavelet transform (DWT), a method that can diagnose spalling in ball bearings. They conducted systematizing diagnosis procedures that served to select the appropriate techniques to increase the effectiveness of fault diagnoses. In a similar study, Seljuk Erkaya and Şaban Ulus [6] examined how vibration and noise measurements can be used to detect possible faults in simple cooling fans. Their results indicated that the acoustic emission (AE) technique effectively detected system faults in their experiments. Wen Zheng et al. [7] examined noise frequencies resulting from fan bearing faults, a typical fault type in cooling fans. The authors used noise frequencies of vibrations that were detached through wavelet soft thresholding methods. They obtained the spectrum characteristic of the recreated signs. The failure form of a signal was formerly separated by relating its typical frequency with characteristic faults frequencies in a model. The authors used simulations to diagnose vibrations signs from spectral analyses of cooling fans.

Gama and Eissa [8] reviewed the current vibration analysis methodologies used to diagnose faults in rotating machines. They found that vibration response measurements provided valuable information on common faults. The general classes of methods were reviewed and particular difficulties were highlighted for each method. The authors concluded that signal processing methods are useful for vibration signal analysis and that these methods can be widely applied in condition monitoring and fault diagnostics.

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The diagnosis of faults in rotating systems is a daunting and difficult task for those who operate and maintain technical machinery. Failed machines lead to economic losses and safety issues owing to unpredicted and unexpected production stoppages. Therefore, the production of rotating equipment should be monitored to improve machine operation consistency and reduce inaccessibility. Effective condition monitoring requires an effective fault diagnosis that carefully considers the following four steps:

1) Data acquisition
2) Parameter extraction
3) Fault analysis
4) Decision making

A fault decision resulting from a faulty diagnosis should specify the type, size, location, and point in time of the most probable fault.

3. Objectives

I conducted a vibrational and acoustical experimental analysis of a cooling fans with different fault characteristics including broken fans and cracked fan blades. I aimed to determine the vibrational and acoustical system response to these faults and identify variations in vibrational and acoustical measurements of different fault characteristics. I used finite element analysis of the blade using ANSYS to define the natural frequencies and mode shapes of the blade structure.

4. Methodology

Vibration signal identification is one of the most important methods used for monitoring the condition of cooling fans to diagnose faults within rotating systems. This is because these methods always carry the dynamic data of the system. Effective operation of the vibration signals, however, depends upon the efficiency of the applied signal processing techniques for fault diagnostics. Through the quick progress of the signal processing techniques, the analysis of stationary signals has mostly been based on identified spectral techniques such as Fourier transform (FT), fast Fourier transform (FFT), and short time Fourier. (FFT). I used all three of these techniques to analyze measures of vibration signals in this study.

A fault in a fan is an irregularity in the functioning of the fan that is typically results from damage to a fan component. The common types of machine faults include unbalanced fans, shaft misalignments or a bent shaft, damaged or loose bearings, damaged gears, or faulty or misaligned belt drives.

In this investigation, I used a simple, five blade electric cooling fan (Table 1). The cooling fan was a SUNON P/N 2123XSL with 5 blades. The impeller material was thermoplastic PBT of UL 94V-0 (density 1.43 g/cc, flexural modulus 2.85 GPa) [10]I applied four different artificial faults to the fan blade (Fig. 1).

Table 1. Specifications of the fan used in this study [10]

Voltage(V)	Current (I)	Frequency (HZ)	Fan Speed	Noise Level
220 V	014 A	50/60 HZ	2700 RPM (45 HZ)	49 dB

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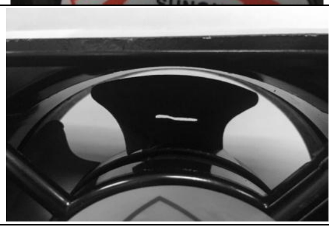
Fault Type	Case No. and Fault Description	Artificial fan fault
Six artificial holes	7 mm diameter case 1 8 mm diameter case 2 9 mm diameter case 3 10 mm diameter case 4 11 mm diameter case 5 12 mm diameter case 6	
Three broken fan blades	25% of fan blade broken case 7 50% of fan blade broken case 8 100% of fan blade broken case 9	
Three vertical cracks	10 mm vertical crack case 10 15 mm vertical crack case 11 20 mm vertical crack case 12	
Three horizontal cracks	5 mm horizontal crack case 13 10 mm horizontal crack case 14 15 mm horizontal crack case 15	

Figure 1: Artificial fan faults experimentally applied to the fan blade

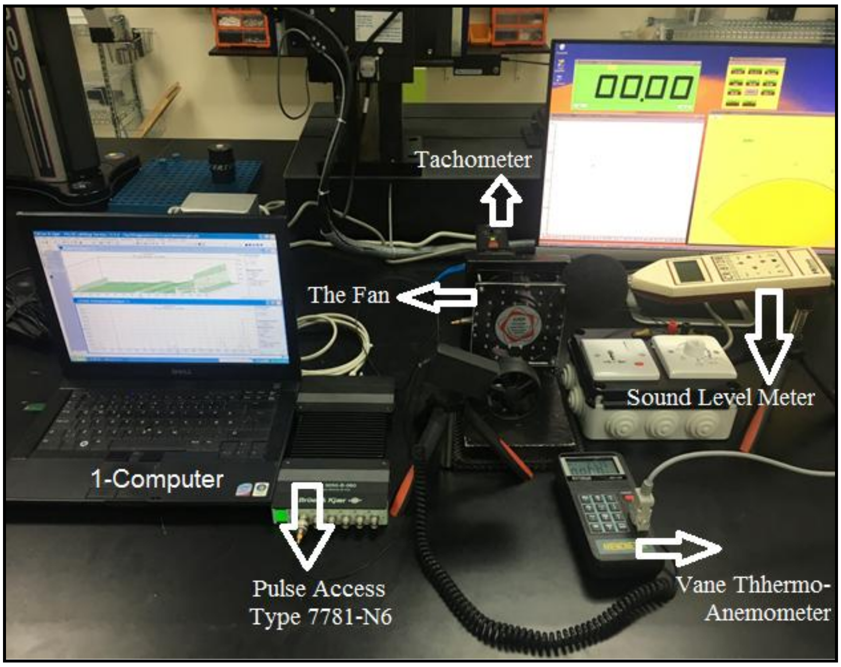


Figure 2: Instruments used to measure vibration and acoustics of each of the 15 experimental cases

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I used the following equipment to measure the vibration and acoustics of each of the 15 experimental cases (Fig. 2): Vane thermo-anemometer data logger, PR4/6-channel input module LAN-XI 51.2 kHz type 3050, PULSE access type 7781-N6, and sound level meters.

5. Results and Discussion

5.1. Modal Analysis for the Cooling Fan Model

I used a finite element analysis using ANSYS for the impeller of the cooling fan model to investigate the mode shape and resonances of the experimental fans. The results indicated that the fan blades could be described by six mode shapes (Figs. 3-8).

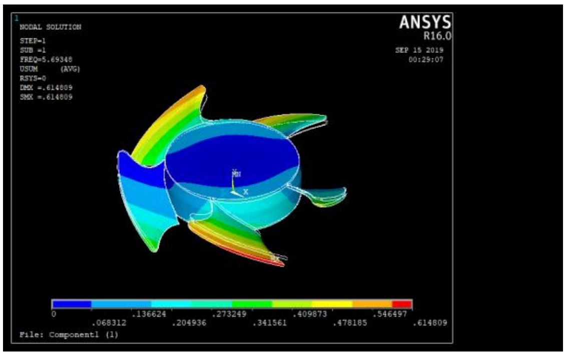

Figure 3: 1st mode, 5.693 Hz

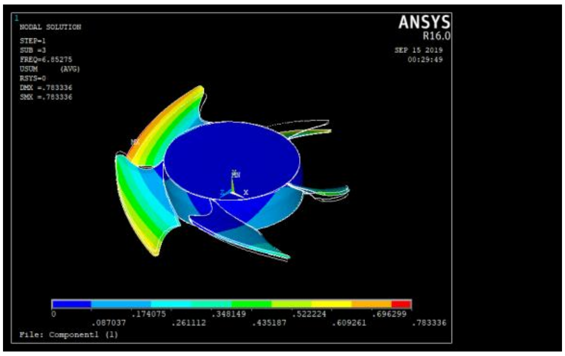

Figure 4: 2nd mode, 6.85 Hz

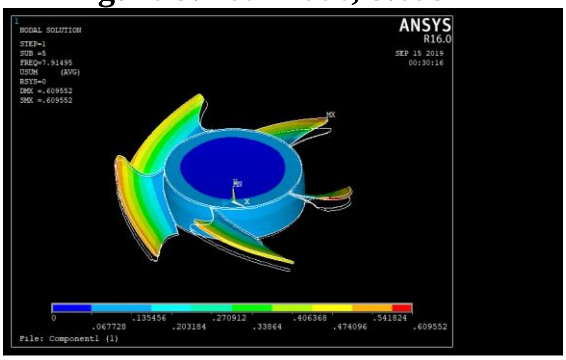

Figure 5: 3rd mode, 7.91 Hz

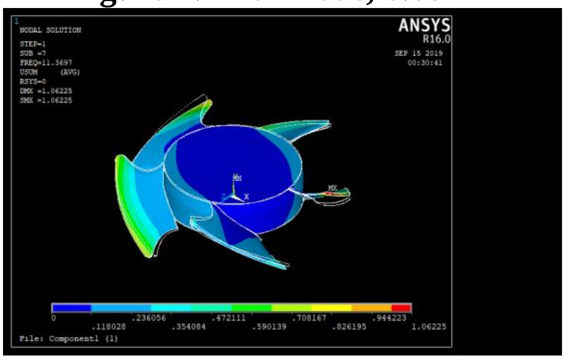

Figure 6: 4th mode, 11.36 Hz

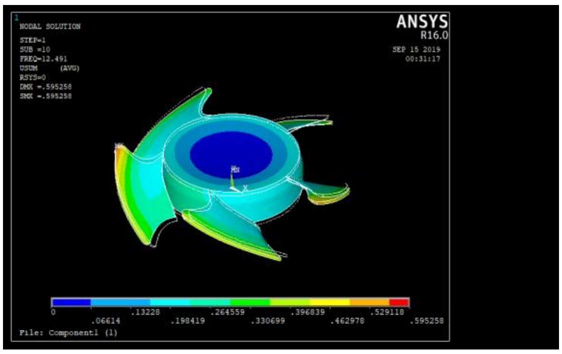

Figure 7: 5th mode, 12.49 Hz

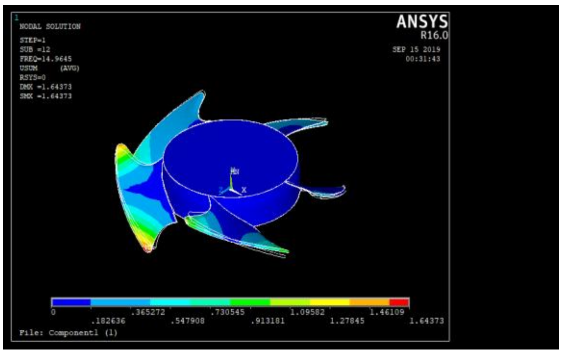

Figure 8: 6th mode, 14.96 Hz

5.2. Experimental Analysis

Vibration and noise measurements were collected to evaluate the system responses to the four types of introduced faults. I used a PULSE system with six channels to determine

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the steady state vibration for different faults (Fig 1) and a sound level meter CR812B (Fig. 2).

5.2.1. Acoustic and Vibration Analysis of Holes in the Fan Blade.

Six different artificial holes were introduced to the fan blade with different diameters (case 1: ϕ 7mm; case 2: ϕ 8mm; case3: ϕ 9mm; case 5: ϕ 10mm; case 5: ϕ 11 mm; and case 6: ϕ 12 mm; Fig. 1). The results indicated that these types of faults unbalance the fan system, which is detected with measurements of 45 Hz (1x of the fan speed) and 700 Hz (15.5x of the fan speed). Furthermore, an acoustic and vibration measurement showed that when the diameter of the holes was increased, the acceleration amplitude gradually increased from 0.01 – 0.035 m/s2. Similarly, the fan noise level increased from 60-63 dB as the hole diameter increased. Thus, the increasing of the blade hole diameter affected the balance of the fan system and resulted in an increase in the measurements of vibration and acoustics (Figs. 9, 10, 14).

5.2.2. Acoustic and Vibration Analysis of Broken Fan Blades.

I used three types of broke fan blades in these experiments, characterized by the percentage of one fan blade that was removed (case 7: 25%; case 8: 50%; and case 9; 100%). The results showed that these types of faults unbalance the fan, as indicated by a system response at 45 Hz (1x of the fan speed). Additionally, acoustic and vibration measurements showed that when the size of the broken blade removal was increased from 25%, to 50%, and then to 100%, the acceleration amplitude of the system vibration response gradually increased from 0.18 to 0.5, and then to 1.2 mm/s2). Similarly, the fan noise level increased 60.75 – 62.5 dB as the size of the broken portion of the blade increased. These resulted indicated that a broken blade affected to the balance of the fan system to a greater degree than other types of faults (Figs. 9, 11, 15). Moreover, this type of fault does not impact the acoustics of the system as much as other fault types.

5.2.3. Acoustic and Vibrational Analysis of Vertical Cracks to the Fan Blade.

I applied three different crack sizes to the blade (case 10: 10 mm vertical crack; case 11: 15 mm vertical crack; and case 12: 20 mm vertical crack). The results indicated that these types of faults unbalance of the fan, as indicated by a system response of 45 Hz (1x of the fan speed) and 700 Hz (15.5x of the fan speed). Furthermore, an acoustic and vibration measurement showed that when the size of the vertical crack increased (10, 15, and 20 mm), the acceleration amplitude of the system vibration response gradually increased (0.004 – 0.005 m/s2). Similarly, the fan noise level increased (62.25 – 63.75 dB) as the vertical crack size of the blade was increased (Figs 9, 12, 16). These results indicate that a vertical crack in a blade has a greater impact on the system noise than a broken blade and has less of an impact on system vibrations.

5.2.4. Acoustic and Vibration Analysis of Implemented Horizontal Crack to the Fan Blade.

I used three different sizes of horizontal cracks to the fan blade (case 13:5 mm horizontal crack; case 14: 10 mm horizontal crack; case 15: 15 mm horizontal crack). The results indicated that these types of faults unbalanced the fan as indicated by a system response of 45 Hz (1x of the fan speed) and 700 Hz (15.5x of the fan speed). Furthermore, acoustic and vibration measurements showed that when the size of the horizontal crack was increased (5, 10 and 15 mm), acceleration amplitude of the system vibration responses did not respond. The noise level did increase (62.25 – 63.75 dB) with an increase in the size of the horizontal crack (Figs. 8, 13, 17).

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Horizontal and vertical crack faults had a greater impact on noise measurements than artificial hole faults and broken blades (Fig. 9). Furthermore, measures of system vibration were greatly increased by broken fan blades more than other fault types (Figs. 4-7).

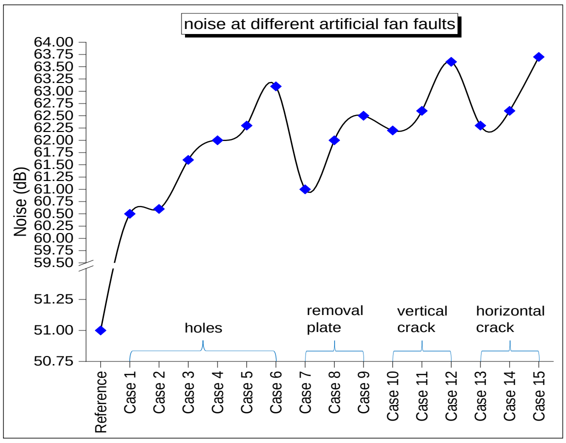


Figure 9: Noise level with different artificial fan faults (case 1 to case 15)

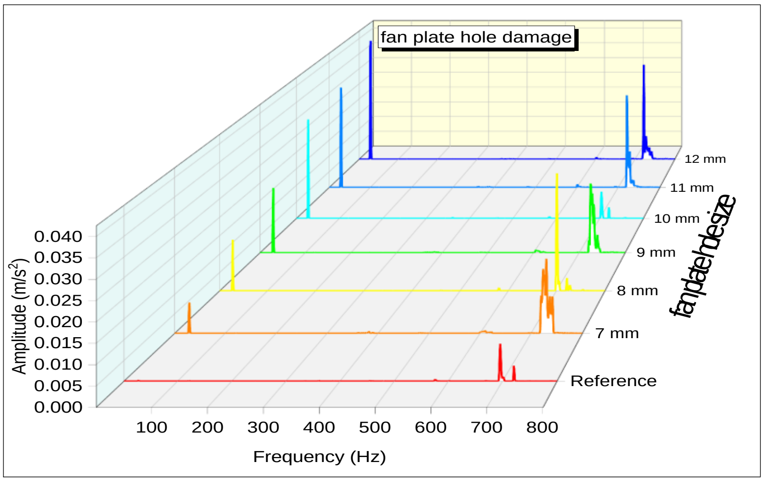
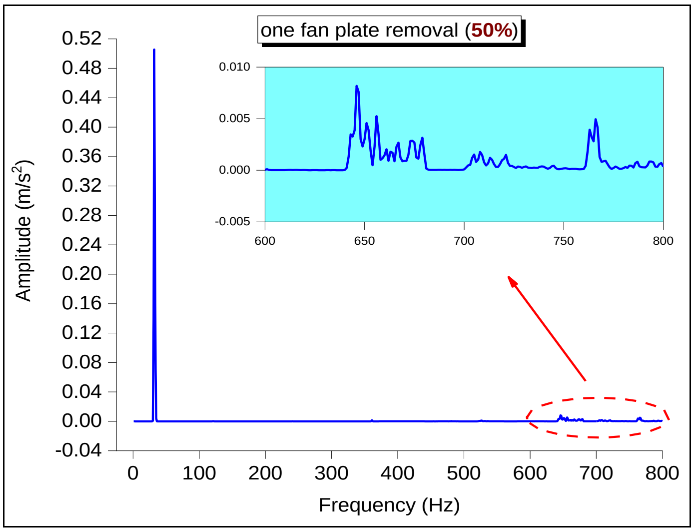


Figure 10: System amplitude response at frequency domain for cases 1-6 (hole size).



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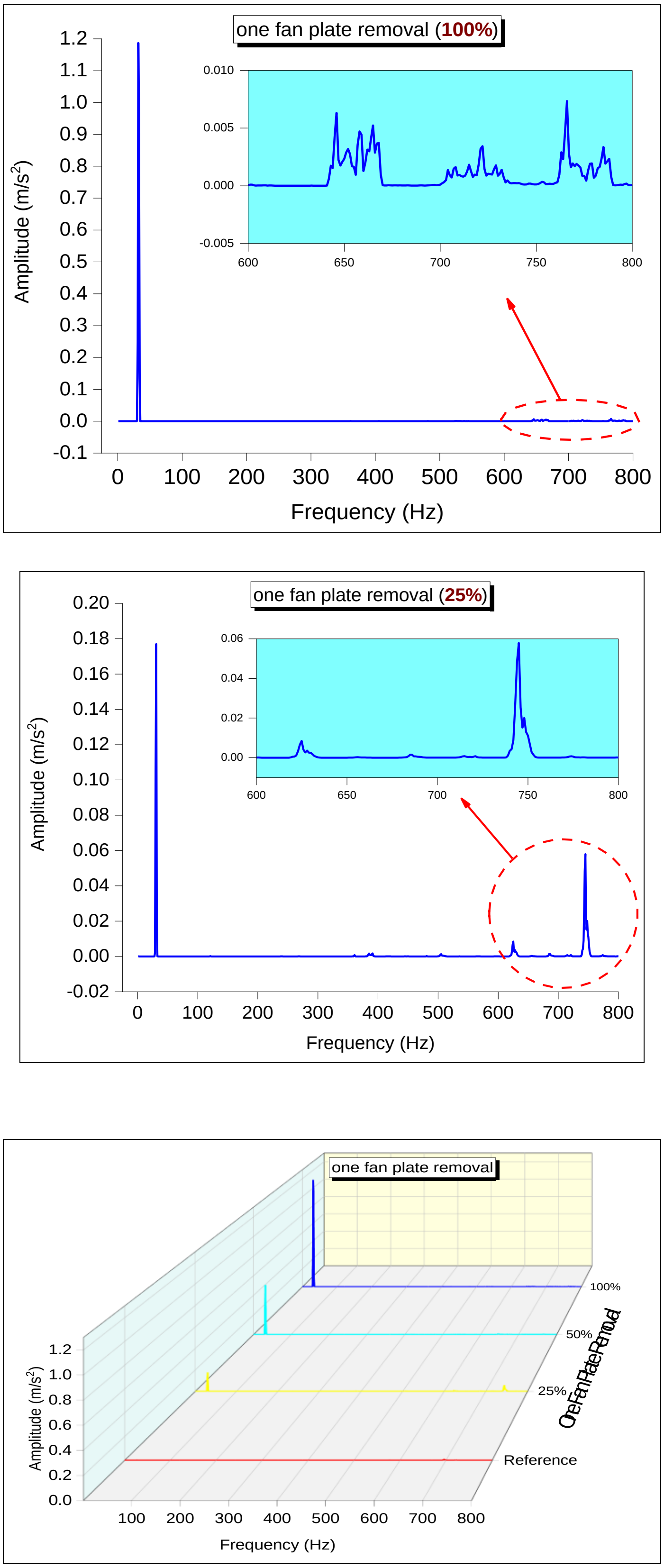

Figure 11: System amplitude response at frequency domain with different broken fan blades (cases 7–9)

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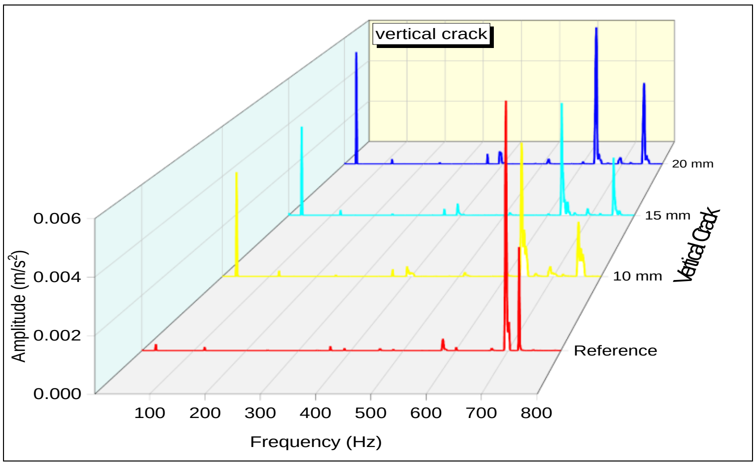

Figure 12: System amplitude response at frequency domain with different implemented vertical cracks to the fan blade (cases 10-12).

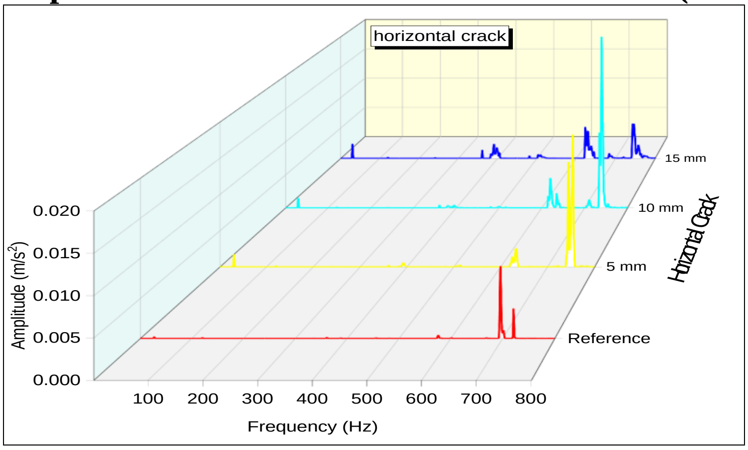

Figure 13: System amplitude response at frequency domain with different implemented horizontal cracks to the fan blade (cases 13-15).

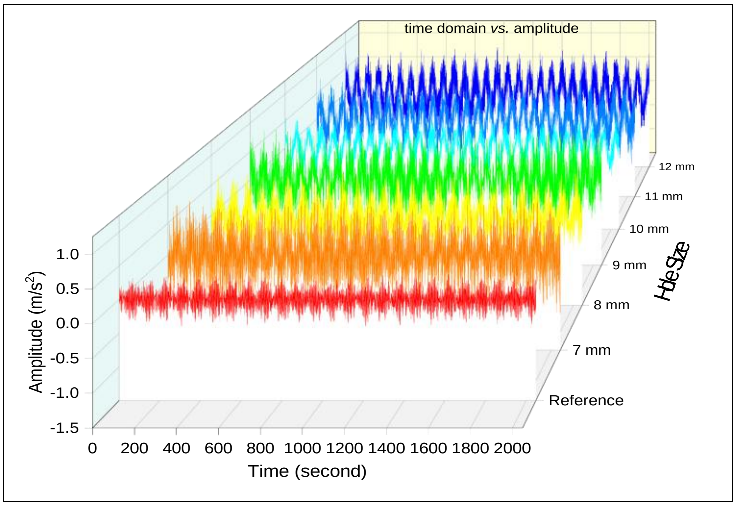

Figure 14: System amplitude response at time domain with different implemented hole size to the fan blade (cases 1- 6)

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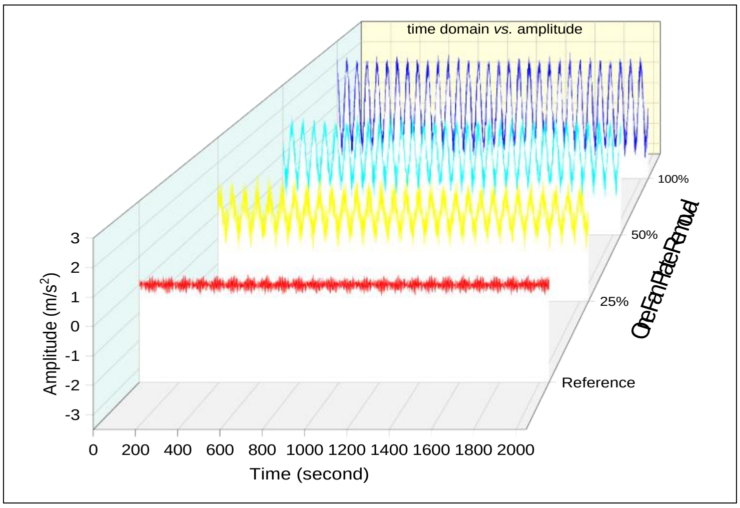

Figure 15: System amplitude response at time domain with different broken fan blades (cases 7-9)

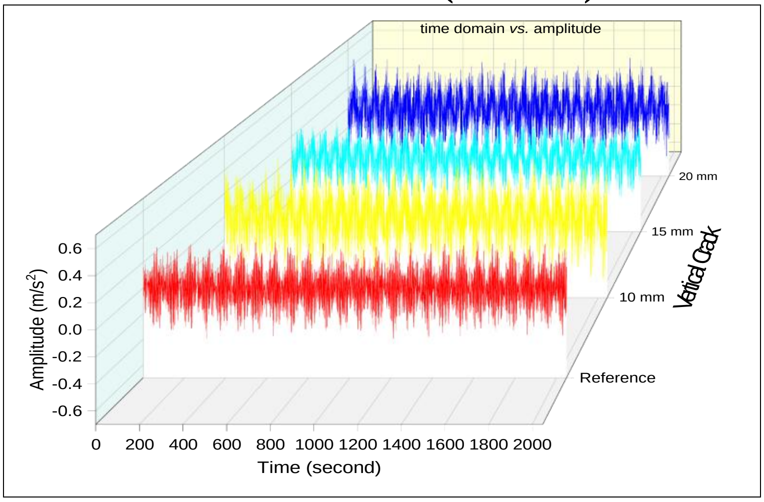

Figure 16: System amplitude response at time domain with different implemented vertical cracks to the fan blade (cases 10-12)

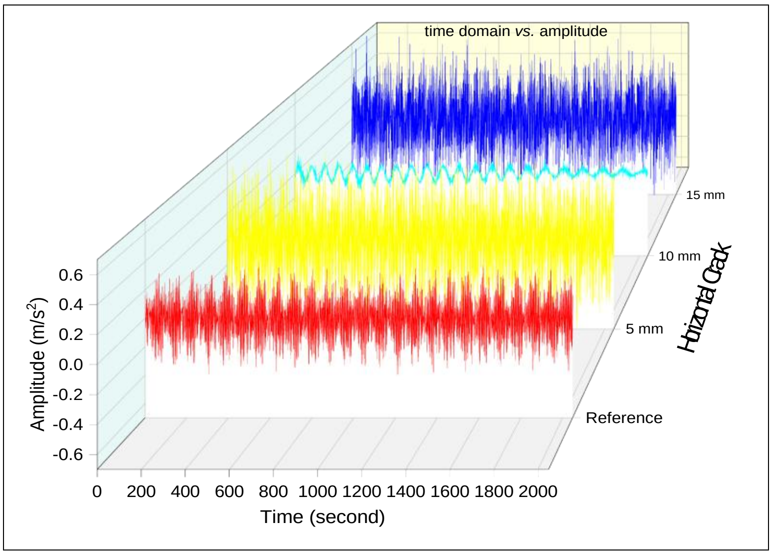

Figure 17: System amplitude response at time domain with different implemented horizontal cracks to the fan blade (cases 13-case 15)

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6. Conclusion

In this study, I experimentally manipulated several cooling fan fault types and then measured the resulting vibrational and acoustic signatures of the faults. This research provides an experimental framework for the identification of potentially expensive cooling fan failures and has implications for practice in industries that rely on cooling fans to maintain their technical equipment.

Most current vibration monitoring systems used in monitoring systems compute and classify vibrational data, to identify possible fan faults. These data are used to quickly develop response plans. For example, several industrial projects demonstrated that the link between vibration analysis and process parameters signify a fast and reliable tool that could be used for condition-based descriptions of machines in operation.

The results of the study presented here indicate that noise and vibration measurements can be used to effectively detect possible faults in fans systems. The artificial broken fan blade was more greatly affected than other fault types according to the vibrational system response. However, according to the acoustics measurements of the different fan faults, the results indicated that horizontal and vertical crack faults were more affected by the noise level in the fan than the artificial hole and broken faults.

Diagnostics that use measurements of vibration are essential in the identification of fault types, their effects on the system, the system's limitation, the source of damage, and the potential problems inherent to rotating machines. These types of diagnostics serve to help identify possible sources of damage and their respective probabilities and to identify and avoid serious operational situations with short reaction times. Experts should use these diagnostics to solving complex fault problems and to avoid large system disasters.

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