Condition Monitoring of rotating machinery through Vibration Analysis

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Received 31 August 2012; revised 21 July 2013; accepted 17 December 2013

Condition monitoring, commonly referred to as predictive maintenance, a proven approach to improve the reliability and productivity in any industries. Its underlying philosophy is that technology can be used to measure and evaluate the condition of plant assets and equipment; enabling intelligent decisions in regard to maintenance activities. Maintenance processes are adopted by almost all the industries and are going well with preventive maintenance, but could not totally implement the predictive maintenance to practice, especially in the small and medium scale industries. Predictive maintenance by condition monitoring techniques will increase the efficiency, industrial safety and will reduce the maintenance cost. This paper gives the brief idea of condition monitoring in a nutshell referring to vibration analysis.

Key words: Condition monitoring, Maintenance, Vibration

Introduction

Condition monitoring is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure. The application of condition monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs which is typically much more cost effective than allowing the machinery to fail. Out of the various condition monitoring techniques, vibration signal analysis is used in a general way for fault diagnosis of mechanical equipment. Any change in a system condition will result in a change in dynamic response, so vibration signals carry a great deal of information about the equipment condition. Many techniques have been reported for fault diagnosis based on vibration signals, and they aim at finding some efficient fault features from the vibration signals. However, it is still a challenge to look for effective techniques that can isolate specific features from the vibration signals. The developments of vibration measurement and analysis for monitoring the condition of rotating machinery while in operation are most important one in the vibration monitoring. These have been in all three areas of interest, namely fault detection, diagnosis and prognosis. Of these areas, diagnosis and prognosis still require an expert to determine what analyses to perform and to interpret the results. In this paper authors discusses the effort performed by various researchers in the area of the condition monitoring and also developed a test rig capable of simulating machine faults, namely unbalance, shaft misalignment and its effects are investigated.

Overview of vibration monitoring

Condition of any machineries can be monitored either online or offline mode through a proper data acquisition and efficient signal processing unit. Vibration monitoring comprises of several emerging and promising hardware, software components that offer a flexible and yet reliable approach for diagnosing a new systems. A model based technique for fault diagnosis of rotor–bearing system is described. The fault condition and locations of faults are successfully detected by this model based technique. The effect of the coupling misalignment on the bearing vibration, adapting arithmetically the exciting forces or moments due to the misalignment is evaluated.

Diagnostic systems

The basic principles of machinery diagnostics and several specific malfunction symptoms supported by simple mathematical models are presented. The various malfunctions included are unbalance, excessive radial load, rotor-to-stator rubbing, fluid induced vibrations, and loose stationary and rotating parts, coupled torsional-lateral vibration excitation,
and rotor cracking. The diagnostic systems using the Spectra Quest Machinery Fault Simulator, Triaxial vibration measurements were taken at each end of the coupling on the motor and rotor bearing housings. Data was collected at several other locations of the Simulator. The results indicate that the speed and the coupling stiffness have a strong effect on the vibration spectra. The level and type of misalignment had a significant effect on the vibration signature.

**Data acquisition system**

The various tests on a machinery fault simulator under various operating conditions is performed. Operating data is simultaneously acquired using a multi-channel data acquisition system. Since misalignment produces dominant motion at the rotor running speed and its harmonics, this data is used to construct an operational deflection shape (ODS). The emphasis is on correlating the ODS of the machine when properly aligned with its ODS following induced shaft misalignment. The results of this work will provide a new perspective of machinery fault detection. The aim is to develop a more reliable tool for determining shaft misalignment and other machine faults from operating data.

**Severity of defects**

The rise of vibration problems associated with structures, which are more delicate and intricate machines, which are faster and more complex, and production processes, which are automated and interlinked is explained. Information on the practical treatment of alignment methods and preparations is provided. A general guideline for alignment tolerances was illustrated. A theoretical model of a complete motor rotor flexible coupling, discusses the system response undergoing angular misalignment is presented. An experiment on a rotor dynamic test apparatus to predict the vibration spectrum for shaft misalignment is performed.

**Analysis of defects**

Various researchers have analysed the presence and effects of the defects in a rotating system. The improper aligning of shafts through couplings often leads to severe vibration problems in many rotating machines is explained clearly. The rotor bearing system is modelled using higher order finite elements by considering deflection, slope, shear force, bending moment with eight degrees of freedom per node. The reaction forces and moments developed due to flexible coupling misalignment are derived and introduced in the model which increases the harmonics with misalignment can easily be modelled by using finite element analysis. The location of the coupling with respect to the bending mode shape has a strong influence on the vibrations. They numerically evaluated the effects of coupling misalignment on the 2X vibration response of a rotor-coupling bearing system. The problems connected with dynamics of mechanical system at certain radial misalignment of shafts are investigated in the offered work. As an objective of research, the system of two shafts connected by elastic centrifugal ring coupling. In the coupling, connecting radially misaligned shafts, an internal moment of resistance to rotation is arising.

**Response of the system**

A clear correlation between misalignment & vibratory symptoms that it produces to aid machinery diagnostic engineers to distinguish between shaft misalignment and other problems that exhibit similar vibration symptoms using vibration analysis is established. The dynamic response of two Jeffcott rotors connected by rigid-type couplings with parallel misalignment is studied. The study investigated the steady state and transient response of the system and concluded that the presence of lateral and torsional coupling is coupled. The general equations of motion are derived and given in dimensionless form to represent the general case. The expected vibration frequency for a misaligned metallic-disc flexible coupling based on the analysis of the structural vibrations produced by misalignment is determined. Further, they showed experimentally, through real-time spectrum analysis, that all the theoretically predicted vibration frequencies are produced by a misaligned metallic-disc coupling, but the 2× and 4× running speed components show the largest changes as misalignment increases.

**Prognosis**

The steady-state vibration response at integer fraction of the first bending natural frequency is discussed. Full spectra and orbit plots are efficiently used to reveal the unique nature of misalignment coupling characteristics under misalignment condition. Full spectrum analysis of vibration signal. Several investigators have provided vibration identification charts which indicate that the coupling misalignment, generally, produces a frequency which is twice the shaft speed frequency. An experiment to study the vibration parameters of the system such as amplitude,
velocity and acceleration in vertical direction were measured at the bearing points is performed. A proposed back propagation neural network has been used for vibration parameters prediction of a rotating mechanical system at the bearing points using real data. Fixed system measurements such as working speeds were used as inputs to the network. This kind of neural network predictors would be designed as a controller of such systems. Finally, vibration parameters of rotating systems could be predicted for all directions.

Rotor-Bearing Test Rig: Identification of Unbalance and Misalignment

The rotor-bearing test rig is fabricated which consists of an AC motor, a self designed coupling, a single-disk rotor. The rotor shaft of length 900 mm is supported by three identical pillow radial bearings of bearing span of 500 mm. The diameter of the rotor shaft is 12 mm, a disk of outer diameter 50 mm, weighing 1000 grams with the provision for unbalance of 40 grams at a radius of 30 mm is mounted on the mid-way of the bearing supports. The bearing pedestals and motor support are firmly mounted on steel base. Using the radial screws the disk is fastened to the rotor shaft, there are four threaded holes symmetrically at a radius of 35 mm to hold any desired amount of unbalance mass. By varying the bearing pedestals various misalignments can be induced. Using the tachometer the speed is measured and it is varied by adjusting the power supply to the motor. Using the sound and vibration tool kit available in the LABVIEW software a condition monitoring system is developed interfacing with a non-contact accelerometer of make NI 9233 with a sensitivity of 0.9 g. An effective continuous signal extraction system is developed for monitoring of misaligned rotor and unbalanced rotor signatures and the extracted signals are diagnosed in time domain analysis. The experiment is conducted for the speeds ranging from 600 to 2000 rpm. The signals are captured by placing the accelerometer in axial position on the top of bearing housing. After achieving perfect alignment in offline conditions, then a base line data is captured this can be used for further comparison. The responses are compared across the three bearing ends. For various modifications, amplitude of the vibrations is measured and the spectrum is plotted with horizontal scale of speed in orders of RPM and vertical scale is velocity in mm/sec. The response illustrates the level of the velocity is within the limit in comparison with the vibration severity chart. The velocity spectrum for the coupling end of the rotor-bearing setup is shown in the Fig 1. An experimental based investigation has been made into the dynamics and control of rotor vibration due to unbalance and shaft misalignment. The vibration along the drive side is lesser in comparison to coupling end of the rotor. The level of vibration due to unbalance is greater than the normal condition. The vibration value at non drive end of the test rig is illustrated in Fig 2. Values of the velocity significantly vary with respect to the types of faults. For parallel misalignment the velocity is lesser in comparison with the angular misalignment, the velocity for the unbalance significantly increases with respect to the speed.

Conclusion

The various aspects of condition monitoring, vibration analysis, predictive maintenance, and related sensors are reviewed and presented in this paper. The procedure for detection, diagnosis & prognosis is
discussed. The vibration monitoring test rig is developed with various modes of machine failure is in deed capable of generating common machine faults. The base signal was found to be within the safe limit as per the vibration severity chart. Then as per the design of experiments the various faults are stimulated in the test rig, correspondingly, the vibration signals are extracted. From all the characteristic curves it is found that the velocity value increases after reaching the speed of 800 rpm. In comparing the spectrum of all the defects, unbalance has produced higher vibrations at all the end conditions. The values of displacement and velocity for a speed of 1000 rpm is higher for a faulty condition in comparing with healthy condition irrespective of the drive, coupling or non drive ends. The values of velocity significantly increases as the misalignment increases from 0 mm to 2 mm.

References
5 Surendra N.Ganeriwala (Suri) & Zhuang Li & Mark H. Richardson, Using operating deflection shapes to detect misalignment in rotating equipment, IMAC XXVI, February 4-7 (2008).
7 Pitorwoski, Shaft alignment handbook, Marcel Dekker, New York, 1986.