Analysis of Transverse Vibration Acceleration for a High-speed Elevator with Random Parameter Based on Perturbation Theory

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The problem of randomness of design parameters objectively exists in the high-speed elevator cabin system. The definite and random part of the acceleration response expressions were derived according to perturbation theory and the transverse vibration acceleration response of the observation point was analyzed. The sensitivity expressions of various random parameters to the acceleration response were deduced by solving the random response of expression and comparing the coefficients of various parameters of the random part. The different impacts of various parameters on the acceleration response were analyzed according to the expression of acceleration response sensitivity. Based on the displacement response covariance matrix and random parameter covariance matrix, the standard deviation characteristic of the acceleration response was obtained and analyzed. The results showed that the random parameters made the acceleration response to be more discrete. Additionally, the randomness of the geometrical parameters had the greatest influence on transverse acceleration. The results can provide a reference for anti-vibration design of high-speed elevators and safety assessment.

1. INTRODUCTION

As a means of transport in high-rise buildings, the elevator’s speed was rapidly increased with the increase of the height of buildings. The current high-speed elevator’s speed is more than 2.5 m/s is known as the high-speed elevator. With the increase of elevator’s speed, the transverse vibration problem due to rail harshness has become more and more serious. In recent years, many domestic and foreign scholars have studied the vibration of the cabin system. Noguchi et al. used frequency-domain analysis based on principal component analysis to perform operational modal analysis of an elevator car. Yin et al. transformed many important factors such as rail harshness, flexion of the rail, and the guide shoe’s defects into the contact force of rail to guide shoe, and established a multi-DOF transverse vibration model of a high-speed elevator car. Xia and Shi established a transverse vibration model of an elevator car by studying real-time interface stiffness between the guide rollers and the guide shoe. They took rail harshness as the input excitation to study the transverse vibration of an elevator car. In the product design stage, all of the parameters are definite. However, due to the influence of actual installation circumstance, live debugging, manufacturing errors, installation errors, the influence of temperature and uncertainty of physical parameters of materials, etc., the parameters of the same batch of elevator products are different. For an actual product, its parameters are uncertain and present some randomness. For example, Li and Liao analyzed a shear wall’s vibration response. In the case of the variation, the coefficient of elasticity modulus was 0.3 and the vibration power spectral density of the top of the shear wall was increasing exponentially. However, most of the existing literature about the elevator car’s vibration does not consider the random parameters of an elevator car or approximate them as definite parameters. In fact, these random parameters not only affect the eigenvalues and eigenvectors of the system in each mode, but also have an effect on the statistical properties of the response. Therefore, studying the response to random parameters is significant to the structure of elevator car vibration damping, reliability sensitivity analysis, and safety assessment.

Zhang et al. studied the frequency response function of a statistical feature of one and two degrees of freedom random structure using the Monte-Carlo method. Zhang et al. used the stochastic finite element method to study reliability characteristics of a mechanical structure component under complex loading conditions. The Monte-Carlo numerical modeling method is highly accuracy, but for large and complex structures, it is time consuming. Thus, it is suitable for the comparison of methods but not suitable for practical engineering structural analysis. The stochastic finite element method needs to set up all kinds of random parameters corresponding to the stochastic finite element characteristic matrix, which causes much inconvenience to its computer program design. Therefore, it is necessary to find a random perturbation method to avoid the establishment of a random finite element characteristic matrix which can be realized easily via computation.

2. CONSTRUCTION OF A RANDOM PARAMETER CAR VIBRATION MODEL

The establishment of the car model is the basis for solving the differential equations of the motion of car system. The model should not be too simple, for it could not accurately reflect the actual situation. On the other hand, the model cannot be too complicated because the amount of calculations will be too large or even impossible to solve. In Fig. 1, a car vibration model is established. A rectangular coordinate system \( oxyz \) is established with the barycenter of the car as the origin. The roller guide shoe system is simplified into a spring damping system. Each system provides the \( x \) and \( y \) directions of the two forces, and so the whole system of the car has 5 DOF along the \( x \) and \( y \) directions and around the \( x \), \( y \) and \( z \)-axis rotations.

For convenient calculation, suppose that the horizontal distances from guide wheel 1, 2 and guide wheel 3, 4, to the cen-