Dynamic Response Measurement of the Head Arm Assembly of a Hard Disk Drive by Numerical Analysis and Experiments

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The dynamic response of the head arm assembly (HAA) of a hard disk drive to an impact load was obtained from a 3D non-linear finite element model using ANSYS/LS-DYNA and from experiments using a modified levitation mass method (LMM). In the finite element model, the impact load was created by modeling the mass as a rigid body and making it collide with the HAA. The velocity, displacement, acceleration, and inertial force of the mass were then obtained from the time history data of the finite element analysis. In the LMM, a mass that was levitated with an aerostatic linear bearing, and hence encountered negligible friction, was made to collide with the actuator arm, resulting in a dynamic bending test for the arm. During the collision, the Doppler frequency shift of the laser beam reflected from the mass was accurately measured with an optical interferometer. The velocity, displacement, acceleration, and inertial force of the mass were accurately calculated from the measured time-varying Doppler frequency shift. A good correlation between the experimental data and FEA results was observed. The FEA was also used to investigate the dynamic response of the HAA to impact by different masses.

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1. Introduction

A hard disk drive (HDD) is a non-volatile storage device that stores digitally encoded data on rapidly rotating platters with magnetic surfaces. Recently, applications for hard disks have expanded beyond computers to digital video recorders, iPod digital music players, digital cameras, and video game consoles. A HDD consists of a motor, a spindle, platters, read/write heads, an actuator, frame, an air filter, a head arm assembly (HAA), and electronics. As non-traditional applications of hard disk drives emerge, their mechanical robustness under shock and other mechanical loadings during different states is of greater concern. Due to the small size of HDDs, the forces involved in these disks are of 0.01 N in magnitude. As such, measuring these forces directly is difficult; displacement, frequency, and mode shapes are measured instead. Dynamic force measurements made using static measuring devices can be inaccurate. Other methods, including acoustic emission signals,[1] force identifications,[2] and direct measurements,[3] have been applied in several studies to measure the contact forces in the head/disk interfaces, but the success of these methods has been limited. In the levitation mass method (LMM), the inertial force of a mass levitated using a pneumatic linear bearing is used as the reference force for the objects being tested, such as force transducers, materials, and structures.[4-7]

Finite element analysis (FEA) has been widely used to investigate the dynamic behaviour of the structures subjected to impact load.[8-10] Many studies have applied FEA to examine the dynamic response of the HAA of an HDD. Shi and Shu et al.[11-13] performed a drop test simulation of a head actuator assembly subjected to half-sine acceleration pulses. A pseudo-resonance phenomenon was observed and investigated by both finite element (FE) simulation and a single-degree-of-freedom (SDOF) model. The FE model included only the head actuator assembly and involved no contact behavior. An FEA of a Seagate Bali II disk drive actuator assembly was reported by Aristegui and Geers.[14] However, the numerical results were not verified experimentally in this study. Edwards[15] developed a complete finite element model of a 3.5-inch HDD and performed a transient response analysis. In all these studies, there was no discussion on the forces involved in the disk.

In this paper, an FEA is carried out using ANSYS/LS-DYNA to obtain the dynamic response of the HAA of an HDD upon impact by a rigid mass. The impact between the moving part and HAA was successfully modeled and simulated with suitable elements and an appropriate contact algorithm in LS-DYNA. Experiments were carried out to validate the FEA results obtained. The impact force measured in experiments was also determined from the simulations. Finally, a parametric study was conducted.

2. Finite Element Analysis

A finite element model of the HAA of a Maxtor HDD was developed in commercially available software, ANSYS 9.1. The simulation was subsequently carried out using LS-DYNA. The HAA consisted of an arm, a hinge, a suspension, a connector, a gimbal, and a slider.[6] They were meshed with explicit thin structural shell elements, SHELL163, which is a four-node element with both bending and membrane capabilities. Real constant sets included the various thicknesses of the parts of the HAA. The HAA was made to collide with a mass that was modeled as a rigid body and meshed with explicit 3-D structural solid elements, SOLID164. This element is defined by eight nodes having the following degrees of freedom at each node: translations, velocities, and accelerations in the nodal x, y, and z directions. The resulting FE model is shown in Fig. 1. The hinge, connector, suspension, and gimbal were made of stainless steel, the arm was made of aluminum, and the over mold was made of epoxy. The coil was inlaid into the over mold. The coil was made of layers of winding copper threads and hence its material properties were anisotropic. However, for simplicity, the coil was assumed to be isotropic in the model. The rigid mass was assumed to be made of steel, and no deformation was allowed during impact. During the analysis, automatic surface-to-surface contact was applied between the HAA (target part) and the rigid body (contact part), and friction was neglected during the collision. Finally, the velocity and acceleration of the rigid body were obtained from the time-history data generated by the software.

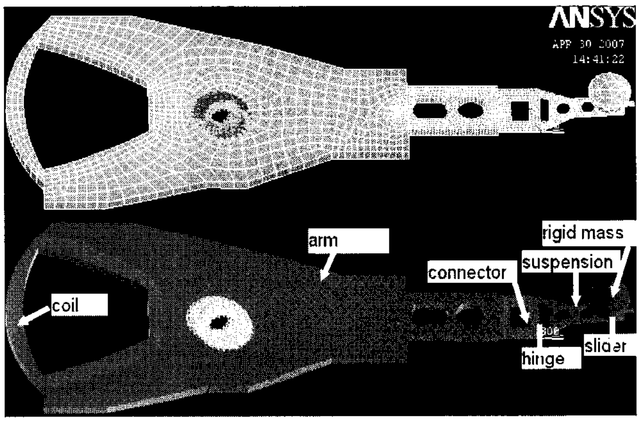


Fig. 1 Finite element model of the HAA of an HDD

3. Experimental Setup

Figure 2 shows a schematic diagram of the experimental setup used to evaluate the dynamic response of the HAA of a Maxtor HDD to impact by a rigid mass. In Fig. 2, NPBS is a non-polarization beam splitter, PC is a computer, LD is a laser diode, and PD is a photo diode. The rigid mass is indicated as the "moving part" and was made of aluminum with a square pole shape. The HAA was attached to the tilting stage. The inertial force of the moving rigid mass was used as the reference force applied to the HAA. An aerostatic linear bearing was used to obtain linear motion with negligible friction acting on the mass, *i.e.*, the piston-shaped moving part of the bearing. An initial velocity was manually given to the mass. A corner-cube prism ("CC") that forms part of the interferometer and a metal block with a round-shaped tip were attached to the moving part, resulting in a total mass M of approximately 21.18 g. The inertial force acting on the mass was obtained by measuring the velocity with an optical interferometer. The total force acting on the moving part, F, is the product of its mass M and its acceleration a, *i.e.*, $F = M a$. The acceleration was calculated from the measured time-varying velocity of the rigid mass. In the optical interferometer, the light source was a Zeeman two-wavelength He-Ne laser incident on a polarization beam splitter (PBS). One beam was transmitted to the signal arm and then reflected from the corner cube attached to the mass. The other beam was reflected from the beam splitter and onto the reference arm. After propagation in the Michelson interferometer, the signal and reference beams were transmitted through a polarizer (a Glann-Thompson prism at 45 degrees to the polarization of the beams, GTP), and the subsequently interfering beams were then incident on a detector, PD1. This resulted in a beat signal since the beams have slightly different wavelengths. The rest frequency, f_{rest}, was measured with detector PD2. When the object is at rest, $f_{beat} = f_{rest}$ and was approximately equal to 2.7 MHz. A digitizer (model: 5102; manufactured by National Instruments Corp., USA) recorded both signals from PD1 and PD2 with 5M samples for each channel at a sampling rate of 20 MS/s. The measurement duration of the digitizer was 0.25 seconds. The mass velocity was obtained by measuring the induced Doppler shift in the signal beam of the laser interferometer and by using the following equations:

$$v = \lambda_{air} (f_{Doppler})/2 \quad (1)$$

$$f_{Doppler} = -(f_{beat} - f_{rest}) \quad (2)$$

where $f_{Doppler}$ is the Doppler shift, λ_{air} is the wavelength of the signal beam in the air, f_{beat} is the beat frequency, (*i.e.*, the frequency difference between the signal beam and the reference beam), and f_{rest} is the rest frequency defined above. More details about the experimental setup can be found in Ref. 5.

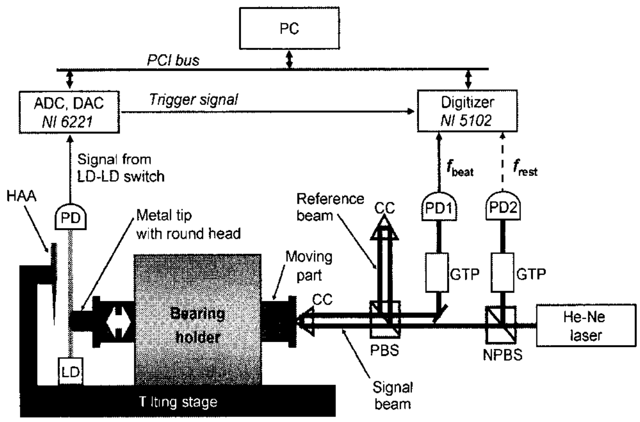
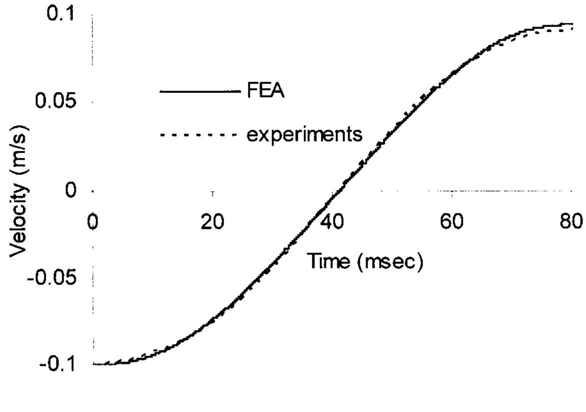


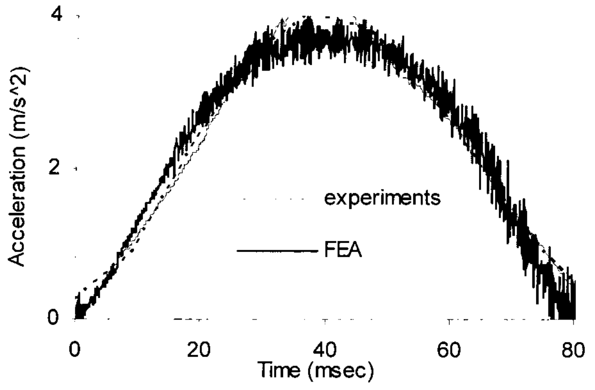
Fig. 2 Experimental set-up of the LMM[5]

4. Results and Discussion

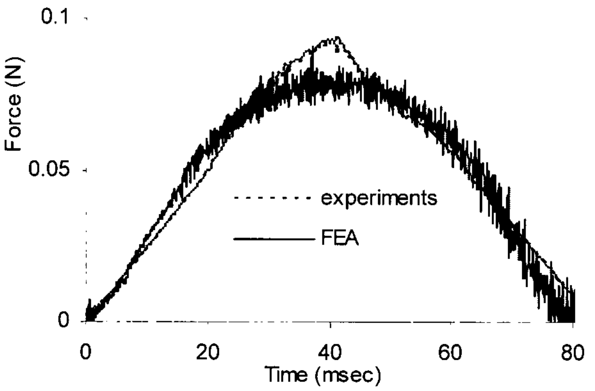
Figure 3 compares the results (velocity, acceleration, inertial force, and position of the mass) from the FEA and experiment. The velocity and acceleration of the rigid mass were obtained from the time-history data of the FEA simulation, and were then used to determine the impact force (product of mass and acceleration). For the experiments, the velocity was calculated according to Doppler's theory given by Eq. (1).



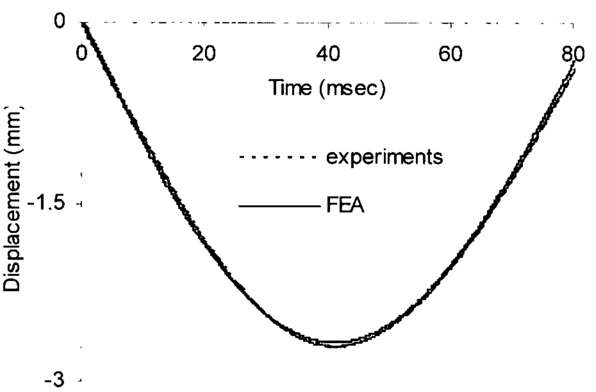
(a) velocity



(b) acceleration



(c) force

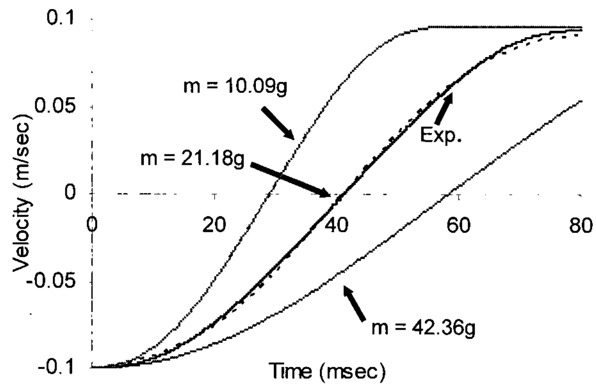


(d) displacement

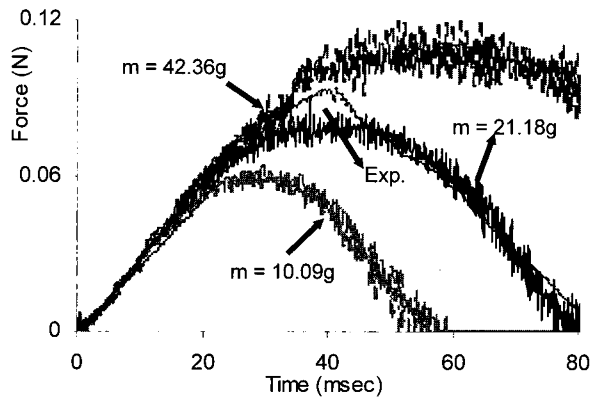
Fig. 3 Comparison between finite element analysis results and experimental data

The acceleration was obtained by differentiating the resultant velocity data with respect to time, enabling the impact force (which is the inertial force of the rigid mass) to be calculated with $F = M a$. A good agreement between the results of the FEA and experimental data was observed for all quantities, *i.e.*, velocity, acceleration, impact force, and position. The maximum value of the impact force obtained from the experiments, F_{max}, was 94 mN, which is comparable to the value of 91 mN obtained from FEA.

Having successfully validated the FE model, it was extended to study the effect of collisions by different masses on the HAA. Figure 4 shows the change in velocity and impact force acting on the mass. The velocity of the rigid mass was prescribed to be 0.1 m/s. When the mass doubled, the contact time increased and the impact force varied non-linearly. The experimental noise increased due to the higher energy transfer involved. This was because there were various nonlinear effects present, such as the nonlinearity due to large deformations, *i.e.*, change of contact angles. No failure, especially at the hinge of the HAA, was observed, despite its large deformation. This analysis is useful to find the maximum force that various parts of the HAA can withstand. In the LMM, only the frequency is measured during the collision; all other quantities, such as velocity, position, acceleration, and force, are calculated afterwards. This makes the LMM a simple test method



(a) velocity



(b) impact force

Fig. 4 Effect of different masses' impact on the dynamic response of the HAA

5. Conclusions

The dynamic response of the HAA of a Maxtor HDD to impacts by a rigid mass was obtained by FEA and experiments. An impact force with an order of magnitude of 0.01 N was measured in the experiments and obtained in simulations. Good agreement between the FEA results and experimental data was observed. The FEA model was extended to study the effect of impact by different sized masses on the dynamic response of the HAA. As the mass increased, nonlinear effects, such as longer deformation and change of contact angle, played a critical role in the dynamic response of the HAA.

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