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Review of Vibration Signal Processing towards Faults Diagnosis

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Abstract – *Problems occurs in any machineries are of great distress to maintenance engineers. On several occasions the stability conditions of rotating machinery changes the operating conditions between two interconnected units of machineries. Varying situations attracts many designers and engineers for detailed investigations in the rotating systems. The occurrence of faults may be due to the two reasons, one is fault which occurred during the design stage itself, second one being fault occurring during running conditions. This paper discusses about the second situation in connection with vibration signal processing due to the faults. Satisfactory operation of machine depends on the occurrence and severity of the fault. The occurrence of the fault in any system and its changes relates to the quality of the final product. Fault depends on damage, which in turn depends on defect. The common types of machine faults are unbalance, shaft misalignment, damaged / loose bearings, damaged gears, fault of misaligned belt drive, mechanical looseness.*

Keywords: *Unbalance, Misalignment, fault Diagnosis*

INTRODUCTION

Fault detection using vibrational analysis involves analyzing the vibrational signature for signs of fault. Any predominant fault results in increased vibration level which has energy concentrated at certain frequency levels. The relation of the predominant vibration frequencies with the forcing frequency gives an idea about the source of the fault. The increased amplitude of the predominant frequencies indicates the severity of the fault. Relations between faults and fault signatures can be developed. A fault is an irregularity in the functioning of the equipment which results in component damage, energy losses & reduced efficiency of the machine. Rotating machines are becoming increasingly precise and operating at higher speeds due to the progress and demand of modern technology. These machines should offer stable functioning and higher operating efficiencies even under the most severe conditions. The primary factors that degrade the performance of machines operating at a high speed are vibration and accompanying problems such as fatigue and noise. It is quite common to relate the condition of a machine with its intensity of vibration. Machinery vibration increases or becomes excessive due to the mechanical trouble present in it like misalignment, unbalance, worn gears or bearings, looseness and so on. Following section of this paper discusses about the severity of the defects and its effects.

Severity of Defects

The latest developments of measuring vibration and its analysis for monitoring the condition of rotating machinery while in operation have been discussed [1]. These have been in all three areas of interest, namely fault identification, analysis and forecast. Of these areas, analysis and forecast still require an expert to determine what analyses to perform and to interpret results. The rise of vibration problems associated with structures, which are more delicate and complicated equipment, which are faster and more complex, and manufacturing processes, which are automated and interlinked are explained [2]. The occurred problems are directly related with demands of lower investment, running and maintenance costs in concurrence with the necessities of increased productivity and

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efficiency. Consequently, there has been requirement for a better understanding of causes of vibration and its dynamic response of complex machinery as well as individual components. The pie chart in Figure 1 shows the percentage of defects in a rotating system.

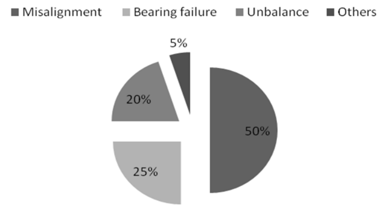

Figure 1: Percentage of defects in a rotating system.

Types of Misalignment

Misalignment a familiar phenomenon occurring in a rotating machinery. Operating frequency of machinery doubles when two coupled shafts are not aligned. The vibration caused by misalignment has a high axial component rather than other components. Aligning of the rotational centres of two or more shafts of machines to operate under normal operating conditions is called as misalignment.

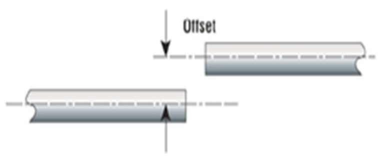

Figure 2 Offset misalignments

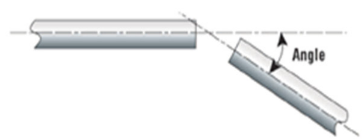

Figure.3 Angular misalignment

Offset (Parallel) misalignment is the distance between the shafts centers of rotation measured at the plane of driving unit to driven unit (Mils) shown in the Figure.2. Angular misalignment is the difference in the slope of one shaft of moveable machine as compared to slope of the stationery machine (Mils/1") illustrated in the Figure.3. The major sources and symptoms of misalignment are shown in table 2

Table 2 Symptoms of Misalignment

TYPES OF MALFUNCTIONS	**SOURCES**	**SYMPTOMS**
Misalignment	Poor alignment methods Good alignment methods - but poor practices Inaccurate readings Pipe strain Thermal growth Bent shafts Cocked bearings, Poor shimming practices Soft foot Poor bases and foundations Improper grouting Coupling run out Poor tolerances	Amplitudes are higher in one particular direction. Axial amplitudes are greater than 50% of radial amplitudes. Motions between vertical and horizontal directions are different.

Effect of Misalignment

Investigation on the stability of two rotors connected by a flexible mechanical coupling subjected to angular misalignment and its effects was clearly illustrated[3].The results illustrates that an increase in angular misalignment or mechanical coupling stiffness terms leads to raise in the model stability region. C.B. Gibbons [4] stated that misalignment of machinery shaft causes reaction forces to be generated in the coupling which affects the machines and are often a major cause of machinery vibration. The reaction forces generated by the couplings are described for each type of coupling in current use and especially for the several types of non lubricated couplings. Piotrowski [5] has provided information on the illustrative treatment of alignment methods and its preparations. A common guideline

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for alignment tolerances is given. Xu and Marangoni [6] described a theoretical model of a complete motor rotor flexible coupling, discussing the system response under angular misalignment. They pursued a vibration analysis based on a theoretical model and its validation. They found out that shaft misalignment tends to show up as a series of harmonics of the shaft running speed, the 2X rpm harmonic being predominant. The closer to the systems' natural frequencies these harmonics are, the higher their magnitude. V. Hariharan and P.S.S. Srinivasan[7] were performed a experiment on a rotor dynamic test apparatus to predict the vibration spectrum for shaft misalignment. The experimental and numerical (ANSYS) frequency spectra were obtained and validated.

Unbalance

Unbalance is a result of uneven distribution of mass and causes vibration which can be transmitted to the bearings and other parts of the machine during operation. Imperfect mass distribution can be due to material faults, design errors, manufacturing & assembly errors and especially faults occurring during operation of the machine. Effective operation can be achieved and determination of the machine & ultimately fatigue failure can be arrived.

Reasons for Unbalance

- ✓ The shape of the rotors is unsymmetrical.
- ✓ Unsymmetrical mass distribution exists due to machining or casting error.
- ✓ A deformation exists due to a distortion.
- ✓ An eccentricity exists due to a gap of fitting.
- ✓ An eccentricity exists in the inner ring of a bearing.

Assume that a weight with a mass of (m) is added to a balanced rotor having a thin dish shape at a distance from its centre. When this rotor is rotated at a speed of N, the generated centrifugal force is expressed as,

$$P = m\,r\,\omega^2 \quad \text{--- (1)}$$

When ω represents the angular speed of rotation, $\omega = 2\pi N/60$ the centrifugal force P changes its direction as the rotor rotates which repeatedly acts on the bearing & so causes vibration of the whole machine. Unbalance causes a moment which gives an object the wobbling movement characteristic of the vibration of rotating structures. A Static Unbalance occurs when the mass/inertial axis of a rotating mass is displaced from and parallel to the axis of rotation. Static unbalances can occur more frequently in disk-shaped rotors due to the thin geometric profile of the disk allowing for an uneven distribution of mass to have an inertial axis that is nearly parallel with the axis of rotation.

$$U = m * r \quad \text{--- (2)}$$

Where U = Unbalance, m = mass, r = distance between unbalance and the centre of the object. When the mass/inertia axis and the Shaft axis intersect on geometric centre axis then it is called as Couple Unbalance. It occurs frequently in elongated cylindrical rotors.

$$U = m.r.d \quad \text{--- (3)}$$

Where d = distance between the two unbalance masses. When the mass/inertia axis does not intersect with shaft axis then it is called Dynamic Unbalance. It occurs virtually in all rotors.

Effect of Unbalance

Unbalance (also referred to as imbalance) exists when the center of mass of a rotating component is not coincident with the center of rotation. It is practically impossible to fabricate a component that is perfectly balanced; hence, unbalance is a relatively common condition in a rotor or other rotating component. A.W. Lees, J.K. Sinha and M.I. Friswell [8] have explained & suggested the reliable estimation of the state of the rotor unbalance (both amplitude and phase) from a single run-down is a feasible procedure. Now a method has been proposed that can reliably estimate both the rotor unbalance and misalignment from measured vibration during a single machine run-down.

Bearing Defects

Due to the close relationship between motor system development and bearing assembly performance, it is difficult to imagine the progress of modern rotating machinery without consideration of the wide application of bearings. In addition, the faults arising in motors are often linked with bearing faults. In many instances, the accuracy of the instruments and devices used to monitor and control the motor system is highly dependent on the dynamic performance of bearings. Bearing vibration can generate noise and degrade the quality of a product line which is driven by a motor system. Heavy bearing vibration can even cause the entire motor system to function incorrectly, resulting in downtime for the system and economic loss to the customer.

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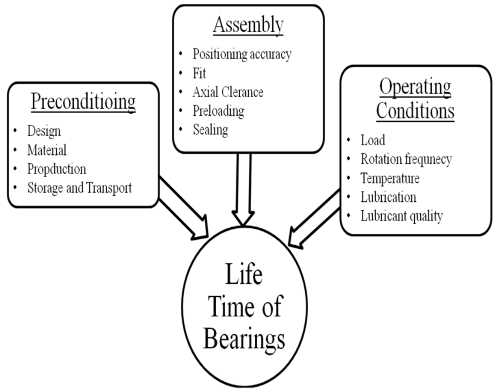

Figure1.4 Life time of Bearing

Proper monitoring of bearing vibration levels in a motor system is highly cost effective in minimizing maintenance downtime both by providing advance warning and lead time to prepare appropriate corrective actions, and by ensuring that the system does not deteriorate to a condition where emergency action is required. Thus, it is important to include bearing vibration diagnosis into the scheme of motor system fault diagnosis. The ball bearings itself act as a source of vibration, even in the absence of defects. The level of vibration can be increased due to the defects on one of the elements of a ball bearing. An impulse is created when a rolling element strikes to a defect on one of the races, which are periodic with a certain frequency due to the rotation. In case the defect occurs on the inner or outer race, repeated each rolling element strikes a defect is known as "Ball-pass frequency". As bearings are often used to form a bearing–rotor system, the speed of the rotor (or shaft) Fs is very important to the movements of bearings. All other frequencies are a function of this frequency. Similar to the ball pass inner raceway frequency FBPI, the ball pass outer raceway frequency FBPO is defined as the rate at which the balls pass a point on the track of the outer raceway. The value FBPO is a function of the number of bearing balls NB and the difference between the outer raceway frequency and the fundamental cage frequency Fc .The ball rotational frequency FB is the rate of rotation of a ball about its own axis in a bearing. This frequency can be calculated from either the ball pass inner raceway frequency FBPI or ball pass outer raceway frequency FBPO. The vibration signals from bearings with inner and outer race fault can be compared with fault-free bearing. Impulses from a defect in outer race have approximately equal amplitudes. Impulses created from a defect on the inner race have different amplitudes and still periodic. The behavior can be fulfilled as the impulses are amplitude modulated. The impulses arises due to the resonance from bearing elements, the amplitude is directly related to the applied force on the ball bearing. Since the impulses are of short duration, the spectra will exhibit many harmonics. The amplitude of the defect is useful for the effective decision making. The life time of the bearing mainly depends on the three factors viz preconditioning, assembly and its operating conditions, illustrated in the figure 1.4.

Stability

Vance [9] discussed the response and stability of a single Jeffcott rotor on hydrodynamic bearings and presented the whirl stability characteristics of hydrodynamic bearings as a function of the equilibrium eccentricity

Critical Speed

Angular velocity that excites the natural frequency of a rotating object, such as a shaft, propeller, lead screw, power transmission systems or gear is called as critical speed. As the speed of rotation meets the natural frequency, the object starts to resonate, which increases system vibration. The resulting resonance occurs regardless of orientation. The rotational speed is equal to natural frequencies that speed is referred to as critical speed. There are two main methods used to calculate approximate critical speed by Rayleigh Ritz method and Dunkley's method. At critical speeds, the amplitude of vibration of rotors is excessively large and a large amount of force is transmitted to the bearings or foundations. The systems may even fail because of violent nature of vibrations in the transverse direction. Therefore, it is important to find the natural frequency of the rotating system to avoid the occurrence of critical speeds.

Critical speed, $N_C = \frac{}{-}$, rpm

where δ = deflection of shaft in m. Critical speed plays a vital role in the life time of the shaft and in turn depends on the various factors shown in the figure 1.5

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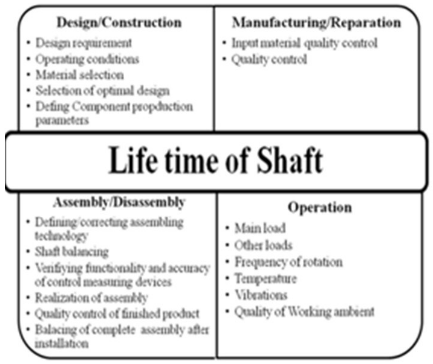

Figure1.5 Life time of Shaft

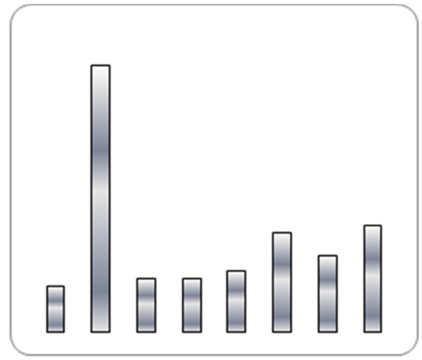

Figure % of Failure of different machineries of a process industry

Table 1: Vibration Causes and Identification

Sl. No	FAULT	FREQUENCY	DIRECTION OF VIBRATION
1.	Rotating unbalance	Same as running speed	Radial
2.	Misalignment	2*speed	Radial, Axial
3.	Roller bearing defect	at ball or roller speed ultra sonic frequencies (20-60khz)	Radial, Axial
4.	Oil film whirl in high speed turbo machines	0.5*speed	Radial
5.	Damaged or worn gears	No of teeth* rpm	Radial

Table 1.1 illustrates the general guide lines for identifying the cause of vibrations. The relation between the fault and frequency, amplitude and direction of vibration, are given. This is a useful guide for pin-pointing the cause in case vibration levels at certain frequency are seen to increase.

Conclusion

The art of identifying every possible failure mode of a component and then predicting its dynamic properties such as progression rate to failure and the resulting impact on the system can be a difficult and even impossible task. The various causes of vibration and its effects are discussed briefly

References

1. Robert B. Randall, "State of the Art in Monitoring Rotating Machinery – Part 1" The Journal of Sound and Vibration, 2004.
2. Wilfried Reimche, Ulrich Südmersen, Oliver Pietsch, Christian Scheer, and Fiedrich-Wilhelm Bach "Basics Of Vibration Monitoring For Fault Detection And Process Control" June 2 to 6, 2003.
3. K.M. Al-Hussain, "Dynamic stability of two rigid rotors connected by a flexible coupling with angular misalignment", Journal of Sound and Vibration, vol. 266, pp. 217–234, 2003.
4. C. B. Gibbson, "Coupling Misalignment Forces" Proceedings of the fifteenth turbo machinery symposium, Gas Turbine Laboratories, Texas, 1976.
5. Pitorwoski, Shaft Alignment Handbook, Marcel Dekker Inc, Newyork, 1986.
6. M. Xu and R. D. Marangoni, "Vibration analysis of a motor-flexible coupling-rotor system subject to misalignment and unbalance. Part I: theoretical model analysis. & Part II: experimental validation", Journal of Sound Vibration, vol. 176, pp. 663-679. 1994.
7. V. Hariharan and PSS. Srinivasan "Vibration Analysis of Shaft-ball Bearing System" Indian Journal of Science and Technology, Vol.2 No. 9, Sep 2009.
8. Sinha J.K, Elbhbah K, A future possibility of vibration-based condition monitoring of rotating machines, Mechanical Systems and signal processing, vol 34, pp 231-240, 2013.
9. J.M. Vance, "Rotor dynamic of Turbo machinery", Wiley, New York, 1988

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