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Review

An efficient method to reduce ill-posedness for structural dynamic load identification

Jie Liu *, Xianghua Meng, Dequan Zhang, Chao Jiang, Xu Han

State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, PR China

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A B S T R A C T

For the inverse problem of structural dynamic load identification, high system ill-posedness is a main cause leading to instability and low accuracy. In this study, an efficient interpolation-based method is proposed to reduce ill-posedness availably and identify dynamic load stably. The load history is discretized into a series of time elements, and the load profile in each time element is approximated through interpolation functions. Then, in the whole time domain, the dynamic responses under interpolation function loads are calculated through a few finite element analysis and then assembled together to form a global kernel function matrix for load identification. Using singular value decomposition (SVD), the ill-posed degree of the global kernel function matrix can be analyzed. Compared with the conventional Green kernel function method (GKFM), the ill-posedness of global kernel function matrix in the proposed method is significantly reduced. Especially, when the length of time element is selected appropriately, the global kernel function matrix is entirely well-posed and the corresponding dynamic load can be stably identified without any regularization operation. Numerical examples demonstrate the effectiveness of the proposed method and the correctness of identified load.

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* Corresponding author.
E-mail address: liujie@hnu.edu.cn (J. Liu).

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1. Introduction

In the practical engineering problems, dynamic load plays an important role in many research fields such as vibration control, fault diagnosis, and structural optimization design. Some kinds of dynamic loads can be measured by professional measuring equipment, but most of them are very difficult to measure directly, such as ice loads acted on offshore platform, road excitation applied to vehicle. The main reason is that the force transducers cannot be inserted into the contact surfaces. Thus, load identification technique is developed to indirectly reconstruct the time history of dynamic load.

Dynamic load identification belongs to the second class of inverse problem. At present, there are two main kinds of load identification methods, namely the frequency-domain method [1,2] and time-domain method [3–5]. In frequency-domain method, the frequency response functions and response spectrums of system are used to inversely calculate the load spectrums in modal coordinate system, then time history of load is derived through modal coordinate transform. Time-domain method depends on the mapping relation from dynamic load to structural response to identify the time history of exciting load. In recent years, a series of effortson time-domain methods had been made for dynamic load identification with an acceptable accuracy. Ory et al. [3] used the modal coordinate transform to decouple the differential equation. The dynamic load was described as step function in each sampling period to establish a forward model for dynamic load identification. Kreitinge et al. [6] proposed a sum of weighted acceleration technique based on the weighted sum of the measured acceleration response. However, the identified accuracy was sensitive to the measured points and the weighted coefficients. Chan et al. [7–11] studied the moving load identification of vehicle-bridge system and developed a series of identified methods. Liu et al. [12,13], used unit impulse function or Heaviside step function to approximate the dynamic load. The exciting load was described as the linear superposition of the unit singal. The kernel function matrix was decomposed using SVD [14] and regularization technique [15] was used to reconstruct the identified load. However, it shown that due to the small singular values, a little noise in the measured response had a great negative influence on the identified accuracy. Liu et al. [16,17], used shape functions to approximate the response, and applied the Galerkin theory to overcome the effects of noise and improve the accuracy of dynamic load identification. Xun and Ou [18] transformed the differential equation of system motion into an integral equation by the virtual work principle, which can eliminate the structural acceleration response without the calculation error. Wang and Yang [19] investigated an interval identification method for dynamic loads. The time series of the uncertain displacement responses were quantified by the interval vectors and the Green's function was discretized to obtain the interval linear equations. Mao and Xie et al. [20] used transient statistical energy analysis method to identify the impact load, and designed experiment to study two-plate and three-plate coupling systems. Qiao et al. [21] applied the cubic B-spline collocation method and a modified GCV criterion for impact load identification. Li et al. [22,23] developed two identification methods for distributed dynamic load. However, when the forward model of load identification is established, most of the above mentioned methods involve in SVD in the identification process of dynamic load. In addition, the small singulars of the global kernel function matrix decide the great degree of system ill-posedness and lead to a large identified error. Although regularization technique can overcome the ill-posedness of load identification by filtering small singular values, the regularization operator influences the big singular values simultaneously, which has great negative influence on the identified accuracy of dynamic load. If a well-posed global kernel function matrix can be constructed to inverse dynamic load without any regularization operation, it will further enhance the stability and accuracy of load identification.

For this reason, this paper proposed a method to establish a new global kernel function matrix, which can efficiently reduce ill-posedness and improve the identification accuracy for dynamic load. This method divides the whole time history of dynamic load into a series of time elements, and the load profile in each time element is approximated by interpolation functions, such as radial basic interpolation functions and Lagrange interpolation functions. The dynamic responses of each interpolation function loads are calculated through the numerical methods. Similar to the establishment of global stiffness matrix in finite element method (FEM), all interpolation function responses are assembled as a global kernel function matrix in the whole time domain. Hence, the forward model for dynamic load identification is reconstructed. Then, SVD technique provides an effective tool to analyze ill-posedness of the global kernel function matrix. The examples show that under the same discretization of time history, the ill-posedness level of the reconstructed global kernel function matrix is obviously lower than the traditional GKFM. This is beneficial to identify a more stable and accurate load. The outline of this paper is organized as follows: Section 2 establishes a forward model based on the traditional GKFM. Section 3 builds a forward model based on the proposed global kernel function matrix. Section 4 analyzes the ill-posedness based on SVD. Section 5 provides two the numerical examples. Section 6 gives some conclusions.

2. Formulation of load identification based on GKFM

In general, dynamic load can be described as a superposition of the unit impulse signal in time domain. According to the linearity and time-invariant assumption for load identification problems, the response caused by dynamic load can be expressed as [12],

$$y(t) = \int_0^t p(\tau)g(t-\tau)\mathrm{d}\tau \tag{1}$$