Journal of Sound and Vibration 366 (2016) 133–148

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Impact localization and identification under a constrained optimization scheme

Qiaofeng Li*, Qiuhai Lu

Applied Mechanics Laboratory, School of Aerospace, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form
12 October 2015
Accepted 3 December 2015
Handling Editor: K. Worden
Available online 30 December 2015

Keywords:
Load identication
Impact identication
Impact localization
Gradient projection method
Complex method
Inverse problem

ABSTRACT

Load identification becomes essential when direct measurement of structure loads is unavailable. In this paper, a method for localization and identification of impact is proposed. The location of impact is first determined with an error functional indicator using the Complex Method. The identification of impact history is then considered a constrained optimization problem. The solution of the problem is found using Gradient Projection Method. Both numerical and experiment results proved the validity of the proposed method. The identification process is faster and more robust with the techniques introduced. Further discussion and advice for implementation are also provided.

1. Introduction

Information on structure loads is crucial in various areas, such as damage monitoring, fatigue testing and reliability analysis. However, the direct measurement of structure loads is often impossible. Indirect methods must be developed to identify structure loads based on a limited set of response measurements.

Two main categories of indirect methods can be reviewed in research articles: frequency domain and time domain methods. Frequency domain method was first implemented by Bartlett and Flannelly [1] to determine hub forces in a helicopter model. Doyle [2] developed a waveguide model and used spectral analysis to determine force on a bimaterial beam. Liu et al. [3] employed enhanced least squares and total least-squares method to identify loads in frequency domain. In his research, the error in both the FRF matrix and the structural response is considered. Mendrok and Uhl [4] successfully adopted a modified version of modal filtration to identify loads. Wentzel [5] also used modal filter to reproduce the stress at critical points of structures in reliability testing, since damage corresponds directly to structural stress other than displacements. Frequency domain methods often require Fourier Transform or other harmonic transform of sufficient long data, thus limiting their own application. Impact identification is often implemented in time domain, since impact time history is often short and not suitable for Fourier Transform. Jacquelin et al. [6] reconstructed an impact on a circular embedded Kirchihoff plate and analyzed the differences between parameter choice criterions for deconvolution in time domain. Law et al. [7] used bending moment and acceleration measurements to identify the interaction forces between a moving vehicle and a bridge. Wang and Chiu [8] optimized the impact amplitude to minimize the error between theoretical

* Corresponding author. Tel.: +86 10 62782567.
E-mail address: li-qf13@mails.tsinghua.edu.cn (Q. Li).

http://dx.doi.org/10.1016/j.jsv.2015.12.010
0022-460X/

and experimental structural response. Since the identification model relates to the locations of measurement gauges and impact, many approaches developed assume that the location of the impact is known, which is often not the case in engineering practice. To solve this problem, Gaul and Hurlebaus [9] adopted wavelets to identify the arrival time of the impact wave to different sensors, and thus back calculated the position of impact. Staszewski and Worden [10] implemented neural network to identify the location and amplitude of impact. This method requires large amounts of training beforehand, thus is considered not suitable for large structures. Doyle [11] introduced a genetic algorithm to determine the impact location. Choi and Chang [12] employed two loops to find the optimal of impact time history and location. However, it should be noted that the result suffers large noise components due to lack of regularization and constraints. Wang and Chiu [8] divided a beam into several parts and iterated over the parts to find an optimal one. Hu et al. [13] also used this idea. They used embedded piezoelectric sensors to identify the impact force. The computational and experimental strains are compared. The true location is the one that minimizes this discrepancy. However, these two studies suffer the same problem: the location is chosen from a known set of possible locations, which is often not practical in reality. In this paper, a constrained optimization scheme for impact identification is proposed. The location is determined with the Complex Method without a priori knowledge, and the time history of the impact is identified by optimizing a regularized error functional under certain constraints. Numerical simulations and an experiment on a cantilever beam are conducted to demonstrate the presented method.

This paper is organized as follows. In Section 2, an inverse model for impact localization and identification, together with regularization techniques, is proposed. In Section 3, the localization indicator is given. Both numerical simulation and experiments are carried out to validate the proposed method. Further discussion and implementation advice are provided in Section 4. Concluding remarks are made in Section 5. The advantages and disadvantages of the method are also discussed.

2. Impact localization and identification scheme

2.1. The inverse model

In this paper, the inverse model, i.e. the relation between the unknown force and the measured structural response, is constructed with modal superposition method. Some assumptions should be noted here. Since modal superposition method is used, the system must be linear elastic. And the force to be identified should be or can be modeled as a point force. For a continuous system, for example, a cantilever beam, its modal shape function ϕ_i, satisfies

$$\int_{\Omega} \phi_i m \phi_j = m_i \delta_{ij} \tag{1}$$

where m is the mass distribution function, δ is the Kronecker delta function, and Ω is the integral space. Then, the ith-order modal equation of the structure is

$$m_i \ddot{q}_i + 2\xi_i \omega_i \dot{q}_i + \omega_i^2 q_i = Q_i(t) \tag{2}$$

where m_i, ξ_i, and ω_i are the ith-order modal mass, damping ratio, and natural circular frequency, respectively. $Q_i(t)$ is the ith-order modal force series

$$Q_i(t) = \int_{\Omega} \phi_i f(t) \tag{3}$$

Given Eq. (2), the convolution relation between the ith-order modal force and ith-order modal response is written as

$$q_i(t) = Q_i(t) * h_i(t) \tag{4}$$

where $h_i(t)$ is the ith-order impulse response function:

$$h_i(t) = \frac{1}{m_i \omega_i \sqrt{1-\xi_i^2}} e^{-\xi_i \omega_i t} \sin\left(\omega_i \sqrt{1-\xi_i^2}\, t\right) \tag{5}$$

In this study, the influence of damping is assumed negligible. Eq. (5) is simplified as

$$h_i(t) = \frac{1}{m_i \omega_i} \sin(\omega_i t) \tag{6}$$

Since the location of impact is a point in the integral set, the modal force equation (3) can be simplified:

$$Q_i(t) = \phi_i(s_f) f(t) \tag{7}$$

where s_f is the impact location. Then the displacement response is obtained through modal superposition

$$x(t) = \sum_i \phi_i(s_r) q_i(t) \tag{8}$$

where s_r is the location of measurement gauge. Considering the above equations, the relation between the displacement