On the Instabilities in a Switchable Stiffness System for Vibration Control

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A strategy for vibration control in which the stiffness is switched on and off between a minimum and a maximum value within each oscillation cycle is considered in this study. The strategy has been shown to help greatly in decreasing residual vibrations, thus increasing the effective damping ratio in lightly-damped systems. This work explores the effect of the delay during the stiffness switching. In this study, it is predicted theoretically how a certain value of delay could cause instabilities, and experimental results are presented.

1. INTRODUCTION

Mechanical vibration is an undesirable condition that could lead to fatigue, noise, damage, and other harmful effects to structures, machines, and humans. There are different methods for vibration suppression, either through control of the vibration source, structural modifications, or vibration isolation. The vibration isolation method involves the use of a resilient element located between the vibration source and the receiver, normally modelled mathematically as an elastic element and viscous damper in parallel.[1] When the properties of these elements, i.e. damping and stiffness, have a fixed value, the isolator is said to be passive. However, there are some isolators in which the properties are able to change in real time depending upon the excitation, the so-called semi-active vibration isolators. Lately, there has been a growing interest in the use of semi-active isolation systems mainly for random and deterministic vibration, while few works exist on shock isolation. Most of the work has been done in the field of variable damping; for instance, some switchable or semi-active damping strategies based on the skyhook damper concept have been studied,[2] and Waters, et al. showed that reducing the damping to a lower value during a shock input can lead to better isolation performance.[3]

In the field of switchable stiffness strategies, Winthrop presented an important review in which different methods to achieve variable stiffness were documented.[4] A control strategy for transient vibrations was proposed by Onoda[5] considering an on/off logic aimed to extract energy, based on the switchable stiffness concept presented by Chen for structural vibration control.[6] A resetting technique was considered by Jabbari, et al.[7] and Leavitt, et al.,[8] also based on switchable stiffness with the objective of extracting energy from a mechanical system while having a high stiffness value at all times. Switchable stiffness control has recently been investigated theoretically and experimentally by the authors of this paper, as a means of energy dissipation in lightly damped systems.[9,10] The strategy developed by Ledezma, et al.[9] comprises a mass supported by two springs, one of which can be disconnected. Switching in and out of the spring involves a two-stage control strategy — stiffness control during the shock to reduce the maximum response of the payload, and reduction of the residual vibration after the shock has occurred. The theoretical simulations presented demonstrate that it is possible to obtain better shock isolation by switching the stiffness in lightly damped systems, and this concept was demonstrated experimentally.

This paper explores the second part of the strategy presented previously by the authors,[9,10] namely the residual control of vibrations, which involves switching in real time the actual stiffness of the system. It was found that a delay in the switching could lead to instabilities. Time delays in active vibration control may result in the unstable motion of a controlled oscillating system and hence limit the development and application of vibration control. Haiyan,[11] and later Gu,[12] summarized the recent studies on the dynamics of controlled systems with time delay. Due to the possibility of instabilities as a result of delays, this work gives an insight into the stability of the system, prediction of the maximum delay, and some of the practical issues involved.

2. SWITCHABLE STIFFNESS BACKGROUND THEORY

The switchable stiffness strategy presented by the authors is described briefly here, focusing on the residual vibration control. It is important to mention that residual vibration is the