DETECTING THE MISALIGNMENT IN BEARING SHAFT

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Abstract— **In today's competitive Industrial environment, it is very essential to achieve maximum availability of plant and machines. The Industrial equipments are subjected to regress operating conditions and therefore the possibilities of break down from various inaccuracies and problems are quite significant. Therefore, a dynamic predictive maintenance based on machinery problem diagnostics is a must in ensuring trouble free operation. Machinery vibrations are manifestation of the health condition of operating machines. Hence the accurate measurement and correct interpretation of vibrations can help in precisely diagnosing machinery problems during operation. The aim of this is to investigate how the acoustic signals can be used for state monitoring of the operating machines. The Fast Fourier Transform method is used to analyze the characteristics of the machine, based upon which the machinery problems during operation can be diagnosed precisely. The Fast Fourier Transform of and the acoustic signals are Computed. On time state monitoring in the running condition of the machine is performed, which eliminates the need for a separate day for maintenance when the machines are shut down for monitoring the machine health condition. Hence a reliable process for the state monitoring of the machine health is put forward.**

If the vibration amplitudes are high, the health of the machine is not good. Similarly the noise produced by the machines during the operation is also the indication of condition of the machine. Therefore amplitudes of these signals can also be used for the condition monitoring. The acoustic diagnosis of machine state is as efficient as vibration monitoring and cost effective.

Keywords—FFT, acoustic signals, vibration, Machines

1. Introduction

Acoustics refers to the study of sound, namely, its production, transmission through solid and fluid media, and any other phenomenon engendered by its propagation through media. Sound may be described as the passage of pressure fluctuations through an elastic medium as the result of a vibrational impetus imparted to that medium. An acoustic signal can arise from a number of sources, e.g., turbulence of air or any other gas, the passage of a body through a fluid, and the impact of a solid against another solid.

The Fast Fourier Transform method is used to analyze the characteristics of the machine, based upon which the machinery problems during operation can be diagnosed precisely.

The most common defects which are associated with plants are misalignment, bend shaft, Mechanical Looseness, Coupling Defects, Loose Foundation Bolts, Cracks in Foundation, Cracks in Structure, Piping Forces, Aero Dynamic Forces, Resonance Condition, Defects in Bearings, Gear boxes, Belt driven system, Electrical Defects etc.

In general, all the defects in different machines can be grouped into 5 categories. Unbalance of one or more parts, Misalignment of system, Out of tolerance, Reaction to some external forces and unbalanced magnetic forces in drive motors/generators.

Higher the value of FFT, higher is the vibrations which in turn indicate the fault in the machine. Thus the state of the machine is determined.

2. On-machine Monitoring Using Acoustic Signals

The acoustic and vibration signals can be closely allied together. The main advantage of acoustic signal is that they are airborne. Hence the microphone is enough to capture the signals whereas in vibration monitoring, the sensor has to be mounted on the machine under interest hence error in the monitoring may be produced due to misalignment of the sensor. As sound signals are airborne, the portable system can be realized. The system employing acoustic signals for monitoring consist of four units as shown.

1. Machine under mounting
2. Mike
3. Filter
4. PC for signal processing

The only disadvantage of this technique is that while capturing the sound signals there is a chance for the other signals to interrupt. The signal processing software to compute FFT of the signal used in this method is auto signal software. The state of the machine is determined with the value of FFT as done in the vibration monitoring.

The mike pin connected to the PC is placed 1-2cm away from the machine so that it is not in direct contact with the machine. The mike is covered by the EMR filter to prevent the noise signals from the environment being capture. Hence the noise from the machine is captured by the mike pin through the sound recorder and then is given to the PC with some suitable signal analysis software such as AUTOSIGNAL and MATLAB. FFT of the signals is plotted and using that, the machine state is predicted. Through the analysis of number of samples obtained from the machines, the standard FFT values for the vibration and acoustic signals to determine the health condition of the machine is found as follows. The condition of the machines is categorized into three states. They are Normal, alert and alarm. The state monitoring of the machines can be done effectively using the vibrations of the machine as well as the sound signals. Even though both the acoustic and vibration signals can be utilized for the condition monitoring, it is proposed that the acoustic signals may be employed by the industries for on-machine monitoring for the predictive maintenance as the acoustic analysis cost less than the vibration analysis.

3. Shaft Misalignment

Shaft alignment is the positioning of the rotational centers of two or more shafts such that they are co-linear when the machines are under normal operating conditions. Proper shaft alignment is not dictated by the total indicator reading (TIR) of the coupling hubs or the shafts, but rather by the proper centers of rotation of the shaft supporting members (the machine bearings).

There are two components of misalignment—angular and offset. Offset misalignment, sometimes referred to as parallel misalignment, is the distance between the shaft centers of rotation measured at the plane of power transmission. This is typically measured at the coupling center. The units for this measurement are mils (where 1 mil = 0.001 in.).

Angular misalignment, sometimes referred to as "gap" or "face," is the difference in the slope of one shaft, usually the moveable machine, as compared to the slope of the shaft of the other machine, usually the stationary machine. The units for this measurement are comparable to the measurement of the slope of a roof (i.e., rise/run). In this case the rise is measured in mils and the run (distance along the shaft) is measured in inches. The units for angular misalignment are mils/1 in.

As stated, there are two separate alignment conditions that require correction. There are also two planes of potential misalignment—the horizontal plane (side to side) and the vertical plane (up and down). Each alignment plane has offset and angular components, so there are actually four alignment parameters to be measured and corrected. They are horizontal angularity (HA), horizontal offset (HO), vertical angularity (VA), and vertical offset (VO).

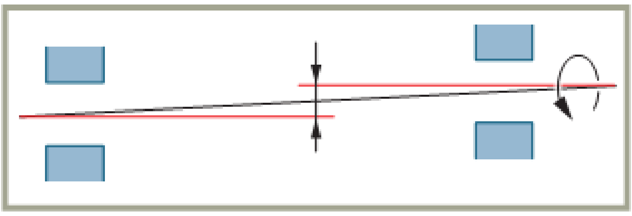


Fig.3.1 Concentricity defect

Fig.3.2 Misalignment between centerline of shaft and bearing housing

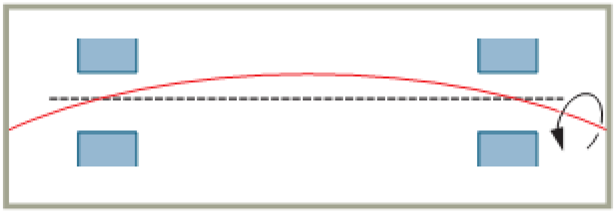


Fig.3.3 Linearity defect

The value of these alignment errors and the influence on bearing life is determined by calculation. The diagram below shows the results. It shows that the drop in service life is very fast and that alignment errors must be kept within very narrow tolerances.

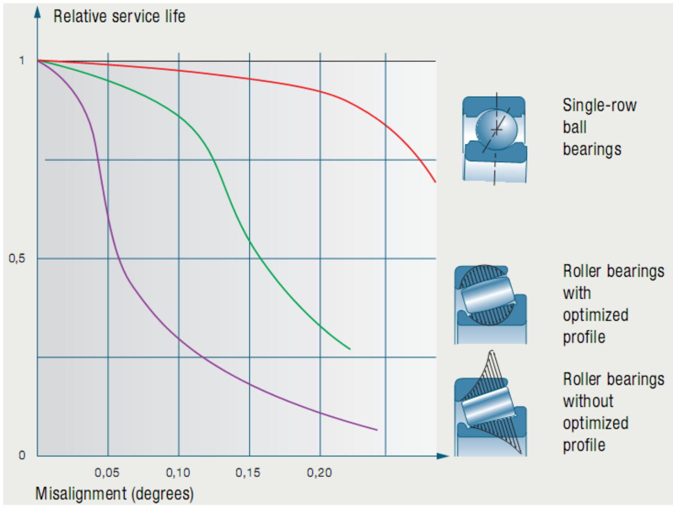


Fig.3.4 Graph of Service life vs. misalignment

Relatively small amounts of shaft misalignment can have a significant impact on the operational life of bearings. Summary of Maintenance and Reliability Center research notes that a 5-mil offset misalignment can reduce expected bearing life by as much as 50 percent in some cases. Bearings precision manufacturing components designed to operate with clean lubrication but restricted operating condition. Not able to withstand operating for long time at elevated temperature caused by misalignment. Not manufactured to operate long periods with misalignments imposing axial shock loads on carefully machined and honed components. In addition to the damage imposed on bearings through the misalignments itself when mechanical seals fails, bearing has to be removed from shaft assembly, sometimes refitted or replaced. Removal and refitting itself can cause damage.

4. Fast fourrier transformation (FFT)

FFT is essence, decomposes or separates a waveform on function into sinusoids of different frequencies .It identifies or distinguishes the different frequency sinusoids and their respective amplitudes. The Fourier transform *f(s)* of function *f(x)* is expressed as

$$f(s) = \_\ f(x)\ exp\ (-i\ 2\_xs)\ do. \qquad (1)$$

Applying the same transform to *f(s)* gives

f (w) =_ f (s) exp (-i 2_ws) ds. **(2)**

If *f(x)* is an even function of *x*, that is *f(x) = f(-x)*, then *f(w) = f(x)*. If *f(x)* is an odd function of *x*, that is *f(x) = -f (-x)*, then *f(w) = f(-x)*. When *f(x)* is neither even nor odd, it can often be split into even and odd parts. It is often useful to think of functions and their transforms are occupying two domains which are called as upper and lower domains.

5. Selection and Positioning of Microphones

The free field occurs as a region that is not subjected to reflected waves, as is the case in an open field or in an anechoic chamber. The presence of a microphone in the sound field disturbs the field. A microphone designed to compensate for this disturbance is called a free-field microphone. In order to obtain maximum accuracy in measurements, the free-field microphone should be pointed toward the noise source [0◦ incidence, as shown in Figure 5]. Microphone sensitivities are also stated in terms of mV/Pa. The disturbance of the sound field by the presence of the microphone depends on the sound frequency, the direction of propagation, and the size and shape of the microphone. At higher frequencies, where the wavelength of the sound is small compared with the principal dimensions of the microphone, reflections from the microphone cause the pressure acting on the microphone diaphragm to differ from the actual free-field sound pressure that is supposed to be measured. Because a wavelength of 1 inch corresponds to 13,540 Hz, a 4-cm microphone will not provide accurate free-field measurements of noise in the frequency range in the neighborhood of 13 kHz and above. Even at 6 kHz, the error for a 4-cm microphone can exceed 2 dB. The converse of the free field is the diffuse field which occurs as the result of multiple reflections. A random-incidence microphone is utilized in measuring sound in diffuse fields; it is omnidirectional in that it responds uniformly to sound arriving from all angles simultaneously. Pressure microphones are designed to yield a uniform frequency response to the sound field including the disturbance produced by the microphone‘s presence. This type of microphone may also be used in diffuse fields. Using a free – field microphone in a diffuse field will result in lessened accuracy unless special circuitry in the measurement system provides compensating corrections.

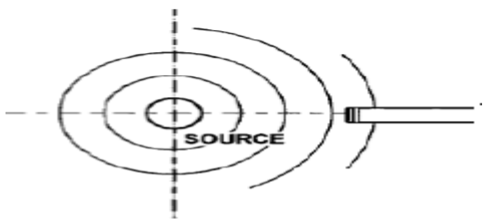
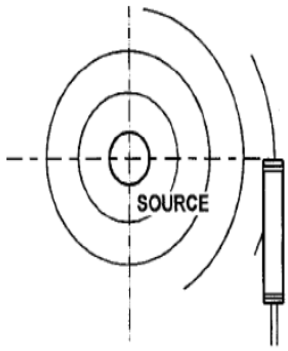


Fig.5.1 0° Incidence



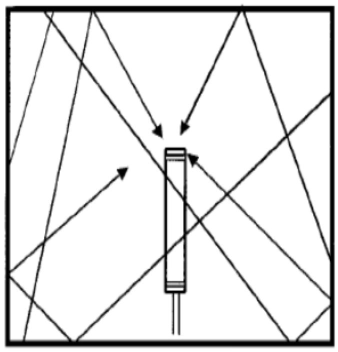


Fig.5.2 90° Incidence fig.5.3 Diffuse field

6. *Case Study*

In this case study we diagnose the defect of misalignment in the bearing shaft. An experimental setup is made for the analysis purpose. We have taken the cage bearing (NBC make, 6004) having 9 balls for our study. A motor (200 watt) is used to drive bearing arrangement and a mike (Logitec make, 20 Hz to 16000 Hz frequency range) is used to record the acoustic signal generated by the bearing housing by placing it 1cm apart from that. In first set of reading shaft is made to run at 1460 rpm with the help of motor and without any misalignment by providing support at pulley which is mounted at the other end as shown in figure 4.1. Later weight is applied to introduce the misalignment in the shaft as shown in figure 4.2 at three different levels by own weight of shaft and pulley, adding further 2kg and adding 5kg (in total), which is also measured in terms of angle as 0.35, 0.72 & 1.04 degrees respectively. Signal (in wav format) generated by the bearing is recorded for 2 sec duration with the help of mike and saved in the computer for the processing.

These signals then processed in the Matlab6.0 software for generating the raw signal, FFT(Fast Fourier Transformation) and decomposition at 6th level by using db4 as mother wavelet.

Fig. 6.1 Experimental se up with support at the end

Results and Discussions

Raw signal (amplitude vs time), Fast Fourier Transform FFT (energy vs frequency domain) are drawn and compared in this section. A simple raw signal of case having no misalignment is shown in *Fig. 9* and the other cases of misalignment are having almost similar view of raw signal as in case of no misalignment. FFT's are also shown below for four different cases given below.

Case 1: FFT of Shaft without misalignment rotated at 1460 rpm

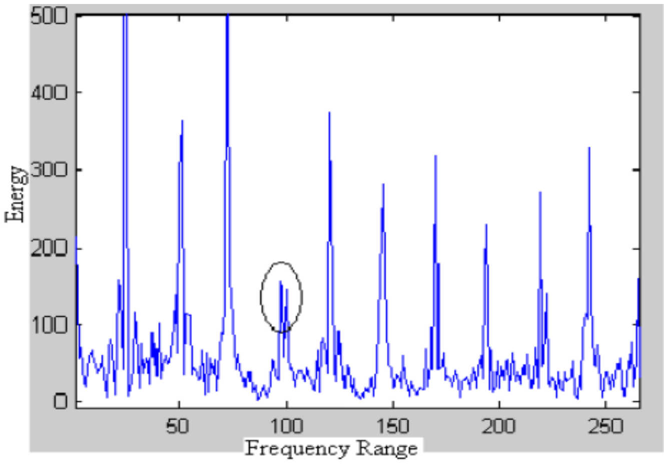


Fig.6.2 FFT of signal without misalignment at 1460 rpm

Case 2: FFT of Shaft with misalignment because of its own weight of shaft and pulley (Equivalent to 1 Kg point load at the pulley) at 1460 rpm

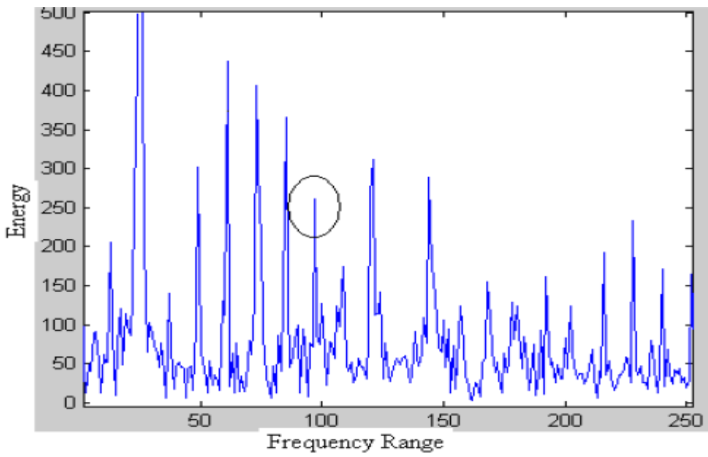


Fig.6.3 FFT of the signal having misalignment because of its own weight

Case 3: FFT of Shaft with misalignment with 1.5 Kg additional load at the pulley at 1460 rpm

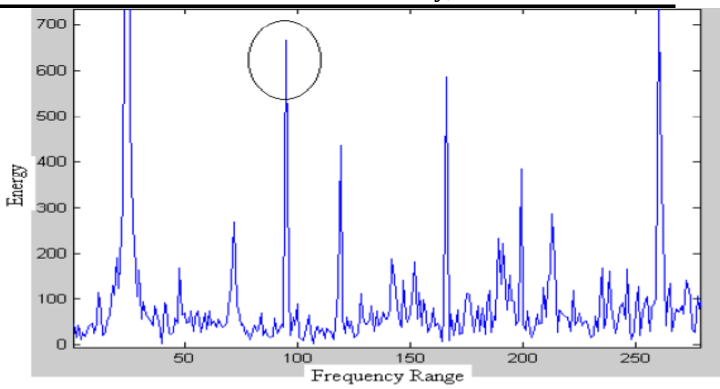


Fig.6.4 FFT of the signal having misalignment because of its own weight and additional 1.5 Kg load at 1460 rpm

Case 4: FFT of Shaft with misalignment with 3.0 Kg additional load at the pulley at 1460 rpm

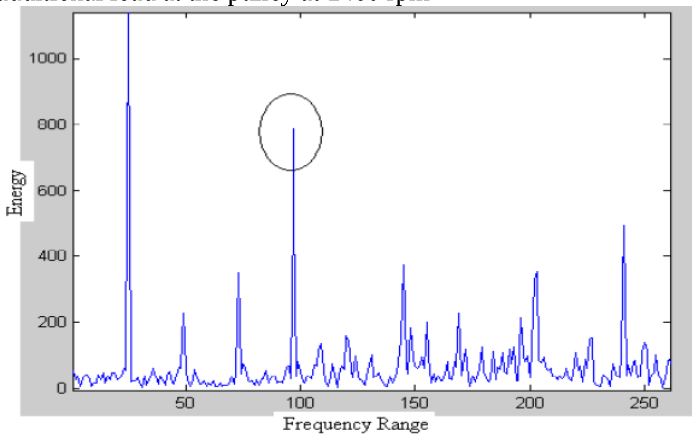


Fig.6.5 FFT of the signal having misalignment because of its own weight and additional 3 Kg load

The peaks are coming at the multiple of 24.3Hz which are the harmonics of fundamental frequency of rotation, this can be calculated by 1460 / 60= 24.3 rotation per second (Hz). We have marked the energy values corresponding to 4th consecutive peak of 24.3 Hz (ie 97.2Hz) on each FFT graph and their respective values are measured as 155, 255, 650, and 780 for the Case1, Case2, Case3 and Case4 respectively.

7. Conclusion

In this we have analyzed the fault of misalignment in bearing shaft by using acoustic signal and developed a method to identify such defects. From the experiments following conclusions can be drawn.

1) It is demonstrated that, although the environment influences acoustic signal for condition monitoring, it does not significantly reduce the extraction of useful diagnostic information. It has been demonstrated that acoustic condition monitoring can effectively be used for detection of misalignment in bearing arrangement.

2) The graphs drawn by using FFT for the fault misalignment. Also the signs of increasing misalignment can be noted down clearly with functions.

3) In vibration monitoring using acoustic signal have certain advantages over the conventional vibration measuring techniques. Firstly in this sensors do not alter the behavior of the machine due to its non-contact nature. And time based information is not lost in this method.

4) Acoustic based method provides considerable freedom in positioning of the microphone. For instance, in this application, small variations in distance and plane of the microphone with respect to the bearing had a little influence in detecting the main characteristics of the bearing acoustics. On the other hand, small change in the location of the accelerometers based method had a bigger impact in detecting the main characteristics of the bearing vibration.

5) The method developed can be used for the condition monitoring and for predictive maintenance of the ball bearing for the misalignment.

8. References

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