Mechanical Systems and Signal Processing 86 (2017) 177–187

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

A new method for arrival time determination of impact signal based on HHT and AIC

Mingzhou Liu[b], Jiangxin Yang[b], Yanpeng Cao[b], Weinan Fu[b], Yanlong Cao[a,b,*]

[a] The State Key Laboratory of Fluid Power Transmission and Control, College of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China

[b] Key Laboratory of Advanced Manufacturing Technology of Zhejiang Province, College of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China

ARTICLE INFO

Keywords:
Impact signal
Arrival time
HHT
AIC
Instantaneous frequency

ABSTRACT

Time-difference method is usually used to locate loose parts in nuclear power plant, the key to which is estimating the arrival time of impact signal caused by the crash of loose parts. However, the dispersion behavior of impact signal and the noise of nuclear power station primary circuit have negative effect on the arrival time determination. In this paper, a method of arrival time determination of impact signal based on Hilbert-Huang Transform (HHT) and Akaike Information Criterion (AIC) is proposed. Firstly, the impact signal is decomposed by Empirical Mode Decomposition (EMD). Then the instantaneous frequency of the first intrinsic mode function (IMF) is calculated, which characterizes the difference between the background noise and the impact signal. The arrival time is determined finally by AIC function. The proposed method is tested through simulation experiment which takes steel balls as the real loose parts. The deviation between the arrival time determined by proposed method and the real arrival time distributes stably under different SNRs and different sensor-to-drop point distances, mostly within the range ± 0.5 ms. The proposed method is also compared with another AIC technique and a RMS approach, both of which have more dispersive distribution of deviation, quite a lot out of the range ± 1 ms.

1. Introduction

The loose part monitoring system (LPMS), designed to monitor abnormal vibration signals from the reactor, is one of the most important elements which ensure the safe operation of nuclear power plant. Once a part in the Reactor Coolant System (RCS) looses and drops, it hits the wall of reactor pressure vessel and other components, which may cause serious damage to the nuclear power plant. So it is necessary to estimate the location of loose parts, which is one of the main function of the LPMS. Approaches have been proposed to solve the issue of loose parts localization. Olma [1], Jeong [4], etc., calculated the intersegment of two hyperbola obtained by getting the arrival time difference of two impact signals and wave velocity. Kim [2] proposed a time-frequency analysis approach using Wigner-Ville distribution. Park [3] adopted a time domain method based on energy contour. Huawen et al. [5] used Hilbert-Huang Transform (HHT) and dispersion characteristics of bending waves propagated in a plate to locate the loose parts. Time difference approach is the most widely used technique in this issue, the key of which is determining the time when the impact signal reaches the sensor. The mostly used approaches to calculate arrival time of impact signal are peak value method, time domain

* Corresponding author at: The State Key Laboratory of Fluid Power Transmission and Control, College of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China.

E-mail address: sdcaoyl@zju.edu.cn (Y. Cao).

http://dx.doi.org/10.1016/j.ymssp.2016.10.003
Received 24 April 2016; Accepted 1 October 2016
0888-3270/

accumulation [1,7], RMS [8], high-order statistics [18], energy contour [3], etc.

The peak value method is the most arbitrary one, which takes the maximum of a time series as the arrival time of impact signal. However, it has a great short coming that it ignores the vibration with small amplitude before the peak value. In other words, it takes no account of the time interval between the real arrival time and the time of peak. Time domain accumulation determine the arrival time by calculating the sum of the time series in a sliding window. It sets a threshold in advance and determine the time when the accumulation in the window exceeds the threshold. However, it cannot get the accurate result under strong interference of noise. Similarly, the RMS and energy contour method are subject to the influence of noise. High-order statistics approach calculates the kurtosis or higher statistics to distinguish the background noise and useful signal. This approach is applicable when the recorded signal converts from a random distribution to non-random one.

Except the approaches above, there are another type of methods based on AIC to determine the arrival time of impact signals. According to Akaike Information Criterion (AIC), a time series can be divided into two locally stationary autoregressive processes which correspond to non-informative part (noise) and informative part (signal) containing arrival time [9,10]. For fixed order AR process, the point at which the AIC is minimized, determines the separation point of the noise and signal. This approach is called AR-AIC picker which has been widely used to detect the arrival time in seismology [11–13]. Maeda [17] defined the AIC function which can be calculated directly from seismograms, and accurately calculated the arrival time of seismic wave. For time series x of length N, the AIC function is defined as:

$$AIC(k) = k\ \log(\mathrm{var}(x[1,\ k])) + (N - k - 1)\log(\mathrm{var}(x[k+1,\ N])) \tag{1}$$

where k is the range through all signal points and $\mathrm{var}(x[1,\ k])$ indicates the variance of the corresponding interval from 1 to k of the time series x. The minimum of the AIC function determines the arrival time of the impact signal. AIC function is also used in the AE signal detection [14–17]. Applying an adapted automatic AIC picker, Kurz et al. [16] successfully determined the location of AE from concrete based on Maeda's equation. Firstly the envelope of the signal was calculated by using Hilbert transform. Then a window of several hundred sample points, before and after this onset which is decided through a constant threshold value, is cut off the envelope. The arrival time of the AE signal is determined by the AIC picker applied on this window. AIC approaches usually preprocessing the signal using a certain method in order to feature the change of a certain parameter, on which the AIC function is calculated and arrival time is obtained.

However, the machine activity and the circulating high pressure cooling water cause vibration of the prime circuit and the pressure vessel, which means the signals acquired by the LPMS are mixed with strong background noise. Besides, the vibration induced by the impact contains multiple components with a wide range of oscillating frequency, and the corresponding waves transmit at various velocity. These bring troubles to the determination of arrival time.

On the issue of the difficulty in determining the arrival time of impact signal, a new method based on HHT and AIC is proposed in this paper. Firstly, HHT is operated on the noisy impact signal, and the instantaneous frequency of first mode is obtained. Then the AIC function is calculated, the minimum point of which is the sample point corresponding to the arrival time. The feasibility and accuracy of the proposed method is testified by comparing the result with the manual arrival time determination of the impact signal without noise. The comparison with Kurz method and a RMS approach shows the advantage of the proposed method.

2. Instantaneous frequency

Impact signal contains various kinds of waves like bending wave, transverse wave, longitudinal wave, etc. It has components or modes with multiple frequencies, which travel at different speeds. It causes the dispersive behavior of the impact wave, that is, the high frequency components with small amplitude arrive at the sensor earlier than the low frequency ones with large amplitude. As is

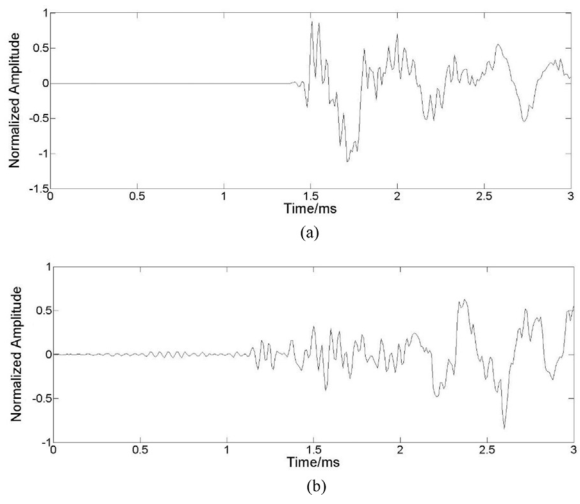

Fig. 1. Wave forms of the impact signals received by sensors with different distances to sensor: (a) 0.3 m, (b) 5 m.