Operational Shock Failure Mechanisms in Hard Disk Drives

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Abstract

The work performance of a hard disk drive (HDD) in mobile devices depends very much on its ability to withstand external disturbances. In this study a detailed multi-body structural model integrated with a complete air bearing model is developed to investigate the disk drive's response during external shocks. The head disk interface (HDI) failure mechanisms when the HDD is subjected to different shock cases are discussed. For a negative shock case in which the disk initially moves towards the head, with long pulse width, the air bearing becomes very stiff before the slider crashes on the disk, and the HDI fails only when the external load overcomes the air bearing force. For other shock cases, the slider contacts the disk due to a negative net bearing force caused by the slider-disk separation. Finally a stiffer suspension design is proposed to improve the drive shock performance, especially during a positive shock, as under these conditions the slider contacts the disk primarily due to the stiffness difference of the different drive components.

1. Introduction

There has been an increased demand for disk drives in mobile computing devices in the past two decades. In such applications, the HDDs are often subjected to various external disturbances. Studies of the structural responses and HDI failures during external shocks can be very beneficial for modifying the HDD's structural designs in order to improve its work performance.

Many experimental and numerical studies have been carried out to investigate the work performance of HDDs during operational shocks [1-8]. Most of these were focused on accurate measurement of structural response or on developing more accurate models by considering additional components of the system. Some of them also studied the HDI failure mechanisms. Kumar et al. [8] studied the mechanics at the HDI caused by an input shock. In their study, experiemntal measurements were used to determine the impact position between the slider and disk, and 1-DOF disk and 2-DOF head suspension assembly (HSA) models were applied to investigate the disk dynamic effects on the slider's vibration. However, the impact point on the slider and how the slider contacts the disk are still open to research.

In our investigation, we use the structural-fluid model developed by Li et al in [7] to research the HDI failure mechanisms when the drive is subjected to different shocks (different impact directions and impact surfaces).

2. Operational Shock (Op-Shock) Simulator

The structural model is the full model developed in [7] which includes a rotating disk, a spindle motor, a head actuator assembly (HAA), a pivot and a base plate. The air bearing between the slider and disk is governed by a generalized Reynolds equation. An Op-shock simulator is developed by solving the fluid-structure interaction problem to find the slider's flying condition. In this simulation, the air bearing force on the spinning disk is negligible in comparison to the inertia force. However, the disk deformation affects the air bearing response. So it is a one-way coupling method.

3. Shock model and structural model analysis

A shock is modeled as a half sine acceleration wave which is defined by its pealkamplitude and its pulse width. The pulse width determines the excitation frequency according to the following relation:

$$f = \frac{1}{2T_{pw}}. \tag{3}$$

Such a shock is shown in Fig.1, in which the amplitude is 400G (G is the acceleration of gravity) and the pulse width is 2ms. A positive shock is defined as one that causes the disk to initially move towards the slider, while in a negative shock, the disk is initially followed by the slider. This investigation is carried out for a 2.5'' form factor HDD.

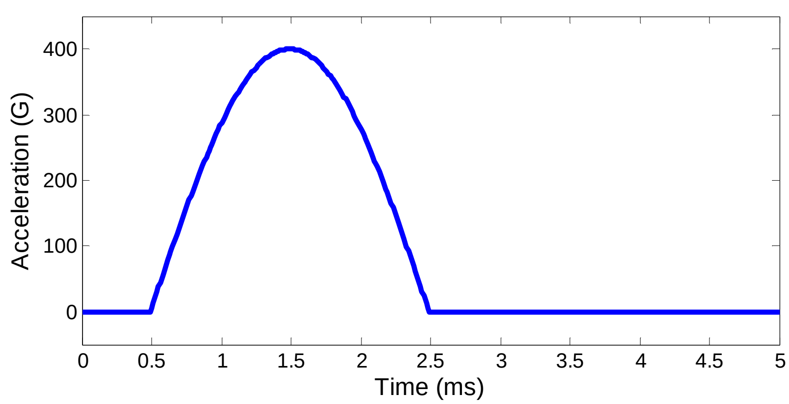

Figure1 Op-shock model

The first few modal frequencies of the disk and HAA are listed in Table 1. It shows that the HAA's second mode frequency is very close to the disk's third forward mode frequency. It is also observed that the HAA's first mode frequency (472 Hz) is very close to the shock excitation frequency with pulse width of 1 ms, and the disk's first mode frequency (1043 Hz) is very close to the shock excitation frequency with pulse width 0.5 ms.

Tab.1 Structural model frequencies

HAA		Disk		
Mode	Frequency (Hz)	Mode	Frequency (Hz)	
			Forward	Backward
1st bending	472	(0,0)	1043	1043
2nd bending	1631	(0,1)	1210	850
Flexure	2489	(0,2)	1604	885

4. Results and Analysis

The minimum clearance between the slider and the disk surface (h_{min}) is used as the failure criterion. In our study, HDI "failure" is defined as the condition when h_{min} becomes less than zero. In the following sections, we study the pulse width effects on the HDI failure, and we describe two observed HDI failure mechanisms.

4.1 Pulse width effects on HDI failure

The HDI response is very sensitive to the shock pulse width. Figure 2 shows the minimum clearances for two negative shock failure cases with different shock pulse widths. The shock excitation frequency for Fig.2(1) is 1000 Hz which is very close to the disk's first mode frequency. The disk's internal resonance causes energy transfer from the disk to the slider, so that the slider tends to separate from the disk even when the drive is subjected to a negative shock, which causes slider-disk contacts. That is why the slider-disk collision is observed after the shock period, which is from 0.5 ms to 2.0 ms in Fig. 2(1). However, for a longer shock pulse width case (Fig. 2(2)), the slider contacts the disk during the shock period (0.5-2.5 ms). That means the shock excitation effect is dominant in the structural response, while the resonance effect is not significant in this long pulse width case.

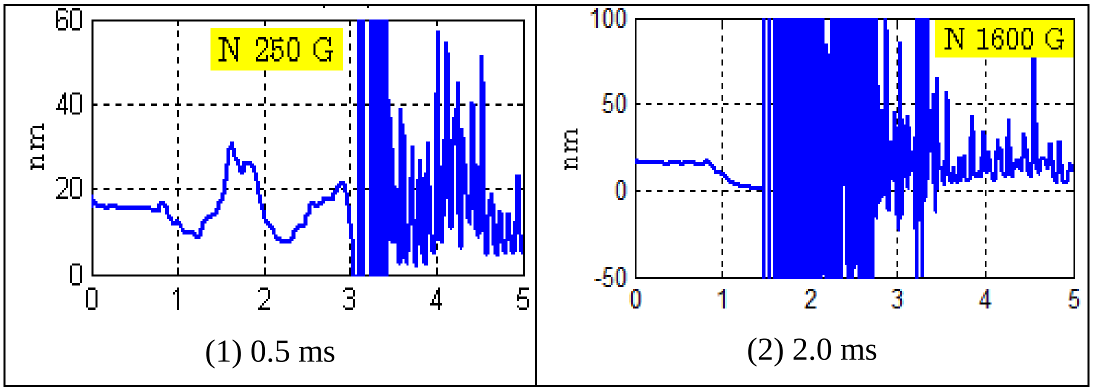

Figure 2 Minimum clearance for two different shock cases with pulse widths: (1) 0.5 ms; (2) 2.0 ms.

4.2 HDI Failure Mechanisms

The HDI failure mechanisms can be categorized into two types after comparison of the HDI failures for different shock pulse widths. One type is for negative shocks with long pulse widths, another is for all other shocks. We first examine a positive shock with short pulse width (0.5 ms) and then a negative shock with long pulse width (2.0 ms) for explanation.

4.2.1 Positive shock with pulse width 0.5 ms

Figure 3(1) shows that the slider is able to fly over the disk successfully when the positive shock amplitude is 300 G as the minimum clearance remains larger than zero all the time. But the slider crashes on the disk when the amplitude is increased to 400 G (Fig. 3(2)). From the zoomed-in part of the minimum clearance (Fig. 3(4)), we see that the minimum clearance decreases from positive to negative directly without any oscillation. The air bearing forces presented in Fig. 3(3) show that the net bearing force (grey curve) decreases to a negative value before the minimum clearance becomes zero. The slider is pulled back to the disk due to the negative net bearing force until it crashes on the disk.

This phenomenon is called "head-slap". It can be explained as follows: when the relative displacement between the slider and the disk increases, the air between them expands. The net bearing force decreases to zero when the head-disk spacing is big enough, and the HAA's bending modes become excited. The phase difference between the HAA and disk vibration causes the head-slap and HDI failure. Since the HDI failure strongly depends on the suspension design, an improved suspension design is expected to give a better HDD work performance.

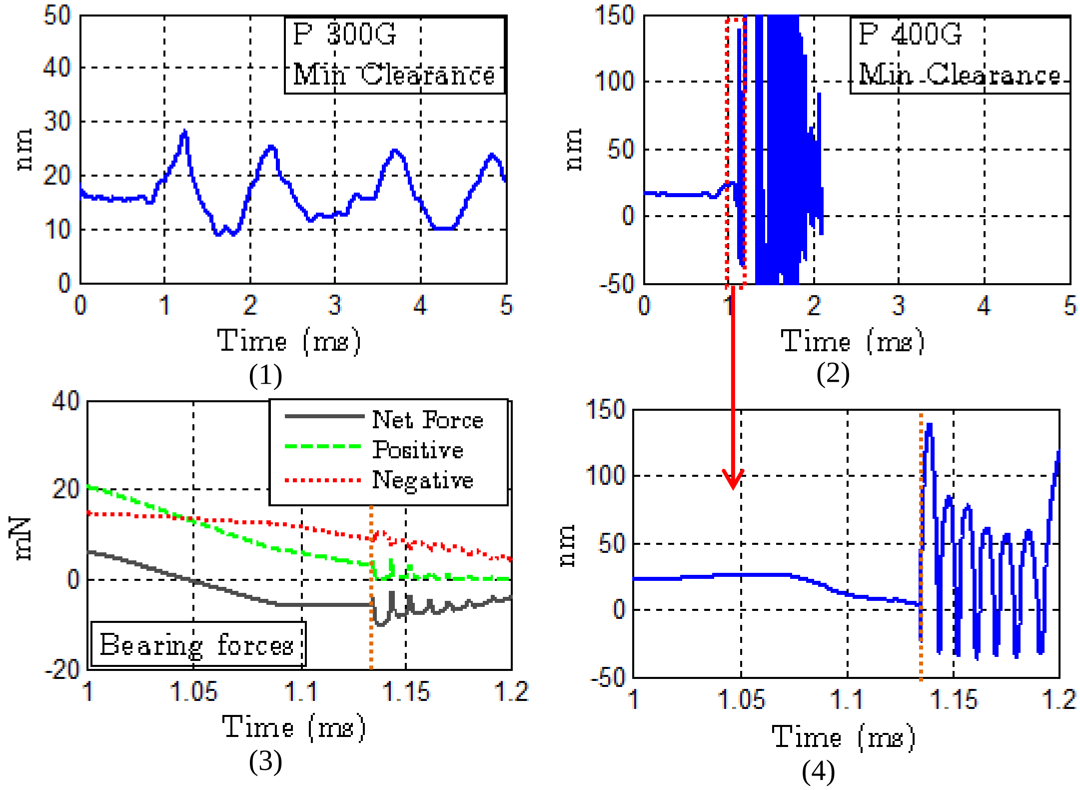

Figure 3 Failure mechanism for shock with short pulse width of 0.5 ms: (1) minimum clearance for positive shock 300 G - no failure; (2) minimum clearance for positive shock 400 G - failure; (3) air bearing force corresponding to the case in (2); (4) zoom in of minimum clearance in (2).

The slider' relative pitch and roll during a zoomed-in period (1-1.5 ms) are plotted in Figs. 4(1) and 4(2). It is observed that the air bearing instability leads to negative values of pitch and roll. The x and y coordinates of the slider's minimum clearance location presented in Figs. 4(3) and 4(4) indicate that the slider contacts the disk first at the inner trailing edge corner and then the contact point moves along the inner edge to the leading edge.

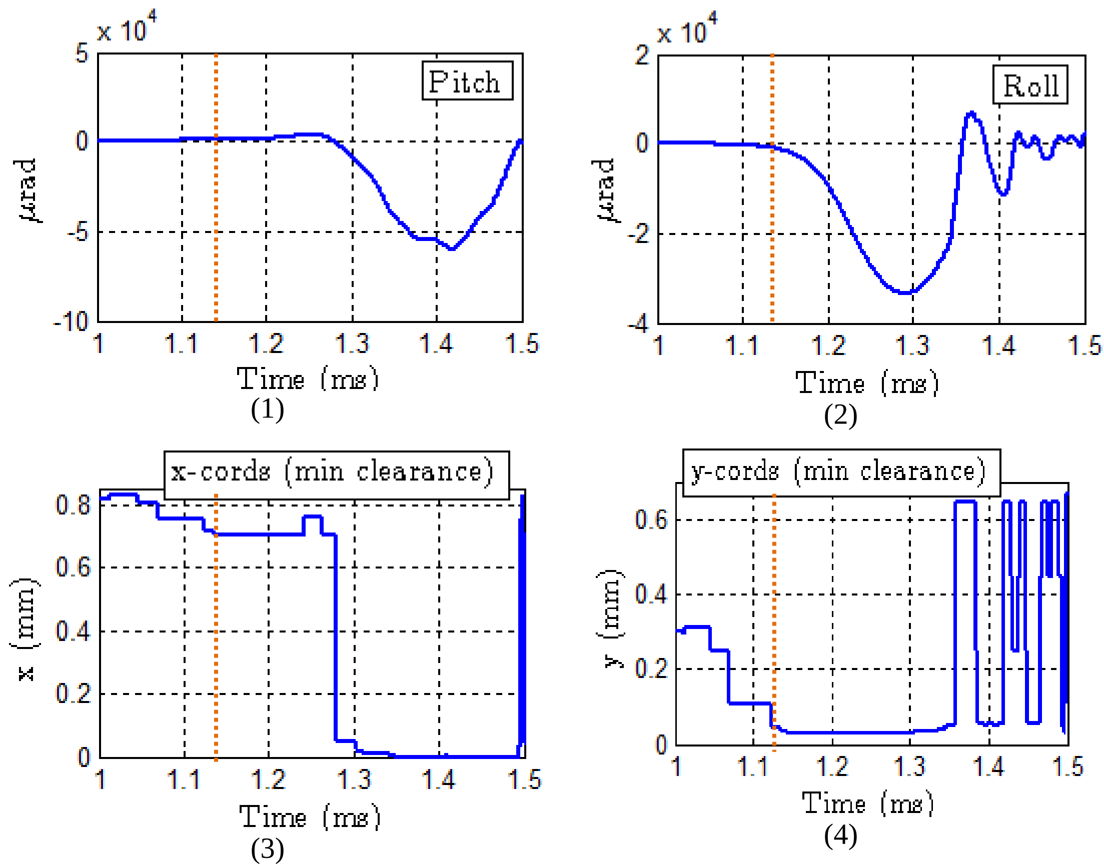

Figure 4 Slider's flying parameters for positive shock 400 G: (1) relative pitch; (2) relative roll; (3) x-coordinates for slider's minimum clearance point; (4) y-coordinates for slider's minimum clearance point.

4.2.2 Negative shock with pulse width 2.0 ms

The minimum clearance in Fig.5 shows that when the shock amplitude increases from 1500G to 1600G the slider crashes on the disk. From the zoom-in part of the minimum clearance (Fig. 5(4)), it is observed that the slider oscillates for a while before it contacts the disk. Figure 5(3) shows that the net air bearing force is positive before the minimum clearance becomes zero. Thus, the air bearing is stable before the slider crashes on the disk. In this negative shock case, the air flow is compressed so that the air bearing becomes very stiff. That is why the net bearing force in Fig. 5(3) is relatively large. The slider crashes on the disk only when the inertia load of the shock overcomes the air bearing force. The slider-disk contact position movement along the slider is shown in Fig. 6. It indicates that the slider contacts the disk first at the leading edge center, and then the contact point moves along the leading edge.

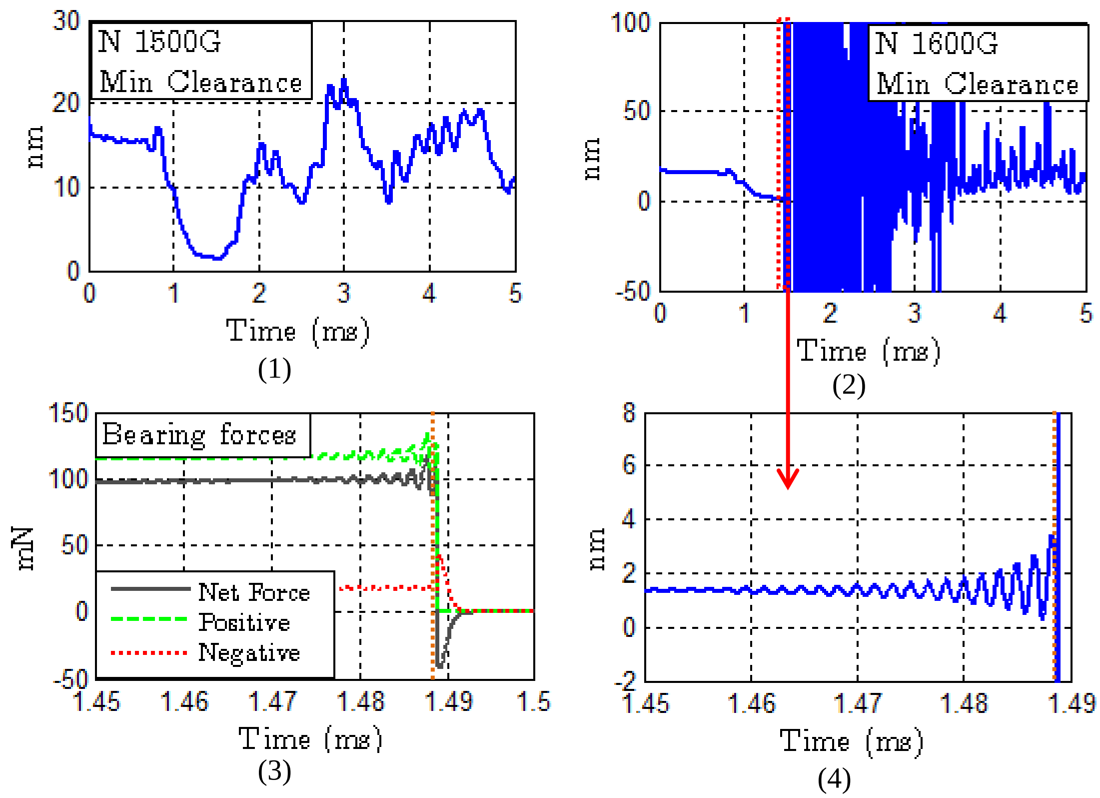

Figure 5 Failure mechanism for shock with long pulse width of 2.0 ms: (1) minimum clearance for negative shock 1500 G – no failure; (2) minimum clearance for negative shock 1600 G - failure; (3) air bearing force corresponding to the case in (2); (4) zoom in of minimum clearance in (2).

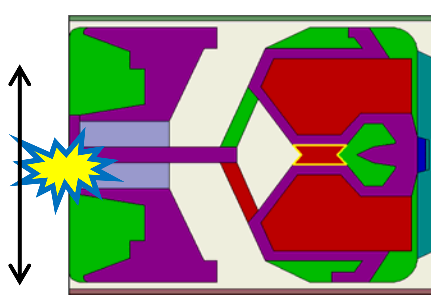

Figure 6 Slider's crash location

4.3 Different suspension design with increased stiffness

As discussed in section 4.2.1, the suspension design can have a significant effect on the HDD's work performance during op-shock events. In order to investigate how the suspension stiffness affects the HDI response, we increased the stiffness of the flexure, which is one component of the suspension, as shown in Fig.7, to twice and four times its original value. In order to evaluate the result of these stiffness changes we examine the "critical shock", which is defined as the maximum shock before the HDI fails. This is a very important measurement for determining the work performance of a HDD. Figure 8 shows the critical shocks as functions of the shock pulse width for the three different flexure stiffness cases. It is observed that these flexure design changes affect the HDD's work performance very little when it is subjected to a negative shock with long pulse width. However, for other shocks such as positive shocks or negative shocks with short pulse width, the critical shock value increases as the flexure stiffness increases.

Figure 7 The flexure component on the suspension

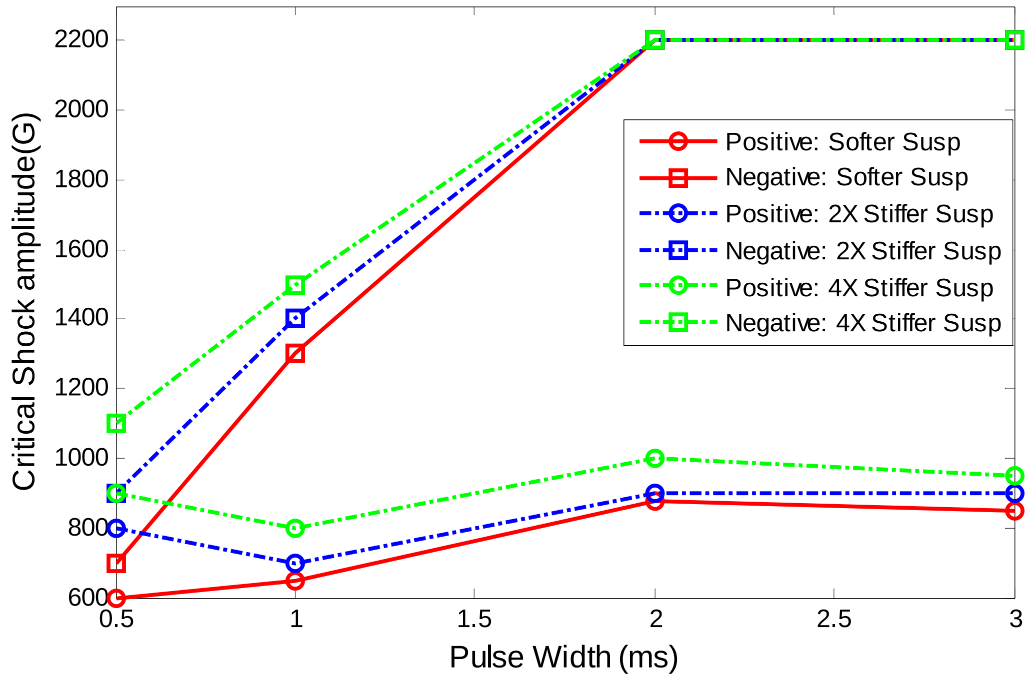

Figure 8 Critical shock dependence on pulse width for three flexure designs

5. Conclusion

In this study we applied a multi-body full HDD model and a complete air bearing model to study the HDI failures when the HDD is subjected to different kinds of shocks. It is found that for a negative shock with long pulse width the HDI fails when the disk's inertia load of the shock overcomes the air bearing force, and the failure always occurs during the shock pulse period. For other shock cases, head slap due to the head-disk separation and snap back is the main cause of HDI failure. For the shock cases with short pulse widths, the HDI failure does not necessarily appear during the shock pulse period but the residual vibrations of the disk and suspension may cause slider-disk contacts.

From the failure mechanism analysis and the critical shocks for three different suspension designs, it is observed that a stiffer flexure design can improve the HDD's work performance for the HDD system we used in this study.

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