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Fast drive of displacement magnification mechanism with flexure hinge using loading type impact damper†

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Abstract

A displacement magnification mechanism which uses flexure motion guide using elastic hinges can realize smooth frictionless motion but has poor vibration damping capability. An impact damper is a damping mechanism which uses collision energy to dissipate vibration energy. If the damper is used for vibration control of the flexure mechanism, it may be able to dissipate unexpected vibration without killing the merits of the flexure mechanism. In the paper, a loading type impact damper is applied to settle down transient vibration of a displacement magnification mechanism. We investigate differences of damping effect by setting conditions of the damper. It is shown that the impact damper can eliminate residual vibration at step response effectively without steady state error. The experimental displacement magnification mechanism with impact damper can settle down less than 1/5 of the response without the damper under appropriate setting conditions. Influence of natural frequency ratio between damper and displacement magnification mechanism is investigated. Influences of indentation at impact point are also examined.

Keywords: Displacement magnification mechanism; Flexure mechanism; Impact damper; Vibration control

1. Introduction

A displacement magnification mechanism which magnifies the displacement of a fine motion actuator such as stack type piezoelectric actuator is often used for precise measurement or positioning technology. In the mechanism, a flexure motion guide using elastic elements such as elastic hinges is usually adopted in order to eliminate the influence of friction such as stick-slip motion [1, 2]. A flexure guide mechanism can realize smooth frictionless motion but has poor vibration damping capability. Therefore, the displacement magnification mechanism which uses a flexure guide has a problem that when the mechanism is driven quickly, long settling time is required due to residual vibration.

An impact damper is a damping mechanism which uses collision energy to dissipate vibration energy. The idea of reducing the vibration of a mechanical system by attaching a container in which a solid particle is constrained to oscillate was conceived in 1944 by Lieber and Jensen [3]. There are many works on particle damping and single-mass impact damper [4-8]. A particle vibration damper uses a combination of impact and friction damping [4]. As the impact damper does not use both solid and viscous frictions, it remains the merit that frictionless motion can be realized when it is applied to the displacement magnification mechanism using a flexure guide. Other conventional passive dampers have more or less sliding parts such as oil seal parts. The sliding parts cause stick slip motion. The motion has a bad influence on the damped objects especially on fine motion device such as displacement magnification mechanisms.

The purpose of the research is development of a displacement magnification mechanism which can settle down quickly by means of an impact damper. Usually the impact damper is used for a rougher motion system than displacement magnification mechanism. Application of the impact damper to a fine motion device such as the displacement magnification mechanism for piezoelectric actuator is a novel challenge in the field of precision engineering.

Impact dampers can be classified roughly into two types: the external type, whose impactor is set on ground base (see Fig. 1), and the loading type, whose impactor is set directly on the controlled object (see Fig. 2). The authors have previously shown the performance and problems of the external type [9]. This paper deals with the loading type impact damper. Though the loading type damper makes the natural frequency of the object low, it can work effectively for step motion of various heights.

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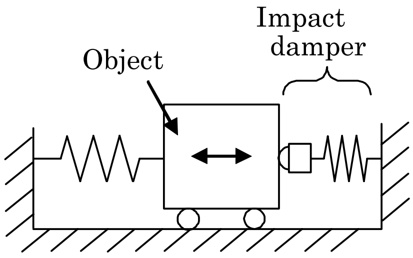

Fig. 1. Model of external type impact damper.

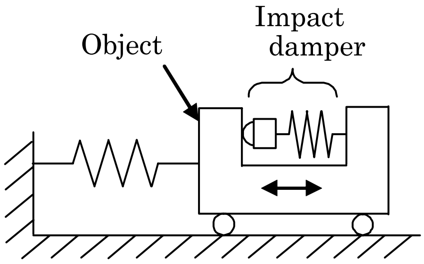

Fig. 2. Model of loading type impact damper.

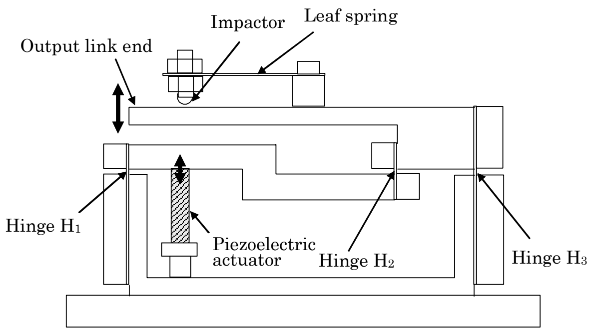

Fig. 3. Experimental mechanism.

2. Experimental mechanism

Fig. 3 shows a schematic view of the displacement magnification mechanism with loading type impact damper manufactured for experimental investigation. The mechanism is about 55x125x10 mm, and the length of the last output link is 105 mm. In the figure, elastic hinges H_1-H_3 connect two link levers and ground walls, and a stack type piezoelectric actuator (AE0505D16 made by NEC-Tokin with generative displacement and force of about 17 μm and 850 N) drives the mechanism. The actuator is able not only to push but also pull a connected lever because of appropriate preload. The actuator pushes up or pulls down the first link lever. Then the lever rotates taking hinge H_1 as the rotation center and pushes up or pull down the second link lever through the hinge H_2. Finally, the last lever rotates taking hinge H_3 as the rotation center. The displacement of the actuator is magnified at the end point of the second lever. The actual magnification factor from the actuator to the end point is about 45. Namely, the maximum actuator displacement of 17 μm is magnified to about 770 μm at the output end. Leaf springs made of phosphor bronze are used as the elastic hinges. The first mode natural frequency of the displacement magnification mechanism is about 104Hz. An impactor whose impact point is hemispherical is set on the output link lever. When the mechanism is driven transiently, the output link lever vibrates and collides with the impactor. Then the impactor works as an impact damper.

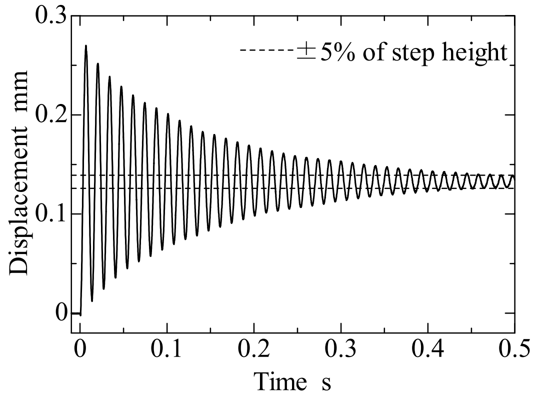

Fig. 4. Step response without damper.

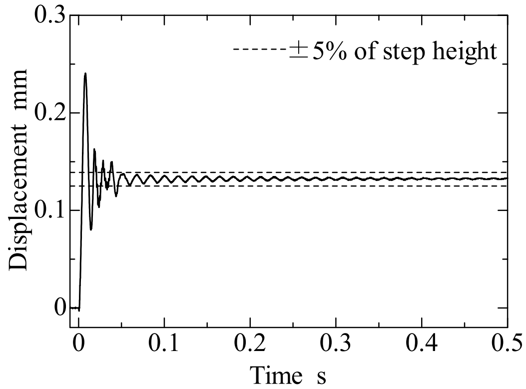

Fig. 5. Step response with the impact damper.

3. Damping characteristics

Using the experimental mechanism shown in Fig. 3, characteristics and performance of the damper are investigated experimentally by observing step responses. Displacements of the output point and impactor are measured with two CCD-laser displacement sensors at the same time. Settling time is investigated for some setting conditions of the damper. In this paper, the settling time is defined as the time at which the output point of the displacement magnification mechanism settles down into ±5% of the final value of each step response.

3.1 Effect of the impact damper

Figs. 4 and 5 show time responses of the displacement magnification mechanism for stepwise drive by the piezoelectric actuator. They are the results for the cases without and with

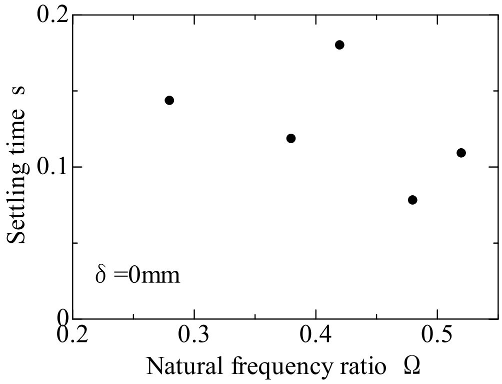

Fig. 6. Settling time for natural frequency ratio.

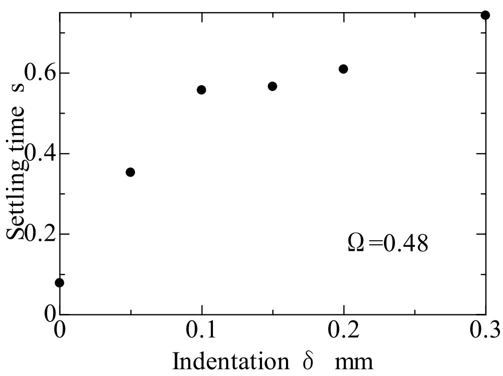

Fig. 7. Settling time for indentation.

the impact damper, respectively. Setting conditions of the impact damper for the results in Fig. 5 are the most appropriate values determined experimentally. From these figures, it is clarified that the impact damper has high performance of damping. The settling time is less than 0.1s for the case with the damper, while it is more than 0.5 s for the case without the damper.

3.2 Change of settling time for natural frequency ratio

As timing of collision is very important to for impact dampers, the ratio between natural frequencies of the displacement magnification mechanism (ω_m) and impact damper (ω_d), $\Omega=\omega_d/\omega_m$, is one of the most influential factors on the damping performance. Fig. 6 shows the difference of settling time for the change of the frequency ratio Ω. The ratio is changed by means of thickness or material stiffness of leaf spring of the impact damper. The natural frequency of the displacement magnification mechanism, ω_m, is fixed in at a constant value. These results show that about 0.5 of the natural frequency ratio makes settling time short. The reason why the results are obtained is that the timing of the motions of the impactor and output link lever is adequate at about Ω=0.5. Timing at which the impactor returns from a peak point to an equilibrium point with downward velocity is the same as the timing at which the lever returns from valley point to the equilibrium point with upward velocity, under condition which that Ω=0.5.

3.3 Change of settling time for indentation

Fig. 7 shows the relationship between settling time and indentation of the damper. The indentation is adjusted by changing the thickness of the spacer inserted between the impactor leaf spring and output link lever. Appropriate indentation is different for each setting condition. The results show that the best indentation is 0 mm for Ω=0.48.

4. Conclusions

A loading type impact damper is applied to eliminate residual vibration of a displacement magnification mechanism which has poor damping potential due to flexure guide. An impact damper is usually applied to a rougher motion mechanism than such a fine mechanism as the displacement magnification mechanism. This study was novel trial of an impact damper. It was shown that the damper can work very effectively even for the fine motion mechanism. Following results are obtained.

(1) Settling time of the object with the damper is less than 1/5 of the one without the damper under appropriate setting conditions of the damper.

(2) Frequency ratio of damper and displacement magnification mechanism to be controlled is a very important factor to exercise the damping ability. A ratio of about 0.5 is the most appropriate value. Namely, the natural frequency of the damper should be approximately half of the one of the displacement magnification mechanism.

(3) Most appropriate indentation of the impactor at impact point is 0 mm under a frequency ratio of about 0.5.

References

[1] J. P. Choi, H. J. Lee, N. G. Lee, S. Kim, A. Chu and B. H. Kim, Design of micro positioning system having flexure hinges, *Proc. of the 3rd International Conference of Positioning Technology*, Hamamatsu, Shizuoka, Japan (2008) 285-290.

[2] N. Henmi, Y. Mori, M. Tanaka and H. Tanaka, Analysis of a three-degrees of freedom flexure hinge mechanism, *Proc. of the International Conference on Mechatronics and Information Technology*, Ube, Yamaguchi, Japan (2001) 345-348.

[3] P. Lieber and D. P. Jensen, An acceleration damper: development, design and some applications, *Trans. ASME*, 67 (10) (1945) 523-530.

[4] H. V. Panossian, Structual damping enhancement via non-obstructive particle damping technique, *ASME J. Vibr. Acoust.*, 114 (1992) 101-105.

[5] N. Poppelwell and S. E. Semetgicil, Performance of bean bag impact damper for a sinusoidal external force, *J. Sound Vib.*, 113 (2) (1989) 193-223.

[6] S. F. Masri, Steady-state response of a multidegree system

with an impact damper, *Trans. ASME, Ser. E, J. Applied Mechanics*, 40 (3) (1973) 127-132.
[7] R. K. Roy, The application of impact dampers to continuous system, *Trans. ASME, Ser. B*, 97 (4) (1975) 1317-1324.
[8] K. Mao, M. Y. Wang, Z. Xu and T. Chen, Simulation and characterization of particle damping in transient vibrations, *Trans. ASME J. Vibration and Acoustics*, 126 (4) (2004) 202-211.
[9] N. Henmi and M. Tanaka, Amplifying mechanism vibration settling by external impact damper, *Int. J. Automation Technology*, 3 (3) (2009) 304-307.

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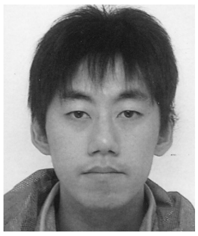

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