Gear Fault Diagnosis Using Bispectrum Analysis of Active Noise Cancellation-Based Filtered Sound and Vibration Signals

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Fault diagnosis using acoustical and vibration signal processing has received strong attention from many researchers over the last two decades. In the present work, the experiment has been carried out with a customized gear mesh test setup in which the defects have been introduced in the driver gear. Classical statistical analysis including higher-order statistics, namely bispectrum analysis, has been incorporated to detect the defects. However, in order to improve the signal-to-noise ratio of the captured signals for accurate defect detection, an adaptive filtering has been proposed. Active noise cancellation (ANC) has been applied on the acoustical and vibration signals as a denoising filter. The least mean square based ANC technique has been implemented considering the signals from healthy gear meshing as the background noise. The focus of this experimental research is to evaluate the appropriateness of the ANC technique as a denoising tool and the subsequent bispectrum analysis for identifying the defects. The performance of the ANC filtering was evaluated with most widely accepted standard filters. A synthetic signal, close in nature to the actual signal, has been investigated to ascertain the adequacy.

1. INTRODUCTION

Safety, reliability, efficiency, and performance of rotating machinery are major concerns in the industry. In this situation, the task of condition monitoring and fault diagnosis of rotating machinery has significant importance. Many methods have already been widely used in a variety of industries for predictive maintenance. It has been widely accepted that the structural defects in rotating machinery components can be detected through monitoring acoustical and/or vibration signals. The machine condition monitoring process consists of three stages of signal processing: (1) acquisition of acoustic or vibration signals, (2) signal pre-processing and extraction of the fault feature, and (3) diagnosis of the defect.

Various signal processing techniques have been identified and proposed by many researchers in this context. The most common method is the fast Fourier transform (FFT) to obtain the power spectrum to investigate the frequency components of the entire signal. However, it is a well-known fact is that the acoustical or vibration signals from a rotating system is composed of a large number of non-stationary signals, particularly in the presence of a localized, defect such as bearing pitting or gear tooth fracture. Short-time Fourier transform and related time-frequency and time-scale techniques have often been used to detect such non-stationary defect signatures. Another fact is that typical defects in machinery components have been characterized by particular vibration patterns.[1] Loutas et al. have reported that the acoustical emission (AE) technique is more effective in the early stages of defect identification compared to vibration monitoring, particularly in the case of a crack in the gear. Regionally linear behaviour of AE parameters has been observed by them where the associated gradients change proportionally with the crack propagation rate.[2] Some potential defects, namely spalling of the gears and bearings, clearances, etc., induce periodic impulses in acoustical and vibration signals of rotating machines. Such impulses may excite the eigenmodes of the structure and the sensor. The statistical parameters such as the root mean square (RMS) value, kurtosis, crest factor, skewness, peak value, and signal-to-noise ratio (SNR) are most widely used to detect the defect. These indicators are easy to implement; however, the complexity of the mechanisms involved may give rise to serious errors in interpretation. A detailed study was conducted by Dron et al. on the influence of certain parameters on the value of the crest factor, kurtosis, and RMS value.[3] In order to carry out condition monitoring of the gear meshing using acoustical and vibration signals analysis, the selection of such statistical indicators needs to be well suited to the impulsive nature of the excitatory forces generated by the defects. Thus, reliability in fault diagnosis can be achieved if, and only if, the acquired signals are free from any background noise. Therefore, the major challenge is to remove background noise from acoustical and vibration signals captured at the faulty condition using appropriate signal processing. The intention of signal denoising is to minimize the influence of the unwanted noise without affecting the defect signatures.

Over the last decade, the performance of active noise cancellation (ANC) systems has been improved primarily due to the integration of digital signal processing. The merging of active noise cancellation techniques and digital signal processing has enabled the control of noise dynamically and adaptively. In practice, active noise control is mainly used for duct-like systems such as blowers, ventilation systems, or enclosures like aircraft and vehicle cabins, headphones, and control rooms.