Envelope Detection and Cepstrum Analysis for Gear Fault Diagnosis – A Comparative Study

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Abstract. *While operating a gear with local fault impulse is created, the high-frequency shock vibration is then generated and the vibration amplitude is modulated by the pulse force. Both the envelope and cepstrum analyses are useful tools to identify the fault frequencies and distinguish them from other frequency contents. Since the envelope analysis method provides an important and effective approach to analyse the fault signals of high-frequency impact vibration, it has been applied to the roller bearing fault diagnosis successfully. The intent of this article is to introduce these two tools and compare them between in a pragmatic way and to demonstrate their properties by using practical example of a gear fault. All the experimental data are acquired from vehicle gearbox which is tested on the laboratory stand equipped with three dynamometers; the input dynamometer serves as internal combustion engine, the output dynamometers introduce the load on the flanges of output joint shafts. The pitting defect is manufactured on one tooth of pinion gear on the output shaft. The results obtained from practical experiments prove that Cepstrum analysis provides a clear indication of fault for machine parts such as vehicle gearbox in addition to evaluate the efficiency of the common envelope analysis.*

Keywords: Cepstrum Analysis, Envelope Detection, Gear Fault Diagnosis

1. Introduction

The vibration signal obtained from operating machines contains information related to machine condition as well as noise. Further processing of the signal is necessary to elicit information particularly relevant to gear faults. Many techniques have been employed to process the vibration signals in gear faults detection and diagnosis. In the early stage of gear's faults, those periodic impulse components usually submerged in noises and the harmonic components such as gear meshing frequency components and rotating frequency components. Therefore, it is difficult to detect gear's local faults by using envelope analysis of the vibration signals of the gear effectively. Aiming at that problem, a method for fault diagnosis of gears based on resonance-based sparse signal decomposition and envelope spectrum was proposed [1]. From the previous work, the experimental results indicate that limited information can be found from the time-domain signals. The key features of those signals comprise of a large number of sinusoidal waveforms of overlapped dissimilar frequencies. Considerable interference between vibrations signals make it difficult to figure out useful information regarding to the gears conditions [2]. Since the cepstrum estimates the average sideband spacing over a wide frequency range, it is applicable to both detection and diagnosis of gear faults. In particular, Cepstral analysis has the advantage of identifying the fault period without regard to system characteristics, namely frequency (or impulse) response. The other methods that make use of the frequency spectrum usually depend on system resonance that provides a high signal-to-noise ratio. The cepstrum was used to separate and extract the periodic components of the dense modulated signals being difficult to identify, and based on that it also was recognized the rotating speed-frequency of fault positions, the type and location of faults were diagnosed using meshing frequency and rotating speed frequency obtained with these two kinds of spectral analysis methods. [3]. The challenge lies in coming up with a highly reliable and cost efficient monitoring system which though not necessarily comprehensive but should be capable of tracking down the major causes of gear failures and give an early indication thereby enabling effective preventive maintenance and eventually reduce costs per failure [4].

2. Signal Processing

Envelope Signal Processing

Envelope Signal Processing is a two-stage process. The first process involves band-pass filtering of the time domain signal using a band pass filter that center on the region of high frequency energy. The second stage of the process is to pass this filtered time signal through an envelope in order to extract the repetition rate of the spiky bursts of energy. The envelop analyzer is an electronic circuit that demodulates or rectifies the signal. The result of passing the signal through the envelop analyzer: The extracted signal is the repetition rate of the impacts [1].

Cepstrum Analysis

Cepstrum, which is an anagram of spectrum, is a nonlinear signal processing technique used to identify and separate harmonic families in the spectra of gearbox signals. Table 1 compares the terms used in the spectral and Cepstral analyses. Exact definitions vary across the literature. The different cepstrum forms can be found [3]:

$$C_{cplx} = \frac{1}{2\pi} \int_{-\pi}^{\pi} log\left[X(e^{j\omega})\right] e^{j\omega n} d\omega \quad (1)$$

$$C_{real} = \frac{1}{2\pi} \int_{-\pi}^{\pi} log\left|X(e^{j\omega})\right| e^{j\omega n} d\omega \quad (2)$$

The cepstrum is complex if the phase information of the original time waveform is preserved. The complex cepstrum has the corresponding inverse complex cepstrum. In this case the time waveform can be reconstructed from a modified cepstrum. On the other hand, if the input of the inverse Fourier transform is real (no phase information), for example, the magnitude of the Fourier transform of the signal, the cepstrum is real-valued.

Table 1. Comparison of terms used in spectral and cepstral analyses .

Spectral analysis	Cepstral analysis
spectrum	cepstrum
frequency (Hz)	quefrency (second)
harmonic	rahmonic
filter	lifter

3. Description of the test set-up

Experimental set-up

The measurements are conducted on an open loop test bed which consists of three dynamometric machines. Our purpose, we did the measurements in steady state regimes only. Fig. 1 shows the real photo of arrangement layout of test rig components with indication of the position of accelerometer and tachometer (left figure) and the internal arrangement of gears, shafts and bearings in the investigated gearbox (right figure).

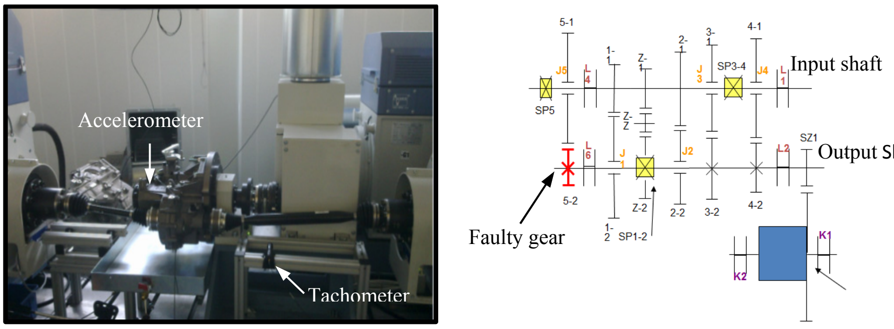

Fig. 1. Open loop test bed used for investigation of faults and internal arrangement of in the investigated gear.

The gearbox used for our measurements is the type most commonly used in small and mid-size passenger cars: a five-speed gearbox with final drive gear and front wheel differential.

Description of the Artificial Damage

The pinion for fifth speed has artificially fabricated fault on one tooth only. The total surface area of the pit is 4.58 mm^2. The gearwheel is treated as damaged if the surface of damage on one tooth is greater than 4% of the tooth surface. In our case the damage equals 3% of the tooth surface. This means there is a significant pit, but the pinion gear can't yet be treated as damaged.

4. Experimental procedures and results

A Brüel & Kjaer portable and front-end type 3050-B-040 4channel input Module 50 kHz analyzer is used. The speed is measured using a Tachometer Type MM360, and a tri-axial (Telta Tron type 4524B) accelerometer was used to record the vibration acceleration signals, both mounted upon the gearbox case as shown in Fig. 1. The vibration signal in vertical and radial terms is presented in this article. The sampling frequency used was 6.4 kHz and signals of 0.5 sec duration were recorded.

Fig.2 and Fig. 3 show the cepstrum analysis and envelope spectrum of original time signals in vertical direction for the faulty gear (37 teeth) on the output shaft in fifth speed, input shaft speeds 2000 rpm and 3000 rpm and constant input torque 130 Nm. Fig.2a and Fig. 3a illustrate, that the damage is the driven gear, by presentation the number of rahmonics of driven shaft rotation as the source of the problem. Cepstrum indicates periodicity at 22.2 ms (45 Hz, rotating frequency of output shaft) and 14.8 ms (67.56 Hz, rotation by the output shaft). On another hand as shown in Fig. 2b and Fig. 3b, the Envelope Detection for the gear fault has an amplitude modulating effect on its characteristic frequencies. The characteristic frequency of the faulty gear and its harmonics are presented at rotating frequency 45 Hz and 67.6 Hz at the two operating speeds respectively, and constant input torque 130 Nm. It is evident that both the methods were effective in identifying the gear defect.

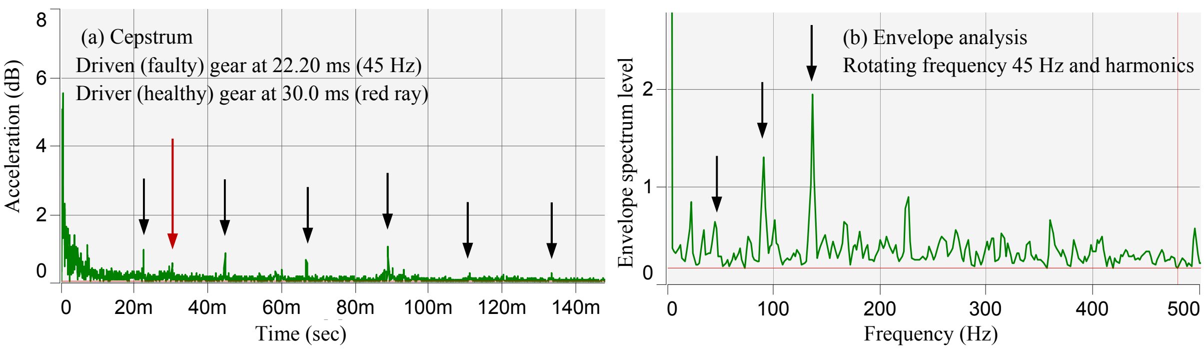

Fig. 2. Cepstrum and Envelope analyses for the faulty gear in fifth speed, at speed 2000 rpm and load 130 Nm.

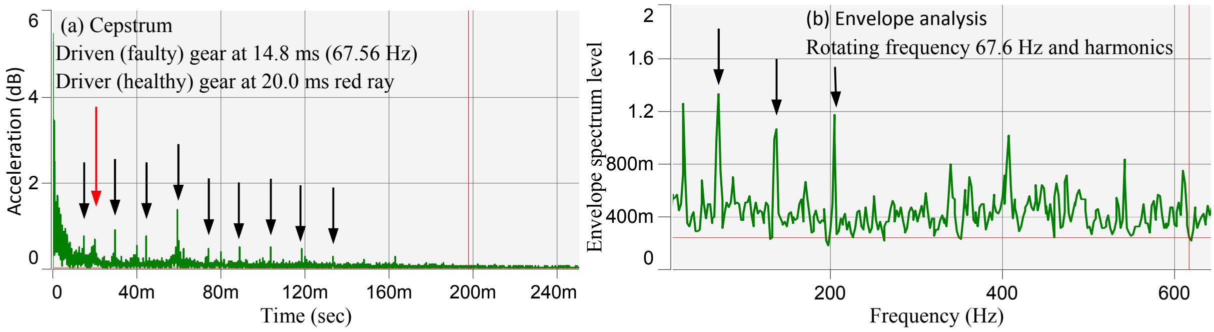

Fig. 3. Cepstrum and Envelope analyses for the faulty gear in fifth speed, at speed 3000 rpm and load 130 Nm.

5. Conclusion

In the present paper cepstrum and envelope analyses are used to a gear fault diagnosis in the early stage of gear's fault. Real comparative study was done; results show that the two methods are effective and reliable but the disadvantage of conventional envelope analysis is, that the central frequency of filter has to be chosen in advance, which demands some experience. Concerning the comparison, the squared envelope analysis was discussed in a separate publication [5]. Cepstrum technique appears to be efficient for detecting changes not easily notable in the spectrum. Major benefit of using cepstrum technique would be earlier damage identification because it is clear and easier to separate periodic events (fault) from random events (noise).

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