A Novel Improved Full Vector Spectrum Algorithm and its Application in Multi-sensor Data Fusion for Hydraulic Pumps

He Yu, Hongru Li, Yaolong Li, Yifan Li

PII: S0263-2241(18)30927-8
DOI: https://doi.org/10.1016/j.measurement.2018.10.011
Reference: MEASUR 5951

To appear in: *Measurement*

Received Date: 16 July 2018
Revised Date: 8 September 2018
Accepted Date: 4 October 2018

A Novel Improved Full Vector Spectrum Algorithm and its Application in Multi-sensor Data Fusion for Hydraulic Pumps

He Yu[1], Hongru Li[1,*], Yaolong Li[1],Yifan Li[2]

1 Army Engineering University, No.97 Heping West Road, Shijiazhuang 050003, Hebei, China; 13832329446@163.com (H.Y.); bywddt@163.com (Y.L.)

2 University of California, Riverside, CA 92521, USA; 364721315@qq.com

* Correspondence: lihr168@sohu.com

Abstract: The full vector spectrum is an effective and efficient tool for homologous multi-sensor data fusion in rotating machinery. However, this methodology just takes Fourier Transform to obtain the harmonic trajectory information hidden in multi-sensor data and it has some drawbacks of processing nonlinear, multi-frequency and noise-containing data. To address this critical issue, this paper provides a novel approach called EWT-VCR based on Empirical Wavelet Transform (EWT) and Variance Contribution Rate (VCR) to improve the adaptability and accuracy of the fusion method. EWT is introduced as a signal preprocessing technique to decompose complex signals into variable frequency bands. And VCR is proposed to denoise, fuse EWT components at different frequency bands, and enhance useful harmonic components. The full vector spectrum technology is utilized to carry out the full vector information fusion of the improved multi-sensor signals for further spectrum analysis. The proposed methodology is applied to multi-channel vibration signal fusion for hydraulic pumps to detect specific frequencies related to pump's degradation process and a novel degradation feature named Full Vector Factor Entropy (FVFE) is extracted to describe hydraulic pump's degradation process during its life cycle. The effectiveness of the proposed methods is validated through two experimental cases.

Keywords: hydraulic pump; data fusion; full vector spectrum; EWT; VCR; degradation feature

1. Introduction

A hydraulic pump is one of the core components of hydraulic systems and is widely used in modern industry and transportation, due to its advantages of high force-to-weight ratio, quick response, and high control accuracy [1]. Considering that safety and reliability of a hydraulic pump are crucial to the whole hydraulic system [2], it is necessary to monitor the hydraulic pump's operating conditions timely with a proper degradation feature.

Some published studies have been focusing on the degradation feature extraction of rotating machinery based on signal processing techniques [3-5]. And these methodologies utilized acoustic, thermal, vibration and even electrical signals and have been successfully applied to fault diagnosis and degradation state identification of rotating components like bearings or motors [6]. Nevertheless, unlike the above situations, a hydraulic pump's structure is relatively complex, not to mention its harsh working environment. In this case, sensors in hydraulic systems cannot be always reliable. Apparently, the monitoring data obtained by a single sensor is not enough to accurately reflect the actual working status of a hydraulic pump. Once the sensor is faulty, it may result in a large error in the process of degradation feature extraction. Therefore, it's common that there are multiple sensors arranged in hydraulic systems monitoring the hydraulic pump's operating data including but not limited to: vibration, pressure, flow and temperature [7]. Previous studies indicate that vibration signals are one kind of typical and frequently-used operating data [8, 9]. According to the failure mechanism of hydraulic pumps, the shock and noise caused by the failure of the internal key friction pair will be transmitted from different directions to the pump shell in the form of vibration [10]. The vibration signals contain abundant degradation state information. Whereas hydraulic pumps are one kind of irregular rotating components indeed and the vibration energy distribution in different directions is obviously different. Thus it is imperative to fuse the multi-channel vibration signals for a better understanding of the hydraulic pump' overall degradation state.

Multi-sensor data fusion has been a hot topic in many engineering areas and kinds of exciting fusion technologies have been developed rapidly these years. In order to predict wind speed accurately, Zhang et al. [11] proposed a RBF Neural Network based on PCA and ICA and conducted multi-sensor data fusion to fuse wind direction, temperature, air pressure, humidity and roughness that are related to wind speed. Ref. [12] reduced the uncertainty of fault identification through the fusion of different sensor information and improved the reliability of diagnostic results. Reference [13] showed us many