ARTICLE IN PRESS

Mechanical Systems and Signal Processing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Customized maximal-overlap multiwavelet denoising with data-driven group threshold for condition monitoring of rolling mill drivetrain

Jinglong Chen [a], Zhiguo Wan [a], Jun Pan [a], Yanyang Zi [a,*], Yu Wang [a], Binqiang Chen [b], Hailiang Sun [c], Jing Yuan [d], Zhengjia He [a]

[a] State Key Laboratory for Manufacturing and Systems Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
[b] Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, PR China
[c] Beijing Institute of Astronautical Systems Engineering, Beijing 100076, PR China
[d] Shanghai Institute of Radio Equipment, Shanghai 200090, PR China

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form
2 July 2015
Accepted 20 July 2015

Keywords:
Condition monitoring
Customized maximal-overlap multiwavelet
Rolling mill drivetrain
Data-driven group threshold

ABSTRACT

Fault identification timely of rolling mill drivetrain is significant for guaranteeing product quality and realizing long-term safe operation. So, condition monitoring system of rolling mill drivetrain is designed and developed. However, because compound fault and weak fault feature information is usually sub-merged in heavy background noise, this task still faces challenge. This paper provides a possibility for fault identification of rolling mills drivetrain by proposing customized maximal-overlap multiwavelet denoising method. The effectiveness of wavelet denoising method mainly relies on the appropriate selections of wavelet base, transform strategy and threshold rule. First, in order to realize exact matching and accurate detection of fault feature, customized multiwavelet basis function is constructed via symmetric lifting scheme and then vibration signal is processed by maximal-overlap multiwavelet transform. Next, based on spatial dependency of multiwavelet transform coefficients, spatial neighboring coefficient data-driven group threshold shrinkage strategy is developed for denoising process by choosing the optimal group length and threshold via the minimum of Stein's Unbiased Risk Estimate. The effectiveness of proposed method is first demonstrated through compound fault identification of reduction gearbox on rolling mill. Then it is applied for weak fault identification of dedusting fan bearing on rolling mill and the results support its feasibility.

1. Introduction

Metallurgy and steel industry are the important industries among the national economy, and these developments have quite intimate relation with the economic foundation. As the core equipment in steel industry, rolling mill is used to implement the process of metal rolling. During the rolling process, typical operating conditions of rolling mill refer to extreme mechanical situations including large values of tensions and forces [1]. In some cases, these extreme mechanical situations can lead to different kinds of faults on rolling mill, which might bring about serious accidents and huge economic

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

http://dx.doi.org/10.1016/j.ymssp.2015.07.022
0888-3270/

Please cite this article as: J. Chen, et al., Customized maximal-overlap multiwavelet denoising with data-driven group threshold for condition monitoring of rolling mill drivetrain, Mech. Syst. Signal Process. (2015), http://dx.doi.org/10.1016/j.ymssp.2015.07.022

losses. So, the realization of stability and security operation on rolling mill is significant and always draws a lot of attention for enterprise [1]. In fact, rolling mill is chronically running under complex and harsh operating condition of fatigue, heavy loads, etc., and gear or bearing as the key component of rolling mill drivetrain inevitably generates various faults. Once accidents appear in rolling mill drivetrain, they will directly result in enormous economic losses and serious casualties. Especially, because suffered more harsh environment such as elevated temperature, etc., hot strip finishing mill equipment more easily generates serious mechanical faults compared with cold-rolling mill. Hence, condition monitoring and fault diagnosis of rolling mill is of great importance and indispensable for guaranteeing product quality, realizing long-term safe operation and avoiding of significant economic losses.

Regardless of the technique factor, the capability of any condition monitoring system mainly relies on two key components: the type and number of sensors, the associated signal processing and simplification methods applied to extract important information from the acquired various signals [2-3]. Condition data acquisition refers to collecting the required variables (e.g. speed, temperature, voltage) as well as turning them into electronic signals. Recent years, vibration analysis have achieved great progress and therefore continues to be one of the most popular technology applied for the condition monitoring and fault diagnosis of mechanical equipment [4]. The remaining key component is how to process the measured vibration data in order to obtain the current condition features. One possible solution is to treat the measured vibration data as a process which can be parameterized using simple statistical analysis (mean, maximum, minimum, etc.) or advanced higher order statistics (kurtosis, etc.) [5]. The further approach is to process the measured vibration data in the frequency domain (fast-Fourier transform, etc.) [5]. But these approaches does not make much sense when the measured vibration data is collected under the non-stationary operating regime. Unfortunately, engineering practices have demonstrated that condition information data gathered from machine-integrated sensors usually appears non-stationary characteristic [6]. Thus, due to the complex mechanical structure and various operation environment, more effective signal processing method is indispensable and should be developed and introduced for condition monitoring and fault diagnosis of rolling mill drivetrain.

Some interesting studies related to condition monitoring and fault diagnosis of rolling mill have been reported recently in the literature. Li et al. designed a fault diagnosis scheme for hydraulic gauge control system of strip rolling mill based on wavelet transform and neural networks, and the analyzed results on the varied fault features demonstrated the effectiveness on the proposed diagnosis system [7]. Shao et al. pay attention on study the vibration characteristic of twenty-high rolling mill with local defect on roll surface using the time-varying contact stiffness and proposed an adaptive noise cancellation method based on beehive pattern evolutionary digital filter for fault feature extraction [8-9]. Chu et al. carried out fault diagnosis using support vector machines through parameter optimisation via artificial immunisation algorithm for turbo pump rotor [10]. Yuan et al. developed multiwavelet sliding window neighboring coefficients denoising algorithm with optimal blind deconvolution for gearbox fault diagnosis of rolling mills [11]. Daniel et al. applied the dimensionality reduction technique, called t-SNE, to visual exploratory analysis of the dynamic behaviors in a cold rolling process and supplied a possible way for detecting the chatter fault [1]. Li et al. proposed adaptive stochastic resonance method on the basis of sliding window for driving gearbox fault detection in a hot strip finishing mill [12]. Cai et al. developed sparsity-enabled signal decomposition strategy based on tunable *Q*-factor wavelet transform for gearbox localized fault detection of rolling mill [13]. Chen et al. investigated a new technique called customized lifting multiwavelet packet information entropy for resonance condition identification of rolling mill [14]. Chen et al. applied overcomplete rational dilation discrete wavelet transform for gearbox fault detection of rolling mill [15]. Serdio et al. carried out residual-based fault detection based on soft computing techniques for condition monitoring of rolling mill [16]. Ming et al. adopted cyclic Wiener filter and envelope spectrum analysis for weak fault feature detection of rolling element bearing [17]. These mentioned studies have provided critical insight on condition monitoring and fault diagnosis of rolling mill. However, there are still abundant issues to be addressed in this task. One important aspect of them is how to effectively identify compound fault and detect weak fault from measured noisy vibration data of faulty component in rolling mill drivetrain and exactly assess the current operation condition. Due to the complexity of equipment and the correlation of structures, several faults often appear at the same time and the features of each fault are coupled together. This kind of failure form is called compound faults [6,12]. In these situation, mechanical fault detection turns into a challenge task, especially in the operational condition with strong background noise.

As a powerful tool for describing the non-stationary signal, wavelet transform (WT) [18-19] has already shown its tremendous strength in mechanical equipment condition monitoring and fault diagnosis because of its advantage on multi-resolution analysis and abundant basis functions [20-21]. Recent years, many scholars have paid a lot of attention to wavelet denoising technique with appropriate threshold shrinkage rule on signal processing to improve the SNR for fault feature extraction and has have made some progress and applications. According to the algorithm flow of wavelet denoising technique, the performance of wavelet denoising method mainly relies on the three factors such as the appropriate selections of wavelet base, transform strategy and threshold rule [22].

Different from Fourier transform, a specific fault symptom can be detected and extracted by WT on the basis of appropriate selection the basis function from the existing basis function library, which is greatly beneficial with the condition feature identification. However, the selection of basis function is not uncontrolled because there are limited basis functions in the library. And any inappropriate wavelet basis function employed in the special engineering application will directly decrease the accuracy of the condition feature extraction. So it is a vital step to select an appropriate wavelet basis function for the measured condition vibration data processing. In fact, any fixed basis function which is not related to the