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Frequency domain averaging based experimental evaluation of gear fault without tachometer for fluctuating speed conditions

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ABSTRACT

In the purview of fluctuating speeds, gear fault diagnosis is challenging due to dynamic behavior of forces. Various industrial applications employing gearbox which operate under fluctuating speed conditions. For diagnostics of a gearbox, various vibrations based signal processing techniques viz FFT, time synchronous averaging and time-frequency based wavelet transform, etc. are majorly employed. Most of the time, theories about data or computational complexity limits the use of these methods. In order to perform fault diagnosis of a gearbox for fluctuating speeds, frequency domain averaging (FDA) of intrinsic mode functions (IMFs) after their dynamic time warping (DTW) has been done in this paper. This will not only attenuate the effect of fluctuating speeds but will also extract the weak fault feature those masked in vibration signal. Experimentally signals were acquired from Drivetrain Diagnostic Simulator for different gear health conditions i.e., healthy pinion, pinion with tooth crack, chipped tooth and missing tooth and were analyzed for the different fluctuating profiles of speed. Kurtosis was calculated for warped IMFs before DTW and after DTW of the acquired vibration signals. Later on, the application of FDA highlights the fault frequencies present in the FFT of faulty gears. The result suggests that proposed approach is more effective towards the fault diagnosing with fluctuating speed.

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1. Introduction

Devastation of mass and material in industries due to post diagnostics techniques such as root cause failure analysis, fracture analysis, etc. has lead towards the emergence of early diagnosis through vibration analysis. Thus, vibration analysis has proved to be an efficient technique in the detection of faulty gears of various mechanical systems employed in different industrial sectors [1–3]. But, in the real-time conditions, fluctuations in the speed at which the gearbox operates which results in smeared frequency spectrum and as a consequence, it becomes difficult to locate the fault frequencies. Therefore, such fluctuating condition has made the existing techniques such as, Fast Fourier Transform (FFT), Time Synchronous Averaging (TSA), cepstrum, etc., ineffective [4,5]. Various experiments on spectral analysis [6–8] suggest to be incompetent alone, as they produce erroneous results and are limited to fluctuating speed and load environment. All of the above methods have made some achievements to health monitoring and fault diagnosis. However, each of these methods has their own limitation of fluctuating speed environment.

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In real life, the wind velocity and the output load doesn't remain constant, these parameters makes the wind turbine to face fluctuations in speed. Under fluctuating speed conditions, it becomes difficult to diagnose the gear fault. Further, to comment about the severity of fault and type of fault becomes challenging. Therefore, to diagnose faulty gear box under fluctuating speed, an effective signal processing technique, should possess the following characteristics:

(a) Capability to process non-stationary, nonlinear signals: analysis based instinctively on data;
(b) Highly robust method;
(c) Should be fast and neither computationally complex nor expensive in order to perform on-line monitoring.

Method for fault diagnosis based on time-frequency resolution i.e. Empirical Mode Decomposition (EMD) which follows Hilbert Transform (HT) is one of the efficient techniques. EMD with an aim of fault diagnosis is useful in the extraction of the Intrinsic Mode Functions (IMFs), or mono-component functions that comprises the original signal. Various studies [9–11] have highlighted that number of components (high-frequency component, low-frequency components, and noise) present in a gear vibrational signal have a strong influence on the fault diagnosis capabilities. These multi-components mask the fault features of the gear vibration signals. Liu et al. [12] used B-spline EMD followed by spectrum of HT to diagnose gearbox faults and found that it can enhance the crack excited transients in a better way as compared to wavelet transform. Qin et al. [13] did an investigation on iterated Hilbert Transform and enforced it to mechanical fault diagnosis containing multi-component AM-FM signals. In 2009, Yang improved the conventional EMD method and proposed a new Hilbert spectrum method [14].

The key component of EMD is IMF; the selection of the IMF is based on operation skills thus, there are frequent chances of getting erroneous results are high. Furthermore, hypothetical data and computational complexity limits the use of these methods. However, it has better representation in time-frequency domain and capability of separating the signal into different components based on oscillations of signal [15]. Additionally, frequency domain averaging is found very effective by decomposing and attenuating the noise components from the signal [16], and can prove to be benefiting as no key phasor signal or reference signal is required. Thus the use of tachometer is non-essential. Therefore, utilizing IMF for FDA after DTW can prove to be a novel approach towards, fault diagnosis under fluctuating speed conditions.

The scheme of this approach has been illustrated in Fig. 1. The organization of this paper is as follows: the main steps of the EMD, DTW and FDA are discussed in Section 2 respectively. Section 3 illustrates a simulation study conducted to verify the proposed approach of FDA by diagnosing the fault phenomenon generated in a gearbox by a localized gear defect under fluctuating speed conditions. Subsequently, the performance evaluation of proposed method is also expressed. Section 4 illustrates the description of experimental test-setup. The experimental findings are presented and followed by the discussion in Section 5. Conclusions about the effectiveness and the diagnostics capability of the method are reported in Section 6.

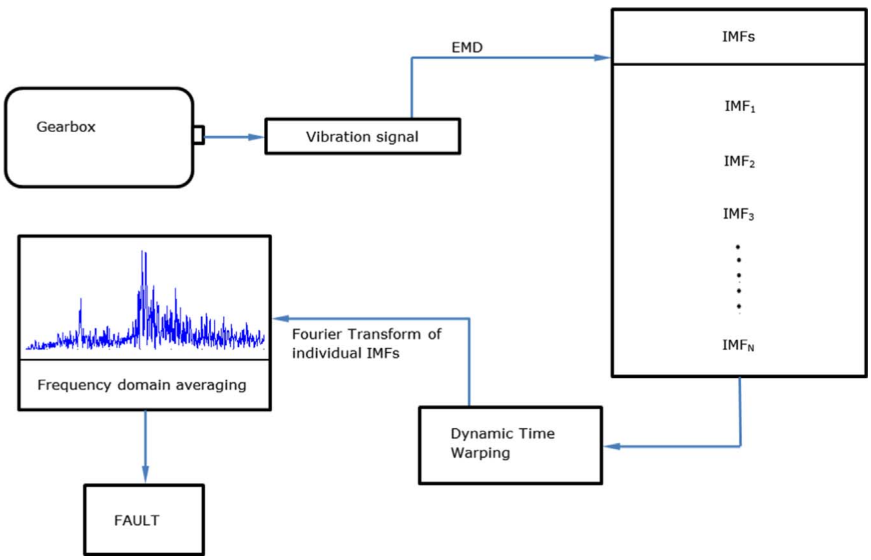

Fig. 1. Scheme of fault diagnosis method.

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