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Experimental application of a vibration absorber in structural vibration reduction using tunable fluid mass driven by micropump

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ABSTRACT

A new design of tuned mass damper was proposed in this study to reduce the structural vibration of a machine platform subjected to varying excitation frequency, e.g. disturbance from the unbalance mass of motor in different rotational speeds. The absorber mass was changed by pumping of fluid between the liquid chambers of the vibration absorber. With the stiffness remained unchanged, the absorber's natural frequency could be tuned accordingly. Thus, reduction in machine vibration could be obtained by tuning the natural frequency of the absorber according to the frequency of external harmonic disturbance. Firstly, the variations of natural frequency and damping ratio of the absorber with different tuned masses were measured experimentally. The natural frequency results showed that the adjustable ranges for the first two modes could all reach more than 30%. Then, the absorber was installed on a machine platform and its performance was investigated under external disturbance at the natural frequency of the platform. It was found that, due to the effect of damping increase originated from the fluid sloshing inside liquid chamber, the vibration reduction effect from the absorber was limited. To improve this situation, we added a horizontal separation panel inside the liquid chambers, and the experimental results showed that the liquid sloshing was alleviated, and effectively reduced the damping ratio of absorber. Thus, the system became more stable and the control efficiency was effectively improved.

1. Introduction

The first vibration absorber was invented by Frahm in 1911 [1]. Consisting of spring, mass, and damper, vibration absorber is a simple and efficient device for vibration reduction of structures. Since then, many researchers have devoted their efforts to the development and refinement of this tuned vibration absorber (TVA) [2,3]. Although the design of TVA is simple, it is passive and only effective for a very narrow frequency band around the designed frequency. Moreover, the operation of most machines usually covers different rotational speeds, which cause the structure of a machine under excitation over certain frequency span. Not only the alteration in external excitation but also the change in structure

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characteristics due to aging can diminish TVA's performance drastically. In view of this shortcoming, Yamaguchi and Harnpornchai [4] used multiple tuned-mass dampers with distributed natural frequencies to suppress harmonically forced single mode response of structures. However, the multiple tuned-mass dampers become bulky and complicate the implementation.

Following the dynamic vibration absorber (DVA) proposed by Ormnodroyd and Den Hartog [5], many efforts from researchers have been concentrated on the development of adaptively tunable vibration absorbers [6]. Among them, active vibration absorbers use senor and actuator to generate counter action to modify the structural response. On the other hand, semi-active vibration absorbers adaptively tune their system characteristics to meet performance goal. In view of the requirements of low power consumption, hardware simplicity, robustness, and reliability, semi-active vibration absorber presents a promising alternative to both fully passive and active ones.

According to its working principle, the semi-active dynamic vibration absorber can be categorized into three types: variable stiffness [7–25], variable damping [26,27], and variable inertia [28–30], although some have combined effects. If the tuning of DVA is achieved by using material's property change upon activation, the variation in stiffness and damping is usually inseparable. For example, the phase transformation of shape memory polymer (SMP) due to temperature change [16], the activation of electrorheological (ER) fluid in the pre-yielding region by electric field [22], and the control of magnetorheological (MR) elastomer by magnetic field [23,24]. Although the power consumption required for maintaining the property change is usually low comparing with active system, the minimization of power consumption for isolated system is still a crucial concern for long term operation of semi-active system.

Among the proposed DVAs using variable inertia, the most common design mechanism is the adjustment of mass location with respect to a hinge point, either by sliding along a hinged rod [28] or adjusting the moment arm [29,30]. For this actuation of inertia change, a motor and locking device are necessary, which are usually bulky and infeasible for compact system with small dimensions. Because of the rapid development of micro-fluidic technology, micropumps with adequate pumping capability have been available in the market [31]. Furthermore, the piping for transmission of liquid is usually more flexible in spatial configuration than the mechanical transmission. However, on a moving system, the gravity center of fluid can change with the system motion. The system characteristics alter accordingly. It can complicate the design significantly and is not considered herein. Thus, a semi-active vibration absorber with variable inertia controlled by pumping liquid among different liquid chambers in stationary structural system is proposed in this study. The design and performance measurement of a variable inertia dynamic vibration absorber consisting of micropump and liquid distribution pipeline system was investigated.

2. Design and formulation

The vibration absorber studied in the paper is schematically shown in Fig. 1. Basically, the absorber was constructed with two liquid chambers mounted on an aluminum beam. To increase the sensitivity of changing mass on the vibration characteristics of the beam structure, these two chambers were located at the corresponding maximum amplitude points of the first two natural modes, respectively. By using micropump and solenoid valve, the liquid could be filled in or withdrawn from the liquid chambers via the silicone tubing. Thus, distribution and mass was adaptively tuned and dynamic characteristics of the absorber were altered accordingly.

Based on the proposed design configuration, the structure of absorber can be considered as a beam composed of segments with different cross-sectional properties. A simplified stepped beam model was adopted in the formulation of absorber design. The detail of using transfer matrix method to find the natural frequencies was presented in a previous paper [32]. Because the liquid medium was unable to withstand shear loading under quasi-static situation, only mass effect of the liquid was taken into account in the theoretical formulation.

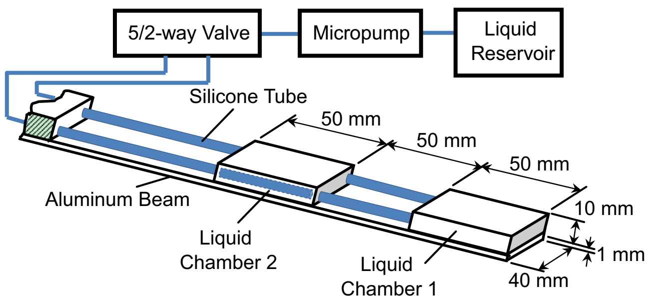

Fig. 1. The schematic diagram for the vibration absorber with tunable liquid mass proposed in this study.