

HEALTH MONITORING OF INDUCTION MOTOR FOR VIBRATION ANALYSIS

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Abstract: Condition-based maintenance (preventive, predictive, on-line) requires some means of assessing the actual condition of the equipment/machinery in order to optimally schedule the maintenance. Condition monitoring techniques help to detect early failure of machinery. A continuous Machine Condition Monitoring is needed to monitor the system to capture the real time data from the equipment under test such as rotating and reciprocating machinery for a condition based maintenance scheduling. The differences between the actual and desired performance behavior allow the operators to predict and identify the problems before they cause the equipment to fail thereby reducing the catastrophic failures and the consequences. While vibration monitoring is still the prime factor for the early detection of problems with rotating machinery the track of temperature, rotational speed and motor flux equally find important for machine condition monitoring. The more sophisticated software such as LABVIEW® helps to improve the capabilities of vibration-monitoring systems. An example is National Instruments Sound & Vibration Assistant that divide the frequency spectrum into specific bands that correlate to specific known potential failure modes based on the knowledge on the geometry of the machine. For instance, rotor imbalance often produces a recognizable vibration signal that has a frequency of one times the turning speed of the machine, while offset misalignment often produces a vibration signal that has a frequency that is two times the turning speed of the machine. A fan motor is used as a test bench for vibration analysis in this research. The choice of fans is as they can generate blade pass frequency (which is the number of blades times speed) and as the blades are hitting something, the housing is quite flexible, or an acoustical resonance is present which equals blade pass frequency. The objective of this research is to collect the electrical and mechanical signatures to analyze the maintenance requirements in a predictive nature. Experimental

investigation is carried out in this research in an attempt to monitor and analyze the effect of vibrations in real time.

Key word: Health Condition Monitoring, Vibration Analysis, Order Analysis

1. Introduction

Machine Condition Monitoring has been based on vibration measurements. However the performance of preventive and predictive machine condition monitoring can largely be improved by integrating some other process parameters using a deterministic and stochastic measurement analysis [1]. Fig. 1 shows a block diagram of the general approach of a typical on-line condition monitoring that uses measurements taken while a machine is operating with a fault. Different types of sensors can be used to measure signals to detect these faults. Typical signal processing techniques are applied to these sensor signals to extract particular features which are sensitive to the presence of faults. Finally, in the fault detection stage, a decision is made as to whether a fault exists or not.

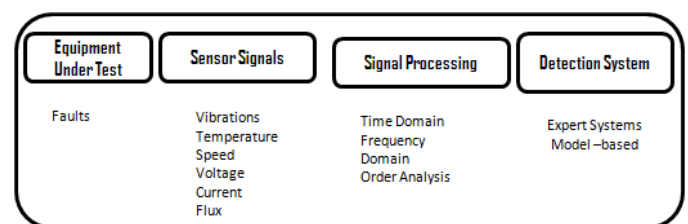


Fig.1 Condition Monitoring System

A system is created which is capable of acquiring vibration generated by a faulty motor, the effect on the speed and the temperature using a sensing setup. The data recorded in real time is compared with the data acquired from a similar reference motor in good

condition. The comparisons are done simultaneously to pertinently understand the impact of random vibrations generated. The vibrations are generated by breaking two blades and creating misalignment to the base of the motor under test. NI-USB 6008 data acquisition module is used together with LABVIEW® and the analysis is carried out using sound and vibration suite. A personal computer or laptop running on Microsoft Windows® operating system is used for this purpose.

Section II presents background on vibration analysis. Section III introduces virtual instrumentation. Section IV presents the methodology, section V presents the aspects of system design. Section VI is divided into two sections; the first section discusses the experimental investigations on machine condition status and the second section describes the vibration analysis on the data signal acquired in real time. Section VII enumerates the inferences.

2. Vibration Analysis

The harmonic, periodic and/or random motion of a rotating machine is often referred to as vibration. Vibration analysis is the most commonly used technology used to monitor this. A vibration measuring instrument (referred as sensor) separates the frequencies and quantifies the amplitude. Since the vibration frequency and amplitude cannot be measured by sight or touch, the instrument helps to convert the vibration into a usable product that can be processed and displayed along a frequency axis. The sensor output is proportionate to how fast the machine is moving (frequency) and how much the machine is moving (amplitude). The frequency describes what is wrong with the machine and the amplitude describes relative severity of the problem. The frequency of the vibrations can also be mapped since certain frequencies will only be present when conditions that indicate an impending defect are present. Comparison of the vibration spectra of new equipment versus equipment that has been used will provide the information required to make a decision when maintenance intervention is required. Misalignment, looseness is the most common problems that generate vibrations in operating machines. When this occurs, a small amount of

imbalance can cause high distortion in the signal. Also, the machine is easily shaken by a small excitation from other machines. Order analysis is a technique for analyzing noise and vibration signals in rotating or reciprocating machinery. Some examples of rotating or reciprocating machinery include aircraft and automotive engines, compressors, turbines, and pumps. Such machinery typically has a variety of mechanical parts such as a shaft, bearing, gearbox, blade, coupling, and belt. Each mechanical part generates unique noise and vibration patterns as the machine operates. Each mechanical part contributes a unique component to the overall machine noise and vibration [4]. One of the most common analysis methods to analyze noise and vibration signals is fast Fourier Transform (FFT) analysis. The FFT power spectrum identifies and quantifies the frequency components of noise and vibration signals. FFT power spectrum can be used for machinery diagnostic purposes by associating certain frequency components with specific mechanical parts. Fig. 2 illustrates an FFT analysis performed on vibration signals generated by a PC fan.

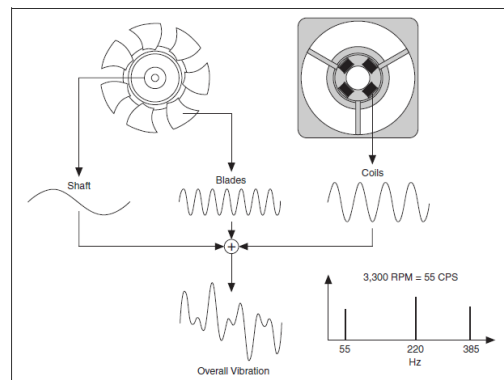


Fig. 2 FFT and order analysis on the fan [6]

The Order Analysis VIs included in the Sound and Vibration Measurement Suite presents the capability to calculate and examine rotational speed and extract the order components from the original noise or vibration signal. Power distribution can be measured as a function of either time or rotational speed and measuring the phase and magnitude of any order component as a function of rotational speed is made easy. Data is displayed in waterfall, orbit, polar, or bode plots. Using the order analysis, the machine's

faults can be diagnosed by knowing the order. Fig. 3 below shows the type of fault that can be diagnosed in reference to the level of order [6]:

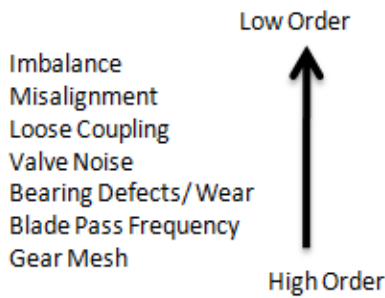


Fig. 3 FFT and order analysis on the fan [6]

3. Virtual Instrumentation

Virtual instrumentation is a combination of measurement from a control hardware and application software to create user-defined instrumentation systems. This research project solely developed using the LabVIEW® and the NI Sound and Vibration Toolkit. LabVIEW® is a graphical programming which can be used to built data acquisition and instrument control application in contrast to text-based programming languages that uses the flow of data for program execution. LabVIEW® contains a comprehensive set of tools for acquiring, analyzing, displaying, and storing data, as well as tools to help troubleshoot failures in scheme and code program. Majority of measurement and design laboratories around the globe have adoptee National Instruments technology to enhance the engineering experience for the students and researchers. The proposed virtual instrumentation system is shown in Fig. 4

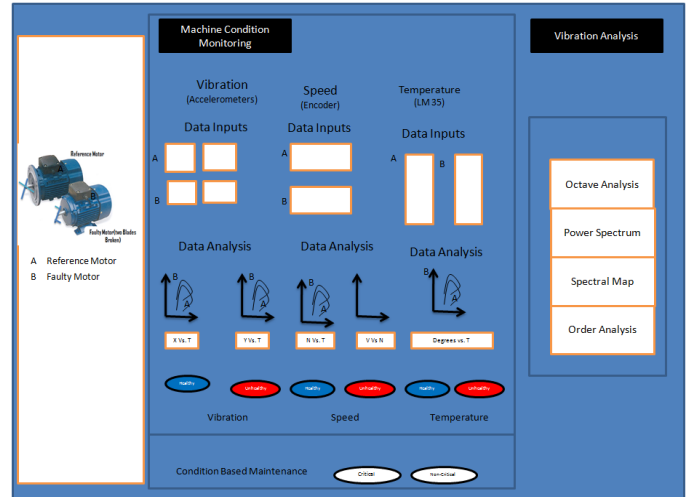


Fig. 4 Block diagram representation

4. Methodology

The primary objective of this system is to monitor the operational condition of the machine/equipment under test to alert the user for maintenance schedule. Further the acquired vibration signal from the machine under test (MUT) is also analysed using signal processing tool to determine the origin of such vibration.

The methodology implies three basic steps:

Step 1: Monitoring

- Data collection from healthy motor
- Data collection from faulty motor

Step 2: Data Processing

- Using Order Analysis

Step 3: Decision Making

- Using model based system (previous knowledge)

The experimental procedure consists of three segments namely the test bench setup, the sensing setup and the data handling setup. The system is mounted on a wooden board with proper wiring and electrical grounding as well. Vibration monitoring device a dual axis accelerometer is mounted onto the MUT and a temperature sensor LM35 and a optical encoder for speed measurement is also mounted onto the experimental test bed. The Data Acquisition Module is the heart of the system where this module holds the responsibility to perform signal and information acquisition. The National Instruments

6008 DAQ module is used and the mode of communication is established by using USB. To understand the effect and for a thorough investigations a similar machine under ideal conditions is used. A simple block diagram representation is as detailed in the Fig. 5.

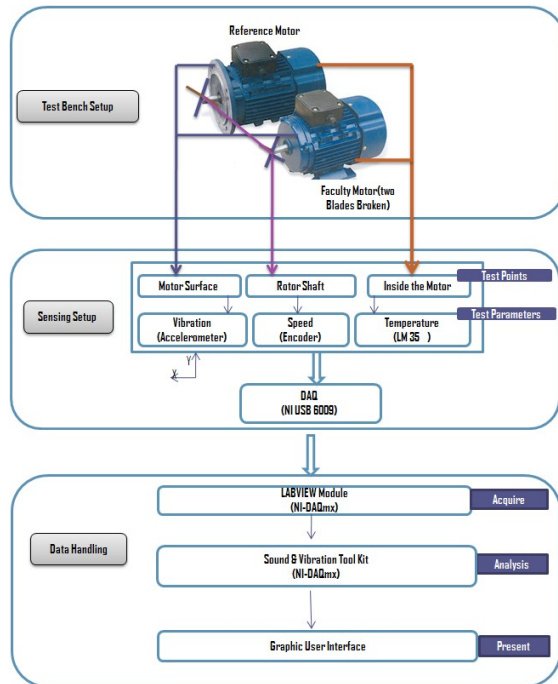


Fig. 5 Block diagram representation

5. System Design

The design of the hardware incorporated with the paper is a rapid prototype where the materials are found correlating to the cost as well. Fig. 3 shows the system module setup with the HMI interface panel.

Test Bench Setup

The test bench comprises of a reference motor in good condition and a faulty motor with same specifications. NI USB 6800 is used as a hardware interface to the system.

Sensing Setup

The sensing setup comprises of vibration measurement using accelerometer, the speed measurement using optical encoders and temperature measurement using LM35.

Data Handling

(a) Data Acquisition

National Instruments NI USB DAQ is used to communicate the sensor measurements into the LABVIEW® environment. The low cost multifunction data acquisition card (DAQ) for USB (NI USB-6008) is used for the purpose of acquiring and capturing the test data to disk for analysis. The USB-6008 uses the NI-DAQmx driver software and is compatible with LABVIEW®. A programming interface is developed for the acquiring the data and the trapped data are then analyzed using the sound vibration suite and the results are generated.

(b) Data Analysis

The Hardware setup which acquires the useful data of current and voltage is interfaced with a personal computer (Windows OS) via the USB hub using the NI-DAQmx driver software. The data is analyzed using the NI tool kit for fault identification part of the equipment under test.

(c) Data Presentation

A Graphical User Interface (GUI) is developed for user understanding and evaluation of the whole system under test. Motor A represents a reference motor (in good condition) and the Motor B represents a similar motor with fault condition.

Using LABVIEW® guide toolbox, a GUI is developed to present the results obtained from the harmonic analysis of the power line in a user friendly manner. Fig 6 shows the GUI developed for the Machine Condition Monitoring. A second interface is developed for the vibration analysis and is developed using Sound and Vibration Tool kit of National Instruments. The design of the software caters the requirement of the monitoring aspect where all the desired parameters are placed and analyzed.

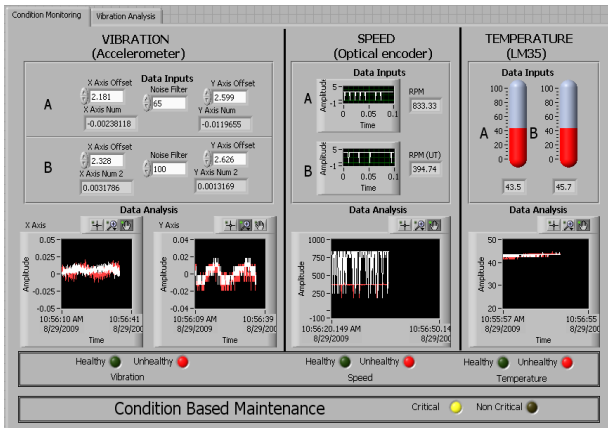


Fig. 6 Layout for the MCM System



Fig.9 Implementation of the Sensing setup and DAQ unit

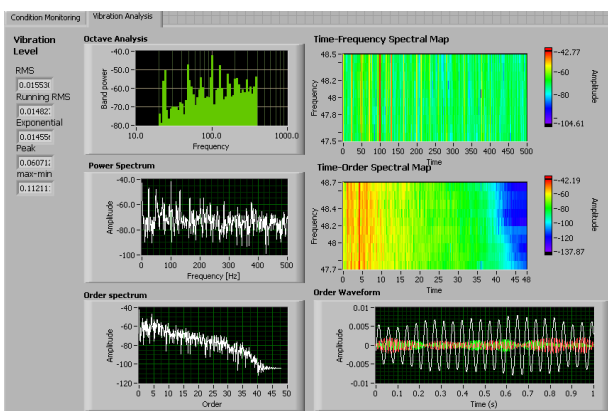
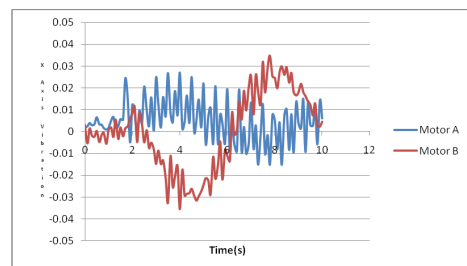


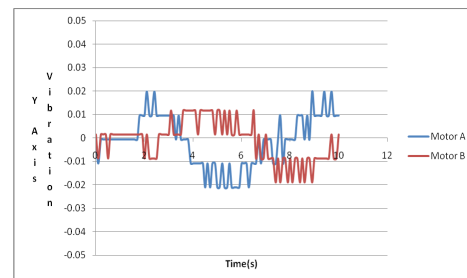
Fig. 7 Layout for the Vibration Analysis

6. EXPERIMENTAL RESULTS

(a) Machine Condition Monitoring



(a) X-Axis Vibration



(b) Y-Axis Vibration

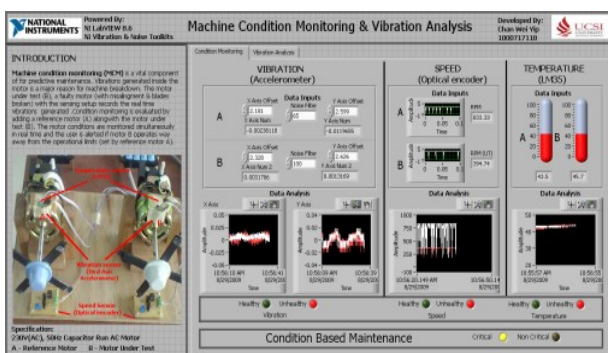
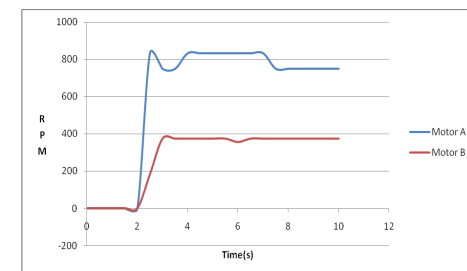
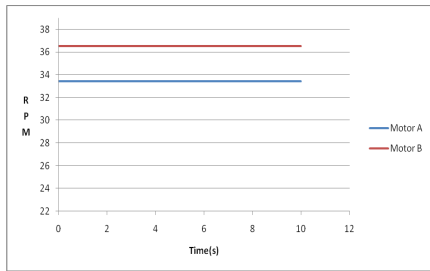


Fig. 8 Integrated Graphical System Design

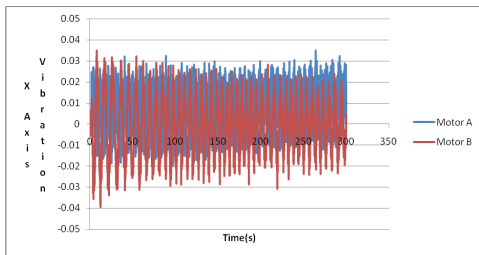


(c) Speed

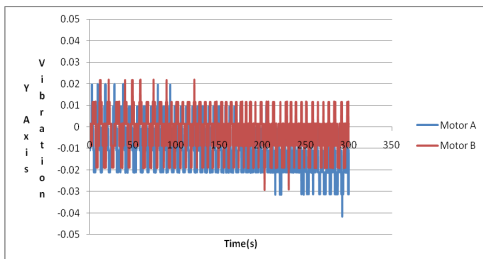


(d) Temperature

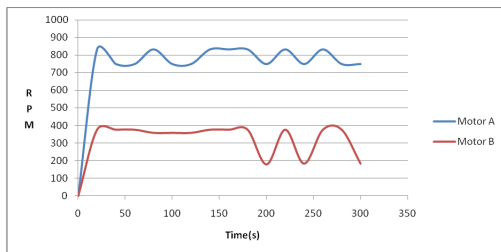
Fig. 10 Short run test (10 sec)



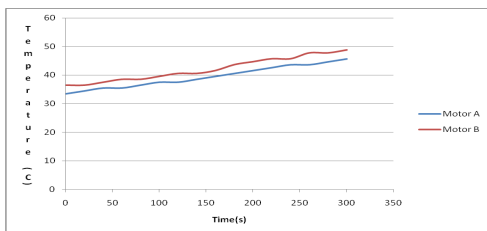
(a) X-Axis Vibration



(b) Y-Axis Vibration



(c) Speed

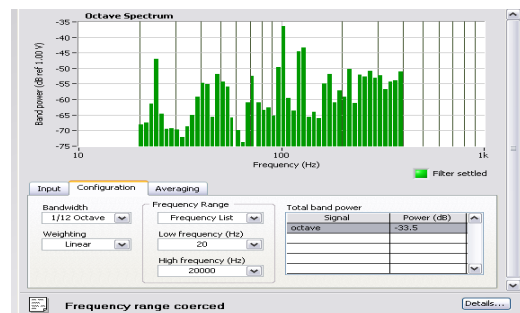


(d) Temperature

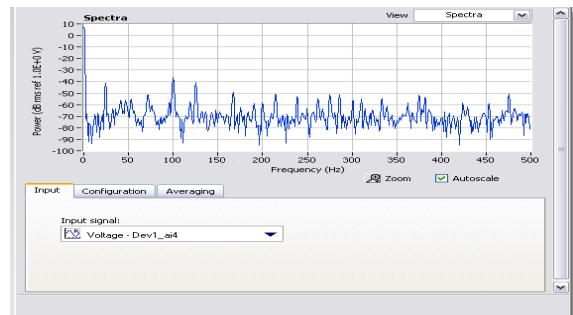
Fig. 11 Long run test (5 min)

(b) Vibration Analysis

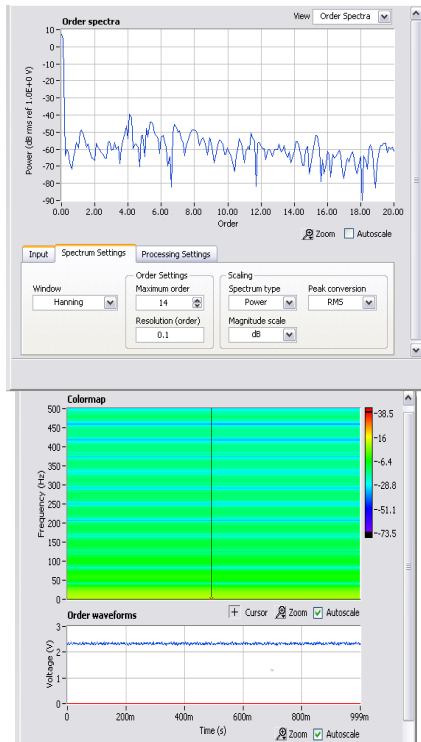
The frequency of the vibrations can also be mapped since certain frequencies will only be present when conditions that indicate an impending defect are present. Comparison of the vibration spectra of new equipment versus equipment that has been used will provide the information required to make a decision when maintenance intervention is required. The frequency of 1st order is 25Hz, based on this frequency, the 2nd and following order can be checked by refer to the frequency of Nth order times 25Hz.



(a) Octave Analysis



(b) Power Spectrum



(c) Order Power Spectrum
(d) Order Waveform

From the ‘Octave Analysis’, ‘Power Spectrum’ and ‘Order Power Spectrum’ graph, the amplitude at 4th order (100hz) and 5th order (125hz) ,which is highlighted in red line on the figure above, are very high. Base on the order, diagnose of machine faults can be known, judging the Nth of order, the fault of motor is imbalance, misalignment, loose coupling or damage of fan blade. In order to determine the faulty part of the motor, ‘spectral map’ and ‘order waveform’ are required. In the spectral map and order waveform, the 4th order (100 Hz) and 5th order (125 Hz) shows some the symptom on the spectral map, within the map, there is some blue line which represents the fault occurs in the motor under test. Base on the analysis, the analysis is determine the fault of the motor can be imbalance, misalignment, loose coupling or damage of fan blade.

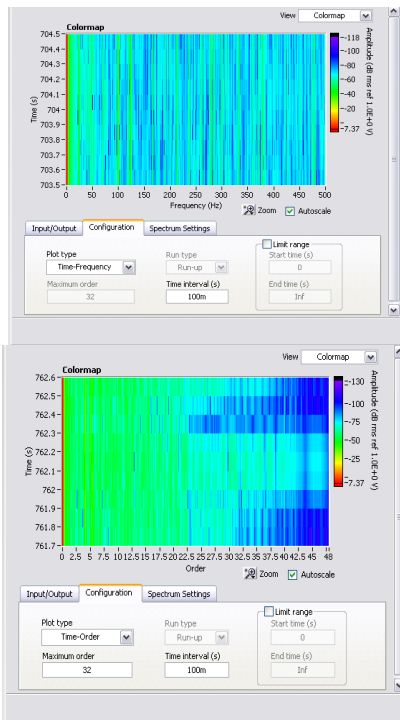
The motor under test exhibits vibration at 25Hz (1st Order), 100Hz (4th Order) and at 125Hz (5th Order). The vibration caused at 25Hz (low order) effected due to imbalance, miss alignment or loose coupling, where as the vibration at 100Hz & 125Hz (high order) are due to the blade defects, all other vibration faults caused at the harmonics of operating RPM are due to loose- mount, bearing defects etc.

Machine Data

230V, 50Hz 1φ Capacitor Run Induction Motor

7. Conclusion

Condition monitoring of induction machines provides relative advantages for industrial plant management. Besides the increased reliability of the system, maintenance scheduling can be improved, thus reducing costs and loss of productivity. This paper has presented the predictive method of induction machine condition monitoring. The implementation of the MCM system for vibration analysis is developed, tested and validated. The results obtained using the system HMI interface is measured in real time sequence and vibrations on the MUT are observed. The developed MCM system has the ability of vibration analysis by using advance signal analysis, such as Gabor order analysis and wavelet analysis. Although this paper reports only on generated vibrations further work can be worked out



(e) Spectral Map (Time-Frequency Plot) (f) Spectral Map (Time-Order Plot)

Fig.12 Vibration Analysis

with multiple sensor measurements and also detectable using these techniques and is the subject of further work in this area

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