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Research Article

Detection of Fault in Gear Box System using Vibration Analysis Method

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Abstract

In gearboxes, load fluctuations on the gearbox and gear defects are two major sources of vibration. Further, at times, measurement of vibration in the gearbox is not easy because of the inaccessibility in mounting the vibration transducers. For detecting different type of gear tooth faults an experimental data is taken from single stage gearbox set up with help of FFT analyser. Vibration analysis techniques are used for detection of fault in gear system, fluctuation in gear load.A method for detecting the evolution of gear faults based on time- frequency analysis through MATLAB. The various types of defects can be created on gear tooth such as one corner defect, two corner defect, three corner defect, Missing tooth, inadequate lubrication, wear formation etc. By comparing Signals of defective condition with healthy (ok) condition through FFT analyser in which, analysis is carried out with the signal to trace the sidebands of the high frequencies of vibration. The validation is done successfully by taking input signal from FFT analyser to MATLAB program. It is for calculating effective statistical parameters in defective condition for time & frequency domain analysis. The actual position in angle of rotation for one tooth missing in gearbox is also investigated by using MATLAB program. It is also helpful tool for health monitoring of gears in different conditions.

Keywords: *Gears, defect detection, one tooth missing, condition monitoring*

1. Introduction

Productivity is a key weapon for manufacturing companies to stay competitive in a continuous growing global market. Increased productivity can be achieved through increased availability. Managing industries into the 21st century is a challenging task. Increasing global competition, fast technological change, consumer's awareness towards total quality, reliability, health and safety, environmental considerations and changes in management structure not only provides many companies with considerable opportunities to improve their performance but also the much needed competitive edge to those firms that strategically plan for the future and will make use fully the advantages of modern manufacturing techniques and methods. Gear mechanisms are an important element in a variety of mechanical systems. For that reason, early fault detection in gears has been the subject of intensive investigation and many methods based on vibration signal analysis have been developed. Conventional methods include crest factor, kurtosis, power spectrum and cepstrum estimation, time-domain averaging and demodulation, which have proved to be effective in fault diagnosis and are now well established (S.J.Lourdes, 2004)

The aim of using gears in machinery is primarily to transmit power or rotary motion between shafts whilst maintaining the intended angular velocity ratio together with smooth motion transfer and high efficiency. These criteria are usually achieved unless a gear is defective. When a fault affecting one or more gear teeth develops on a gear, the performance of the gear system deteriorates and desired motion transfer deviates from the intended. If a gear fails due to any reason, the resulting damage may affect either all the gear teeth on a gear or only a few teeth, and several failure modes (e.g. scuffing, pitting, abrasive wear, bending fatigue cracks) are associated Tooth surface failures are generally termed distributed gear faults and are mainly caused by excessive stress together with an Inadequate lubrication. (Shengxiang Jia *et al*, 2006; Ales Belsak *et al*, 2007; Isa Yesilyurt, 2004).The monitoring of a Gearbox condition is a vital activity because of its importance in power transmission in any industry. Techniques such as wear and debris analysis, and acoustic emissions require accessibility to the Gearbox either to collect samples or to mount the transducers on or near the Gearbox. Vibration analysis is one of the most important condition monitoring techniques that are applied in real life. Most of the defects encountered in the rotating machinery give rise to a distinct vibration pattern (vibration signature) and hence mostly faults can be identified using vibration signature analysis techniques. Vibration Monitoring is the ability to record and identify vibration Signatures which makes the technique so powerful for monitoring rotating machinery. Vibration analysis is normally applied by using transducers to measure acceleration, velocity or displacement (G.Diwakar, 2012).

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Condition monitoring of gear box system is of considerable importance to industry since an early detections of faults in them can prevent failures in the machines. The philosophy of machine condition monitoring is to monitor the state of a machine and to detect any deterioration in condition, to determine the cause of this deterioration and to predict when failure can be expected. The result is the maximization of machine availability and maximum utilization of the machine elements (bearings, gears etc.) Vibration analysis is the most commonly used technology used to monitor the condition of the machine. The frequency of the vibrations can also be mapped or represented, when certain frequencies will be present. The conditions then indicate about the impending defect of that system. Comparison of the vibration spectra of new equipment versus equipment that has been used will provide the information and make a decision, whether the maintenance is required or not.

Gearboxes are often critical components of machine requiring the application of condition monitoring techniques. Condition monitoring of Gearboxes implies determination of condition of gears and its change with respect to time. The condition of these gears may be determined by the physical parameters like vibration, noise, temperature, wear debris, oil contamination, etc. A change in any of these parameters called 'signatures' would thus indicate the change in the condition or health of the gears. Fault diagnosis is conducted typically in the following phases: data acquisition, feature extraction, and fault detection and identification as shown in Figure 1. Effective feature extraction techniques are very critical for the success of fault diagnosis.

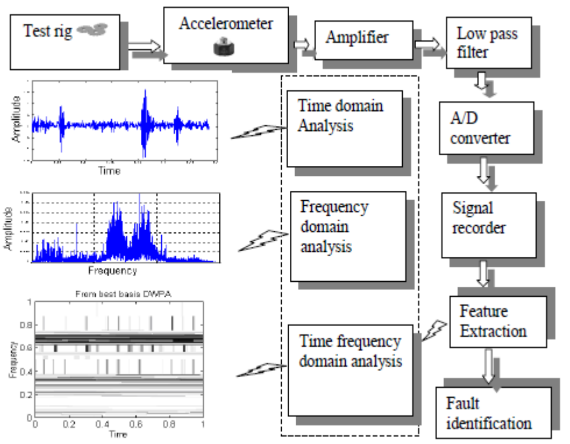

Fig.1 Overview of fault diagnosis based on vibration signals analysis

Vibration signals collected from sensors and then processed are often contaminated by some noise and can thus be unusable for directly diagnosing machine faults. (Chia Hsuan, 2011)

The main objective of this study is to identify and examine Damage in gear teeth commonly found in the transmission system and establish fault detection method and pattern feature parameters from the vibration signatures. Four cases of experimental vibration signatures are examined: (a) undamaged gear, (b) preset gear tooth damage only. In order to provide better fundamental understanding of the vibration signatures, all four cases above are examined and compared in the time domain, the frequency domain, and the joint time frequency domain. Results obtained from three different signal domains are analyzed to develop possible indicative parameters that measure the integrity and the wellness of gear components. (Chia Hsuan, 2011)

2. Experimentation

2.1 Experimental set up

It is decided to make planned faults, such as like one corner defect, two corner defect, three corner defect, one tooth is missing. in the gearbox. The analysis of vibration of each fault is carried out separately. For that purpose, gears of same specifications is taken and on each gear separate faults are made. The vibration of each faulty gear and gear without any fault is obtained. Thus the signals obtained is analyzed which are valuable for the fault diagnosis. Details of gearbox & gears are given in Table 2.1 & 2.2.

Table 2.1 Specifications of gearbox

Sr. No.	Particulars	Specifications
1	Power	0.5 Hp
2	Input rpm	1000 rpm
3	Input frequency	1000/60 =16.66 Hz
4	Output rpm	565 rpm
5	Output frequency	565/60 = 9.41 Hz
6	No. of stages	1 Stage

Table 2.2 Specifications of gears

Sr. No.	Particulars	Specification (Pinion)	Specification (Gear)
1	Type	Spur	Spur
2	No. of teeth	26	46
3	PCD	54.86 mm	97.06 mm
4	Module	2.11	2.11
5	Speed(rpm)	1000	560

Fig 2.Experimental set up

The input to the gearbox is AC motor which is coupled to gear shaft through coupling. Output shaft of gearbox is connected to rope brake dynamometer. So that power is transmitted from motor to dynamometer through gearbox. The schematic figure of vibration measurement for fault diagnosis of gearbox shown in Fig.2

2.2 Test Procedure

In test procedure the gearbox is allowed to run at its rated power and speeds by applying different load conditions of 0 kg, 1 kg, on rope brake dynamometer having diameter of pulley 125 mm. For vibration measurement magnetic base accelerometer is place on the top just below the location of bearing in axial & radial direction of gearbox. By making all above arrangements, readings are taken for healthy gear with good lubrication condition & different condition of gears having various faults with different load conditions This data in the form of Vibration spectrums is stored in FFT analyzer for further analysis

For formation of manual faults on gear tooth, three different gears are used. For that, the spur pinion & gear having 26 & 46 teeth respectively and module of 2.11mm is selected. The common type's faults of gear tooth are as follows, a) one corner defect on gear tooth. b) Two corner defect on gear tooth c) three corner defect on gear tooth. d) One tooth missing) improper lubrication f)wear formation.

Out of that for analysis purpose, one tooth missing fault is considered. Refer Fig. 3.

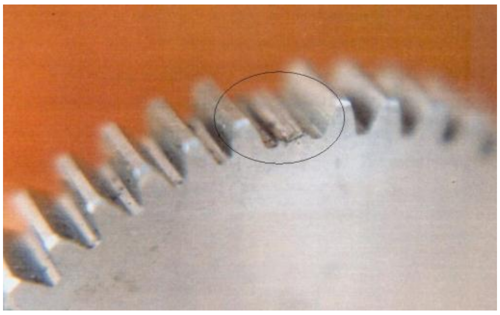

Fig.3 One tooth missing defect

3. Processing of signals

The processing of signal is carried out by developing the MATLAB program in which the input data is taken from different types of defects in the form of.csv files and output data is in the form of time & frequency waveform. The feature extraction parameters are calculated by using same MATLAB program of respective defect condition. The program is as follows,

For determining the 24 parameters as per following Table 3.1 and additional parameters like standard deviation, kurtosis, RMS , crest factor are also determine along with 24 parameters,

The MATLAB program is develop for getting the plot for time domain, frequency domain, one revolution of gear & feature extracted parameters. Collections of the calculated values are in table & then these calculated values get converted in normalized value format (T.H. Loutas, 2011).

Table 3.1 Details of statistical parameters

Time domain parameters	Frequency domain parameters
$p1=\frac{\sum_{n=1}^{N}x(n)}{N}$	$p12=\frac{\sum_{k=1}^{K}s(k)}{K}$
$p2=\sqrt{\frac{\sum_{n=1}^{N}(x(n)-p_1)^2}{N-1}}$	$p13=\frac{\sum_{k=1}^{K}(s(k)-p_{12})^2}{K-1}$
$p3=\left(\frac{\sum_{n=1}^{N}\sqrt{\lvert x(n)\rvert}}{N}\right)^2$	$p14=\frac{\sum_{k=1}^{K}(s(k)-p_{12})^3}{K(\sqrt{p_{13}})^3}$
$p4=\sqrt{\frac{\sum_{n=1}^{N}(x(n))^2}{N}}$	$p15=\frac{\sum_{k=1}^{K}(s(k)-p_{12})^4}{Kp_{13}^2}$
$p5=\max\lvert x(n)\rvert$	$p16=\frac{\sum_{k=1}^{K}f_k s(k)}{\sum_{k=1}^{K}s(k)}$
$p6=\frac{\sum_{n=1}^{N}(x(n)-p_1)^3}{(N-1)p_2^3}$	$p17=\sqrt{\frac{\sum_{k=1}^{K}(f_k-p_{16})^2 s(k)}{K}}$
$p7=\frac{\sum_{n=1}^{N}(x(n)-p_1)^4}{(N-1)p_2^4}$	$p18=\sqrt{\frac{\sum_{k=1}^{K}f_k^2 s(k)}{\sum_{k=1}^{K}s(k)}}$
$p8=\frac{p_5}{p_4}$	$p19=\sqrt{\frac{\sum_{k=1}^{K}f_k^4 s(k)}{\sum_{k=1}^{K}f_k^2 s(k)}}$
$p9=\frac{p_5}{p_3}$	$p20=\frac{\sum_{k=1}^{K}f_k^2 s(k)}{\sqrt{\sum_{k=1}^{K}s(k)\sum_{k=1}^{K}f_k^4 s(k)}}$
$p10=\frac{p_4}{\frac{1}{N}\sum_{n=1}^{N}\lvert x(n)\rvert}$	$p21=\frac{p_{17}}{p_{16}}$
$p11=\frac{p_5}{\frac{1}{N}\sum_{n=1}^{N}\lvert x(n)\rvert}$	$p22=\frac{\sum_{k=1}^{K}(f_k-p_{16})^3 s(k)}{Kp_{17}^3}$
	$p23=\frac{\sum_{k=1}^{K}(f_k-p_{16})^4 s(k)}{Kp_{17}^4}$
	$p24=\frac{\sum_{k=1}^{K}(f_k-p_{16})^{1/2} s(k)}{K\sqrt{p_{17}}}$

Instantaneous value of the shaft displacement can be defined by Smax, and the displacement from the mean position is a maximum. It should be noted that implicit in the definition of Smax is the requirement to know the time-integrated mean value of the shaft displacement.

The measurement of Smax is limited to those measuring Systems which can measure both the mean and alternating values. This parameter is obtained from direct FFT analyser. It is related to 0-P displacement of shaft centerline of gearbox.

4. Result and Discussion

4.1 One tooth missing condition (OTM)

a) Spectral analysis

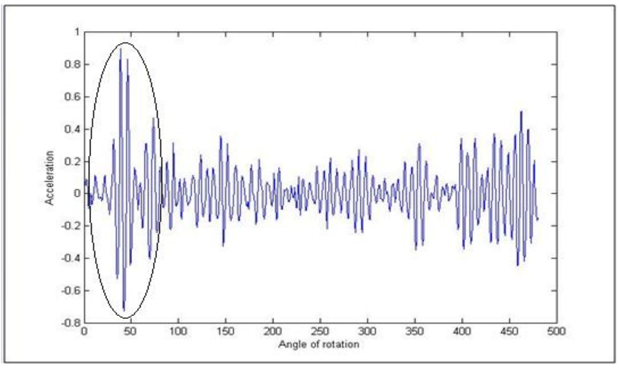

Fig. 4 Plot for one revolution of gear containing of OTM condition (1000rpm) in MATLAB

From Fig.4, it is clear that the amplitude of acceleration is suddenly increased by nearly 45-50° of angle of rotation of gear for one revolution. Since while taking the readings in OTM condition the position of missing gear tooth is nearly 50° from direction of revolution of gear.

So we can conclude that the position of missing gear tooth is identified which is at 45-50° with sudden increase in amplitude level.

b) Using Feature extraction analysis

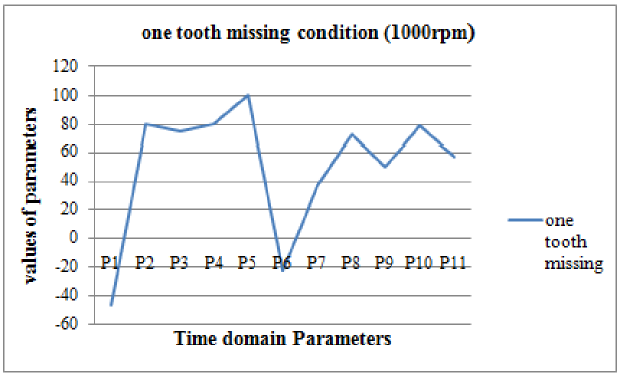

Fig.5 plot for of OTM condition Vs Time domain Parameters

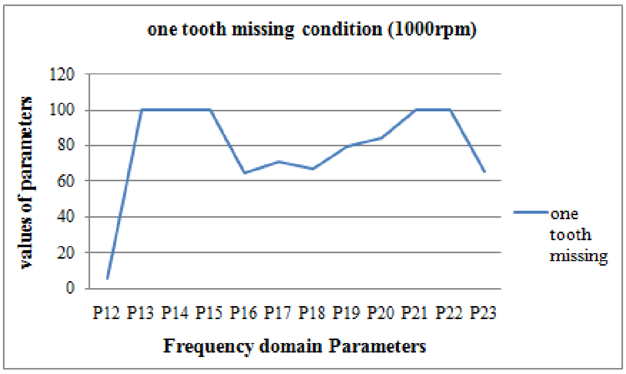

Fig.6 plot for of OTM condition Vs frequency domain Parameters

The above plots shows comparison of vibration feature extraction time & frequency domain parameters which are calculated using signal data respective to one tooth missing condition at 1000rpm. The respective Observations are as follows:

From time domain parameter plot;

1) the range of values of parameters like P1 & P6 is minimum value (Negative)
2) Parameters like P2, P3 and P4 are having linearly upward variation in their values.

From frequency domain parameter plot;

1) The parameters like P13, P14, P15, P21, P22 having constant values approximately 100%
2) Value variation can be seen in parameters like P16 to P20.

Observation from Fig 7 plot: Smax parameter is linearly increased from one tooth missing defect at 500rpm, 700rpm & 1000rpm. The maximum value of Smax is at one tooth missing at 1000rpm and minimum value at one tooth missing at 500rpm.

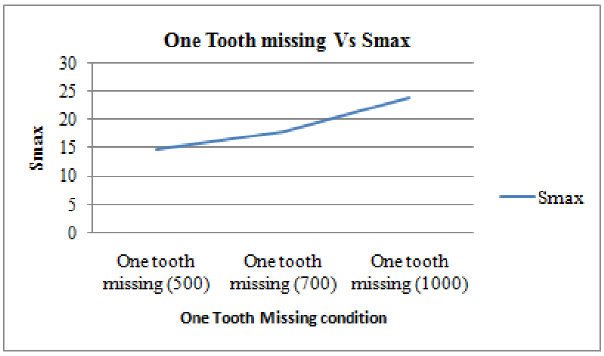

Fig.7 Plot for of OTM condition Vs Smax Parameter

Conclusions

1) The one tooth missing (OTM) condition is detected by using statistical analysis of vibration signal. The most effective statistical parameters such as P1, P2, P3, P4, P6, & Smax.
2) The position of one tooth missing is detected by observing the plot of one revolution of gear tooth in MATLAB at an angle of approximately 48°.
3) This method is effective to examine the different type of defects in gearbox system.
4) The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub harmonics &multiples of frequencies is due to the presence of fault in the Gearbox.
5) This paper has investigated the detection of Gear fault using vibration monitoring & feature extraction parameters.

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