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Stochastic resonance in a nonlinear mechanical vibration isolation system

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ABSTRACT

This paper concerns the effect that a stochastic resonance can have on a vibration isolation system. Rather than reducing the transmitted force, it is shown that it is possible to significantly mask the component of the force transmitted though the isolator, when the system is excited harmonically. This can be achieved by adding a very low intensity of random noise to the harmonic excitation force. The nonlinear mechanical vibration isolation system used in the study consists of a vertical linear spring in parallel with two horizontal springs, which are configured so that the potential energy of the system has a double-well. Prior to the analytical and numerical study, an experiment to demonstrate stochastic resonance in a mechanical system is described.

1. Introduction

In certain nonlinear systems, increasing the level of noise causes an increase, rather than a decrease, in the quality of signal transmission [1]. This counter-intuitive phenomenon was first used in the context of noise enhanced signal processing in 1980s [2–4]. Stochastic resonance has been widely investigated in many technical fields [5–8], such as electronic systems [9,10], quantum systems [11], signal processing [12], mechanical systems [13,14], chemistry [15] and biology [16].

Experimentally, stochastic resonance was studied in the Schmitt trigger system where the signal to noise ratio (SNR) was first used to describe the phenomenon [17]. Later, McNamara observed stochastic resonance in a bi-stable ring-laser experimental rig [18]. Stochastic resonance in sensory biology is being explored in the experiments on single crayfish neurons and in the perceptive brain function by experiments on people's ability to resolve ambiguous figures [19,20].

The combined influence of nonlinearity and random excitation on dynamical systems gives rise to phenomena that are of interest for practical applications [21,22], such as vibration absorption, energy harvesting [23] and sensing. However, applications of stochastic resonance within bi-stable mechanical systems are still relatively rare in literature, especially in

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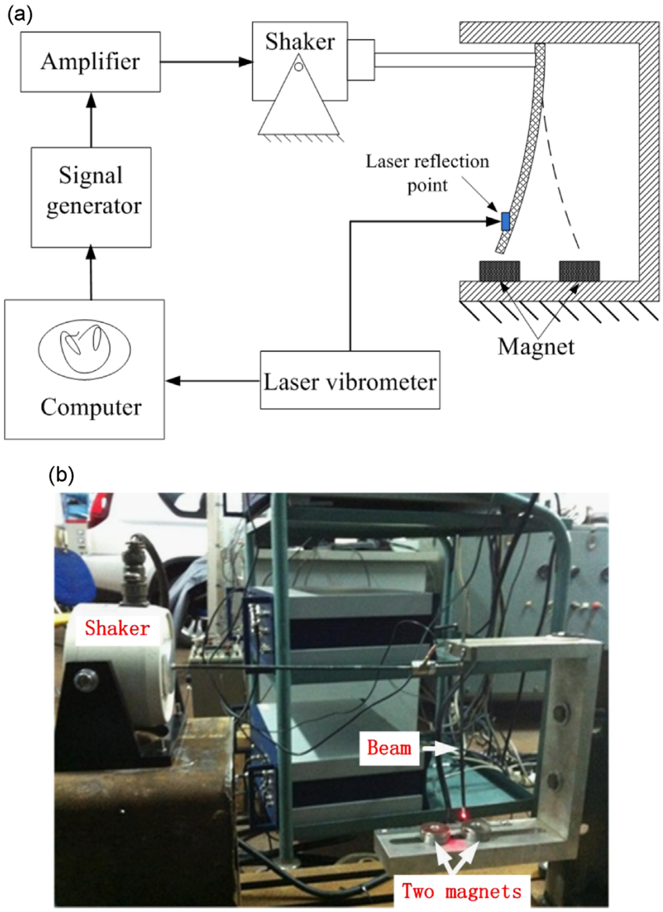

Fig. 1. Experimental test rig, comprising of a cantilever beam and two magnets, to demonstrate the characteristics of the stochastic resonance. (a) Schematic, (b) photograph.

vibration isolation. Experimental investigation of the application of stochastic resonance in practical mechanical vibration systems has not been fully addressed.

This paper investigates the stochastic resonance phenomena effect in a vibration isolation system. A vibration isolation model consisting of three springs [24–29] is used to demonstrate a stochastic resonance and to show how this can be used to mask the harmonic component of the force transmitted through the isolator. The bi-stable effect is achieved by incorporating auxiliary springs at right angles to the main suspension stiffness. These act as a negative stiffness. Further, an experimental study is conducted on a cantilever beam with a fixed magnet at the end (a so-called Moon beam [30]), which exhibits stochastic resonance. Both the three spring system and the Moon beam are examples of a double-well system. Although only single-degree-of-freedom (SDOF) systems are considered in this paper, the framework may also be used to investigate stochastic resonance phenomena in coupled arrays of nonlinear oscillators [21].

Exact analytic expressions describing the amplification of the external signals in stochastic nonlinear systems can be obtained for only for a few special cases, but the particular dynamic behavior of a double-well system can be approximately analyzed using FPE – Fokker Planck equation. Based on the matrix continued fraction method [31], direct integration of a Langevin equation is used here [32], since the authors' intention is to investigate the stochastic resonance of a double-well system when it is excited by both the harmonic and random excitation. Monte Carlo simulations are used to check the results.

2. Experimental observation of stochastic resonance

A schematic and a photograph of the experimental test rig, which was used to demonstrate the characteristics of a stochastic resonance [30,33], are shown in Fig. 1(a) and (b), respectively. The test rig consists of a steel cantilever beam of length 200 mm, thickness 1 mm and width 8 mm. Two magnets were positioned close to the beam tip to ensure that the experimental rig was a bi-stable, symmetric double potential-well system (such a system is described in detail in Section 3, and a plot of its potential energy is shown in Fig. 4(b)). The static displacement of the beam due to the magnetic attraction