Design and Analysis of a Dual-Mass Vibration Suppression Mechanism for Head Actuator Assemblies in HDDs

Hyman Norman Abramson[1,*]

[1] Retired Executive Vice President Southwest Research Institute
* Correspondence: nabramson@swri.edu

Abstract: Hard disk drives (HDDs) suffer from resonant vibrations caused by the flexible pivot and weighty head actuator assembly. These vibrations, induced by operational conditions, impede servo bandwidth enhancement and consequently restrict HDD areal density growth. This article explores a passive control technique to mitigate HDD vibrations by modeling the drive as a central rigid body with flexible, beam-like extensions. We propose a dual-mass dynamic absorber positioned within the HDD's voice coil motor to effectively suppress key vibration modes originating from the VCM fork and head actuator's quasi-rigid motion.

Keywords: HDD, storage, hard disk

1. Introduction

The introduction begins by highlighting a significant trend in HDD technology: the rapid increase in areal density, which is the amount of data stored in a given area of the disk. This growth necessitates a deeper understanding of the dynamics and vibrations that occur within HDDs, as these factors directly impact performance.

The authors explain that the head actuator assembly (HAA) in HDDs exhibits resonant frequencies primarily due to its mass and the inherent flexibility of its components. These resonances are problematic because they can limit the servo bandwidth—the speed and accuracy with which the actuator can position the read/write head. The resonant frequencies of the HAA typically fall within the range of 2 kHz to 10 kHz, with lower frequencies being particularly detrimental to performance [1].

The introduction reviews several strategies previously employed to enhance servo bandwidth. One method involves the use of dual-stage actuators, which combine a conventional actuator with a micro-actuator. While this approach has shown promise, it is not widely adopted due to cost constraints. Another method is the development of new actuator designs that utilize orthogonal forces, which also face commercialization challenges [2,3].

Given the limitations of existing solutions, the authors propose the addition of passive damping to the HAA as a viable alternative. They reference previous work that demonstrated the effectiveness of passive dampers in improving the dynamics of the head actuator. The introduction sets the stage for the authors' investigation into a novel dual-mass dynamic absorber that leverages the unused space within the voice coil motor (VCM) of HDDs to mitigate vibrations [4].

The introduction concludes by outlining the focus of the paper: the design and implementation of a tuned dual-mass damping device that effectively addresses the key resonant frequencies of the HAA. This innovative solution aims to enhance the overall performance of HDDs by improving their dynamic stability and operational efficiency. In summary, the introduction effectively frames the problem of vibration in HDDs, reviews existing methods and their shortcomings, and presents the authors' novel approach to mitigating these issues through a dual-mass dynamic absorber.

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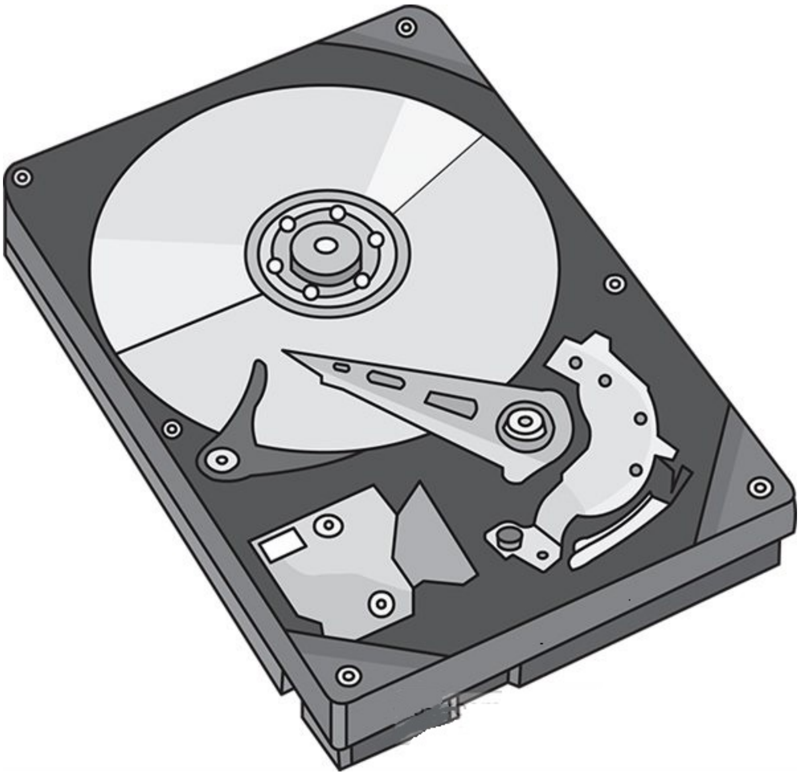

Figure 1. Harddisk

2. Proposed Dual-Mass Dynamic Absorber

The absorber consists of two rigid block masses (0.3 g each) connected to a frame through flexible beams/springs. The natural frequencies of the mass dampers are tuned to coincide with the two main resonant frequencies of the HAA, around 2306 Hz and 4093 Hz. This is achieved by adjusting the total stiffness of the two beams/springs.

Suitable damping is provided by attaching viscoelastic material (VEM) to the surface of each beam. The length or thickness of the VEM can be varied to easily adjust the damping ratio in the tuned damping device.

The absorber is designed to be attached to the hollow space within the voice coil motor (VCM) of HDDs. This allows the device to effectively suppress the key vibration modes produced by the VCM fork and quasi-rigid vibration of the HAA [5]. Seal rubber, similar to that used in HDD covers, is filled into the gaps between the block masses and frame to avoid out-gassing issues in the clean room environment of HDDs. The block masses and frame are made from stainless steel [4].

The total mass of the damping device is 2.0 g, which is much smaller than the 16.5 g HAA. This low mass ensures that the absorber has minimal impact on the overall dynamics of the HAA.

Advantages and Effectiveness

The proposed dual-mass dynamic absorber offers several advantages:

- Simple and practical design that can be easily implemented in HDDs
- Effective in suppressing the two main resonant modes of the HAA
- Low mass ensures minimal impact on the HAA dynamics
- Tuning and damping can be optimized through experiments

The authors demonstrate the effectiveness of the absorber through experiments, showing significant improvement in the dynamics of the HAA. In summary, the dual-mass dynamic absorber is a novel passive damping solution that leverages the unused space within the VCM to enhance the performance of HDDs by mitigating critical vibrations in the HAA.

3. Experimental Setup and Design Optimization

3.1. Experimental Setup

3.1.1. Measurement of Head Actuator Dynamics

The experimental setup is designed to measure the dynamics of the HAA in a commercially available 2.5-inch HDD. The setup includes:

Sinusoidal Excitation: A sweep sinusoidal voltage is applied to the voice coil motor (VCM) of the HDD using an HP35670A signal generator. This method allows for the excitation of the actuator assembly across a range of frequencies to identify its dynamic response.

Response Measurement: The lateral displacement response of the HAA is measured using a laser vibrometer (PSV300). This non-contact measurement technique ensures high accuracy in capturing the vibrations of the actuator [6,7].

Data Processing: The excitation and response data are processed through the HP35670A, which extracts the frequency response function (FRF) between the input voltage and the lateral displacement response. This analysis helps in identifying the resonant frequencies and the overall dynamic behavior of the HAA.

3.1.2. Focus on Resonance

The introduction of the experimental setup emphasizes that the resonance of the actuator assembly is a critical factor limiting the servo bandwidth of the HDD. The arm tip is selected as the measurement point because it is where the vibrations are most pronounced and relevant to the overall performance of the HDD.

3.2. Design Optimization via Experiments

3.2.1. Damping Value Measurement

A second experimental setup is utilized to measure the damping value of the tuned damping device. This setup involves:

Signal Generation: A sinusoidal signal is generated and amplified using the HP35670A, which is then input into a shaker. The shaker simulates the vibrations that the HAA would experience during operation.

Comparison of Vibrations: The vibrations of the HAA are compared with and without the tuned damping device. This comparison is crucial for determining the effectiveness of the damping mechanism. By analyzing the differences in vibration amplitude, the damping value can be quantified.

3.2.2. Results Interpretation

The results from both experimental setups provide insights into the performance of the dual-mass dynamic absorber. The amplitude amplification ratio is measured, which indicates how effectively the absorber reduces vibrations compared to the HAA without the damping device. The findings from these experiments are essential for validating the design and tuning of the damping device.

4. Conclusion

The research presents a novel dual-mass dynamic absorber designed to mitigate vibrations in the head actuator assembly (HAA) of hard disk drives (HDDs). The study identifies that the resonant frequencies of the HAA, primarily caused by its flexibility and mass, significantly hinder the servo bandwidth and, consequently, the areal density growth of HDDs. The dual-mass dynamic absorber effectively targets these resonant frequencies, specifically tuned to coincide with the two main modes of vibration at approximately 2306 Hz and 4093 Hz.

The experimental setup demonstrated the effectiveness of the proposed absorber in real-world applications. Through rigorous testing, the authors established that the dual-mass dynamic absorber significantly reduces the amplitude of vibrations in the HAA. The results indicate that the absorber not only enhances the dynamic stability of the actuator but also improves the overall performance of the HDD. The experimental data corroborate the theoretical predictions made during the design phase, validating the approach taken in this research.

The findings of this study hold substantial implications for the design and manufacturing of HDDs. By integrating the dual-mass dynamic absorber into the voice coil motor (VCM) of HDDs, manufacturers can enhance the performance of their products without significantly increasing costs or complexity. The low mass of the absorber (2.0 g) relative to the HAA (16.5 g) ensures that it does not adversely affect the actuator's dynamics, making it a practical solution for improving HDD performance.

The conclusion also suggests avenues for future research. While the current study focuses on the specific resonant frequencies of the HAA, further investigations could explore the applicability of the dual-mass dynamic absorber in different HDD configurations and other types of mechanical systems facing similar vibration challenges. Additionally, the optimization of damping materials and configurations could yield further improvements in vibration suppression.

In closing, the authors emphasize the importance of addressing vibration issues in HDDs to facilitate ongoing advancements in data storage technology. The dual-mass dynamic absorber represents a significant step forward in passive vibration control, offering a simple yet effective solution to enhance the performance and reliability of hard disk drives. The successful integration of this technology could lead to improvements in data integrity, read/write accuracy, and overall system stability, ultimately benefiting consumers and manufacturers alike.

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