Modal analysis and pulse response of mobile hard disk head actuator arm assembly

Yang Shuyi[1], Liu Deshun[1], Zhao Jiyun[2], Wen Zejun[1]

(1. College of Electromechanical Engineering, Hunan University of Science and Technology, Xiangtan, Hunan 411201, China; 2. China University of Mining and Technology, Xuzhou, Jiangsu 221008, China)

Abstract: Head actuator arm assembly (HAA) is the most important mechanical component of a mobile hard disk drive (HDD) and its shock dynamic response is a principal index of vibration resistance. In this paper, a finite element (FE) model is firstly developed in ANSYS of 2.5 inch (1 inch = 25.4 mm) mobile hard disk. This model includes actuator arm, voice coil motor (VCM) and pivot bearing. The various step modal of HAA is calculated by FE model. Then the actuator arm vibration behavior is simulated with LS-DYNA procedure. The influence of pulse waveform, pulse amplitude and pulse width on the shock response of the relative displacement of the head actuator arm assembly is studied.

Key words: head actuator arm assembly; modal analysis; shock dynamic response

1 Introduction

As an information storage medium, improving of ultraminitype and high-capacity of hard disk drive (HDD) is an important trend in HDD mechanism technology. Recently, storage capacity is enhanced with improving storage density of the HDD. Magnetic recording density is increased with 100 % every year. The main shaft velocity of the HDD has reached 5 400 ~ 15 000 r/min. For the sake of guarantee sensibility of magnetic head to record signal in the disk, space of magnetic head and disk has reached 5 ~ 10 nm. Head actuator arm assembly drives magnetic head and magnetic head seek for signal on the surface of disk. When strong vibration or impulse effect on mobile hard disk drive, the head actuator arm (HAA) will generate different degree surge. Cantilever arm and magnetic head will knock on the disk in a very short time. When magnetic head vibration is on vertical direction, space of magnetic head and the disk is changed. When magnetic head vibration is on level direction, magnetic head deviates from the disk. The HDD working performance is instable when two types of vibrations take place at the same time. Due to complexity of structures of mechanical components and special work mode, the HDD is very sensitive to vibration.

In order to improve vibration resistance, the dynamics characteristic of the HDD has been widely studied. Edwards studied the shock response of an HDD dropped from a height onto a surface with a specific contact stiffness[1]. His simulations demonstrate that surface stiffness characteristics and fall-down height effect on both the magnitude and the pulse width of the impact shock received by the HDD and the dramatic changes in the responses of the internal components of the HDD to these different shocks. A finite element model of the HDD was developed to investigate the response of the HDD to a shock impulse by Jayson et al[2]. In his work, comparison of the simulation results for the two models was used to develop a correlation between the linear and rotary shock tests. The data for displacements of the slider and stress in the suspension was provided. The modal analysis for the suspension of the HDD used ANSYS and some interesting results about nature frequency of the HDD and vibration modes were studied. The results provide the theoretical basis for optimize design of suspension and design of vibration isolator[3,4]. From a dynamics view, a method to reduce rapidly the residual vibration of the mechanical structure and analyzed its transient response under external driving force has been introduced by Zhang[5]. In all the above simulations, the pivot shaft bearing stiffness was often neglected. But Zhou indicated that pivot shaft bearing performance is an important factor to determine vibration resistance of the HDD[6].

In this paper, a finite element (FE) model of the HAA is developed in ANSYS. The overall model includes actuator arm, voice coil motor (VCM) and pivot shaft bearing of a 2.5 inch mobile hard disk drive. Modal analysis of the HAA is simulated and the influ-

Received 8 *December* 2008

ence of the pulse waveform, pulse amplitude and pulse width pulse on the shock response of the relative displacement is studied. Some conclusions are given in the last section.

2 HDD inner structure

Fig. 1 shows an inner structure of the HDD without a base, with major components annotated. Head actuator arm assembly consists of VCM, actuator arm and pivot. The disk is mounted onto a spindle. A special electromagnetic reading/writing device called a magnetic head is fabricated on a slider. The slider is mounted onto a suspension and an actuator arm, which is in turn fixed to a base plate with a pivot. The pivot is a rotating subsystem used to support the arm and allows its rotation in the horizontal plane. When the disk goes round and round with high speed, the air with clinging on the disk come into being air film due to its viscidity between magnetic head and the disk. Magnetic head is held up with supporting force by air film. Magnetic head slide on the disk with synthesis action by preload, oneself weightiness and supporting force. Space of the magnetic head and the disk is still relatively steady range as stabilization operation state. When vibration and impulse effect on the HDD, machine components including disk, magnetic head, cantilever and actuator arm will take place vibration. The HDD breakage may occur on account of air film performance.

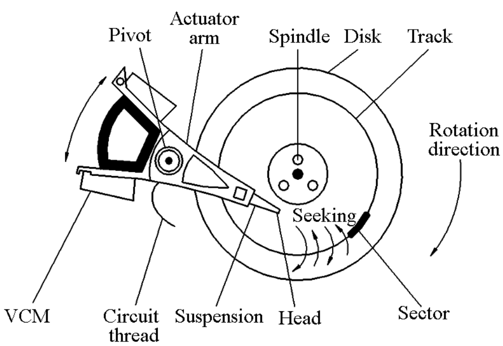

Fig. 1 Inner structure of the HDD

3 Modal analysis of the HAA

In order to get valid transient analysis results, the FE model needs to be carefully verified. Modal analysis is conducted for HAA to verify the FE model. A FE model of a head actuator arm assembly is shown in Fig. 2 and is created by using a commercial FE software package (ANSYS). The material of the actuator arm is aluminum, and stainless steel is used for the pivot. The VCM consists of copper materials. A three dimensional 8-node solid-type element (SOLID45) was used for the solid sections such as inner and outer circle of the pivot bearing, the VCM and actuator arm. 3-D spring-damper-type element (COMBIN14) was used for the pivot bearings. The stiffness along the radial and axial directions of spring elements in the finite element model represents the stiffness of the pivot ball bearing along these two directions. The radial and axial stiffness values are 4.9 kN/m and 0.36 kN/m, respectively. The properties of materials used in this model are listed in Table 1. The whole FE model includes 18 822 elements and 24 279 nodes.

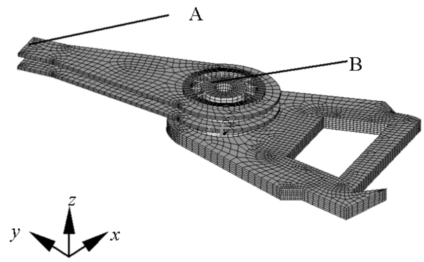

Fig. 2 Finite element model of an HAA

Table 1 Properties of materials

Material	Young's modulus/GPa	Poisson ratio	Density $\times 10^{-6}$/ ($kg \cdot mm^{-3}$)
Stainless steel	200	0.28	7.6
Aluminum	73.1	0.33	2.7
Copper	88	0.29	8.1

Fig. 3 ~ Fig. 8 shows portion modal of the HAA. Partial natural frequencies and modals are listed in Table 2. The value of natural frequency is close to open literature[7,8].

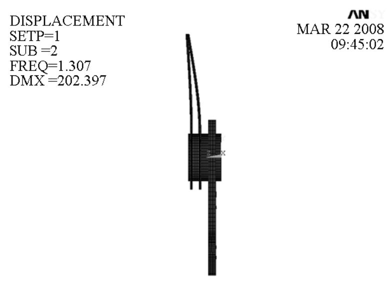

Fig. 3 First bending of actuator arm

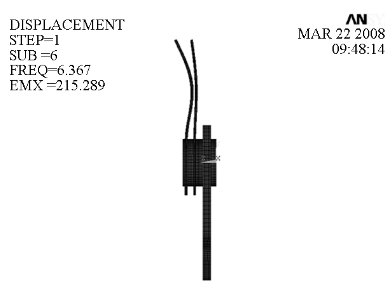

Fig. 4 Second bending of actuator arm

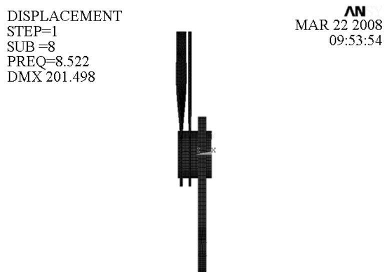

Fig. 5 First torsional vibration of actuator arm

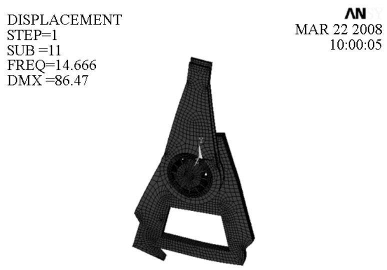

Fig. 6 First crosswise vibration of actuator arm and VCM torsional vibration

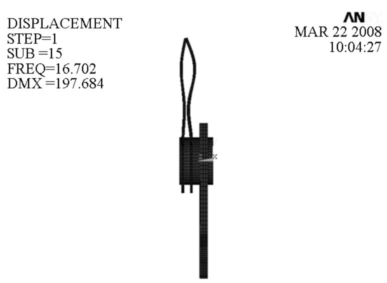

Fig. 7 Third bending of actuator arm

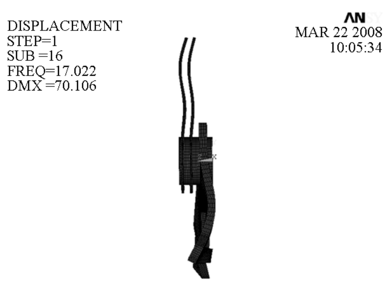

Fig. 8 Third bending of actuator arm and VCM torsional vibration

Table 2 Partial natural frequencies and modals

Modal	Natural frequency/kHz
First portrait bending of actuator arm	1.307
Second portrait bending of actuator arm	6.367
First torsional vibration of actuator arm	8.522
First crosswise vibration of actuator arm and VCM torsional vibration	14.666
Second bending of actuator arm and VCM torsional vibration	15.651

4 Pulse response of the HAA

Generally, the HAA is connected to the base of the drive through the pivot shaft. When a HDD is dropped from certain height, it will accelerate drop due to gravity until it hits the ground, and the head suspension system may knock on the disk in a very short time. The impact during the head slap often leads to failure of the HAA. The vertical vibration of the actuator arm is the most influencing factor to vibration resistance of the HDD. The pivot shaft can be regarded as being fully constrained to the base. A FE model was also constructed for drop test simulation with the LS_DYNA dynamic analyse software and was conducted to study the effect of pulse waveform, pulse amplitude and pulse width on the dynamic characteristics of the HAA. After the modal analysis, the implicit FE model was converted to the explicit format. The corresponding explicit element types are SOLID164 and COMBIN 165, respectively.

4.1 Different pulse waveform response

In order to investigate the pulse waveform effect on the actuator arm behavior, rectangular, half-sine and triangular acceleration pulse are applied on inner circle of the pivot bearing. The acceleration pulse is shown in Fig. 9. Pulse amplitude of three waveforms is 600 g (g is acceleration due to gravity) and pulse width is 0.5 ms. Fig. 10 shows the historical data of relative displacements between the designated node A and the inner circle point B in the z direction for the three different pulse waveforms, corresponding to Fig. 9.

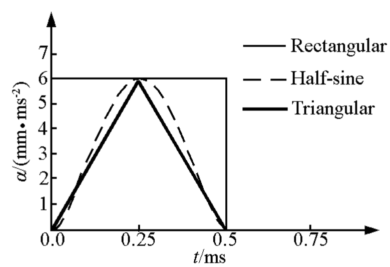

Fig. 9 Acceleration pulse of different waveform

From Fig. 10, it can be found that the maximum relative displacement frequency is homology for different pulse waveform. Because the system pulse response is not only related to the system's natural frequency but also to pulse frequency. It is well known that arbitrariness pulse signal is represented by the Fourier integral and consist of infinitude harmonic component. It is the mostly function that the main frequency of harmonic component $f = 1/t_1$ (t_1 is pulse width) in pulse re-

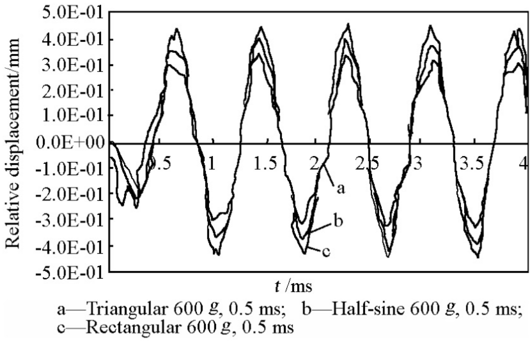

Fig. 10 Relative displacement of different pulse waveform

sponse. **The main frequency of three pulse waveform is** identical due to the same pulse width. In addition, natural frequency of HAA $f=\sqrt{k/m}$ is inherence characteristic.

Fig. 10 shows that the maximum relative displacement amplitude varies for different pulse waveforms. From the energy spectrum point of view, energy of rectangular pulse is the highest, second is half-sine pulse and triangular pulse is least in condition of the same pulse amplitude and pulse width. So, response amplitude increases with pulse energy.

4.2 Different pulse amplitude response

By using the finite element analysis for the actuator arm, the relative displacements are obtained for different pulse amplitudes of triangular acceleration pulse loadings with 300 g and 600 g amplitude. Fig. 11 shows the relative displacement historical data for the two different pulse amplitudes. In Fig. 11, pulse response frequency cannot be distinguished because of their same main frequency. The maximum pulse response amplitude is 1.72×10^{-1} mm with 300 g pulse. The maximum pulse response amplitude is 3.39×10^{-1}mm with 600 g pulse. It implies that the effect of the pulse amplitude to pulse response is linearity.

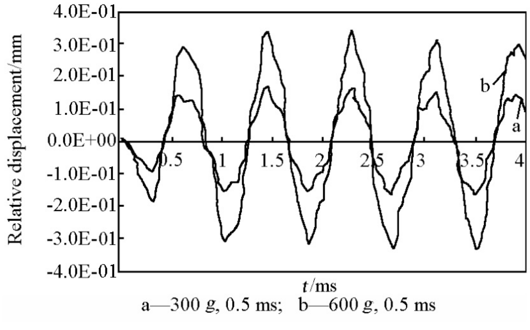

Fig. 11 Relative displacement of different pulse amplitude

4.3 Different pulse width response

Fig. 12 shows the relative displacement historical data for the three different pulse widths of triangular acceleration pulse loadings with 0.75 ms, 1.0 ms and 2.0 ms width.

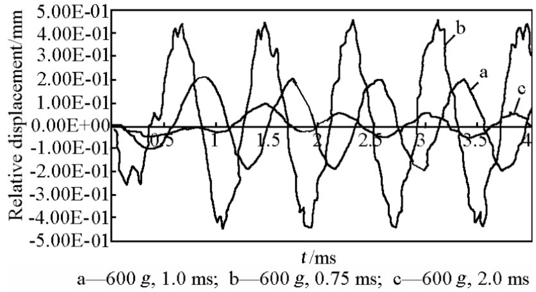

Fig. 12 Relative displacement of different pulse width

From Fig. 12, it can be found that pulse response frequency varies from different main pulse frequencies. Furthermore, the maximum relative displacements occur at different time for different pulse widths with the same amplitude. For 0.75 ms pulse width, the maximum relative displacement occurs at the first oscillation of vibration. For 2.0 ms pulse width, the maximum relative displacement occurs at the third oscillation of vibration and the relative amplitude is the smallest.

4.4 Impact response spectrum

In order to investigate the pulse width effect on the HAA vibration behavior, the width of the applied acceleration pulse varies from 0.25 ms to 4.0 ms. From Fig. 13, it can be found that the maximum relative displacement sharply increases for pulse widths less than 0.5 ms, reaches the peak value at a pulse width of about 0.75 ms, then slowly decreases and approaches a constant value after about 2 ms pulse width.

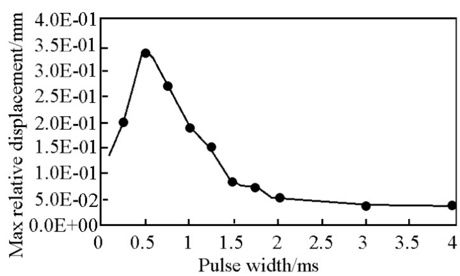

Fig. 13 Maximum relative displacement versus pulse width

The relative displacement reaches the maximum value on the function of impulse. At the same time, system damp often cannot consume large energy. So the HAA is regarded as spring-mass without damp system and takes no account of influence of damp. Response function with triangular acceleration pulse is given by Eqs. (1).

$$x = \frac{A_0}{k}\left(\frac{t}{t_1} - \frac{T}{2\pi t_1}\sin 2\pi\frac{t}{T}\right) \quad \left(0 < t < \frac{1}{2}t_1\right)$$

$$x = \frac{A_0}{k}\left\{1 - \frac{t}{t_1} + \frac{T}{2\pi t_1}\left[2\sin\frac{2\pi}{T}\left(t - \frac{1}{2}t_1\right) - \sin 2\pi\frac{t}{T}\right]\right\} \quad \left(\frac{1}{2}t_1 < t < t_1\right)$$

$$x = \frac{A_0}{k}\left\{\frac{T}{2\pi t_1}\left[2\sin\frac{2\pi}{T}\left(t - \frac{1}{2}t_1\right) - \sin\frac{2\pi}{T}(t - t_1) - \sin 2\pi\frac{t}{T}\right]\right\} \quad (t > t_1) \tag{1}$$

Where A_0 is the amplitude of the pulse, k is coefficient, t_1 is the width of the pulse, T is natural period, t is response time.

From Eq. (1), occurrence time of the maximum relative displacement is not only related to pulse amplitude, but also to pulse width t_1 and natural period T. Different pulse response can be obtained through adjusting the ratio of natural period T and pulse width t_1. The maximum relative displacement may occur during actuation duration or at the end of the duration of the input excitation. It is noted from modal analysis that the first step natural frequency is $f^1 = 1.307$ kHz, the first step natural period is $T = 1/f^1 = 0.765$ ms

Fig. 14 is a transformation of Fig. 13. In Fig. 14, abscissa is frequency ratio ($\alpha = \omega/\omega_n$), vertical coordinates is the maximum dimensionless relative displacement terms $X_{max}/(A_0 \cdot \omega_n^{-2})$.

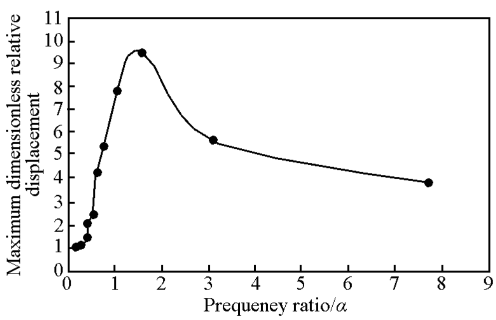

Fig. 14 Maximum dimensionless relative displacement versus frequency ratio

From Fig. 14, it can be found that, a. for the frequency ratio $\alpha = 0.192$, the maximum dimensionless relative displacement is 1.02. For the frequency ratio $\alpha = 1.538$, the maximum dimensionless relative displacement is 9.52. It shows that vibration amplitude of the HAA is very small while frequency ratio $\alpha \leqslant 1$ and the maximum dimensionless relative displacement is sharply increase with frequency ratio α increase. b. For the frequency ratio $\alpha = 1.538$, the maximum dimensionless relative displacement is 9.52. It indicates that vibration amplitude of HAA is the maximum while the frequency ratio α is about 1 (namely the pulse width is about 0.765 ms). c. When frequency ratio α increases from 1.538 to 7.692, the maximum dimensionless relative displacement decreases from 9.52 to 3.82. It illuminates that the maximum dimensionless relative displacement gradually decreases with frequency ratio α increases. At the same time, it shows that when frequency ratio $\alpha \geqslant 1$, vibration amplitude of the HAA is small as the HAA response is too late due to inertia influence under high frequency impulse.

5 Conclusion

In this paper, a modal analysis of the HAA and its dynamic response with several representative pulse loadings are simulated with ANSYS/LS_DYNA. The pulse waveform, pulse amplitude and pulse width effect on the impulse response are studied. It can be demonstrated that the amplitude of vibration response is the highest with rectangular pulse. It is found that occurrence time of the maximum relative displacement is different with the different ratio t_1/T. When the frequency ratio α is about 1, dynamic response of the HAA is fierce. According to theory analysis, impulse function time can be prolonged through reasonable framework and material during design of the HAA. Consequently, vibration amplitude of the HAA will be reduced when vibration and impulse effect on the HDD and vibration resistance of the HDD will be improved.

References

[1] John R Edwards. Fininte element analysis of the shock response and head slap behavior of a hard disk drive[J]. IEEE transactions on magnetics, 1999, 35(2): 863-867.

[2] Jayson E M, Murphy J, Smith P W, et al. Head slap simulation for linear and rotary shock impulses[J]. Tribology International, 2003, 36: 311-316.

[3] Wu Xuepeng, Li Shiqi, Zhu Wenge, et al. Modal analysis of HDD's suspension[J]. Mechine and electron, 2004, 1: 6-9.

[4] Xie Zhengyi, Chen Yunfei. The application of FEM in dynamic study for suspension of HDD[J]. Machine building & Automation, 2005, 34(5): 21-24.

[5] Zhang Jiaqing, Xu Limei, Zeng Sheng. A method to reduce the transient response of the mini-mechanical structure[J]. Journal of Vibration Engineering, 2006, 19(2): 184-188.

[6] Zou Qian, Meng Yonggang, Wen Shizhu, et al. Present situation and developing trend of hard disk spindles[J]. Chinese Journal of Mechanical Engineering, 2002, 38(6): 1-4.

[7] Shu D W, Shi B J, Meng H, et al. Shock analysis of a head actuator assembly subjected to half-sine acceleration pulses[J]. Impact Engineering, 2007, 34: 253-263.

[8] Shu D W, Shi B J, Meng H, et al. The pulse width effect of single half-sine acceleration pulse on the peak response of an actuator arm of hard disk drive[J]. Materials Science and Engineering, 2006, 423: 199-203.

Author

Yang Shuyi, female, was born in 1972. She received her bachelor degree in mechanical engineering from Hunan University of Science and Technology, Xiangtan, China in 1994, and the master degree in mechanical engineering from Guizhou University of Technology, Guiyang, China in 2001. She is a doctor candidate in China University of Mining and Technology, Xuzhou, China, and an associate professor in Hunan University of Science and Technology. Her current research is impact dynamics and robust design. Ms Yang has published more than 20 articles. She can be reached by E-mail: ysy822@126.com

---

Foundation item: Natural Science Foundation of China (Grant No. 50575072); Scientific Research Fund of Hunan Provincial Education Department (Grant No. 07C280)