Journal of Sound and Vibration 377 (2016) 216–225

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Influence of uncertainty and excitation amplitude on the vibration characteristics of rubber isolators

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ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form
4 February 2016
Accepted 26 March 2016
Handling Editor: L. G. Tham
Available online 24 May 2016

Keywords:
Rubber isolator
Vibration characteristic
Nonlinearity
Uncertainity

ABSTRACT

Rubber isolators are widely used in engineering structures, which often exhibit some nonlinearity and uncertainty properties subjected to different environment exciting. In order to study the nonlinear characteristic and uncertainty of a rubber isolator system, the sin-sweep vibration tests with different base exciting level are carried out firstly. Then a single freedom degree mass-spring-damper model is introduced to simplify the rubber isolator system. In the theory model, the spring and the damper are represented by polynomial functions of the relative displacement. The coefficients in the functions are identified by the test data, while the uncertainties of the coefficients are quantified by the principal components analysis (PCA) and Monte Carlo (MC) simulations. The major resonant frequencies and the damping ratios of the isolation system are calculated according to the theory model, the amplitude-frequency nonlinear characteristics are simulated by Runge–Kutta numerical method. The simulation results agree well with the experimental results, which indicate that the nonlinear model and the uncertainty quantifying results are feasible to predict the vibration characteristic and uncertainty of the isolation systems.

1. Introduction

To prevent the electronic equipments of the space flight and aviation structure from the vibration in the work environment, significant efforts on controlling methods such as vibration isolator with damping and dynamic vibration absorber have been devoted to address this issue [1–2]. Rubber isolators stand out as a promising candidate because of its merits such as simple structure, good technological efficiency, high damping and low cost. The constitutive model of rubber material lies in the crux of the understanding rubber isolators. Such constitutive model is often complicated due to frequency dependence, temperature dependence and exiting amplitude dependence [2–4]. The complexity is exacerbated in manufactured rubber isolators due to structural factors like geometry. In order to go into the characterization of the rubber isolator to serve the structure design better, many researches have studied the static and dynamic behaviors [5–12]. One frequently studied dependence is the amplitude dependence. Papoulia and Kelly brought out a visco-hyperelastic rubber constitutive model, which could describe the finite strain response of rubbers used in the vibration isolation at low frequency [5]. Richards and Singh designed the different experimental equipments to study the static and dynamic stiffness of three different rubber

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http://dx.doi.org/10.1016/j.jsv.2016.03.034
0022-460X/

isolators [6]. Sjöberg and Kari brought out a fractional derivatives model for the rubber isolator system, which reflected the amplitude-dependence of dynamic properties of a rubber isolation system [7]. Sjöberg and Kari studied the effects of the nonlinear excitation on dynamic stiffness and damping of a filled rubber isolator, the results showed that the stiffness had strong amplitude dependence under the single harmonic excitation and noise excitation [8]. Recently, efforts have been devoted to the frequency-dependence of the dynamic stiffness via experiment, theory analysis and numerical simulation [9–13]. Power functions, polynomial functions, exponential functions and similar elliptical functions are used to fit and identify the frequency-dependent rubber mount stiffness and damping characteristics. For example, Sun et al. designed experiments to study the amplitude- and frequency-dependent stiffness and damping of some rubber isolator. They fitted the coefficients of the exponential functions representing the spring and the damper by their experiments [13]. With the development of computer simulation, the characteristic of rubber isolators is also studied by the finite element method [14–15]. Shangguan et al. conducted the finite element model of a cylindrical rubber isolator to study its fatigue life [15].

The aforementioned researchers utilize many successful nonlinear modeling, analysis and parameter identification methods for rubber isolator. However, few of them have considered the effect of uncertainty. Uncertainties widely exist in engineering structures. It is especially true for rubber materials due to their dispersive properties. It has been shown that when uncertainty is taken into account the simulation result is more reliable [16–17]. Because the rubber material itself has more disperse material properties, the characterization of the rubber vibration isolator has uncertainty.

In the paper, we take both experimental and analytical approaches to study the nonlinear behaviors of rubber isolators with the consideration of influence of uncertainty. The paper is organized as follows: Experimental investigation on a rubber isolation system is presented in Section 2. The nonlinear model and parameters identification are discussed in Section 3. The influence of uncertainty and excitation amplitude on the frequency and damping is discussed in Section 4. The influence of uncertainty and excitation amplitude on the amplitude-frequency characteristic is discussed in Section 5. Conclusions are presented in Section 6.

2. Experimental investigation

In order to study the effect of the uncertainty and the amplitude-dependent on the dynamic characteristics of rubber isolators, a sin-sweep vibration test is conducted using a LDS 850 electromagnetic vibration test instrument. The testing system is made of a rubber isolation system, a shaker table, the vibration control equipment and accelerometers etc., as shown in Fig. 1. In Fig. 1 the points A1, A2, A3 and A4 are the control points on the base, and the point A5 is the output acceleration response point at the center of the mass block. The input accelerations of base are measured at points A1, A2, A3 and A4, and their vibration levels are well controlled at some vibration level. There are four acceleration vibration levels: 0.5g, 1g, 2g and 4g, where $g=9.8\ \text{m/s}^2$. The vibration isolation system is made of a thick steel disk, a mass block and four rubber isolators. The steel disk is 230 mm in diameter, 10 mm in thickness and 3.26 kg in weight. The vibration test at each acceleration level is repeated seven times. The isolation system is reassembled, and the rubber isolators are replaced after each test case. The resonant frequencies and damping ratios are obtained by the transfer function curves of point A5. The test results are listed in Tables 1 and 2.

Tables 1 and 2 show that the resonant frequencies decrease, but the damping ratios increase as the base excitation acceleration amplitude increases. Moreover, the discrepancy between test result 1 and test result 7 indicates that uncertainty exists in the stiffness and the damping of the isolation system. Then, a nonlinear equation should be introduced to describe the vibration nonlinearity, and the uncertainty should be considered in the dynamic equation.

3. Nonlinear modeling

The rubber isolation system can be simplified to a single degree system made of a nonlinear spring, a nonlinear damper and a mass, as shown in Fig. 2.

Assuming $x_s(t)=P_0\sin\omega t$, the relative displacement y of the mass is written as $y=x-x_s$.

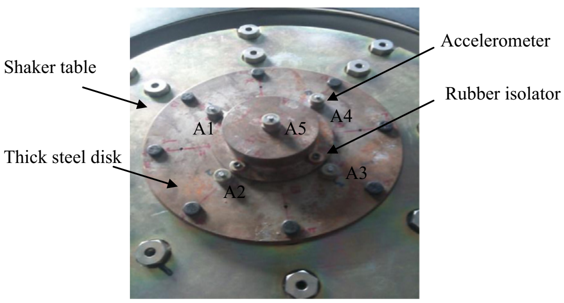

Fig. 1. Shaker table and isolation system.