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Research Article

Design and Development of Test Rig to Estimate Performance of Spur Gears

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Abstract

Online condition monitoring of mechanical systems is gaining importance due to easy detection of root cause of failures. Vibration measurement is a vital tool of online condition monitoring. The present paper describes the experimental observations on pair of spur gears obtained using accelerometer. A test rig has been designed and developed to obtain realistic (in-situ) conditions for spur gear. The developed test setup can be used to vary the speed from 600 rpm to 24,000 rpm. Accelerometer is used to measure the vibration of the system and the acquired signals are analyzed to predict the system performance. To confirm the conclusions from the vibration results, inspection using optical microscope on the gear surface were carried out before and after performing experiments.

Keywords: *Condition Monitoring, Gear pitting, Signal averaging technique.*

1. Introduction

The performance of machines is often depends on the performance of the subsystem such as bearings [Hirani, 2009, Hirani *et al*, 1999, Hirani *et al*, 2000, Hirani *et al*, 2000, Hirani *et al*, 2001, Hirani *et al*, 2001, Muzakkir *et al*, 2011, Hirani *et al*, 2002, Hirani,2004, Hirani,2005, Hirani, Suh, 2005, Hirani, Verma, 2009, Muzakkir *et al*, 2013, Muzakkir *et al*, 2015, Muzakkir *and* Hirani 2015, Rao *et al*, 2000, Muzakkir *et al*, 2015, Muzakkir *et al*, 2015, Muzakkir *et al*, 2015, Hirani *et al*, 1997, Hirani *et al*, 1999, Hirani, 2009, Lijesh *et al*, 2015, Lijesh and Hirani, 2015, Lijesh, Hirani, 2014, Lijesh, Hirani, 2015, Lijesh, Hirani, 2015, Lijesh, Hirani, 2015, Muzakkir *et al*, 2014, , Samanta, Hirani, 2007, Samanta, Hirani, 2008, Shankar *et al* 2006, Hirani, Samanta, 2007, Lijesh, Hirani, 2015, Lijesh, Hirani, 2014, Lijesh *et al,* 2015, Lijesh, Hirani, 2015], seals [Hirani and Goilkar, 2011, Goilkar and Hirani, 2010, Hirani and Goilkar, 2009, Goilkar and Hirani, 2009, Goilkar and Hirani, 2009], brakes [Sarkar, Hirani, 2015, Sarkar, Hirani, 2013, Sarkar, Hirani, 2013, Sarkar, Hirani, 2014, Sarkar, Hirani, 2015, Sukhwani, Hirani, 2008, Sukhwani *et al,* 2008, Sukhwani, Hirani, 2008, Sukhwani *et al,* 2009, Sukhwani *et al,* 2007, Muzakkir *and* Hirani 2015], gears [Shah and Hirani, 2014, Hirani, 2009] etc and the health of the machine is detected by measurement of various parameters such as vibration, noise, lubricant temperatures, ferrography, etc. Monitoring these parameters gives an indication about the abnormalities, i.e. unbalance, misalignment, looseness, wear, faced by the machine. The health of spur gear, a common machine-element used for power transmission, deteriorates due to micro-pitting, pitting, scuffing, abrasive wear, fatigue, fracture, etc. The measurement of vibration of spur gear may provide information of deterioration rate of gear life. In the present work a setup was developed with gear box and the vibration of the system was measured using accelerometers. Power spectrum will be developed from the acquired signal to extract useful information from the acceleration signal. The correlation of variation in the power spectrum value with deterioration rate of the gear (performed by microscopic inspection) is performed and results are presented.

2. Experimental Setup

In the present work spur gears with each 26 number of teeth on driving and driven gear was considered. To vary the speed of motor a variable frequency drive arrangement is used and speed is varied in four different steps with increment of 1000rpm. The test rig is fabricated in such a way that it can incorporate all these sensors as shown in figure 1. In the test rig the Eddy current Dynamometer is used to apply a variable torque. To measure the number of cycles the cycle counter is used.

To detect severe fracture, a simple visual inspection may be sufficient to detect the damage, but the very early detection of defects such as pitting requires the use of more sophisticated signal processing technique to enhance the information contained in the signal average. The vibrations were sensed by an

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accelerometer and charge amplifier unit (B & K type 4366 and type 2635 respectively, Denmark). The data acquisition system was used with the two channels input for the accelerometer and torque sensor (Lorenz, Model DR-2513, Germany). The torque data was collected along with the vibration signals to correlate the effect of torque variation on the vibration levels.

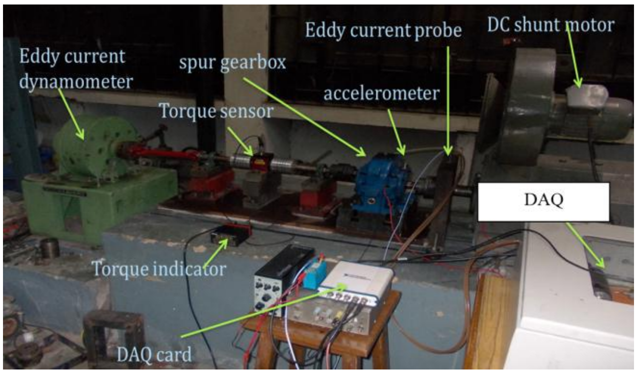


Fig.1 Experimental setup

In gear system the identification of the modulation side bands is more difficult because of greater number of components in the time domain signal. In actual processing of these signals this problem can be overcome by increasing the resolution of the spectrum, but even though it is not always clear from the pattern of modulation sidebands how severe may be a defect.

One alternative technique of vibration analysis is that of signal averaging or time synchronous averaging which is particularly suited for the monitoring of complex machines. As the signal average is exactly periodic, operations such as filtering and elimination of noise can be performed and effectively used in the frequency domain. To obtain the stable spectrum the sampling frequency was changed and then from the data obtained with the data acquisition system the Power Spectral Densities were found using Matlab software.

3. Experimental Observations

Figure 2 shows the time domain signal for the response of 26 teeth at 1000 rpm.

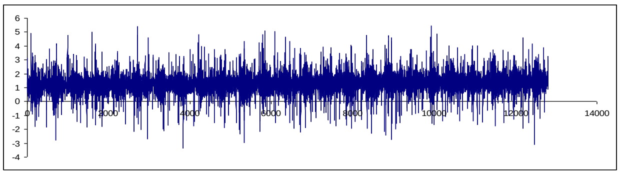


Fig 2. Vibration response signal of gears in time domain at 1000rpm

The spectrum of the acquired acceleration signal with sampling rate of 512 for 106 revolutions is plotted in figure 3. The distributed peaks in the spectrum plot indicate significant deviations. It was initially thought that this may be because of variation in rpm during operation. The experiments were repeated for several trials and it was found that this problem arose due to two reasons (i) variation in rpm and considering (ii) low sampling frequency.

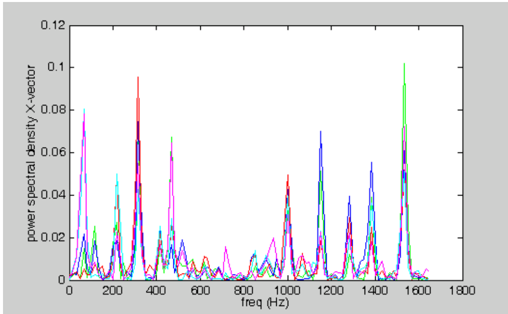
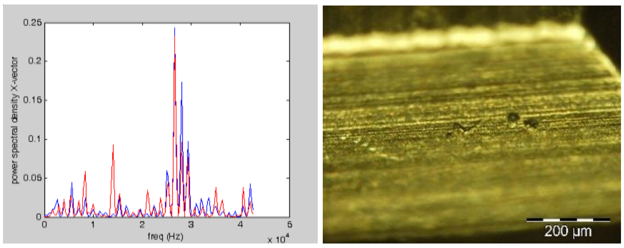


Fig. 3 Frequency Spectrum with 512 samples and 8.533 KHz sampling frequency

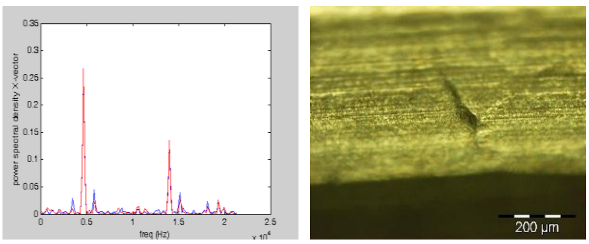
To obtain the stable spectrum of vibrations the sampling frequency of the data acquisition was varied with the facility available in the software of data acquisition system. After averaging and plotting the spectrums, it was found that selecting appropriate sampling frequency increases stability in spectrum signal. The spectrum plot after 1.5x105 revolutions is shown in figure 4(a). The visual inspection performed on the gear surface and is shown in figure 4(b). From this figure pitting on gear surface was observed.



(a) Frequency Spectrum (b) Surface image

Fig.4 Frequency Spectrum and surface image after 1.5x106 revolutions

The setup was operated for 3x106 revolution and the acceleration signals was obtained again. The power spectrum for the obtained signal is shown in figure 5(a). From this signal it can be inferred that power spectrum amplitude has increased. The surface image for this operating condition is shown in figure 5(b).



(a) Frequency Spectrum (b) Surface image

Fig. 5 Frequency Spectrum and surface image after 3x106 revolution

From this figure it can be observed that crack initiated and start growing; and it may result in catastrophic failure. Therefore it can be concluded that from the spectrum plot the initial failure of the gear can be predicted.

Conclusions

To estimate the earlier failure of a gear system, a test setup was developed and acceleration signal was acquire and processed to obtain spectrum signal and visual inspection was performed on the gear surface to observe the gear failure. The test was performed for 1.5x106 and 3x106 revolutions and the following observations were made:

(i) The signal averaging technique with sophisticated data acquisition system can be effectively used to predict the gear wear.
(ii) As pitting increases the gear vibration response increases with increment in sidebands around this frequency.
(iii) Though signal averaging is good for prediction, the amount of data required to be collected is more with more incremental steps of rpm to improve the prediction accuracy.
(iv)The increase in amplitude of spectrum signals indicates the failure in the gear.

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