Damping and negative stiffness characteristics of an electromagnetic mechanism for vibration control

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Abstract. Electromagnetic mechanisms are being increasingly used in vibration control and energy harvesting applications due to their controllability and frictionless operation. They can provide negative stiffness to reduce the total dynamic stiffness of the vibrating system and are thus beneficial for low-frequency vibration control. Damping can be generated in an electromagnetic mechanism by eddy currents or by using shunt circuits. In this study, an electromagnetic system including three static coils, a moving magnet, and a conducting chamber is considered. First, the negative stiffness of the system is measured with quasi-static tests. In the next step, the behaviour of the system at higher frequencies is studied experimentally and the effects of electromagnetic-induced damping on the total magnetic force are evaluated. Findings are compared with numerical/analytical results, and a general design of a dual-purpose vibration control mechanism is proposed.

Introduction

Quasi-zero stiffness (QZS) vibration isolators are a class of nonlinear vibration isolators that take advantage of negative stiffness elements. Electromagnetic elements are a common solution to achieve negative stiffness; hence, different electromagnetic QZS isolator designs and configurations can be found in the literature. Furthermore, electromagnetic elements can provide dissipative forces to reduce mechanical vibrations by eddy current damping or electromagnetic shunt damping [1].

This paper concerns the effects of electromagnetic damping in vibration isolators, behaviour that relatively few papers have concerned, e.g. [2,3]. First, a numerical model is developed that considers the negative stiffness, eddy current damping and electromagnetic shunt damping generated by interacting coils and permanent magnets in different configurations. Numerical results are validated by comparison with experimental quasi-static and dynamic measurements.

Results and discussion

Various configurations are considered. It is seen that using coils in attractive-repulsive mode provides a negative stiffness region with tuneable width and magnitude which are functions of the electromagnetic and physical parameters. On the other hand, magnetic damping is frequency dependent and becomes greater at higher frequencies. An example is shown in Fig. 1.

With appropriate values for input current to coils, conductor dimensions and shunt circuit, we can achieve the desired negative stiffness and damping at the working conditions. Therefore, depending on the application, vibration magnitude and frequency, the proposed design can be used as an isolator, as an electromagnetic damper, or as a dual-function vibration isolator-damper. These findings provide a benchmark for designing a tuneable dual-function vibration control mechanism.

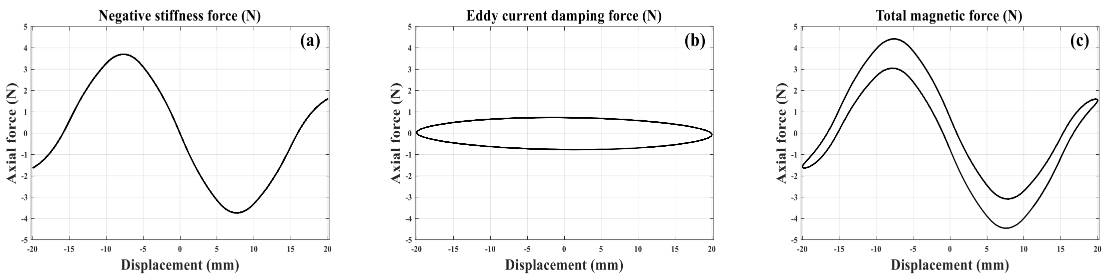

Figure 1: (a) Negative stiffness force, (b) eddy-current damping force, and (c) total magnetic force versus displacement at 10 Hz for three coils and a magnet with the attractive-repulsive arrangement.

References

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