Demodulation of vibration signals for bearing fault detection using a method based on filtering and absolute value

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Abstract: A method for amplitude demodulation of vibration signals is proposed in your study, the method is designed for diagnosis and fault detection. The approach of the method starts by calculating the absolute values of the vibration signal data to make them all positive. Then, a low-pass filtering is applied to obtain an exponential variation of the data on the spectrum of the demodulated amplitude signal. The proposed method is applied to signals from the database, and subsequently, these signals are demodulated using both the proposed method and the Hilbert transform. Both methods reveal high-amplitude peaks at the same frequency values in the demodulated amplitude spectrum.

Keywords: Demodulation, Vibration signal, Amplitude, Peak

1. INTRODUCTION

Undesirable movement, known as vibration, is induced by irregular forces within rotating machinery. The measurement chain responsible for capturing vibration parameters, including displacement, velocity, and acceleration, comprises specialized sensors tailored to specific frequency ranges [1]. Consequently, the displacement sensor is crafted to handle low frequencies, the velocity sensor is adept for medium frequencies, and the acceleration sensor is exclusively utilized for high frequencies [1].
When rotating machines contain faults, the amplitude and frequency of vibration signals undergo modulation, resulting in the introduction of complexities within the signals [2]. The phenomenon of amplitude and frequency modulation of signals involves the multiplication of a high-frequency carrier signal with a low-frequency modulating signal [3]. This high frequency is generated by resonance, resulting in an abnormal increase in amplitude [3]. Due to the complex sidebands present around the resonance frequency in the spectrum of the modulated signal, defect detection becomes unfeasible [3]. However, there is amplitude demodulation, which allows for an exponential variation of the amplitude and ensures simplicity in the sidebands, thereby enabling efficient extraction of defect frequencies [4]. Different demodulation techniques are employed for diagnostic purposes, including the energy separation method, which utilizes the Teager-Kaiser Energy Operator (TKEO) to demodulate signals in terms of envelope amplitude and instantaneous frequency [5]. TKEO is calculated based on the first and second derivatives of the signals, and its design aims to optimize signal energy [5]. Furthermore, demodulation by the Hilbert transform is the most popular method in defect detection, involving the use of an analytical signal associated with the original vibration signal [6].
Demodulation, referred to as envelope analysis, involves extracting information about defects from the instantaneous amplitude, known as the envelope [3]. By employing demodulation methods and vibration signals, the envelope is extracted [7]. Following the determination of the envelope, various tools can be utilized to improve the precision and efficiency of defect diagnosis, including squaring the envelope and taking the logarithm of the envelope [8].In addition, the extraction of fault-related features in envelope analysis is carried out using methods such as the kurtogram, which represents the variation of spectral kurtosis as a function of frequency [9]. There are also several methods developed in this context, such as the autogram proposed by Moshrefzadeh, A et al [10], and the CFFsgram proposed by Zhou, Ning, et al [11]. Bearing fault detection can be achieved using several methods based on vibration signal analysis, such as deconvolution, used to extract the impulse part of the fault-related

signal [12], or the decomposition of the vibration signal into several simple signals using algorithms such as Empirical Fourier Decomposition (EFD) [13] and Successive Variational Mode Decomposition (SVMD) [14]. In a further development, artificial intelligence, including machine learning and deep learning, enables the classification of bearing defect types. The general structure of the artificial intelligence-based diagnostic method consists of the extraction and classification of features determined from vibration signals, which vary as a function of frequency, time or time-frequency [15].

Within this document, a novel method for demodulating vibration signals is put forth. This method encompasses low-pass filtering and the computation of absolute values for vibration parameters, including displacement, velocity, and acceleration.

2. METHODS

We present a new method for demodulating vibration signals, based on the absolute values of the vibration data and low-pass filtering. Figure 1 illustrates the flowchart of the proposed method, which includes the following steps:

- After signal insertion, the absolute values of each signal sample are calculated to make them all positive.
- Once these absolute values have been determined, low-pass filtering is applied, with a pass frequency equal to one third of the signal sampling frequency. Filtering is employed to impart an exponential shape to the variation of vibration signal data. The Butterworth filter is specifically utilized.
- The demodulated amplitude signal obtained after filtering.

The frequencies of the peaks in the spectrum of the demodulated signal play a crucial role in evaluating the effectiveness of the methods, as they allow for the identification of faulty elements in rotating machinery [1].

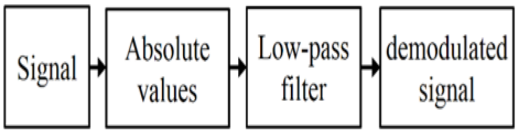

Fig. 1 Flowchart of the method

Thanks to this, a comparison is made between the results of the demodulation methods and the proposed method. The Hilbert transform method is widely used methods. The demodulation process of this method is expressed as follows [16]:

$$H[x(t)] = x(t) * \frac{1}{\pi t} \tag{1}$$

$$a(t) = x(t) + jH[x(t)] \tag{2}$$

$$E(t) = \sqrt{x(t)^2 + H[x(t)]^2} \tag{3}$$

$$E(f) = FFT[E(t)] \tag{4}$$

Vibration signals to be demodulated

We are demodulating the vibration signals available in the XJTY-SY database.

The vibration data of an LDK UER204 bearing is available in this database [17]. The vibrations are collected using two accelerometers, one mounted on the horizontal axis and the other on thevertical axis of the bearing [17]. We demodulate both signals, which are illustrated in the table 1.

Table1 Vibration signals when the bearing rotates at 35Hz with 12 kN

Signals	Sampling frequency	Failed component	Fault frequency
Horizontal	*25.6 kHz*	*Outer race*	*107.9 Hz*
Vertical	*25.6 kHz*	*Outer race*	*107.9 Hz*

3. RESULTS AND DISCUSSIONS

Case 1: demodulation of the horizontal signal

In Figures 2 and 3, the demodulated amplitude of the horizontal vibration signal is presented. Across all spectra, a high-amplitude peak is consistently observed at the same frequencies. The frequency value is very close to the default frequency (108.6 Hz ≈ 107.9 Hz).

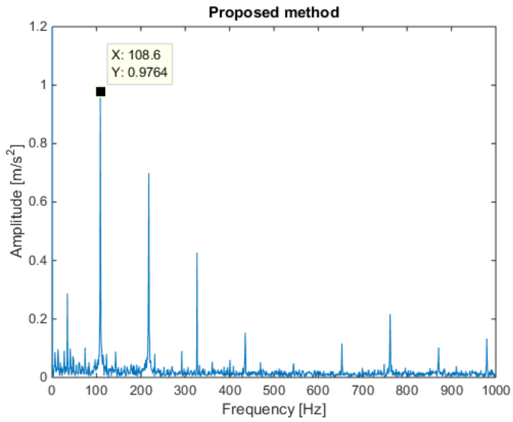

Fig. 2 Demodulation of the horizontal signal using the proposed method

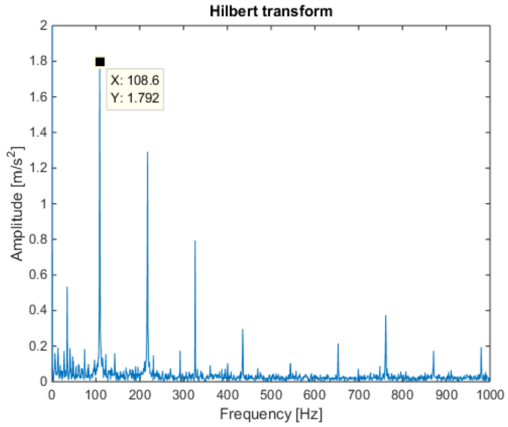

Fig.3 Demodulation of the horizontal signal using the Hilbert method

Case 2: demodulation of the vertical signal

For the demodulation of the vertical vibration signal, the proposed method and Hilbert transform method reveal a significant peak at a frequency of 108.6 Hz≈ 107.9 Hz (see figures 4 and 5).

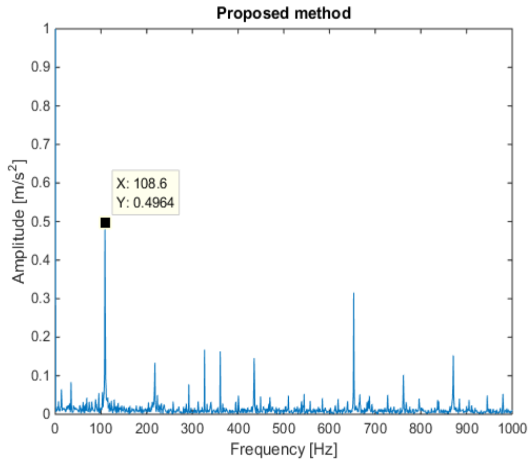

Fig.4 Demodulation of the vertical signal using the proposed method

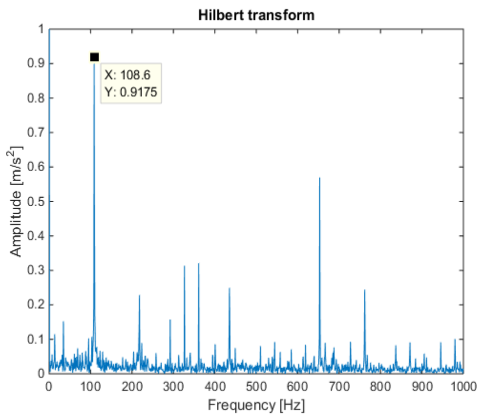

Fig.5 Demodulation of the vertical signal using the Hilbert method

4. CONCLUSION

The vibration signals to be demodulated are sourced from the XJTU-SY databases. In both the first and second cases involving horizontal and vertical vibration signals, all employed demodulation methods yield identical frequency values for the peaks in the demodulated amplitude spectrum of the signals.

According to the demodulation of the signals, the proposed method offers a combination of the demodulation method results and can be used as a final step in the diagnosis and detection of faults through the analysis of rotating machinery vibration signals.

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