DETECTING GEAR TOOTH CRACKS USING CEPSTRAL ANALYSIS IN GEARBOX OF HELICOPTERS

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ABSTRACT

Gears are very important in the transmission of power between two shafts close together with a constant velocity ratio; search in gear damage by using vibration signals is still very attractive, because the vibration signals from gears are not easy to interpret. A failure diagnosis transmission based on Fourier analysis of the vibration signal produced from a speed reducer has shown its limits in terms of spectral resolution. For helicopter safety, early gear fault detection is important to prevent system break down and accident. Among the methods proposed in the literature, cepstral analysis has shown it efficiency. Cepstrum used to identify damage gear, it appears in the cepstrum clear peaks called rahmonic so it is easy to identify the change in the system and able to detect and foresee the development of the lateral band. This paper proposes how to detect faults in gearbox of helicopter by registration signals during flight, with spectrum analysis and cepstrum analysis. Analyzed results show that the proposed method is effective to extract modulating signal and help to detect the early gear fault.

KEYWORDS: *vibration signal processing, tooth crack, cepstrum analysis, diagnosis, gear damage.*

I. INTRODUCTION

Gearboxes play an important role in industrial applications. Typical faults of gears include pitting, chipping, and more seriously, crack. When a gear has a local fault, the vibration signal of the gearbox may contain amplitude and phase modulations that are periodic with the rotation frequency of the gear.

The modulation of the meshing frequency, as a result of faulty teeth, generates sidebands, which are frequency components equally spaced around a centre frequency. The centre frequency called the carrier frequency may be the gear mesh frequency, multiples of bearing ball pass frequency, resonant frequency of a machine component/structure, or the resonant frequency of an accelerometer. [1]

Sidebands are either the shaft rotational speed or one of its multiples. It is well known that the most important components in gear vibration spectra are the tooth-meshing frequency and their harmonics, together with sidebands. Amplitude modulations are present when a gear meshes an eccentric gear or a gear riding on a bent or misaligned shaft. If there is a local gear fault, the gear angular velocity could change as a function of the rotation. As a result of the speed variation, frequency modulations occur. In many cases, both amplitude and frequency modulations are present. The increasing in the number and the amplitude of such sidebands often indicates faulty conditions. A change in the vibration signature can be used to detect incipient faults before they become critical. The use of vibration analysis as one of the fundamental tools for monitoring. several techniques widely used for transmission are such that the waveform analysis, time-frequency analysis, Fast Fourier Transform (FFT) spectrum synchronous average, and the cepstrum. This diagnostic technique based on vibration technology has been monitoring the most attractive because of the effectiveness of the results obtained. In this paper, the authors study a vibration signal recording during the flight of a helicopter by using multiple technologies was presented based on the signal in the time domain and spectral analysis after frequency domain and finally the cepstrum to detect and validate the results of the spectrum.

II. ANALYSIS OF GEAR VIBRATION SIGNALS

X'(t) is the signal of normal gears, where M is the number of tooth-meshing harmonics, X_m and f_m are, respectively, the amplitude and the phase of the m_{th} meshing harmonic, N is the number of gear teeth, t is time, f_s is the shaft rotation frequency, and Nf_s is the meshing frequency. Equation (1) indicates that the vibration signal acquired from a normal gearbox. *:[5]*

$$x'(t) = \sum_{m=0}^{M} X_m \cos(2\pi m N f_s t + \emptyset_m) \quad (1)$$

Changes in vibration generated by a faulty gear tooth can be represented by:

$$a_m(t) = \sum_{n=0}^{M'} A_{mn} \cos(2\pi n f_s t + \alpha_{mn}),$$

$$b_m(t) = \sum_{m=0}^{M} B_{mn} \cos(2\pi n f_s t + \beta_{mn}) \quad (2)$$

The combined modulated vibration signal, x (t), produced by a pair of meshing gears with a tooth fault, is

given in equation (3) with M' is the number of sidebands around tooth-meshing harmonics, A_{mn} and B_{mn} are amplitudes at the n^{th} sidebands of amplitude and phase-modulating signals, respectively, around the m_{th} meshing harmonic, and a_{mn} and b_{mn} are phases at the n^{th} sideband of amplitude and phase-modulating signals, respectively, around the m_{th} meshing harmonic.[5]

$$\begin{aligned} x(t) &= \sum_{m=0}^{M} X_m (1 + a_m(t)) \times \cos(2\pi m N f_s t + \phi_m + b_m(t)) \\ &= \sum_{m=0}^{M} X_m \left(1 + \sum_{n=0}^{M'} A_{mn} \cos(2\pi n f_s t + \alpha_{mn})\right) \times \cos\left(2\pi m N f_s t + \phi_m + \sum_{n=0}^{M'} B_{mn} \cos(2\pi n f_s t + \beta_{mn})\right), \end{aligned} \quad (3)$$

At last, the vibration signal given in Equation (3) is now modified into:

$$\begin{aligned} x(t) = \sum_{m=0}^{M} X_m &\left(1 + \sum_{n=0}^{M'} A_{mn} \cos(2\pi n f_s(t) t + \alpha_{mn})\right) \\ &\times \cos\left(2\pi m N f_s(t) t + \phi_m + \sum_{n=0}^{M'} B_{mn} \cos(2\pi n f_s(t) t + \beta_{mn})\right). \end{aligned} \quad (4)$$

Sidebands within the signal given by Equation (4) will be more complex with dynamic frequency components. Detection of these sidebands will provide important information for fault detection, the signal collected from a gearbox with a faulty gear tooth has the following characteristics such as the Modulation is present, and Modulating signal frequencies represent fault features generated by gears, shafts, or bearings. These frequencies are focused in the low-frequency region. Also the modulating signal may be non-stationary due to the fluctuation of gear/shaft speed, lubrication variations, and shocks generated by a fault. and finally During the development of an early fault, the amplitude of the modulating signal caused by the fault is usually small.[5]

III. GEARBOX FAILURE

RB Randall is one of the pioneers in the case of vibration analysis. Indeed, in the articles [Randa75] and [Randa80a], there is an interesting study on the interpretation of the cepstrum in the case of diagnosis of gearboxes. Figure 1a [Randa82] shows an example of the power spectrum calculated on an accelerometer signal from a gearbox. The complexity of this spectrum makes it difficult to identify the lines. Calculating the cepstrum Figure 1b clearly identifying the presence of two Dirac combs diminishing period equal to the rotation of the pinion and wheel engaged. It should be noted that, unlike the spectrum, cepstrum energy resolution is much better than the low frequencies.

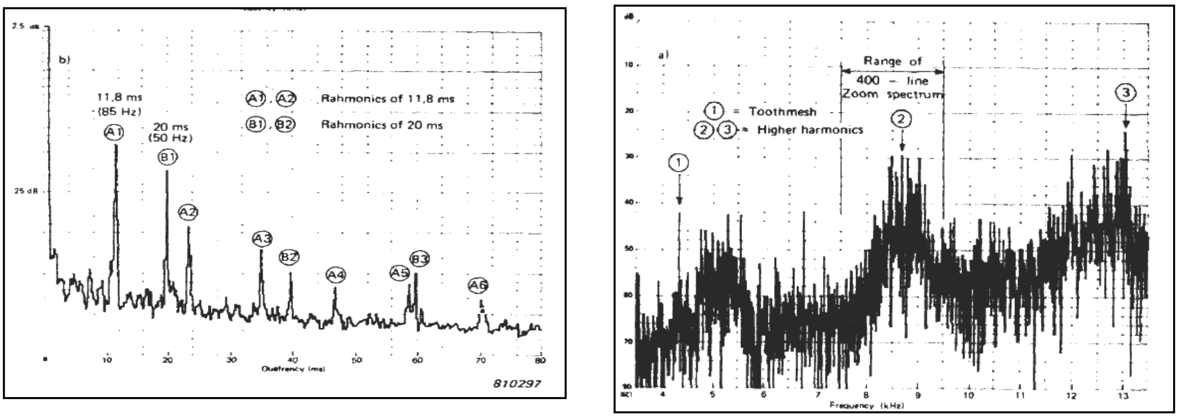

Figure 1 : Analyse cepstrale ; a) spectre de puissance d'une boite de vitesse ; b) cepstre d'énergie [Randa82]

After [Aubli92], [Henri68] there are two main categories of defects. Defects affecting all teeth, wear, pitting, and those located on particular teeth, cracking, chipping. Defects located on particular teeth quickly lead to rupture them, unlike defects such as wear and tear. If one wheel carries a tooth damaged, there is a hard impact, at each turn of the wheel. The spectrum shows a comb of lines whose pitch corresponds to the frequency of rotation of the pinion deteriorates. The cepstral (Fig. 2) component corresponding to the first rahmonic of the damaged gear ,is practically insensitive to the crack dimension. In other words, for this case, the cepstrum analysis gives unclear monitoring information and is not able to detect the presence of the damage. The cepstrum approach was also employed for the axial vibration signals, but the results were not comforting and have not been reported for the sake of brevity.

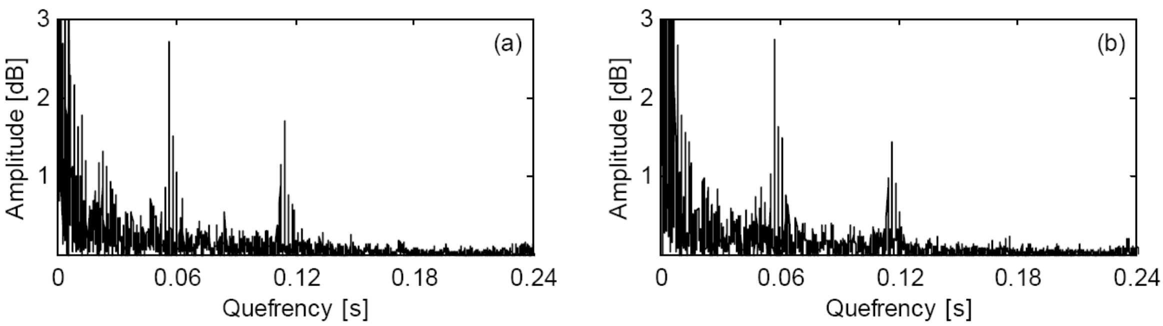

Figure 2: Cepstrum vibration: small (a) and large (b) crack [Aubli92]

IV. RESULTS AND DISCUSSION

MRC SENSOR (Main Gearbox right clutch):

- Meshing frequency is Fe =2634.6 Hz

Table 1:gear mesh frequencies calculations

Shaft	speed	gear teeth
S1	4391 RPM	36
	73.18 Hz	
S 2	1121 RPM	141
	18.68 Hz	

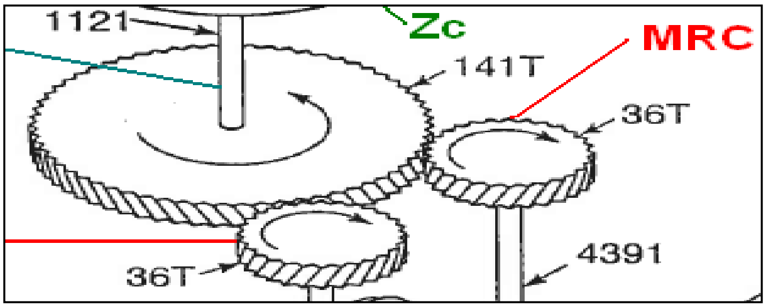

Figure 3: description of part in gearbox of a helicopter

A. Time waveform analysis.

Time waveform is also a major source for any analysis and the proper use of it can give reliable results, this technique is applicable in the assessment of damage gear. time waveforms can be very complex research graphic, but we can often detect problems that other techniques cannot. As a major argument for the use of waveform time is the period of time that could be associated with some form of damage or irregularities.

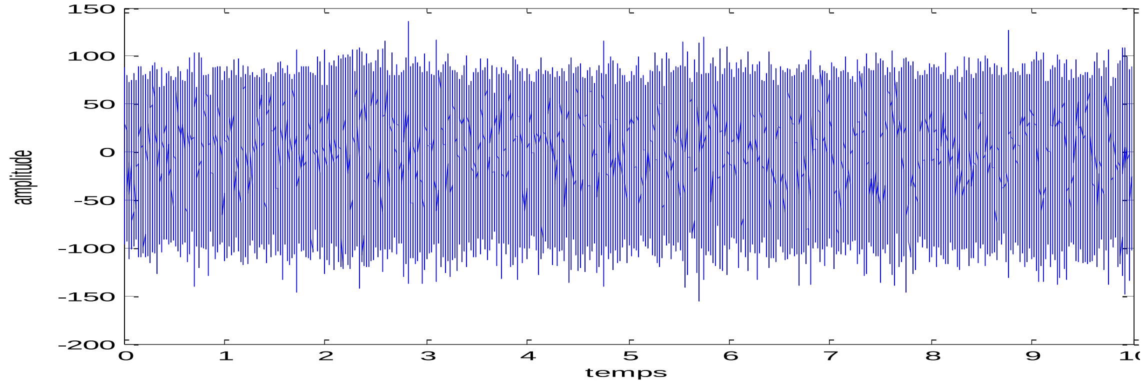

Figure 4: Time domain plot of the normal gearbox

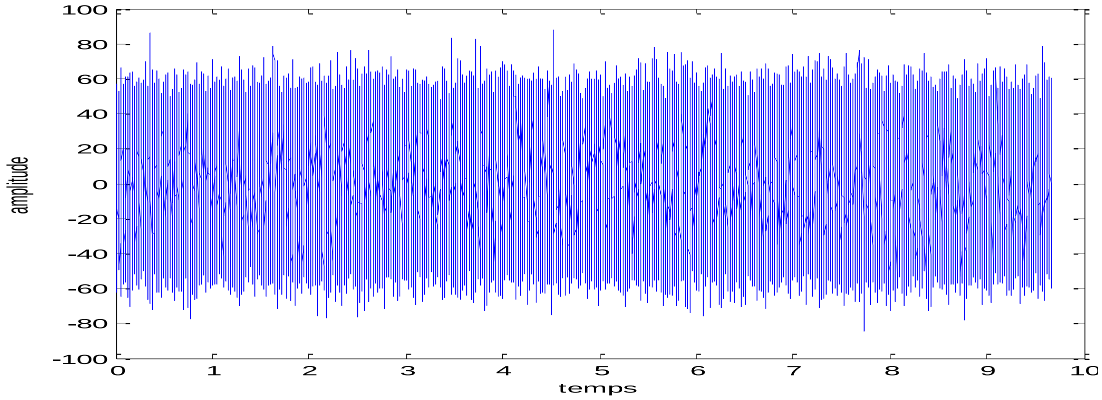

Figure 5: Time domain plot of faulty gearbox

Figure 5 shows the waveform of the indication of problems in the vibration signal transmission shaft rotating with 0.0136 s and frequency of 73 Hz at a speed of rotation of 4391 rpm; which is the rotation of the pignion. The extent of the damage can be better assessed by examining the waveform of the time as it was presented.

B. spectrum Analysis

The technique of spectrum will not have information if changes from the source or the transmission path

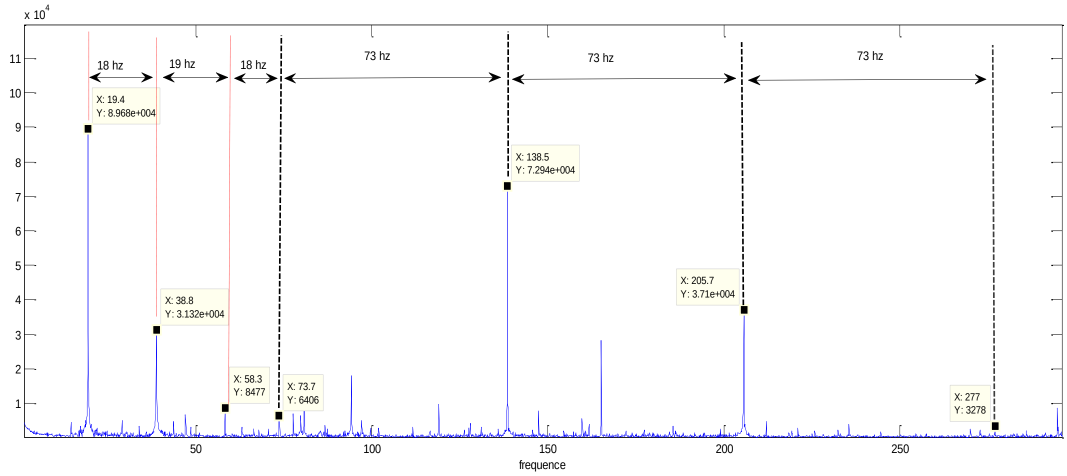

Figure 6: power spectrum of normal gearbox

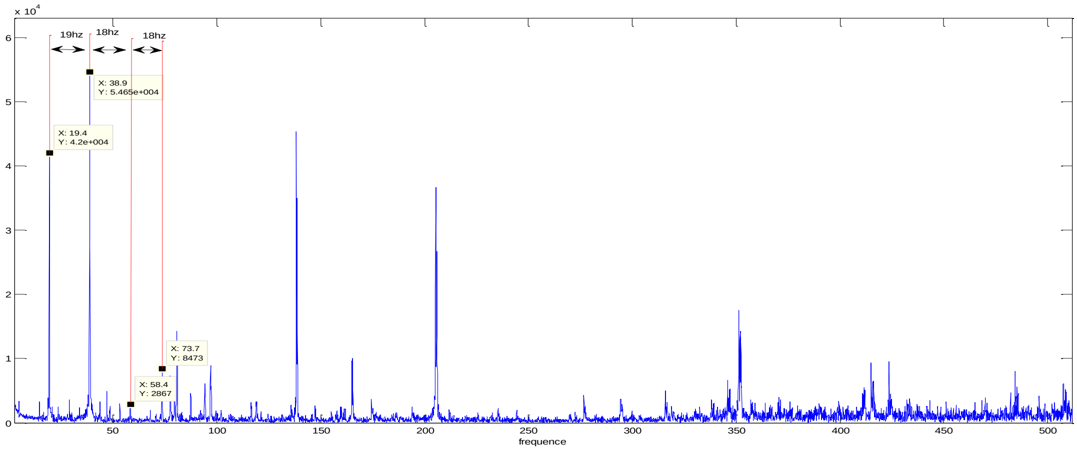

Figure 7: power spectrum of faulty signal vibration

The amplitude at the gear mesh frequency is not used to detect a gear damage because others operating parameters such as loads can affect this amplitude. Figures 6 and 7 shows vibration frequency spectrum of gearbox of a helicopter, presenting fourth harmonics of pinion rotating with 4391 rpm and 73 Hz. and wheel rotating with 18 Hz.

C. Cepstrum analysis

The cepstrum is somehow the spectrum of a logarithmic spectrum and to find the periodicities in the original spectrum.

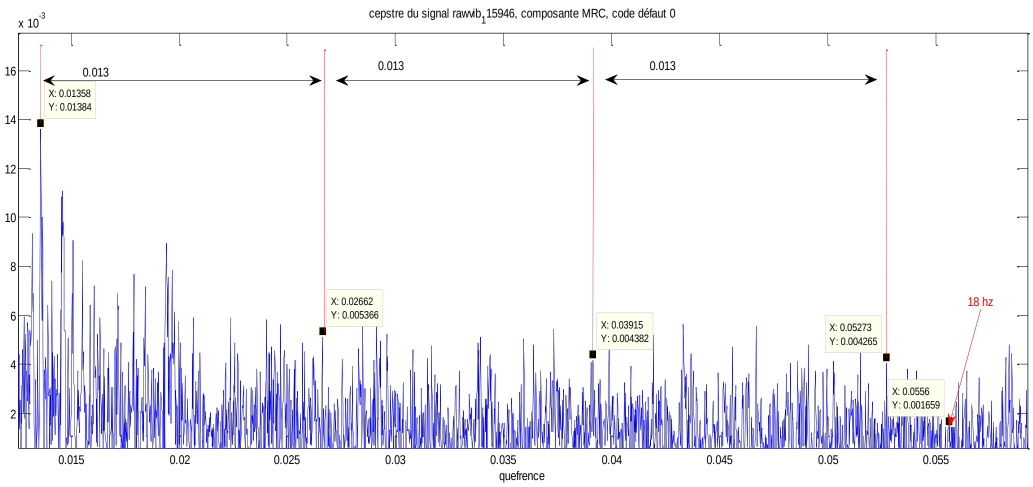

Figure 8: power cepstrum of normal gearbox

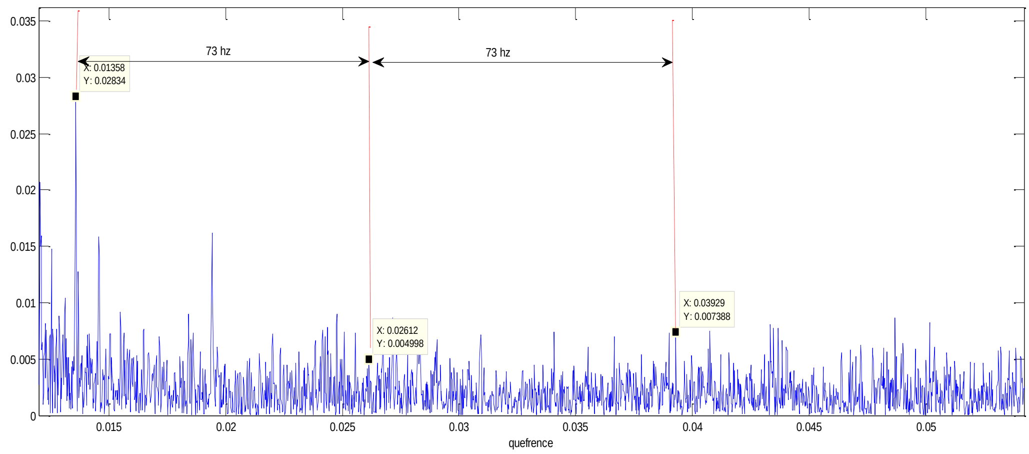

Figure 9: cepstrum of faulty signal vibration

The frequency spectrum technique will not have information if changes coming from the source or transmission path. Harmonics and sidebands in the spectrum represent the concentration of excitation energy caused by the rotation component and they typically used to detect any abnormality in the operation. Cepstrum allows for detecting periodicities in frequency domain usually as results of modulation. Advantages of using the cepstrum in the gear damage identification in the situation of combined effects of the harmonics and sideband in the spectrum appear in the cepstrum as a small number of clear defined rahmonic peaks; it is therefore easier to identify changes in the system. It is able to detect the presence and growth of sideband and to extract the spectrum periodicity.
The spacing of 73 Hz (in figure 9) and high amplitude around rotation of pinion, it is identified as tooth crack problem in the pinion.

V. CONCLUSION

This paper study the effectiveness of some vibration analysis techniques for the identification of problem tooth crack in gear, on the basis of actual data recorded during the flight of a helicopter. in particular, the ability of approaches based on time, frequency. The waveform analysis is very effective in identifying damage. Variation of the amplitude at the frequency of rotation occurs during load variations. Cepstrum technique seems effective to detect significant changes in the spectrum not easily. Major advantage of the use of the cepstrum technique is early identification of damage because it is clearer and easier to see changes.

VI. FUTURE WORK

In future work we will offer a new technique for fault detection based on the geometric mean calculates and computes statistics to extract the vibration severity in the cepstrum, the technique is the automatic detection of defects not require a great analysis.

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