서보라이트 픽스쳐의 진동 특성 개선 방법
Methodology on Improving Vibration Characteristics of Servo Write Fixture

윤태용†, 로저 쿠*, 앤드루 핸런*, 찰스 테일러*
Taeyong Yoon, C. -P. Roger Ku, Andrew K. Hanlon and Charles L. Taylor

(2011 년 8 월 25 일 접수; 2011 년 9 월 20 일 심사완료; 2011 년 9 월 23 일 게재확정)

Abstract

This paper presents a method to improve vibration characteristics of servo track write (STW) fixture. STW fixtures supported by flexible mounts are subject to various vibration sources. Using Finite element analysis (FEA) vibration modes of the fixture are identified. The FEA results suggest certain vibration modes be reduced through design change of flexible mounts to improve vibration responses of the fixture. Based on layered flexible mounts theory a parametric study on shear and bending stiffness is performed to obtain a suitable flexible mount design leading to increased resistance to rocking motion. Experiments confirm improvement of vibration characteristics and drive performance through new mounts design.

Key Words : Servo Write, Frequency response, Flexible mounts, Vibration Isolation, Layered mounts

1. Introduction

Hard disk drives (HDDs) have seen significant increase in capacity for the past decades. As these high capacity HDDs are not feasible without support of high tracks per inches (TPI), importance of servo write process has attracted significant attention from researchers in the HDD industry.

Servo write process refers to a manufacturing process which records servo patterns including servo tracks on the media disks. As the written servo patterns are used for positioning or read/write heads, disk drives after mechanical assembly turn into functional drives through servo write process. Servo patterns written on the disks contain all the necessary information required for positioning of heads for data read and write. Two important performance indices in servo write are track spacing and track quality. Track spacing which refers to the distance between two adjacent tracks eventually determines TPI while the quality of tracks including concentricity and circularity affects performance of HDD.

As servo write process records signals on the disks, any forms of disturbance to this process can cause negative impacts and degrade the quality of servo patterns. There have been researches on mitigating radial propagation error during servo write process via servo control efforts [1]-[2]. There also have been efforts via control design to improve resistance to noise disturbance [3] and external vibration [4]. In-depth study on the characteristics of disturbances in a servo write process was reported for mobile drives in [5]. Although [6] refers to design of flexible mounts for HDD testing to improve rotational vibration (RV) about its vertical axis, studies on vibration characteristics of servo write fixtures are rare in literature. The present study provides methodology to improve servo write process through changing dynamic characteristics of the servo write fixture. The concept of layered flexible mounts is considered for feasibility of improving the vibration response of the fixture in the existence of external vibration. Theoretical backgrounds on layered rubber mounts can be found in [7]-[10] where characteristics of layered flexible mount with a metal shim inserted between two adjacent rubber layers are discussed with both analytical approaches and experiments.

† Hitachi Global Storage Technologies
E-mail : taeyong.yoon@hitachigst.com
TEL : +1-(408)717-8690
* Hitachi Global Storage Technologies

2. Servo Write Process

One of the frequently used servo write methods is self-servo write (SSW) process. In SSW a HDD is initially a complete mechanical assembly having blank media disks inside. External electronics are used to write servo patters on the disks using the HDD's own read write heads. Unlike traditional servo write process, SSW does not require external timing devices. Instead, SSW uses timing and position information from preceding tracks for position control during the propagation of servo patterns. The fact that same read-write heads are used for both positioning/timing and signal recording renders SSW process more susceptible to internal and external disturbances than traditional servo write methods.

Fig. 1 shows a schematic of how servo write fixtures are arranged in a servo writer tester. Multiples of servo write fixtures are attached to a metal shelf through flexible mounts, and the metal shelf is rigidly connected to the main servo write frame. The roll of flexible mounts is to isolate the fixture from the servo write shelf and frame. Servo write fixtures experience various vibration sources which can disrupt the SSW process and lower the quality of written servo patterns. In addition to environmental sources of vibration such as noises coming from floor, a frequently encountered source of disturbance expected from this arrangement is an operation- related vibration. Physical contact with a servo write fixture either human operation or automation can generate vibration and shock events which work as disturbances to the nearby fixtures. Vibration isolation of servo write fixtures, therefore, has been an important aspect of servo write system design.

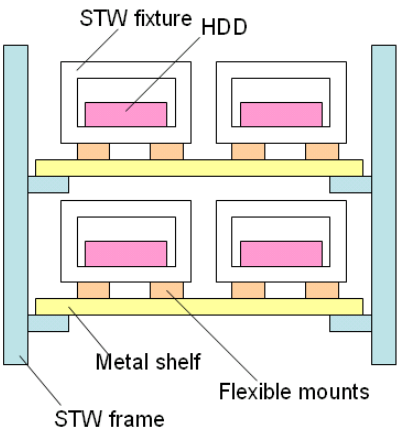

Fig. 1 Schematic of servo writer frame

3. Servo Write Fixture Dynamics

3.1 Vibration Test

Vibration characteristics of a servo write fixture can be obtained with experiments. In order to measure the response of a servo write fixture under excitation, a dummy drive equipped with three tri-axis accelerometers was prepared, and a multi-channel data acquisition system was used to collect acceleration signals from the dummy drive simultaneously. With the signals from the three accelerometers both linear and rotary motion of the fixture can be characterized. The dummy drive was inserted into the servo write fixture and the fixture was mounted on a vibration table through flexible mounts. While the table was vibrating, the transfer function of the fixture vibration was measured with input being the acceleration of the vibration table and output being acceleration signals from the dummy drive. For notational convenience, the definition of the coordinate system used in the experiment is shown in Fig. 2.

Fig. 3 shows the measured transfer functions of the fixture when excitation was applied in the X-direction. X-axis scale is the frequency normalized by the first mode of the fixture for easier identification of important modes' relative locations in the frequency spectrum. The linear response in the excitation direction shown in Fig. 3(a) has a peak at the resonance and rolls off as frequency increases, which is a typical response of a vibration isolation system. Fig. 3(b) shows the angular response about Y-axis has another resonance at a higher frequency than the linear resonance seen in (a). It is notable that with only X-direction excitation applied to the base of the fixture, the fixture experiences both linear and rotary motions. The plot also shows that highly damped characteristics due to inherent damping of flexible mounts.

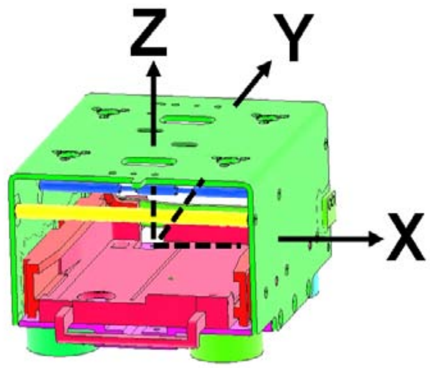

Fig. 2 Coordinate system definition

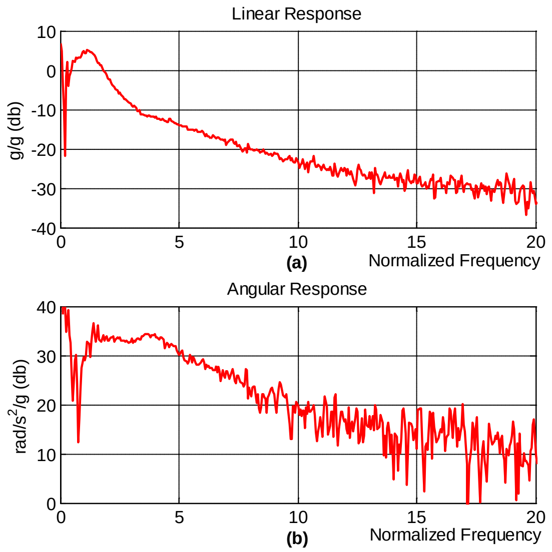

Fig. 3 Frequency response of fixture vibration using accelerometers

3.2 Mode shapes

Since the housing of a servo write fixture is made of steel and this fixture is supported by flexible mounts at the four corners, main vibration modes are 6-DOF rigid body motions without physical deformation of the supported fixture housing or other parts of the fixture. An FEA model was created to understand mode shapes of the fixture, and the mode shapes are presented in Fig. 4. Figs. 4(a), (b), and (c) correspond to translation in X, Y, and Z directions, respectively. Figs. 4 (d), (e) and (f) correspond to the rotation about Z-axis, X-axis, and Y-axis, respectively. The modes in Figs. 4 (e) and (f) are typically called rocking modes. As the rocking mode about Y-axis is higher in frequency than translation mode, the experimental results in Fig. 3(b) suggest that it would be an appropriate approach to reduce rocking motion response of the fixture to expand attenuation range in the frequency response. The present study, therefore, focuses on reducing rocking motion in order to improve vibration characteristics of the fixture.

4. Study on Mounts

An efficient way of changing stiffness characteristics of flexible mounts made of single material is to form alternating layers of rubber and metal, which is called layered rubber mount as in Fig. 5. One of the most interesting characteristics of layered rubber mounts is that bending stiffness can be significantly improved with minimal increase in shear stiffness.

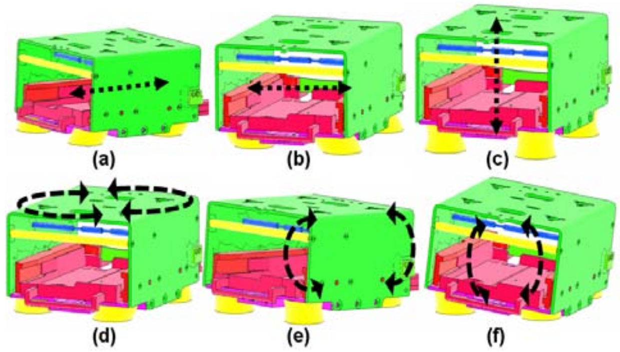

Fig. 4 Vibration modes of the fixture supported by flexible mounts (FEA results)

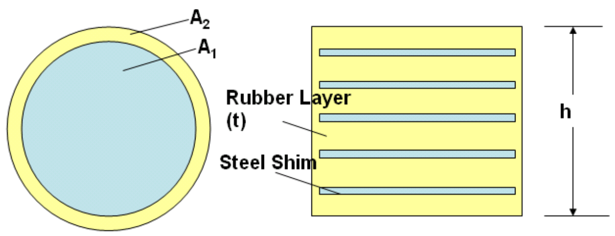

Fig. 5 Schematic of layered rubber mounts

As the present study is interested in reducing rocking motion of the fixture, bending stiffness of the mounts is a primary concern and layered mounts are a good candidate for this purpose. Based on the theories provided in [7]-[10] a parametric study is performed to understand how shear stiffness and bending stiffness change as key parameters change in layered mounts compared with the original mounts made of single-material. Table 1 contains the symbols and descriptions used in the parametric study. In the present study the same flexible material is assumed to be used for layered mounts.

Table 1 Description of variables

symbol	Description
A_1	Area of steel shim
A_2	Cross section area of cover rubber
t_r	Total rubber thickness
t_s	Total thickness of steel shim
h	Total height of the flexible mount
R_s	Radius of steel shim
G	Shear modulus of rubber
E	Young's modulus of rubber
GA_s	Shear stiffness of composite material
EI_s	Bending stiffness of composite material

The shear stiffness of the composite material (layered material) is given as

$$GA_s = G\left(A_1 + A_2 \frac{t_r}{t_r + t_s}\right)\frac{h}{t_r} \quad (1),$$

and the bending stiffness is give as

$$EI_s = E\left(\frac{\pi R_s^4}{4}\right)\left(1 + \frac{2}{3}\left(\frac{R_s}{2t}\right)^2\right)\frac{h}{t_r} \quad (2).$$

In both equations (1) and (2) stiffness of the layered materials is divided by the factor (h/t_r) which is the ratio of the height of the rubber to the total height of the mount.

In the current servo write fixture application, the physical size of the circular flexible mount is fixed, i.e., the diameter and the height. For the present study, metal shim thickness and the number of metal shims will be independent parameters, and stiffness will be calculated using the equations (1) and (2). The height of the mount is 15mm, and the diameter of the shim used is 38mm.

Fig. 6 shows the results of the parametric study in terms of stiffness ratio (stiffness divided by the original flexible mount's stiffness). It can be seen that shear stiffness does not change significantly as the two parameters change. Bending stiffness, however, strongly depends on the number of shims and thickness of shim, increasing up to 20-70 times that of the bending stiffness of the original mount. Since the purpose is to lower the response of rocking motion with minimal impact on lateral mode response, the number of layers should be chosen not increase shear stiffness too much. Due to the nature of large-damping of the mount material present study performs experimental verification of new flexible mounts design rather than FEA simulation. Based on the result of the parametric study in section 4.1 the following two designs are chosen for prototyping. Shim thickness is 1mm, and numerical values of shear and bending stiffness (the ratio to the original stiffness) are listed in Table 2.

Table 2 Stiffness ratios

Design notation	number of shims	Shear stiffness	Bending stiffness
design #1	1	1.058	1.478
design #2	2	1.125	2.934

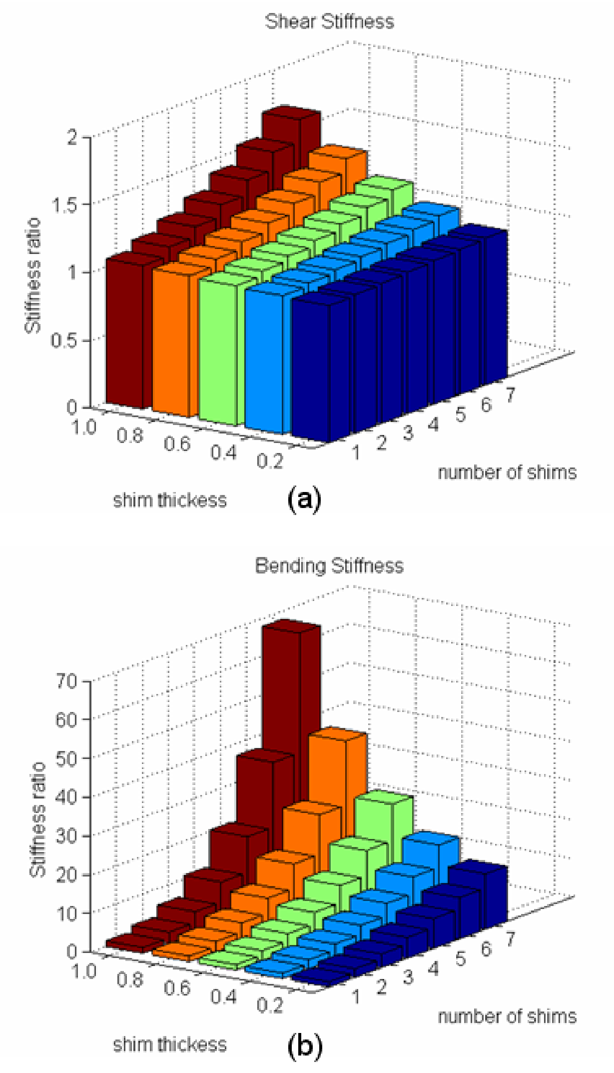

Fig. 6 Shear stiffness and bending stiffness of layered rubber mounts

5. Experiments

5.1 Vibration characteristics

Prototype fixture mounts with selected design in Table 2 were prepared for experiments following the procedure in section 3.1. The fixture was mounted on the vibration table to compare the response of vibration for the prototypes reflecting new mount designs. The same dummy drive was used to measure vibration response. Here sample #1 and sample #2 denote the design having one metal shim and two metal shims in Table 2, respectively. The experimental results are in Fig. 7 with the same frequency scale as in Fig. 3.

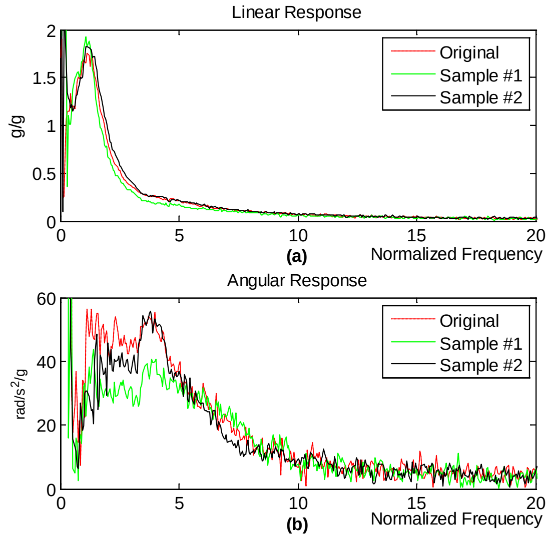

Fig. 7 Comparison of fixture vibration frequency responses using accelerometers

Fig. 7(a) shows the response in Y-direction when vibration is applied in Y-direction. As predicted from the parametric study, no significant change is seen in Y-direction response for all three cases. The rocking motion response, however, shows a notable difference in the range of normalized frequency 1 through 5 for sample #1, as seen in Fig. 7(b). This reduction in vibration response is resulted from the improved resistance to rocking motion through layered structure in the mounts. Sample #2 shows a somewhat different behavior compared with sample #1. Some advantage is seen in frequency region near 6-7, but vibration reduction is smaller than sample #1 in frequency region 1-5.

5.2 HDD PES comparison

The effectiveness of the layered mounts was confirmed through experiments with actual HDDs. In a servo write system in Fig. 1, a HDD was inserted in a fixture (target fixture), and the fixture located next to the target fixture was repeatedly loaded and unloaded to emulate the actual SSW operation in a factory. This is known to create disturbances in the target fixture and affect the quality of the servo patterns being written on the disks. Fig. 8 presents a comparison of PES (position error signal) signals from the HDD in the target fixture for the prototype mounts. Original denotes the PES captured when the target fixture is supported by the original mounts, and sample # 1 and sample #2 indicate the target fixture supported by layered mounts design #1 and design #2, respectively.

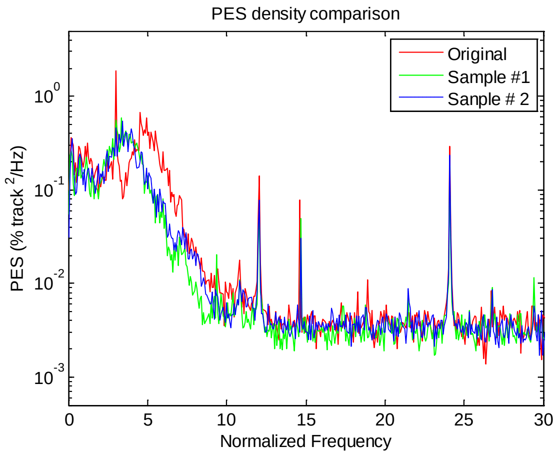

Fig. 8 Operation-induced PES comparison

As the purpose of the experiment is to check any improvement in resistance to the rocking motion when supported with new design of mounts, the operation fixture was supported by the original mounts for all three cases to create the same characteristics of disturbances. The measured PES signals were converted to power spectral density via FFT for easier comparison in the frequency domain. For the case of original flexible mounts, major disturbance is seen at frequency 5 which corresponds to rocking motion of the fixture. Two things are noted for the cases of layered mounts; one is reduction in the rocking motion amplitude with its frequency shifted higher and the other is the amplitude increase at frequency 3 which is likely to correspond to the vertical motion of the fixture. As a common encounter in a design practice, there is a trade-off between the vertical motion response and the rocking motion response of the fixture due to increase in bending stiffness. The samples confirm new layered rubber mounts designs are effective in reducing rocking motion of the fixture and expanding attenuation range in the frequency response as expected.

6. Conclusion

It was shown that servo write fixtures, supported by flexible mounts, possess rocking modes as well as translational modes. When a fixture experiences external vibration the modes of the fixture are excited to affect the HDD inside the fixture. Based on vibration analysis rocking motion which has higher natural frequency than translational modes is identified as the target vibration mode that needs to be reduced to achieve broader attenuation range in the frequency response spectrum.

With the help of layered rubber mounts theories, the trends of shear stiffness and bending stiffness was predicted through a parametric study, and candidate designs were chosen to confirm the effectiveness of new mount design in terms of vibration responses. Vibration test showed reduced rocking motion without degrading the linear direction response. Actual drive level test under servo write process condition verified that the response characteristics changed due to the new mounts, thus reducing the root mean square (RMS) value of PES by 7.5% in the frequency range concerned. Although the actual results of this practice may vary depending on the various operation conditions of servo write including HDD design, the proposed study demonstrates methodology of improving servo write process through adequate vibration isolation of the servo write fixture.

References

[1] Haibei Ye, Member, Vincent Sng, Chunling Du, Jingliang Zhang, and Guoxiao Guo, 2002, “Radial Error Propagation Issues in Self-Servo Track Writing Technology”, IEEE T Magn, Vol. 38, No. 5, pp.2180-2182

[2] Sehoon Oh and Hori, Y., 2008, “Error propagation suppression in Self-servo Track Writer by time-domain control design”, 10th Intl. Conf. on Control, Automation, Robotics and Vision, pp.751-756

[3] Hyun Jae Kang, Choong Woo Lee, Chung Choo Chung, and Ho-Seong Lee, 2009, “Control Design for Self-Servo Track Writing Using a State-Space Disturbance Observer”, IEEE T Magn. Vol. 45, No. 11, pp.5094-5099

[4] Parnupong Thongsuk and Benjamas Panomrattanarug, 2010, “FIR Optimization Control for External Vibration in Self Servo Track Writer”, Intl. Conf. on Instrumentation, Control, Information Technology and System Integration, pp.13-17

[5] K. Akagi and Kazuaki Usui, 2009, “Written-In RRO and NRRO Characteristics in Mobile Hard Disk Drives”, IEEE T Magn, Vol. 45, No. 11, pp.5112-5116

[6] Yasuhiro Matsuda, Shigeo Nakamura, Masahiko Sega, and Yukio Katou, 2009, “Flexible Support Mechanism for Hard Disk Drives to Decrease Vibration Disturbance”, IEEE T Magn, Vol. 45, No. 11, pp.5108-5111

[7] Cheng-Hsiung Chang, 2002, "Modeling of laminated rubber bearings using an analytical stiffness matrix ", Int J Solids Struct, 39, pp.6055-6078

[8] Chan Ghee Koh and James M. Kelly, 1988, “A simple mechanical model for elastomeric bearings used in base isolation”, Int. J. Mech. Sci. Vol. 30, No. 12, pp.933-943

[9] E. I. Rivin, 1999, “Properties and prospective applications of ultra thin layered rubber-metal laminates for limited travel bearings”, Tribology Int, Vol. 18, No. 1, pp.17-25

[10] Hsiang-Chuan Tsai and Shaw-Jiun Hsueh, 2011, “Mechanical properties of isolation bearings identified by a viscoelastic model”, Int. J. Solids Struct, 38, pp.53-74