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Review

# Wavelet transform based on inner product in fault diagnosis of rotating machinery: A review

Jinglong Chen [a], Zipeng Li [a], Jun Pan [a], Gaige Chen [a], Yanyang Zi [a,*], Jing Yuan [b], Binqiang Chen [c], Zhengjia He [a]

[a] State Key Laboratory for Manufacturing and Systems Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
[b] Shanghai Institute of Radio Equipment, Shanghai 200090, PR China
[c] Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, PR China

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ABSTRACT

As a significant role in industrial equipment, rotating machinery fault diagnosis (RMFD) always draws lots of attention for guaranteeing product quality and improving economic benefit. But non-stationary vibration signal with a large amount of noise on abnormal condition of weak fault or compound fault in many cases would lead to this task challenging. As one of the most powerful non-stationary signal processing techniques, wavelet transform (WT) has been extensively studied and widely applied in RMFD. Numerous publications about the study and applications of WT for RMFD have been presented to academic journals, technical reports and conference proceedings. Many previous publications admit that WT can be realized by means of inner product principle of signal and wavelet base. This paper verifies the essence on inner product operation of WT by simulation and field experiments. Then the development process of WT based on inner product is concluded and the applications of major developments in RMFD are also summarized. Finally, super wavelet transform as an important prospect of WT based on inner product are presented and discussed. It is expected that this paper can offer an in-depth and comprehensive references for researchers and help them with finding out further research topics.



**Contents**



* Corresponding author.
*E-mail address:* ziyy@mail.xjtu.edu.cn (Y. Zi).

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## 1. Introduction

Rotating machinery has quite a wide range of applications in industrial equipment. After running in the severe and complex conditions in a long-term such as corrosive environment, strong impact, heavy load or high temperature, some pivotal components of rotating machinery would inevitably generate multifarious faults [1,2]. Once fault appears in rotating machinery, it may lead to catastrophic accidents and enormous economic losses. So it is necessary and significant to identify the fault type and evaluate the fault level as early as possible, especially on weak fault diagnosis and compound fault diagnosis in rotating machinery, which are two important problems in the rotating machinery fault diagnosis (RMFD) [3,4]. Vibration signal analysis continues to be the most useful and popular method in the task of RMFD [5,6]. However, many kinds of mechanical faults, in the process of equipment operation, will generate diversified specific dynamic response signals. Moreover, because of the correlation of structures and the complexity of equipment, the acquired measured vibration signal is complicated and non-stationary, and the fault features are buried in heavy background noise. Consequently, there exists great difficulty in identifying the fault feature from such acquired vibration signals. Engineering requirements have promoted continuing advancement of signal-processing technologies such as the fast Fourier transform, short-time Fourier transform, wavelet transform and etc, which have established a foundation for the condition monitoring and fault diagnosis of rotating machinery and got significant effect in this field [7–9].

Fourier transform (FT) [10,11] and short-time Fourier transform (STFT) [12,13] are treated as types of inner product transform that analyzes the contents in the signal through a pre-determined triangular basis. As the bridge from time domain to frequency domain analysis, Fourier transform is the most widely used signal processing method [14]. But Fourier transform can not provide local feature information in frequency domain and its corresponding relations in the time domain [14]. To address the problem, Gabor proposed a more effective time and frequency localized analysis method, the STFT, and it could be considered as a local spectrum of the signal in a fixed window [15]. In spite of the tremendous achievements of STFT in mechanical fault diagnosis, its effectiveness is still hampered by the inevitable limitation of single triangular basis, which indicates that Fourier Transform would do well in detecting harmonic feature but not the usual impulse feature of rotating machinery fault based on inner product principle.

Unlike FT, wavelet transform (WT) has more choices on basis function to match a specific fault symptom, which is beneficial to fault feature extraction [16,17]. Wavelet theory originates from the idea of dilation and translation and WT is also a type of inner product transform that analyzes the non-stationary contents in the signal through a pre-determined wavelet basis [18]. According to the study from Randall, the similarity between the wavelet basis and the non-stationary contents in the signals plays a decisive role in its successfulness [19]. Moreover, due to the advantage of multi-resolution analysis, WT has already shown its tremendous usefulness in fault diagnosis of rotating machinery [20]. Traditionally, the wavelet transform can be categorized as continuous wavelet transform (CWT), discrete wavelet transform (DWT), and wavelet packet transform (WPT) [21]. However, all these wavelet transform methods are trapped in the selection of wavelet basis because an inappropriate wavelet basis employed in an application will directly influence the accuracy of the fault diagnosis, especially for weak fault diagnosis.