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Multi-cracks identification method for cantilever beam structure with variable cross-sections based on measured natural frequency changes

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ABSTRACT

Cantilever beam's crack identification can provide critical information which is helpful to determine whether the structure be healthy or not. Among all crack identification methods, the methods based on measured structure's natural frequency changes own advantages of simplicity and easy for operation in practical engineering. To accurately identify multi-cracks' characteristics for cantilever beam structure with variable cross-sections, a mathematical model, which is based on the concept of modal strain energy, is established in this investigation. And to obtain cantilever beam's natural frequency result with higher resolution, a signal processing method based on Hilbert-Huang Transform (HHT) is also proposed, which can overcome the disadvantage of fast Fourier transform (FFT) in the aspect of frequency resolution and incapability of handling nonlinear vibration caused by crack breathing phenomenon. Based on above mathematical model and signal processing method, the method of identifying multi-cracks on cantilever beam with variable cross-sections is presented. To verify the accuracy of this multi-cracks identification method, experimental examples are conducted, and the results show that the method proposed in this investigation can accurately identify the cracks' characteristics, including their locations and relative depths.

1. Introduction

For cantilever beam structures in practical engineering, existed cracks will lower their loading capacity, and may cause fractures and further serious faults. Crack identification is considered to be an efficient way to avoid such faults. It can provide critical information to help determining whether the structure should be maintained or replaced. For crack identification, the vibration based method is usually adopted because of its advantage of identifying crack with no requirement to access to regions near the crack location, and consuming less time and cost [1]. Since the structure to be tested does not need to be disassembled from the whole system in most of the cases, the vibration based crack identification is very suitable for on-line monitoring [1–4]. For example, Xingwu Zhang et al. [5] presented a method based on the measured natural frequencies to identify one crack on a beam. M. El-Gebeilya and Y.A. Khulief [6] used the measured vibration signal and

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wavelet transform to identify crack on the inner surface of pipe. Zhixiong Li et al. [7] measured the vibration of complex gear transmission systems in wind turbines by multi-channel sensors, and presented a method to identify gear's crack by analyzing the measured vibration signal.

To accurately identify the existed cracks' characteristics, including their location and depth etc., the primary work for vibration based crack identification is to establish a mathematical model, which describes the relationship of cracks' characteristics and cantilever beam's vibration related parameters, such as dynamic response, modal shape or natural frequencies [8–10]. For uniform cross-section cantilever beam, this mathematical model can be easy derived from its vibration equation [11–13], which is a linear differential equation with constant coefficient. But for variable cross-section cantilever beam, its variable cross-sectional area and moment inertia make it difficult to establish such mathematical model based on its vibration equation. Another important factor that should be considered when establishing the model for multi-cracks identification is that different combinations of existing multi-cracks may cause same changes of vibration related parameter [14,15]. So usually more than one vibration related parameters are adopted for identifying multi-cracks [8,9], and to obtain these parameters, a more complex measuring system is usually adopted in present researches [16,17]. For easy of on-line monitoring application, this investigation only takes natural frequency as a measuring parameter, which is independent of selection of measuring point and can be obtained by one measuring point [18,19]. By introducing the concept of modal strain energy, the relationship between variable cross-section cantilever beam's natural frequency and its modal strain energy is derived, then a mathematical model describing variable cross-section cantilever beam cracks' characteristics and natural frequency changes is established.

After above mentioned mathematical model is established, another key issue for identify variable cross-section cantilever beam's multi-cracks is how to measure its natural frequency changes. In general, structure's natural frequency can be obtained by processing its vibration signal [20]. However, the nonlinear vibration caused by crack breathing phenomenon [21] makes this single processing be difficult [22]. Thus, this investigation proposes a signal processing method based on Hilbert-Huang Transform (HHT), to obtain cantilever beam's natural frequency result with higher resolution, since HHT has capability of processing nonlinear vibration signal [23,24]. The method can decompose cantilever beam's vibration signal into several signal components, which have different frequency band and are respectively related to cantilever beam's natural frequencies in different vibration modes. And applying HHT on those decomposed signal components, the cantilever beam's accurate result of natural frequency is obtained.

To verify the correctness of the multi-cracks identification method, experimental verifications are also conducted in this investigation. Experimental results show that the method presented in this investigation can accurately identify multi-cracks of cantilever beam with variable cross-sections, just by taking natural frequency changes as measuring parameters.

2. Principle of multi-cracks identification

To identify multi-cracks on variable cross-section cantilever beam based on the measured natural frequency changes, following issues should be considered. Firstly, a mathematical model which describes relationship between cantilever beam's natural frequency changes and cracks' characteristics is established. And secondly, cantilever beam's natural frequency changes are required to be accurately measured. Thirdly, by substituting the measured natural frequency changes into the mathematical model, the characteristics of cantilever beam's cracks can be obtained.

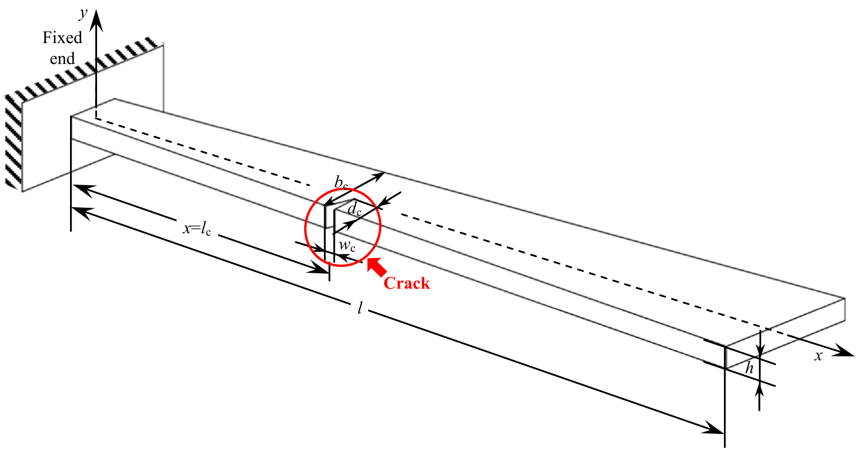

Fig. 1. A cantilever beam's model.