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Experimental characterization of a nonlinear vibration absorber using free vibration

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ABSTRACT

Knowledge of the nonlinear characteristics of a vibration absorber is important if its performance is to be predicted accurately when connected to a host structure. This can be achieved theoretically, but experimental validation is necessary to verify the modelling procedure and assumptions. This paper describes the characterization of such an absorber using a novel experimental procedure. The estimation method is based on a free vibration test, which is appropriate for a lightly damped device. The nonlinear absorber is attached to a shaker which is operated such that the shaker works in its mass-controlled regime, which means that the shaker dynamics, which are also included in the measurement, are considerably simplified, which facilitates a simple estimation of the absorber properties. From the free vibration time history, the instantaneous amplitude and instantaneous damped natural frequency are estimated using the Hilbert transform. The stiffness and damping of the nonlinear vibration absorber are then estimated from these quantities. The results are compared with an analytical solution for the free vibration of the nonlinear system with cubic stiffness and viscous damping, which is also derived in the paper using an alternative approach to the conventional perturbation methods. To further verify the approach, the results are compared with a method in which the internal forces are balanced at each measured instant in time.

1. Introduction

The vibration absorber has become a well-established vibration control measure since the first patent on the device by Frahm in 1911 [1] and the subsequent detailed analysis by Ormondroyd and Den Hartog in 1928 [2]. Since then there has been a substantial body of work on various types of absorbers, most of which are described in a series of review papers [3–6]. This paper is concerned with a specific type of nonlinear absorber in which the stiffness of the device is a function of the excitation level. Roberson [7] was one of the first to discuss this type of absorber in an article where he considered the effects of both softening and hardening springs in the device. Following this concept, several other researchers have reported various aspects of nonlinear absorbers, for example [8–13]. Recently, Zhu et al. [14] investigated the performance of a nonlinear absorber, which has both nonlinear damping and nonlinear stiffness. A recent area of research has involved

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replacing the absorber stiffness with a purely nonlinear stiffness. This was pioneered by Vakakis et al. [15], who showed that energy could be efficiently transferred from the host structure to the absorber – the so-called targeted energy transfer approach. Specific tuning approaches for nonlinear absorbers have been discussed by Viguié and Kerschen [16], and Brennan and Gatti [17].

There has been a vast research effort on nonlinear vibration absorbers, and the literature cited above is only a fraction of that reported. There is, however, a scarcity of papers on the experimental characterization of such devices. This is the primary motivation of the work reported here. There is extensive literature on nonlinear system identification, and a comprehensive review on this topic has been provided by Kerschen et al. [18]. Of particular interest is the method which involves free vibration in which only a measurement of the response is necessary. This is highly appropriate for the lightly damped nonlinear absorber with a hardening stiffness nonlinearity discussed in this paper. The method involves the excitation of the absorber by a shaker, which is driven at a single frequency close to the jump-down frequency, and then switched off [19,20], so that the absorber mass vibrates freely. This approach was taken many years earlier by Parzygnat and Pao [21,22], who studied the transient response during nonlinear jumps of a clamped circular plate, both analytically and experimentally. However, since the 1970s, there have been significant advances in both instrumentation and signal processing on digitized time histories and this facilitates the approach taken in this paper, which closely follows the procedures in [19,20].

The basic idea is to measure the backbone curve and the decay of free vibration, then to relate these to the system parameters as described by Benhafsi et al. [23]. An approach related to this method, in which the backbone curve is estimated from the jump-down frequencies, has been recently reported by some of the authors of this paper [24]. A nonlinear vibration absorber, used in the thesis by Hsu [25], is tested in a particular configuration with an electrodynamic shaker, such that the dynamics of the shaker are largely decoupled from the dynamics of the absorber. The results are compared with an analytical solution for the free vibration of the nonlinear absorber, which is also derived using an alternative approach to the conventional perturbation methods. To further verify the approach, the results are compared with those determined from the Restoring Force Surface (RFS) method [26].

2. Nonlinear vibration absorber and the measured free vibration

2.1. Description of the device

The nonlinear vibration absorber is shown in Fig. 1. It consists of a 7.5 g mass attached to a thin circular brass plate of 0.15 mm thickness and 52 mm diameter, and is described in detail in Ref. [25]. The brass plate is sandwiched between two aluminium rings which provide a clamped boundary. The vibration is in the vertical direction as shown in Fig. 1(b). If the absorber vibrates with a low level, the dominant stiffness is from bending of the plate, and the system behaves linearly. However, as the vibration level increases, in-plane stretching of the plate contributes to the stiffness, resulting in a hardening nonlinear stiffness. Thus, the nonlinear absorber is expected to behave predominantly as a hardening Duffing oscillator with linear damping [27].

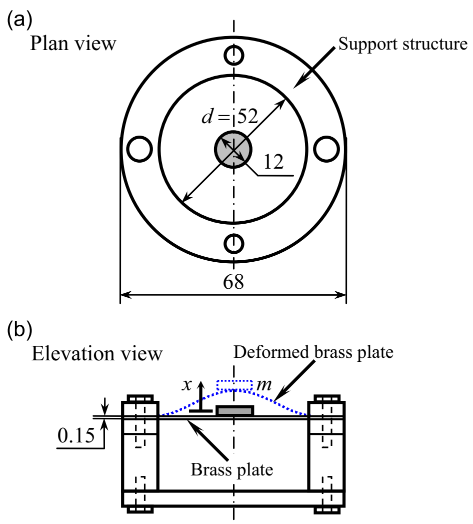

Fig. 1. Drawing of the nonlinear vibration absorber. (a) Plan view and (b) elevation view. x is the displacement of the mass; material propeties of the thin circular brass plate are: density $\rho \approx 8500$ kg/m^3, and Young's modulus $E \approx 110$ GPa. (All dimensions are in mm.)