CHAPTER 4

FAULT DIAGNOSIS OF BEARINGS DUE TO SHAFT RUB

4.1 PHENOMENON OF SHAFT RUB

Unwanted contact between the rotating and stationary parts of a rotating machine is more commonly referred to as rub. It is a serious problem that has been regularly identified as a primary mode of failure in rotating machineries. Rub may typically be caused by mass imbalance, defective bearings or seals, or by rotor misalignment. It causes direct damage to the contacting parts. The damage can range from mild, for light rub, to complete destruction of the machine. The rub can be categorized into partial radial rub and full annular rub. If the rub occurs over a fraction of the vibration cycle, it is called partial rub. If it occurs over the entire vibration cycle maintaining continuous contact, it is called as full annular rub. The former type describes brief intermittent contacts and the later describes more sustained contact between rotor and stator. Identifying vibration signatures caused by rub on bearing housing is very critical in preventing rub related machinery failures. This chapter focuses on the effects of rub material and speed on vibration signatures associated with the shaft rub.

A common problem in newly rebuilt or modified rotors is a slight rubbing condition as the rotor is initially operated. Rotor rubs are not a phenomenon which continues over an extended period. They usually increase
the clearances until the rub has been cleared off. If not corrected, they will wear away the internal clearances till the machine becomes inoperative.

In this chapter, the vibration signature on bearing housing caused by shaft rub is studied by applying a rub against a rotating shaft. Full annular rub was simulated with two rub materials, namely mild steel and aluminum. Experiments were carried out at three speeds 740, 1150 and 1600 rpm. Time domain and frequency domain signals on bearing housing with and without rub were collected and analyzed. Several observations on the effects of rub on bearing housing vibration are presented.

4.2 EXPERIMENTAL FACILITY

The experimental facility depicted in Figure 3.3 is used for rub test also. For this task, a lathe tool post is used to hold the rub tool. The modified experimental facility is shown in Figure 4.1.

Figure 4.1 Experimental test rig

1- Accelerometer, 2- Steady rest, 3- Roller bearing, 4- Blunt Tool, 5- Tool post, 6- Lathe bed, 7- Vibration analyzer, 8- Computer, 9- Chuck, 10- Head stock, 11- Shaft
Figure 4.2 (a) Photograph of experimental setup showing accelerometer and vibration analyzer (b) Alignment of rub tool against shaft

Figure 4.2 (a) illustrates the photograph of the experimental facility with necessary instrumentation. The experimental facility consists of a precision tool room lathe, shaft and bearing system with necessary instrumentation. Tool room precision lathe is a versatile machine tool used in almost all the manufacturing industry. Such a lathe has been chosen for conducting experiments to achieve variable speed drive; to have exact co-axial setup. The shafts are supported by steady rest which lies on a rigid bed. Mild steel solid shaft of 35 mm diameter and 450 mm length between the bearings is used to accommodate the bearing. Two defect-free roller bearings (SKF N307) with 35 mm inner diameter are used. The specification of the bearings used in the present study is given in Table 3.1.

The measuring instruments and measurement settings used in this study are as presented in the previous chapter along with higher resolution of 6400 spectral lines with hanning window.

4.3 EXPERIMENTAL PROCEDURE

Before conducting the experiment, the lathe spindle vibrations are measured and verified to check the ovality and misalignment. After correcting
misalignment and ovality (if any), the defect-free bearings are carefully fitted into the shaft at specified distance (450 mm). One end of the shaft is firmly fixed in the lathe chuck. Two bearings are rigidly supported on the two steady rests shown in Figure 4.1. Aluminium rub tool is rigidly fitted on the tool post. The alignment of rub tool against shaft is as given in Figure 4.2 (b). The rub tool is pressed against the rotating shaft at midpoint between the bearings. Accelerometer is directly mounted over the bearing support to acquire the vibration signals. The accelerometer output signal is directly fed into the dual channel vibration analyzer and it is stored as vibration signatures. Then time domain and frequency domain signals are acquired at three different speeds. The stored data in the vibration analyzer is retrieved through RS 232 interface, connected to the computer for further analysis using DDS 2007 software.

After obtaining necessary signatures with the aluminium rub tool, the aluminium rub tool is replaced by the mild steel rub tool on the tool post and the experiments are repeated.

4.4 VIBRATION SIGNATURES OF BEARINGS

4.4.1 Time Wave Form and Frequency Spectrum of Bearing without Rub

The amplitude of vibrations obtained with the specific time, during the time domain mode and the RMS velocity of the vibrations at various frequencies obtained during the frequency mode are depicted in Figure 4.3. The data shown are obtained at 740 rpm, 1150 rpm and 1600 rpm, which are the speed settings available at the test facility.

In case of time domain signals, with increase in time, the vibration amplitudes (RMS Velocity) vary between ± 0.03 mm/s, ± 0.07 mm/s and ± 0.08 mm/s at 740, 1150 and 1600 rpm respectively. The wave forms are repeated over time without much deviation.
Figure 4.3  Vibration signatures of the bearing without rub (a\textsubscript{1}-a\textsubscript{3}: Time wave form; b\textsubscript{1}-b\textsubscript{3}: Frequency spectrum)
In the frequency domain plots, Figure 4.3(b₁-b₃), at all the three speeds, the values of RMS velocities obtained without rubbing condition are 0.0005 mm/s, 0.0007 mm/s and 0.001 mm/s at 740, 1150 and 1600 rpm respectively. The lower value of vibration amplitude indicates that the bearings shaft system is free from rub. The minor amplitudes are due to minute imperfections during the manufacturing process which cannot be eliminated.

4.4.2 Time Wave Form and Frequency Spectrum of Bearing with Aluminium Rub Tool

The time domain signals of bearing with aluminium rub at different speeds are shown in Figure 4.4. The time wave form indicates the severity of vibration on bearings due to rubbing of aluminium rub-tool against the rotating shaft. The peak to peak vibration amplitude of bearing with aluminium rubbing from time wave form is around 0.33 mm/s at 740 rpm, 1.2 mm/s at 1150 rpm and 2.4 mm/s at 1600 rpm. These amplitudes are comparatively 10 %, 200 % and 110 % higher when compared to the bearing without rub condition at 740, 1150 and 1600 rpm respectively.

Frequency spectrums obtained with aluminium rub are shown in Figure 4.5. Significantly, larger RMS velocity values are noticed in frequency spectrum of aluminium rub when compared to RMS velocity of without rub signatures as shown in Figure 4.3 (b₁-b₃). At 740 rpm, the maximum RMS velocity without rub obtained is 0.0005 mm/s whereas that for the aluminium rubs it is nearly 0.0052 mm/s, i.e. about 10.4 times large. Similarly, 29.4 and 4.7 times larger RMS velocity values are obtained at speeds of 1150 rpm and 1600 rpm respectively due to the rub.

At 740 rpm (referring Figure 4.5), the peak amplitude at 1X and its higher harmonics are 481,629 and 728 Hz with side bands equals the running frequency (of 12.3 Hz) on either side. This indicates the structural resonance
of the bearing housing. For other speeds (1150 rpm and 1600 rpm), similar aspects are observed as shown in Figure 4.5. At 1150 rpm, peak amplitude noticed at 462 and 578 Hz with side bands of 20 Hz. Similarly, at 1600 rpm, peak amplitude occurs at 584 Hz with side bands of 27 Hz on either side.

**Figure 4.4  Time wave form of the bearing with aluminium rub**
Figure 4.5  Envelope spectrum of the bearing with Aluminium rub

From Figure 4.5, it is observed that the magnitudes of RMS velocities are larger over a range of frequencies which indicate the structural
resonance of the system. At 740 rpm, such a resonance band was 200-800 Hz. When the speed increased to 1150 rpm, the band is 200 to 800 Hz. If the speed is 1600 rpm, the band is 380-650 Hz. It is observed that when the speed increases frequency band over which the structural resonance observed becomes narrow. It is due to the friction of the rub tool against the shaft. As aluminium is a soft material the friction considerably increases at higher speeds.

4.4.3 Time Wave Form and Frequency Spectrum of Bearing with Mild Steel Rub Tool

The time domain signals of bearing with mild steel rub at different speeds are illustrated in Figure 4.6. The time wave form indicates the severity of vibration on bearings due to rubbing of mild steel rub-tool against the rotating shaft. The peak to peak vibration amplitude of bearing with mild steel rubbing from time wave form is around 1.36 mm/s at 740 rpm, 1.54 mm/s at 1150 rpm and 1.17 mm/s at 1600 rpm. These amplitudes are comparatively 353 %, 285 % and 46 % higher when compared to the bearing without rub at 740, 1150 and 1600 rpm.

Frequency spectrums obtained with mild steel rub are shown in Figure 4.7. Significantly larger RMS velocity values are noticed in frequency spectrum of mild steel rub when compared to RMS velocity of without rub signatures depicted in Figure 4.3 (b₁-b₃). At 740 rpm, the maximum RMS velocity of with-out rub is 0.0005 mm/s whereas for mild steel rub it is near 0.017 mm/s, about 34 times larger. Similarly 41.42 times and 13 times larger RMS velocity values are obtained at speeds of 1150 rpm and 1600 rpm respectively with the bearing without rub.

At 740 rpm vide Figure 4.7, the peak amplitude occurs sharply at 418 Hz with side bands at the running frequency (of 12.3 Hz) on either side.
This indicates the structural resonance of the bearing housing. For other speeds (1150 rpm and 1600 rpm), similar aspects are observed in Figure 4.7. At 1150 rpm, peak amplitude occurs at 457 and 647 Hz with side bands at 20 Hz. At 1600 rpm peak it occurs at 395 and 632 Hz with side bands at 27 Hz.

From Figures 4.7, it is observed that the magnitudes of RMS velocities are larger over a range of frequencies which indicate the structural resonance of the system. At 740 rpm, such a resonance band is 370-490 Hz. When the speed is 1150 rpm, the frequency band ranges between 350 to 850 Hz. If the speed is 1600 rpm, the band is 350-750 Hz. It is observed that when speed increases the frequency band over which the structural resonance observed increases. In this case also, the frictional force is responsible for the structural resonance frequency at higher speeds. From the tested speeds, the structural resonance shows around 400 Hz.

A careful inspection of Figures 4.5 and 4.7 indicates that the spectra of rub-tool material aluminum and mild steel are similar to each other. Structural resonance is excited by the rubbing with these two rub-tool materials. By comparing Figures 4.5 and 4.7 indicates that there is a common structural resonance excited around 400 Hz for all speeds. The amplitude of frequency spectra below 350 Hz and above 850 Hz, for both aluminium and mild steel rub-tool is very small and similar. The difference of spectra between without and with rub is in the frequency range, i.e. 350 to 900 Hz. The rub excites high frequency structure resonance which is illustrated clearly by the frequency component at 418, 457 and 395 Hz at 740 rpm, 1150 rpm and 1600 rpm respectively. As the speed increases the amplitude is decreases due to wear of the material by rubbing action.
Figure 4.6  Time wave form of the bearing with mild-steel rub
Figure 4.7  Envelope spectrum of the bearing with mild-steel rub
4.5 CONCLUDING REMARKS

The vibration signature bearings due to shaft rubbing are studied by applying two different rub materials, namely aluminium and mild steel. From the frequency spectrum, it can be observed that the rub generates high frequency structural resonances. The profile of the vibration spectrum caused by rubs material changes with the speed, whereas the excited structural resonance positions do not change. For both the rub materials, the resonance occurs at lower speed and at wide band. When the speed increases the resonance frequency band gets increases. This increase of the frequency band is due to the frictional force of the rub material against the shaft. The specific structural resonance might be more dominant in the vibration spectrum caused by one rub material than those caused by other materials. At higher speeds, the rub being excites high frequency structural resonance at the range of frequency in both the cases.