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Simulated and experimental studies on identification of impact load with the transient statistical energy analysis method

B.Y. Mao, S.L. Xie *, M.L. Xu, X.N. Zhang, G.H. Zhang

State Key Laboratory for Strength and Vibration of Mechanical Structures, Xi'an Jiaotong University, Xi'an 710049, China

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ABSTRACT

A new identification method of impact load is proposed based on the transient statistical energy analysis theory in the paper. Firstly, the location and input energy of impact load are identified according to the energy balance equation with a two-stage identification scheme from the averaged kinetic energy responses of subsystems. Secondly, the impact load amplitude spectrum is derived from the identified impact load input energy based on the Parseval theorem under the constant value assumption within each analysis frequency band. Lastly, a parametric fitting approach is developed to reconstruct further the time history of impact load for the given time domain waveform from the identified impact load amplitude spectrum. The impact load identification approach is qualified through the simulated and experimental studies for a two-plate coupling structural system and the simulated study for a three-plate coupling structure system. The results show that the location and input energy of impact load can be identified accurately using the presented method. The derived impact load amplitude spectrums have reasonable agreements with the real ones. As a result, the reconstructed impact load time histories by the fitting method agree well with the real impact load time histories. The present approach provides an effective and feasible way for impact load identification of engineering structures.

1. Introduction

Many engineering structures often suffer from impact loads in operation, for example, rockets, airplanes, ships, vehicles, and punching and forging equipments and so on. The impact loads have commonly severe influences on the safety and reliability of structures. It is thus critical to perform impact response analyses for structures, which may provide a basis for structure design, fault and damage evaluation and reliability analysis. The prediction accuracy of impact response depends on not only the modeling accuracy of structure but also that of impact load. To obtain accurate models of impact loads, two methods can be considered preliminarily: one is to model impact loads by employing the existing theoretical models and measured data, the other is to measure directly impact loads. The former has usually low accuracy due to be unable to consider the coupling effects between excitation sources and excited structures in modeling, while the latter is commonly

* Corresponding author.
E-mail address: slxie@mail.xjtu.edu.cn (S.L. Xie).

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difficult to conduct in the real situations as well recognized. Consequently, it becomes preferable to model impact loads through the identification method.

The past several decades have witnessed the development of impact load identification theory and technique [1–11]. Generally, the main task of impact load identification is to determine the load location and reconstruct the time history of load. Gaul [1] developed a wavelet transform method to identify impact location, which may be applied to the problems related to the in-service structures undergoing impact load. Worden [2] employed the genetic algorithm for identification of load location, the identification results coincided well with the actual situations. Yan [3] also utilized the genetic algorithm to identify the acting location and time history of impact load, the results demonstrated the effectiveness and applicability of the method. However, the presented method is relatively complex. Doyle [4] introduced a deconvolution method, which is similar to Fourier analysis and wavelet analysis, into the impact force identification, this method may deal with the ill conditioned inverse problem resulted from the measured response data. Chandrashekhara [5] and Jones [6] developed an identification method of impact load based on the artificial neural network. Although the identification results are of high accuracy, it needs to be noted that this method usually requires a lot of impulse response data to train the network. Choi [7] proposed a state space model and the optimal smoothing filter identification method, which is capable of identifying the impact load location and time history simultaneously. Hu [8] presented a Chebyshev polynomial identification method which can produce the impact force time history quickly and accurately for the impact locations far away from the fixed edge or free boundaries of plate. Hu [9] also presented a transfer matrix identification method of impact force for composite structures, while this method has low modeling and identification accuracies for complex or large scale structures. Tajima [10] studied impact force identification of CFRP laminated plates, where an optimization method minimizing the errors between the measured strain responses and computed ones is presented for identifying the force location based on reciprocal relationship of strain response. Then the force time history identification can be realized by solving an inverse problem. Jang [11] proposed a novel indirect measurement approach to identify the impact load on a nonlinear system using the dynamic response data of system. In summary, a variety of identification methods have been developed and some successful applications have been reported so far, which enriched and extended greatly the contents of impact load identification theory and technique. Nevertheless, it should be noted that there still exist two factors which may lower significantly identification accuracy of impact load for the abovementioned identification methods, and they are the measuring noises in system response and the modeling errors of system respectively. The impact loads are transient and their pulse widths are generally very short. This feature makes the identifications of impact loads be more sensitive to noise contaminations than those of steady-state loads. At the same time, the energies of impact loads of short period commonly distribute in a relatively wide frequency range, which makes the structural dynamic characteristics have to be considered within wide enough frequency range in identification. It is especially true for the structures of light damping. Unfortunately, the traditional dynamic modeling methods, e.g., the finite element method (FEA) and the modal expansion method, are difficult to yield a satisfied description on the structural dynamic characteristics in broad frequency band. Some hybrid methods, e.g., the asymptotic scaled modal analysis method (ASMA) [12] and the wave based method (WBM) [13], have the potentials to push up the analysis frequency limit through reducing computational costs and thus can be considered to be the extensions of the classical deterministic approaches. As a result, there usually exist errors to some extent in system model used in identification for the most of developed identification methods.

It is known that statistical energy analysis (SEA) theory provides a powerful tool for the response prediction of complex system subjected to broad band excitations [14–16]. In SEA theory, the word *statistical* means that the systems being studied are assumed to be extracted from populations of similar design structures having known distributions of their dynamical parameters, while the details of systems are neglected to some extent. The word *energy* denotes the primary variable of interest, which enables SEA theory to analyze the complex systems including various physical fields (e.g., vibroacoustic coupling system). Note that all energy quantities in SEA theory are time- and space-averaged values. With these features, the SEA models can describe accurately broad band dynamic behaviors of structural systems in the average sense. Over the past several decades, the classical statistical energy analysis theory has been advanced greatly in both width and depth [15–23]. At present, the statistical energy analysis method is frequently employed in some engineering fields such as aerospace [24], vehicle and ship etc. According to the basic assumptions in SEA, the classical statistical energy analysis theory is only applicable to steady-state vibration analysis. Lai [25,26] investigated the statistical energy analysis of system subjected to transient excitations and established the energy balance relationship of transient vibration system which is analogous to the power flow balance relationship of steady-state vibration system. Thus, in the transient SEA theory [26–28], the system dynamic characteristics can be described by energy balance equation. In recent years, the applications of transient SEA theory in some engineering fields have been reported. Iadevaia [29] used the statistical energy analysis for shock pulse predictions of a plate-like structure, the agreements between the SEA based predictions and the measurement results are excellent. Katipally [30] estimated the damping of plates joined at a point employing the transient SEA approach, in which it was attempted to find out the practical limitations of the transient SEA approach and to examine the degree of agreement of the asymptotic loss factor estimations with respect to the traditional power input method (PIM). The above work further demonstrated the feasibility and effectiveness of transient SEA theory in transient vibration analysis.

Based on the statistical energy analysis theory, Xie [31] proposed a load identification method for broadband random excitations. The simulated and experimental studies of load identification were conducted on a plate-shell assembled structural system, and the results show that the input powers of loads can be identified accurately in wide frequency band using the approach. In comparison with the traditional load identification methods, the presented method possesses the