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Fault Diagnosis of Gear box using Cepstrum Analysis

KEYWORDS: Cepstrum Analysis, fault Diagnosis, vibration, Signal processing

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ABSTRACT *This paper provides fault-diagnosis of a gearbox by the use of cepstrum analysis. The result shows that cepstrum provides efficient representation of fault. Vibration signal from gearbox is converted into voltage signal using a piezoelectric transducer. These signals are then analyzed through software utility MATLAB®. The result shows that cepstrum provides efficient representation of fault detection in gear.*

1. INTRODUCTION:

Gearbox is important part in any machinery and it provides speed reduction or increment depending on gear arrangement. Gearboxes are used in various conditions such as high speed and greater load conditions. Any minor fault in gear of such gearbox leads to unexpected failure of machinery. Gearboxes have Complex structure and fault causes significant loss in terms of time and money. Early detection of fault and its location can reduce these losses. For early detection of fault vibration signal from machinery is analyzed. There are many methods for analyzing vibration signal [1]. Many of these methods are effective in simple machinery components but for complex components such as gearbox effectiveness of these methods degrades. For such conditions cepstrum analysis [2-4] serves more efficient results.

In this paper an approximate method for cepstrum analysis is provided. Vibration signal from gearbox is collected with the help of piezoelectric transducer in time domain. This signal then converted in frequency domain by software utility and finally this signal spectrum is converted into cepstrum.

2. Definition of Cepstrum:

The cepstrum is relation with autocorrelation, R (t), given as [5]:

$$R(t) = F^{-1}(|S(f)|^2) \qquad (1)$$

Where F^{-1} () is the inverse Fourier transform [6] and spectrum S (f) is given as:

$$S(f) = F(x(t)) \qquad (2)$$

Where F () is Fourier transform. R (t) is in the time domain. The autocorrelation provides the delay information in a periodic power spectrum.

The cepstrum is defined in similar manner as the inverse Fourier transform of the logarithm of the power spectrum:

$$C(t) = F^{-1}(\log(|S(f)|^2)) \qquad (3)$$

Since the logarithm of spectrum is taken before the inverse Fourier transform the effect of multiplication of different spectrum is converted into addition which can be seen in following:

Spectrum of excitation and path is given in product form as a response as:

$$S_B(f) = S_A(f).|H(f)|^2 \qquad (4)$$

By taking log the multiplication of spectrum is converted into addition

$$\log(S_B(f)) = \log(S_A(f)) + 2\log(|H(f)|) \qquad (5)$$

Now taking inverse Fourier Transform

$$F^{-1}(\log(S_B(f)) = F^{-1}(\log(S_A(f))) + 2F^{-1}(\log(|H(f)|)) \qquad (6)$$

From eq. (6) it can be seen that spectrum form source and path is converted into additive nature in cepstrum. Therefore source and path will have separate peaks for different quefrency. While in autocorrelation from eq. (1) involves convolution that creates more complicated result.

3. Piezoelectric Element used for collecting signal

The accelerometers utilize the phenomenon of piezoelectricity. When a piezoelectric material is stressed, it produces electrical charge. Combined with a seismic mass it can generate an electric charge signal proportional to vibration acceleration. The active element of accelerometers consists of a carefully selected ceramic material with excellent piezoelectric properties called Lead-Zirconate Titanate (PZT). Piezoelectric accelerometers are widely accepted as the best choice for measuring absolute vibration.

The active element of an accelerometer is a piezoelectric material. In this paper piezoelectric element for collecting vibration signals is directly used, instead of accelerometer. Signal obtained from piezoelectric element is verified from Electrodynamics type analog vibration exciter. In which artificial vibration at a particular frequency is produced, which is then collected and calculated by piezoelectric element and converted into Hz in software utility MATLAB®. Result shows a peak at same frequency at which the vibration exciter was set up earlier.

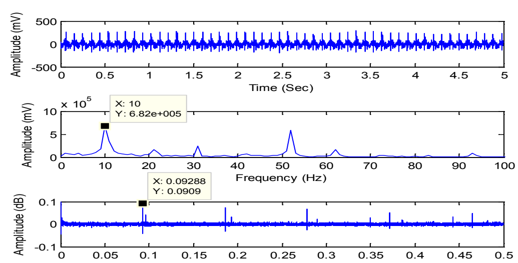

Figure 1 10 Hz data collected and analysed by Piezoelectric element

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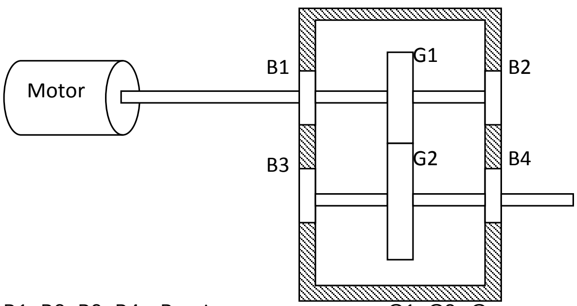
Here the analog exciter is approximately set at 10 Hz. Vibration signal from oscillator is taken by piezoelectric element which is converted into frequency in software utility. This give peaks same at 10 Hz and a quefrency peak at 0.09288 Sec. The above Figure shows that use of piezoelectric element for taking signal is good alternative for accelerometer. Also piezoelectric element is inexpensive as compared to accelerometer.

4. USE OF CEPSTRUM FOR GEAR FAULT DIAGNOSIS:

Fig. 2 shows the block diagram of test apparatus used for this study. It consists of single-stage gearbox driven by 0.5 HP DC motor. A defect has been created on driving gear by removing one tooth of the gear to indicate a condition of gear damage. Driving gear has 32 teeth and driven gear has 35 teeth which gives transmission ratio of 35/32. Speed of the driving gear is 1758 r/min, that is rotating frequency is 29.33Hz. Therefore the tooth mashing frequency is 815Hz. Since the fault is in the driving gear the quefrency component of the fault will be at (1/29.33 = 0.03413 sec). Vibration signal from the setup is collected by piezoelectric transducer placed near bearing B1. The sampling rate is 16000 Hz. The data is collected for time span of 5 seconds. For vibration data collection, an approximate method is introduced in which data from the piezoelectric transducer is captured through microphone port of PC, and analyzed with the help of software utility MATLAB®.



B1, B2, B3, B4= Bearing G1, G2=Gear

Figure 2 Gearbox arrangement

Tooth meshing frequency is very important and by modulation phenomenon it creates sidebands with its harmonics. These sidebands contains information about the fault in the gearbox for example, the spacing between the sidebands gives the location of the source of the fault such that the fault in one or more gear teeth give the modulation effect at time of engagement or disengagement of faulty teeth. This process gives a large amount of sidebands over a significant frequency range.

Fig 3 gives the original vibration signal collected from the gearbox taken over a time span of 5 seconds. From this figure it is clear that there exist some fault in the gearbox but conventional time domain approach is incompetent to detect condition of the fault.

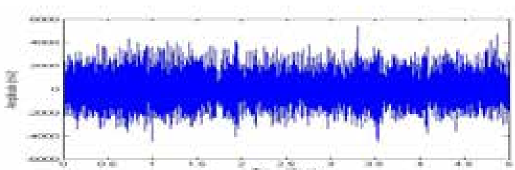


Figure 3 Time domain signal for gearbox with faulty tooth

Fig 4 shows the power spectrum of the collected vibration signal. Peak at 295Hz and 903.1Hz are the result of modulation phenomenon. It can be seen that there exists almost no information about the faulty frequency 29.33Hz. Therefore conventional Fourier method could not be used alone for such fault detection.

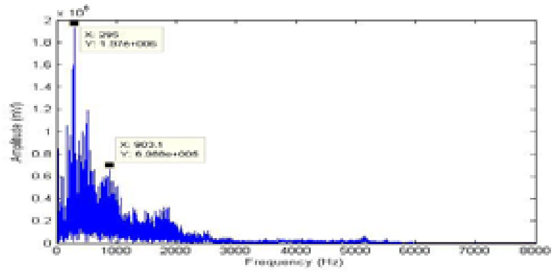


Figure 4 Power Spectrum of signal for gearbox with faulty tooth

Fig.5 shows the cepstrum of the collected signal that is generated by applying eq. (3) on the time-domain signal. Cepstrum shows a peak at quefrency (0.03413 sec) of gear tooth fault and its harmonics with some noise. The fault can be easily identified by a distinct peak in cepstrum analysis.

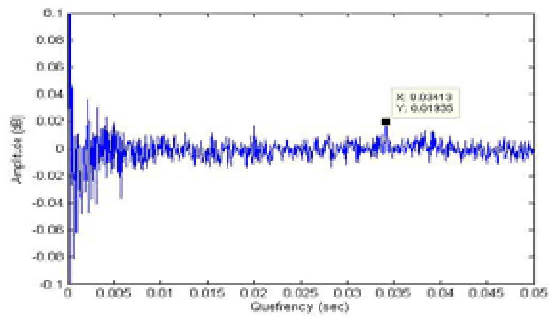


Figure 5 Cepstrum of signal for gearbox with faulty tooth

5. RESULT AND DISCUSSION:

In this paper, first artificial vibration exciter was used to generate vibration to verify that signal recorded by piezoelectric element is accurate. Set up consist of AC motor driving a shaft gear assembly. The instrument used for the experiment includes a piezoelectric element connected to microphone socket through cable, a tachometer to record the RPM of motor and shaft. Also a PC with good configuration having MATLAB®, for storing and analyzing the vibration signal.

Signal from piezoelectric element from set up are recorded and analyzed in software utility MATLAB®. First vibration data is obtained in time domain from set up with the use of piezoelectric element, then the power spectrum of signal is taken. All this work is done in software utility MATLAB®. It can be seen that there exists almost no information about the faulty frequency in frequency-domain. Therefore conventional Fourier method could not be used alone for such fault detection. In the next step, cepstrum of the collected signal is generated by applying eq. (3) on the time-domain signal. Cepstrum shows a peak at quefrency of gear tooth fault and its harmonics with some noise. The fault can be easily identified by a distinct peak in cepstrum analysis.

6. CONCLUSION:

This paper provides a fault diagnosis method based on the cepstrum analysis. An approximate method of data collection by the use of piezoelectric element is introduced. Cepstrum analysis provides a more clear indication of fault for more complex machine parts such as gearbox as used in this paper.

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