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Fault Detection of Two Stage Spur Gearbox using Time Domain Technique: Effect of Tooth Breakage and Improper Chamfering

Shrikant Shukla [1], Vijay Kumar Karma[2]

[1] M. E. Student, Design & Thermal Engineering Department of Mechanical Engineering, Institute of Engineering & Technology, Devi Ahilya Vishwavidyalaya, Indore, Madhya Pradesh, India

[2] Assistant Professor, Department of Mechanical Engineering, Institute of Engineering & Technology, Devi Ahilya Vishwavidyalaya, Indore, Madhya Pradesh, India

Abstract

Gearbox is an important part of a rotating machine in the power transmission systems. Gear is a positive drive element and it transmits power and motion from one shaft to another shaft. Diagnosis of gearbox is a necessity for longer life. This paper deals with fault detection of two stage spur gearbox having tooth breakage and improper chamfering fault in the drive gear, using time domain techniques with the use of MATLAB. For this testing an experimental setup is fabricated. The vibration signals are recorded from test rig by the use of an accelerometer and then obtained data is analyzed to find out different statistical parameters like peak value, crest factor, RMS, kurtosis. Healthy and breakage gears are compared using statistical parameters.

Keywords: *Spur Gear, Fault Detection, Vibration signal, MATLAB, Time domain technique.*

1. Introduction

Gears are the most important mechanisms for transmitting power or torque, which play an important role in many sorts of machineries. Smooth operation and high efficiency of gears are necessary for the normal running of machineries. Therefore, gear damage analysis is an important activity in the field of condition monitoring and fault diagnosis [1]. Early detection of local gear faults in industrial environments is very important to optimize the maintenance schedule and reduce the operating cost of gearbox damage [2]. Failures of the gearbox may cause injury to human beings and important economic losses. To avoid the consequences of any harmful accidents several techniques are developed in condition monitoring to detect faults as early as possible [3].

1.1. Signal Processing

Signal processing is one of the important tools within the field of non-destructive techniques. It contains the theory, algorithms, designs, implementation, and applications related to processing information contained in signals. These signals are mathematically manipulated to modify or improve the information carried by them. It's characterized by the representation of discrete time, discrete frequency, or other discrete domain signals by a sequence of numbers or symbols and therefore the process of those signals [4]. The following are the signal processing techniques:

i. Time Domain Techniques
ii. Frequency Domain Technique
iii. Time Frequency Analysis
iv. Envelope Analysis

1.2 TIME DOMAIN TECHNIQUES

Time domain is the analysis of different parameters with respect to time. These parameters may include mathematical functions, physical signals, or time series of economic and environmental data. There are n numbers of statistical parameters associated with the time domain technique. Some of which are RMS, Peak, Crest factor, Kurtosis, Clearance factor, Impulse factor, shape factor [4]. These are defined as follows:

ROOT MEAN SQUARE VALUE (RMS): It is a measure of the energy content in the vibration signature and hence is one of the most relevant statistical parameter.

$$RMS = \sqrt{\frac{1}{n}\sum_{n} x^{2}(t)} \tag{2.1}$$

PEAK (MAXIMUM VALUE): The peak value of signal is one of the important features for diagnosis. The value indicates the maximum value without any consideration of the time history of the wave.

$$Peak = \frac{1}{2}(\max(x(t)) - \min(x(t))) \tag{2.2}$$

CRESTFACTOR: It is also called the 'peak-to-rms' ratio and is defined as the ratio of peak value of a waveform to its RMS value.

$$CrestFactor = \frac{Peak}{RMS} \tag{2.3}$$

KURTOSIS: Kurtosis is obtained from the fourth order central moment (moment about the mean) of amplitude probability distribution and is defined as-

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$$kurtosis = \frac{\frac{1}{N}\sum_{i=1}^{N}(x(i)-x)^4}{(RMS)^4} \qquad (2.4)$$

IMPULSE FACTOR: The impulse factor which is also found to be an indicator of bearing faults is defined as the ratio of the peak value to mean value of the time signal.

$$\text{Im}\, pulseFactor = \frac{peak}{\frac{1}{N}\sum_{i=1}^{N}|x(i)|} \qquad (2.5)$$

SHAPE FACTOR: Shape factor is defined as the ratio of the RMS to mean value. It represents changes under unbalance and misalignment.

$$ShapeFactor = \frac{RMS}{\frac{1}{N}\sum_{i=1}^{N}|x(i)|} \qquad (2.6)$$

Where, x denotes the mean value of the discrete time signal x (t) having N data points [4].

1.3 Tooth Breakage Defect

When two gears meshes with each other to transmit a load, the teeth of each gear are under bending action due to periodic effect of the load, fatigue crack may occur near the tooth base resulting in ultimate failure of the tooth [9]. Breakage faulty gear is shown in fig below

Broken tooth

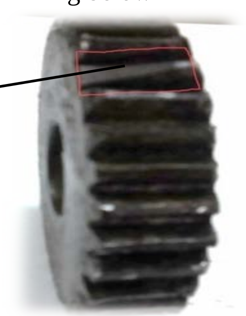

Fig.1.1 Breakage tooth fault

1.4 Improper Chamfer

This defect is due to the improper chamfering during the manufacturing of the gear. Here it is artificially created in the lathe machine.

Improper chamfering

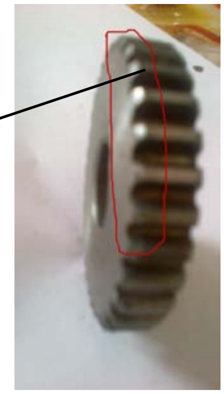

Fig. 1.2 Improper chamfering fault

2. Experimental Set- Up

The experimental set up is shown in fig. 3.1. It includes steel frame, a dc motor and a compound gear box. The input shaft of gearbox is connected to 0.5 HP, 1500 rpm electric motor through Oldham's coupling. All drive shafts are supported at its ends with antifriction bearings. A dimmer is used to speed variation in electric motor. Input or output shaft speed is measured with the help of tachometer. The vibration signal is recorded from the end bearing of driving gear using the accelerometer. The recorded vibration signals are analyzed with the help of MATLAB software. The vibration signals are collected at a shaft speed of 300, 400 and 500 rpm for healthy and faulty gear.

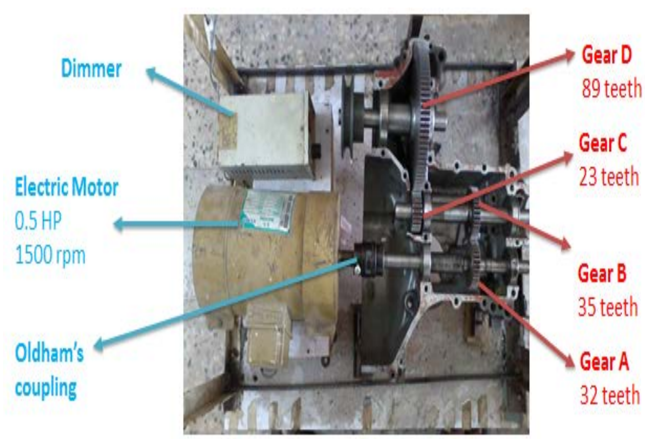

Fig. 2.1 Experimental test rig

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3. Observations

Vibration signals at 300 rpm

The time domain vibration signals for healthy, Tooth Breakage and Improper chamfering condition at 300 rpm speed without loading condition are taken and shown in figure3.1, figure3.2 and figure3.3 respectively.

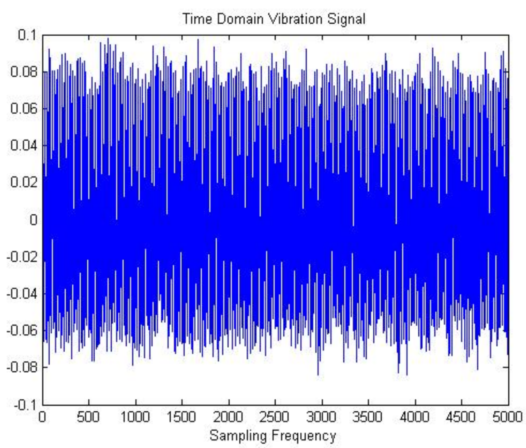

Fig 3.1 Time domain signals of healthy gear at 300 rpm.

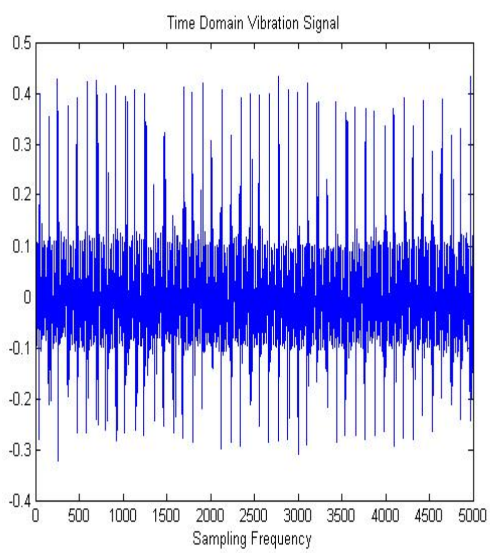

Fig 3.2 Time domain signals of Tooth breakage gear at 300 rpm

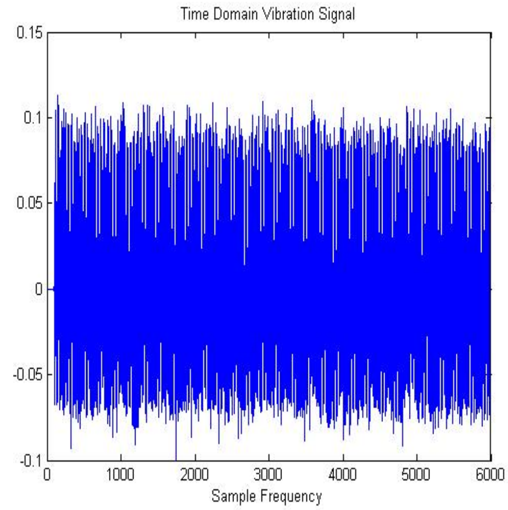

Fig 3.3Time domain signals of Improper chamfering gear at 300 rpm

The time domain vibration signals for healthy, Tooth breakage and Improper chamfering condition at 400 rpm speed without loading are taken and shown in figure 3.4 figure 3.5 and figure 3.6 respectively.

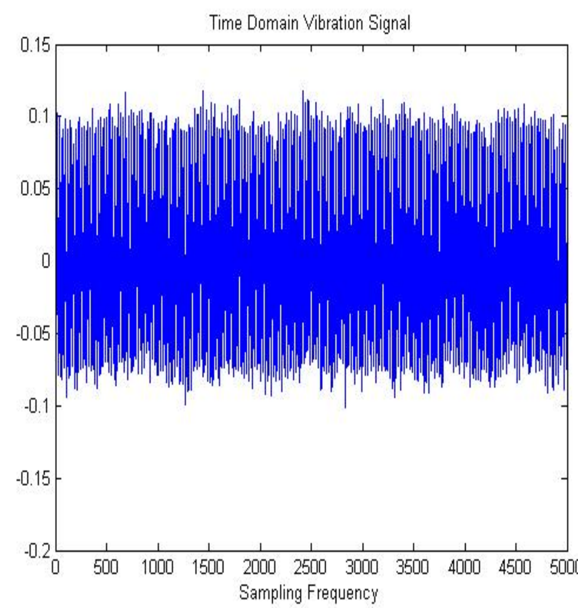

Fig 3.4 Time domain signals of healthy gear at 400 rpm.

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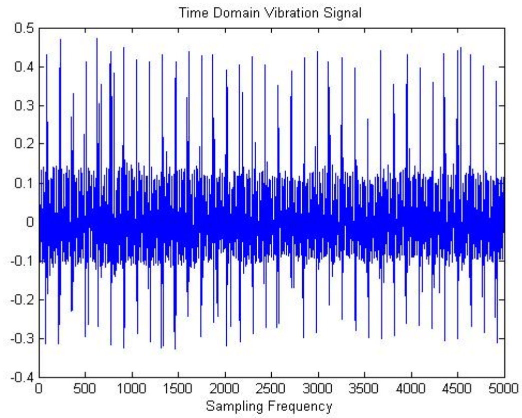

Fig 3.5 Time domain signals of Tooth breakage gear at 400 rpm.

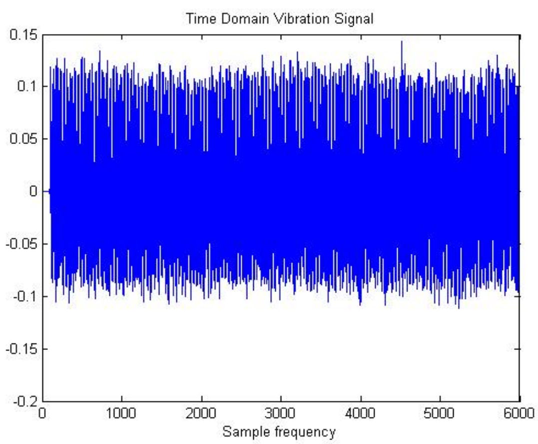

Fig 3.6 Time domain signals of Improper chamfering gear at 400 rpm

The time domain vibration signals for healthy, Tooth breakage and Improper chamfering condition at 500 rpm speed without loading are taken and shown in figure 3.7 figure 3.8 and figure 3.9 respectively.

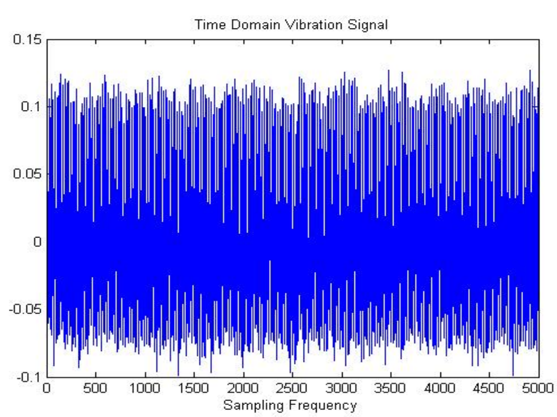

Fig 3.7 Time domain signals at healthy gear at 500 rpm.

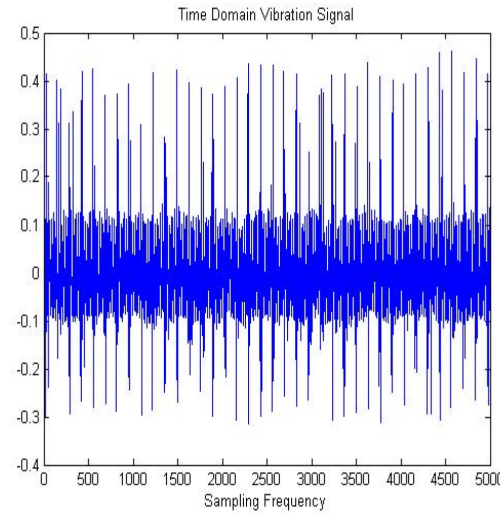

Fig 3.8Time domain signals of Tooth breakage gear at 500 rpm.

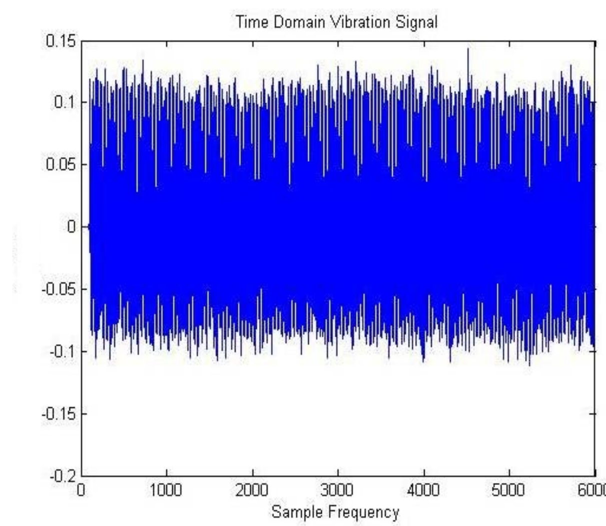

Fig 3.9Time domain signals of Improper chamfering gear at 500 rpm

4. Results and Discussions

By performing the experiments the following tables are obtained.

Table 4.1 statistical parameter for healthy gear

Speed	***Healthy Gear***			
	Peak	***RMS***	***Crest Factor***	***kurtosis***
300	0.100	0.048	2.08	2.082
400	0.1083	0.0518	2.09	2.089
500	0.1103	0.0525	2.10	2.082

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Table 4.2 statistical parameter for tooth breakage gear

Speed	*Breakage Gear fault*			
	Peak	*RMS*	*Crest factor*	*Kurtosis*
300	0.3725	0.089	4.18	5.9
400	0.390	0.0916	4.25	6.038
500	0.42	0.098	4.28	6.44

Table 4.3 statistical parameter for improper chamfering gear

Speed	*Improper Chamfering Gear fault*			
	Peak	*RMS*	*Crest factor*	*Kurtosis*
300	0.125	0.054	2.31	3.17
400	0.128	0.055	2.32	3.22
500	0.132	0.056	2.35	3.25

The below graphs are obtained using these results. The plotted graph shows the comparison between the Healthy Tooth breakage and improper chamfering.

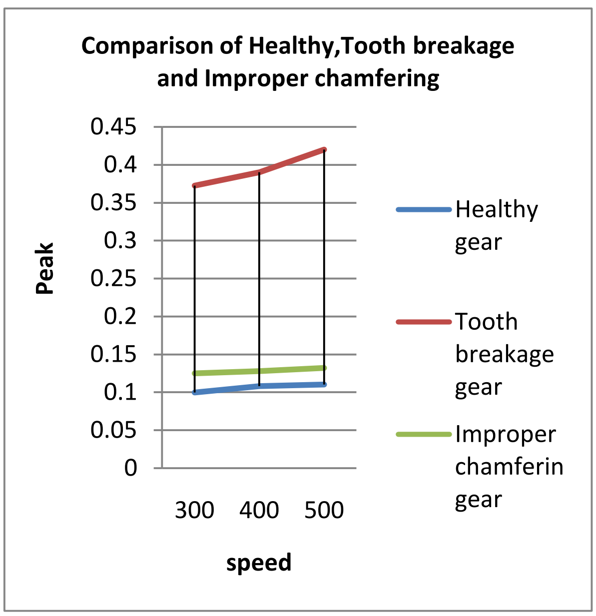

Fig 4.1 graphs plotted between speed and vibration signal peaks

From the graph plotted between vibration signal peaks and speed for healthy gear, peak value is 0.1 at 300 RPM and it is slightly increases from 0.1 with increasing speed. And when peak value is greater than 0.35 it is an indication of tooth breakage gear fault. But in improper chamfering gear the peak values of vibration signal lies very close to healthy gear.

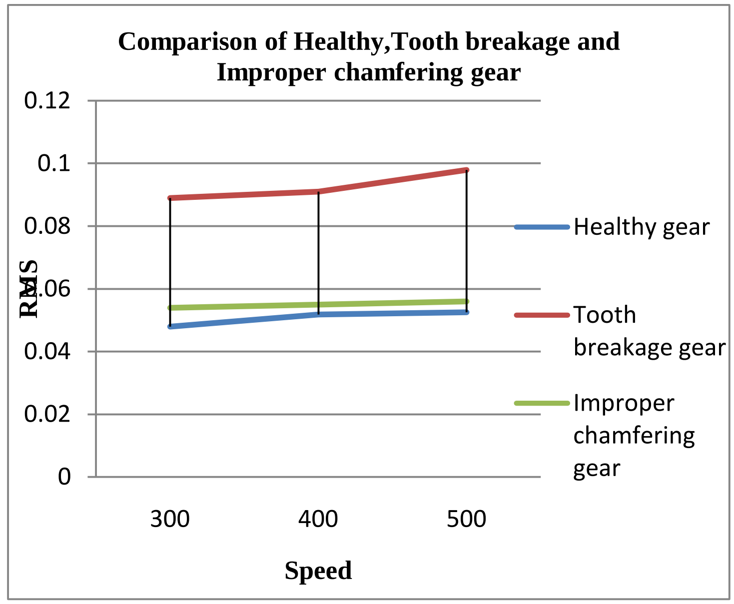

Fig 4.2 graphs plotted between speed and RMS

From the graph between RMS and speed for healthy gear, RMS value is less than 0.05.in Tooth breakage gear it approaches up to 0.1.and in case of improper chamfering RMS value is greater than healthy gear.

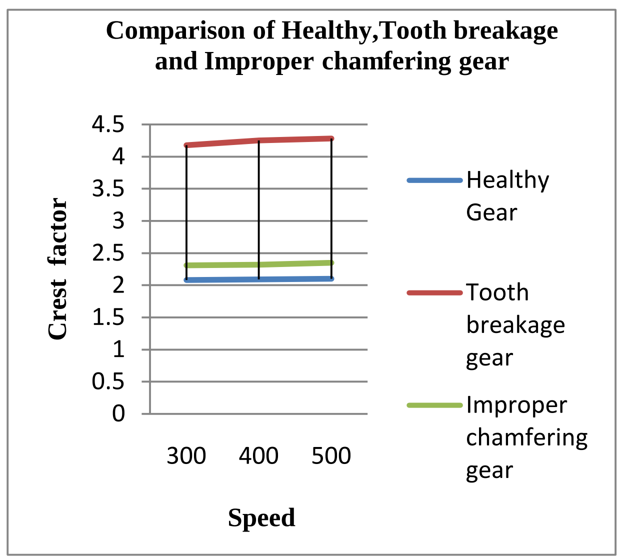

Fig: 4.3 graphs plotted between speed and crest factor

From the graph between crest factor and speed it is observed that healthy gear's crest factor is almost constant with value 2 at various speed but if crest factor increases beyond 4 then it is an indication of Tooth Breakage gear fault. Crest value in case of improper chamfering is approximately 2.4.

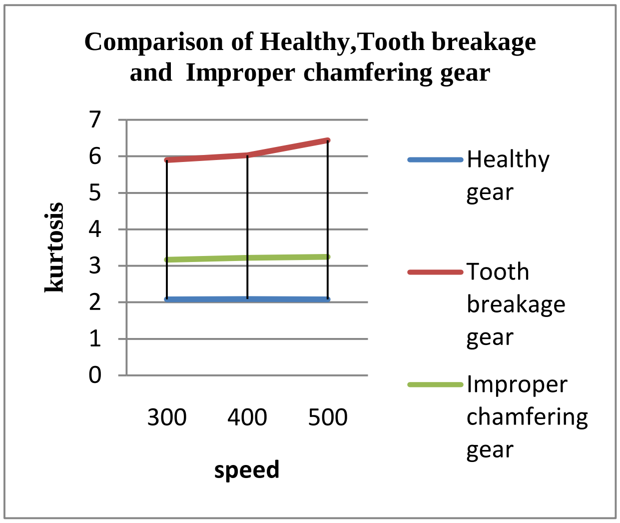

Fig: 4.4 graphs plotted between speed and Kurtosis

The graph between kurtosis and speed then it is observed that kurtosis value is almost constant (i.e. 2) with respect to various speeds. For Tooth breakage gear fault its value exceeded 6 whereas in case of improper chamfering kurtosis value is above 3.

5. Conclusions

In this paper the authors obtain crest factor, peak value, RMS and kurtosis from the time domain technique for Healthy, Tooth breakage and Improper chamfering gears. All parameters have greater values in Tooth breakage gear than healthy gear. Breakage gear has large kurtosis value as compared to healthy gear. All parameters increases with increase in speed in breakage gear but in healthy gear the values are almost constant. Whereas in improper chamfering gear all the time domain values lie between Healthy gear and Tooth breakage gear.

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Shrikant Shukla M.E. Student, 2014, Department of Mechanical Engineering (Design & Thermal Engineering), Institute of Engineering& Technology, DAVV University, Indore, Madhya Pradesh, India.

Vijay Kumar Karma Assistant Professor, Department of Mechanical Engineering, Institute of Engineering & Technology, DAVV University, Indore, Madhya Pradesh, India.