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A new fluctuation assessment method for the step response signals of pressure sensors

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ABSTRACT

In dynamic measurement of a step pressure, the response signals from the sensor are usually influenced by mechanical vibrations. It is difficult to accurately describe the dynamic characteristics of step pressures by directly using the collected response signals therefore leading to unsatisfactory measurement results. In this paper, a new method is proposed to quantitatively assess the fluctuation characteristics of sensor step response signals. Firstly, the collected response signal is partitioned into subsequences, and a series of reconstructed sequences are obtained from each subsequence by introducing the delay and the embedding dimension. Then, an evaluation indicator named fluctuation measure is defined for each subsequence as the average of a specific fuzzy operator for any two reconstructed sequences. Finally, the composite fluctuation measure of the response signal is calculated by taking the ordered weighted mean of fluctuation measures of these subsequences. Measurement experiments with different sensors and vibration conditions are carried out to validate the performance of our method. The results show that the proposed method works well in quantifying the fluctuation characteristics of step response signals. Comparative experiments also demonstrate the superiority of the proposed method over existing approaches.

1. Introduction

Step pressure signals have been increasingly existed in a wide range of fields, such as aircraft engine, military technology, industrial manufacture and so on [1–5]. However, it is difficult to properly characterize the behavior of a step response signals form a pressure sensor in dynamic measurements, because large and unknown fluctuations are inevitably present in the response signals due to vibration interference [6–9]. Therefore, effective methods for assessing the fluctuation characteristics of the step response signals are urgent to ensure the validity and accuracy of pressure sensor in dynamic measurement.

To date, two experimental methods have been developed to assess the fluctuation magnitude of step response signals. The first method was developed by the National Physical Laboratory. They carried out two dynamic pressure measurement tests under the same conditions. In the first test, the pressure sensor was mounted in the regular position, subjected to both

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step pressure and vibration interference. In the second test, the sensor was mounted in a blind hole in the same location with the first mounting. It was exposed to the same vibration effects with the first test, but it was not subjected to the pressure itself. In this case, the underlying pressure response can be determined by subtracting the signals from the two tests. However, the subtraction may not be accurate because of phase shifts between the two response signals. The second method was carried out at Cranfield University [10,11]. An accelerometer was applied to measure the vibration signal. The response signals of the accelerometer and the pressure sensor were then compared in both time and frequency domains. However, only a qualitative comparison was taken into account for the general fluctuation trends of these signals and the variations of the fluctuation characteristics of the sensor step responses under different vibration conditions were not addressed.

In addition to the above methods, many data-driven approaches have been used successfully to analyze of the fluctuation characteristics of time series [12–16], such as wavelet-based methods [17], adaptive fractal analysis [18], and detrended fluctuation analysis and its variants [19–21]. These methods are based on the extraction of the non-stationary trend components from the time series. However, it is impossible to obtain the inherent trend (response to step pressure) in a step pressure measurement because the mathematical model of the sensor is unknown. Furthermore, Kim et al. [22] described a method base on Discrete Fourier Transform (DFT) to measure the fluctuation of engine speed waves. This method requires the harmonic components of the time series to be measured including the fundamental and second harmonic frequency components. Because the fluctuation amplitudes of sensor step responses decrease irregularly in dynamic measurements, the harmonic components cannot be extracted. Therefore, the DFT-based method also fails to evaluate the fluctuation of step response signals. Based on the estimation of an instantaneous time-scaling factor along the signal, Combet et al. [23] proposed a method to assess the relative fluctuation of instantaneous speed. However, this method may become invalid for assessing the fluctuation of the sensor step response signals in a dynamic measurement due to the fast pressure variations. Also, statistical approaches using standard deviation and mean absolute deviation may be used to characterize the fluctuation of the sensor step response [24]. These methods do not need to extract the inherent trend or the special frequency components, but they may be inaccurate because the sensor step response often exhibits a non-linear and unknown distribution under the dynamic conditions [25].

In this paper, a novel method is proposed to quantify the fluctuation characteristics of pressure sensor step responses in a dynamic measurement. In contrast to existing methods, the proposed method accounts for the unique features of a step response. First, the step response signal is normalized to avoid inherent trend. Subsequently, because the fluctuation amplitudes decrease with time, the step response is partitioned into subsequences and the fluctuation characteristics of the subsequences are evaluated separately using a fluctuation measure indicator. Finally, to reduce the influence of the sensor resonance characteristics on assessment results, the fluctuation characteristics of the entire step response is evaluated using an ordered weighted mean method. To validate the performance of the proposed method, measurements are carried out in a shock tube system.

The remainder of the paper is organized as follows. Section 2 introduces the proposed quantitative method to assess the fluctuation characteristics of a pressure sensor step response. The appropriate subsequences number is explored in Section 3. A series of experiments with different sensors and vibration conditions are implemented in Section 4 to verify the performance of the proposed method. Conclusions are summarized in Section 5.

2. Quantitative method for the fluctuation characteristics

Fig. 1 (a) and (b) show an ideal and an actual step response from a pressure sensor, respectively. For the ideal step response, the resonant amplitudes decrease gradually with time and then become stable [26]. The fluctuation characteristics of this type of signals can be described by data-driven methods or statistical methods because the mathematical model of the sensor can be estimated accurately. In contrast, the fluctuation amplitudes of the actual step response decrease irregularly with time and fluctuation is always present in the subsequent time. Three observations can be made for the actual step response [12]: (1) the fluctuations in different time periods are usually quite different due to damping; (2) inherent

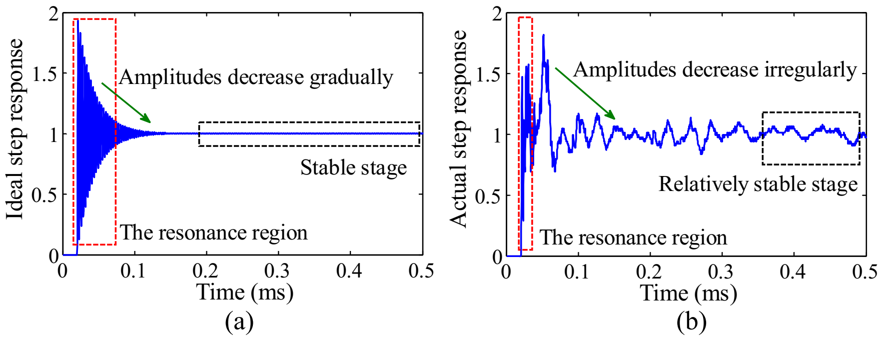

Fig. 1. Comparisons between an ideal and an actual step response of a pressure sensor: (a) an ideal step response and (b) an actual step response.