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A planar shock isolation system with high-static-low-dynamic-stiffness characteristic based on cables

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ABSTRACT

In this paper, a simple and designable shock isolation system with ideal high-static-low-dynamic-stiffness (HSLDS) is proposed, which is intended for the horizontal plane shock isolation application. In this system, the isolated object is suspended by several bearing cables and constrained by a number of uniformly distributed pretensioned cables in the horizontal plane, where the low dynamic stiffness of the system is main controlled by the pretension of the planar cables, whilst the high static stiffness is determined by the axial stiffness of the planar cables and their geometric settings. To obtain the HSLDS characteristic of the system, a brief theoretical description of the relationship between the restoring force and displacement is derived. By obtaining the three-order Taylor expansion with sufficient accuracy of the restoring force, influence of planar cable parameters on the low dynamic and high static stiffness is thus given, therefore, the required HSLDS isolator can be easily designed by adjusting the planar cable length, pretension and tensile stiffness. Finally, the isotropy characteristic of the restoring force of the system with different numbers of planar cables is investigated. To evaluate the performance of the system, a rigid isolated object and flexible cables coupling simulation model considering the contacts of the system is established by using multibody dynamics approach. In this model, flexible cables are simulated by 3-node cable element based on the absolute nodal coordinate formulation; the contact between cable and isolated object is simulated based on Hertz contact theory. Finally, the time-domain shock excitation is converted from the design shock spectrum on the basis of BV043/85 criterion. The design procedure of this isolator and some useful guidelines for choosing cable parameters are presented. In addition, a summary about the performance of the isolators with different numbers of cables shocking in an arbitrary direction is given in the conclusion.

1. Introduction

Shocks are one of the most frequently occurring types of mechanical disturbances. Therefore the isolation capacity of a structure subjected to shock is a vital requirement. For a linear shock isolation system, there is a trade-off between isolation performance and static displacement, it is not always possible to have a significant isolation performance due to physical

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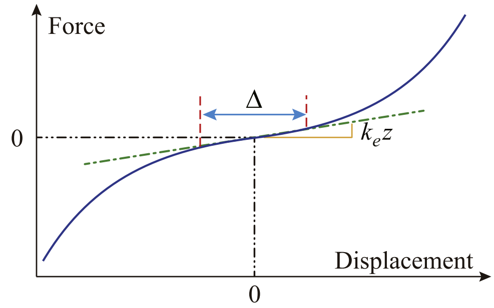

Fig. 1. Typical force–displacement curve of HSLDS isolator.

constraints or space restrictions. In order to overcome this limitation, a number of nonlinear isolation systems with low dynamic stiffness have been developed [1–4].

Recently, the design strategy of nonlinear isolator with high static low dynamic stiffness (HSLDS) has been put forward as a solution for vibration isolation [5–8]. This kind of isolator possesses a high static stiffness which could hold the static loads and minimize the static displacement, whilst a low dynamic stiffness in the neighborhood of the equilibrium position which could reduce the natural frequency and hence achieve vibration isolation at very low frequency [9]. In theory it is possible to design a HSLDS isolation system has zero or near zero dynamic stiffness, therefore, this kind of system is referred to as a quasi-zero stiffness (QZS) isolation system [10]. The typical force–displacement curve of the HSLDS isolator can be approximated by a cubic equation [11]. During the vibration or shock process, the isolated object oscillates, with small amplitude, within the work range Δ around its equilibrium position, as shown in Fig. 1

Several types of HSLDS isolation systems have been proposed, and according to the implement principle can be divided into two main types: the combined positive and negative stiffness isolation system and the single geometric nonlinear isolation system.

The combined positive and negative stiffness isolation system could be implemented by combining a linear isolator with a bi-stable element or mechanism which can provide negative stiffness. The negative stiffness mechanism is introduced to achieve a very low dynamic stiffness by reducing the stiffness of the isolator in the neighborhood of the equilibrium position, and without sacrificing the static load bearing capacity. A lot of configurations have been proposed, and the simplest and most researched model is three-spring model which connecting the linear spring with positive stiffness in parallel with two oblique springs [5]. The two oblique springs, compressed in the horizontal state at the static equilibrium position, provide a negative stiffness when the system vibrates in the neighborhood of the equilibrium position. Platus [12] realized an isolator with low dynamic stiffness by connecting a negative stiffness system which consists of two bars under axial load to a linear spring. Huang [13] achieved a HSLDS nonlinear isolator by adding a negative stiffness corrector which is composed of two buckled Euler beams to a traditional linear isolator. Shaw [14] exploited the negative stiffness exhibited by a transverse composite bi-stable plate to implement the desired HSLDS characteristic.

The geometric nonlinear isolation system makes use of the nonlinear displacement and force characteristic of the elastic element or mechanism. Shoup [15] developed a nonlinear isolator with HSLDS characteristic, the isolator consists of a pair of flexible strips which obtained by clamping initially straight strips in a semicircular shape. Hunt [16] stacked belleville springs to form a softening spring, the suppression bandwidth is increased by exploiting the intermediate section with null slope of the load–displacement curve, and La Rosa [17] increased this section by adopting the belleville spring with variable thickness. Winterflood [18] presented a long-period vertical isolation system based on a torsion crank linkage which makes use of the nonlinearity produced by a torsion-spring crank arm connected to a suspension link. More HSLDS isolators are found in the review of nonlinear passive vibration isolators by Ibrahim [19].

In the aforementioned studies, researchers major concern in the vibration isolation performance of the HSLDS isolator [20,21]. Experimental results show that the HSLDS isolator has a greater isolation region and a lower peak response to base excitation than the equivalent linear system [14,22]. In fact, the isolator can also effectively be used for shock isolation [23], however, the researches on this aspect are seldom discussed. Liu [24] researched the response of the isolator for different shock severity parameters and found that it is beneficial to introduce a HSLDS isolator for shock excitations, but the performances are affected by the parameters and type of the shock excitation. Bin Tang [25] studied the isolation performances of the three-spring isolator under two types of base excitations and proved that when the shock amplitude is small, increasing the nonlinearity is beneficial for shock isolation. Ledezma-Ramirez [26] found that the stiffness nonlinearities could be advantageous in improving shock isolation compared with linear elastic elements.

In view of the good characteristics of the HSLDS system, a novel planar HSLDS isolation system for isolating the horizontal shock excitation in an arbitrary direction based on cables is presented in this paper. The low dynamic stiffness of the system is controlled by the pretension in the planar cables, whilst the high static stiffness is determined by the axial stiffness of the cables and their geometrical configuration. The system is supposed to isolate the vibration and shock excitation, the low dynamic stiffness near the equilibrium position can improve the vibration isolation performance,