Nonlinear vibration isolation via a compliant mechanism and wire ropes

Niu Mu-Qing[*] and Chen Li-Qun[*]

[*]*School of Science, Harbin Institute of Technology, Shenzhen, Guangdong, China*

Abstract. A novel nonlinear isolator is proposed via a compliant mechanism with negative stiffness and wire ropes with hysteretic damping. The compliant mechanism consists of two pairs of tilted flexure beams, and the nonlinear restoring force is modelled based on a beam constraint model. The hysteretic restoring force of the wire ropes is characterized by a Bouc-Wen model. A dynamic model of the nonlinear isolator is established, and a semi-analytical method is developed to analyze the model. Generalized equivalent stiffness/damping ratios are defined for the dynamic systems with multiple nonlinearities. The compliant mechanism exhibits negative stiffness in a limited region, and the region is related to the thickness and tilting angles of the flexure beams. The compliant mechanism with a symmetric restoring force endows the isolator with a stronger stability. The wire ropes improve the high-frequency isolation efficiency due to the frequency-independent property of the hysteretic damping.

Introduction

A nonlinear vibration isolation system with high-static-low-dynamic-stiffness (HSLDS) characteristics is able to perform a low-frequency vibration isolation without large static deflections. The existing HSLDS devices [1] face the problems of joint gaps, assembly errors and frictions. The pre-deformed compliant mechanism is promising to produce negative stiffness with the advantages of no gap, no friction and few assembly. The isolation performance of the HSLDS system can be further improved by introducing nonlinear damping. Wire ropes [2] exhibit hysteretic damping due to inner frictions, and the structure is practical for engineering applications. There is a lot of theoretical and practical motivation for exploring the dynamic characteristics and the isolation performances of the incorporated system with the compliant mechanism and the wire ropes.

Results and discussion

The nonlinear vibration isolator via a compliant mechanism and wire ropes is shown in Figure 1. Based on the nonlinear restoring force models, a dimensionless dynamic model of the nonlinear isolator is established as

$$\eta^2\ddot{y}+\sum_{i=1}^{n_\mathrm{k}}k_i y^i+c\eta\dot{y}+\delta z=\eta^2 a_\mathrm{e}\cos t,\quad \dot{z}=\left\{1-\left[\gamma+\beta\,\mathrm{sgn}\left(\dot{y}z\right)\right]\left|z\right|^{n_\mathrm{b}}\right\}\dot{y}$$

where η, y, c, a_e and t are the frequency, the vertical relative displacement, the linear damping, the excitation amplitude and the time. The elastic restoring force is expressed in a polynomial function with k_i denoting the ith-order stiffness. The hysteretic restoring force z is characterized by a Bouc-Wen model, and δ, γ, β and n_b are Bouc-Wen model parameters. The compliant mechanism consists of two pairs of flexure beams which are up-tilted and down-tilted, respectively. The structure results in a symmetric restoring force and it is beneficial for vibration isolation. The negative-stiffness region can be expanded by decreasing/increasing the thickness/tilting angles of the flexure beams at the cost of larger elastic stress. Three isolators are investigated and marked as "CM" and "WR" denoting the inclusion of the compliant mechanism and the wire ropes, respectively. The frequency responses are shown in Figure 2. The compliant mechanism endows the isolator with a low resonant frequency. The inclusion of wire ropes improves the high-frequency isolation at the cost of a higher resonant frequency.

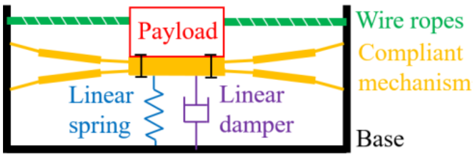

Figure 1: Nonlinear vibration isolator via a compliant mechanism and wire ropes.

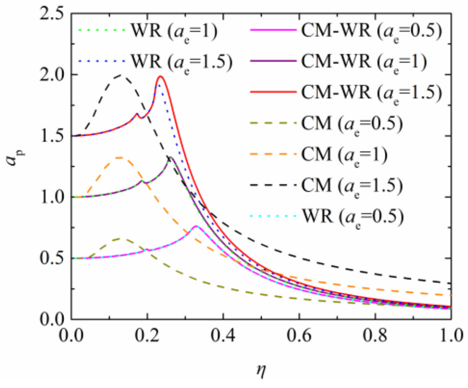

Figure 2: The frequency responses of the isolators with CM-WR/CM/WR structures.

References

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[2] Carboni B., Lacarbonara W. (2016) Nonlinear dynamic characterization of a new hysteretic device: experiments and computations. *Nonlinear Dynam* **83(1)**: 23-39.