Reliability Criteria for Dynamic Load/Unload[1]

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Abstract

Dynamic load/unload (L/UL) has been widely used in portable and removable drives, and the disk drive industry has recently began to apply it in desktop and server drives to eliminate stiction and wear associated with contact start-stop (CSS). There are many design parameters in L/UL systems that affect reliability, such as the slider air bearing, suspension, ramp and operating parameters. In this article, we summarize our recent research work on L/UL. We also discuss the effects of the air bearing design, the suspension and its limiters, L/UL speed, disk rmp, ramp profile, and dimple pre-load. The results should substantially benefit the design for reliable L/UL systems.

[1] This report will be published in Data Storage Magazine.

1. Introduction

L/UL was used in the first hard disk drive – the IBM Ramac 350 in 1957. Its L/UL mechanism was much more complex than today's ramp L/UL designs that first successfully appeared in mobile drives made by Integral in the early 1990's. The ramp L/UL system is now the standard design for removable cartridge drives and drives for mobile computers. It provides two remarkable advantages for mobile drives, i.e., good shock resistance and low power consumption. After IBM implemented the ramp L/UL in its Travel Star mobile disk drives, in which it achieved a record areal density by using MR heads with super-smooth media (lower flying height) in 1997, the drive industry has shown great enthusiasm for the L/UL design. It is now the preferred means to achieve higher density and avoid the stiction and wear problems that would otherwise occur with super-smooth media. More recently L/UL was utilized in IBM's server drives (IBM Ultrastar 18LZX and 36ZX), and superior performances were achieved. It appears that in the near future, almost all hard disk drives will use the L/UL design.

The main design objectives of L/UL are no slider-disk contact or no media damage even with contact during L/UL, small ramp force, and a smooth and short unloading process. From 1988 to 1995, many research works [1-3] on L/UL were conducted in the Computer Mechanics Laboratory (CML) at U.C. Berkeley. After a two-year pause, we resumed this project, and obtained a better understanding of the L/UL system. Our recent results [4]-[8] demonstrate that there are many ways to achieve the desired objectives, because there are many design parameters of the system, such as the L/UL operating parameters, slider air bearing surface (ABS) designs, and suspension parameters. There have been published numerous experimental studies on L/UL, however recent work has shown that numerical simulations can provide much more insight into this complex process.

The suspension model is critical in the simulation. The 4-DOF suspension model [7], which has been experimentally verified, is now used in the simulation. Through these simulation studies, we have gained a much better understanding of the dynamic L/UL process, and this is expected to greatly benefit the design of reliable L/UL systems. In this article, we summarize these recent new findings.

2. Some Design Parameters in L/UL Systems

2.1 ABS design

ABS design is critical for reliable head/disk interfaces. When L/UL is used, there are some new issues in slider design. Most of the current sliders were designed for contact-start-stop (CSS), and we found that few of these slider designs contain the desired features for L/UL. Therefore they are not suitable for L/UL applications [4], because they are likely to contact the disk during L/UL. Even positive pressure sliders, which can still generate sub-ambient pressure during unload because of skew effects, can possibly hit the disk during unload. However, negative pressure sliders are widely utilized in current drives because of their many advantageous features. Figure 1 shows two extremes of ABS designs, and the L/UL performances of most current slider designs are expected to be between them [5]. The two sliders have an almost uniform 30 nm flying height from the ID (21.2 mm, -7.5^{o}) to the OD (45 mm, 16^{o}) at 7200 RPM. In the simulation, the sliders are loaded at a vertical velocity of 25.4 mm/s. Figure 2 shows the air bearing forces, pitch and minimum clearance histories of the sliders during the loading process.

The minimum values of the minimum clearances of slider A remain positive throughout the process. That means no contact occurs between the disk and the slider A. This value for slider B is negative, indicating that slider B contacts the disk during loading. The loading process of slider A is much smoother than that for slider B.

The UL performances with a typical suspension (e.g., HTI 2030) were simulated, and the results are shown in Fig. 3. The sliders are unloaded at the 254 mm/s vertical velocity. We see that slider A can be smoothly unloaded in a short time (<0.4 ms), but slider B generates a large lift-off force (the minimum amplitude of the air bearing force) that causes dimple separation, and it requires a longer time to unload (>1.7 ms). Such long unloading processes significantly decrease the recordable area of the disk, which is unacceptable. It is a somewhat surprising result that if a negative pressure slider design has a good loading performance, it usually also shows a good unloading performance. The design principle for L/UL sliders is to keep the negative pressure regions (not only the cavities) near the center line and trailing edge during the L/UL processes after considering the worst loading conditions and skew effects.

If an ABS has not been designed to have the desirable L/UL performance because of other design constraints, there are several ways to improve the L/UL performance. A sub-optimal slider's performance can be improved by using specially designed suspensions, specially processed sliders [9], different operating parameters, or optimized ramp profiles.

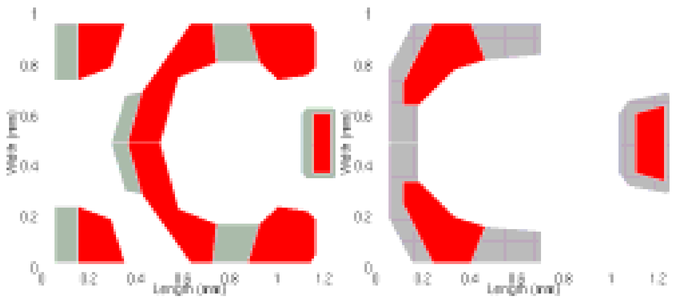


Fig. 1 Two extremes of ABS designs: Sliders A (left) and B (right)

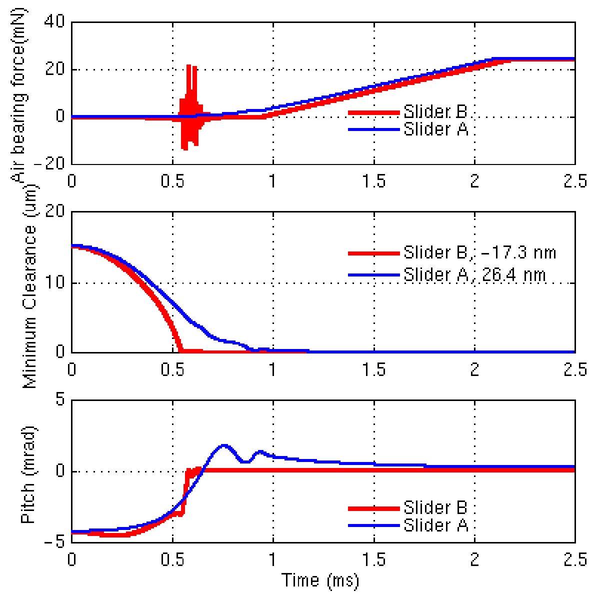
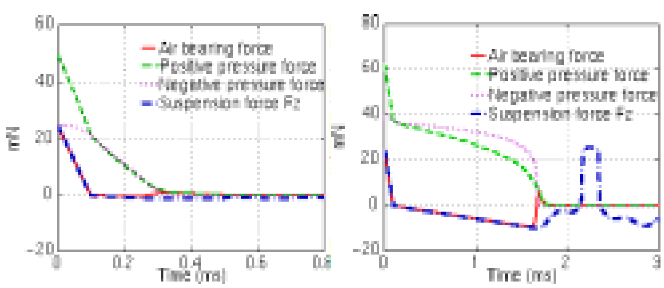


Fig. 2 Loading process



a) Sldier A b) Slider B

Fig. 3 Unloading process without limiters

2.2 Suspension limiters

Although slider A has good L/UL performances, the industry currently employs sliders not designed for L/UL and relies instead on specifically designed suspensions with limiters, to achieve all of the design requirements. The limiters prevent large dimple separation during unload and under operating shock. We found that the limiters don't affect the loading process, while they significantly affect the unloading process [6]. With the limiters on the suspension, the unloading time is greatly shortened but the lift-off forces are increased as are the strong oscillations of the slider after it is unloaded (Fig. 4). The large lift-off force produces a relatively large force applied between the load tab and the ramp, which increases the unloading torque and ramp wear.

Figure 5 shows the unload air bearing force histories and minimum clearances for different x_{d4}, which is the offset that is directly related to the location of the limiters. The non-smooth curves in the force histories and the negative minimum clearances indicate that the slider contacts the disk. We see that slider B can be smoothly unloaded only in a small range of x_{d4}. Figure 6 shows that a large negative value of x_{d4} (-1.0 mm, offset to the leading edge) results in the slider contacting the disk at the trailing edge because of a large positive pitch, although it has smaller lift-off forces. A large positive x_{d4} (offset to the trailing edge) results in the slider hitting the disk at the leading edge because of a large negative pitch, and it also results in a large lift-off force and strong slider oscillations during unload. A large positive offset results in strong slider pitch oscillation and thereby the slider hitting the disk. When large offsets are used, the severe impacts occur after the air bearing disappears. These two limiters are located at the two sides of the slider and near the slider's center. The manufacturing tolerances will result in a spread of offsets x_{d4}, and thereby cause some slider/disk contacts. A better design is to have three limiters as shown in Fig. 7. That is a common sense rule – three points fix a plane.

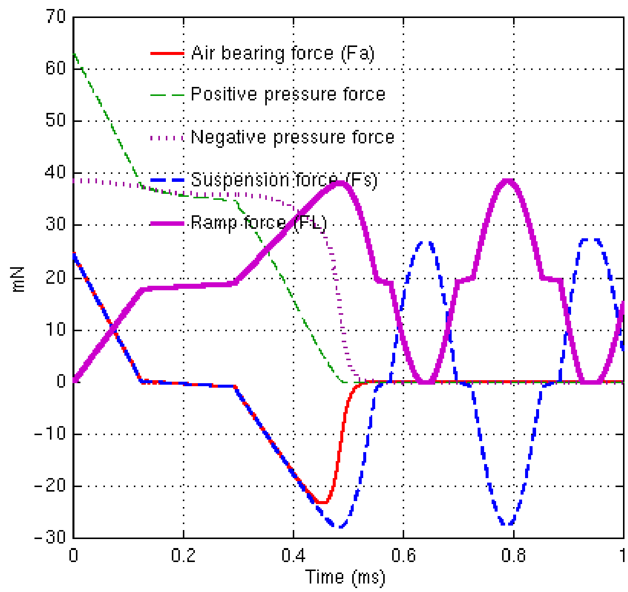


Fig. 4 Force histories of slider B unloaded with limiters

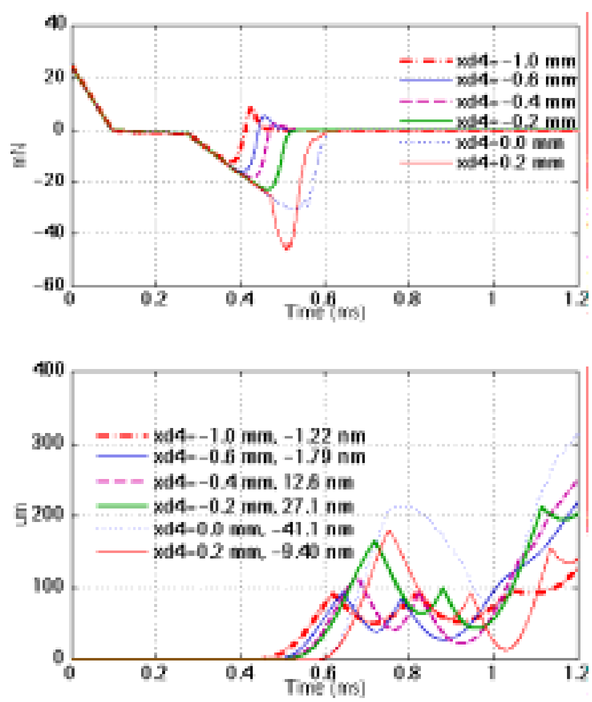


Fig. 5 Air bearing force histories and minimum clearances during the unloading process of slider B

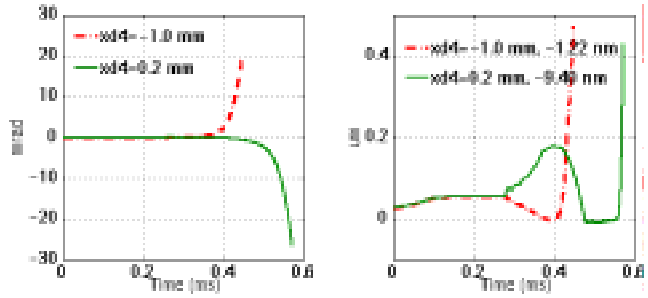


Fig. 6 Slider pitch (left) and minimum clearances (right) during the unloading process of slider B.

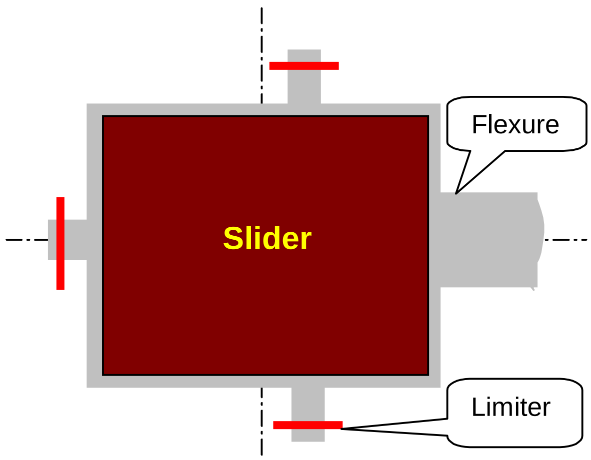


Fig. 7 Arrangement of three limiters

2.3 Static attitudes of sliders

The pitch and roll static attitudes (PSA and RSA) of the sliders affect their steady flying attitudes, and they significantly affect the L/UL performances. Figure 8 shows the lift-off force of slider B for different PSA. We see that a positive PSA causes the slider to be more easily unloaded, because the positive PSA increases the pitch of the slider. Figure 9 shows the loading process of slider B for different PSA. It is observed that a positive PSA can greatly improve the loading performance. However, for many sliders, too large a value of PSA will result in the slider's trailing edge contacting the disk, especially when the sliders experience strong oscillations. Because there is a skew angle during L/UL, the RSA also affects the loading performance. A positive RSA, which has effects that are similar to a positive PSA, can prevent slider/disk contacts.

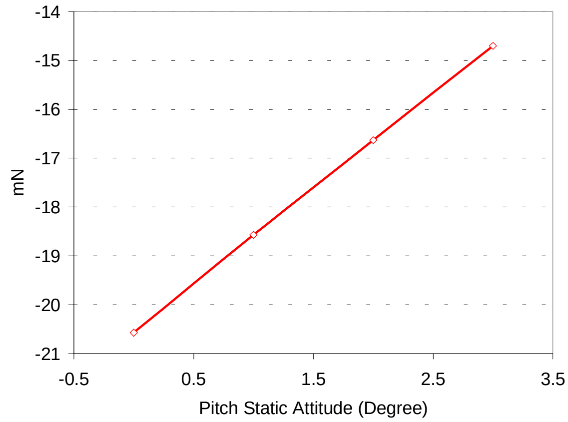


Fig. 8 Lift-off force of slider B for different PSA

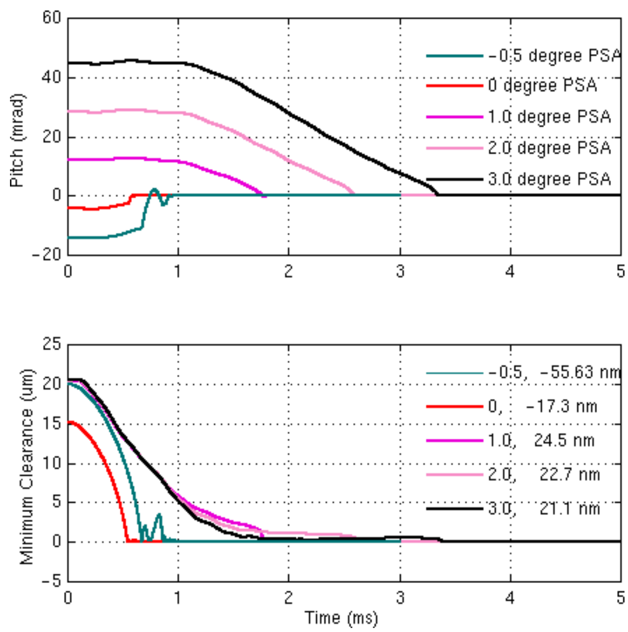


Fig. 9 PSA effects on pitch and minimum clearances of slider

2.4 Disk rpm

Because the disk rpm can be easily specified during the L/UL process in many cases, we simulated the effect of the disk rpm on L/UL performance of the sliders. Figure 10 shows the lift-off force of slider B with respect to the disk rpm. It is seen that a higher or lower disk rpm gives a smaller lift-off force, and a medium rpm gives the largest lift-off force. That is mainly because the disk rpm affects both the suction forces and slider's pitch. The higher the rpm, the larger the suction force, and thereby the larger the lift-off force. On the other hand, the higher the rpm, the larger the pitch, and thereby the smaller the suction force. It should be mentioned that different ABS designs have different relationships between the lift-off force and the rpm.

Figure 11 shows the pitch and minimum clearance histories of sliders A and B loaded at different rpm. All of the minimum values of the minimum clearances in Fig. 11 a) are larger than zero. That means no contact occurs between the disk and the slider A. All of these values in Fig. 11 b) are negative, indicating that slider B contacts the disk during loading. From this figure it can been seen that slider A has a smoother loading process than slider B, and the process is much smoother at the low RPM. Because the centers of the lift (positive pressure) and suction forces shift forward or backward as the air bearing is built up [8], the slider's pitch oscillates. At a higher RPM, there are larger lift and suction forces, so there are stronger oscillations. For slider A, the suction force always generates a positive pitch moment, so it can be smoothly loaded at different rpm. For slider B, the suction force center is located between the slider's center and the leading edge, and this results in a negative pitch moment during the entire loading process, causing contacts between the slider's leading edge and the disk. All of the other simulation results show a similar trend. Therefore, it is strongly suggested that all negative pressure sliders be loaded at lower disk rpm.

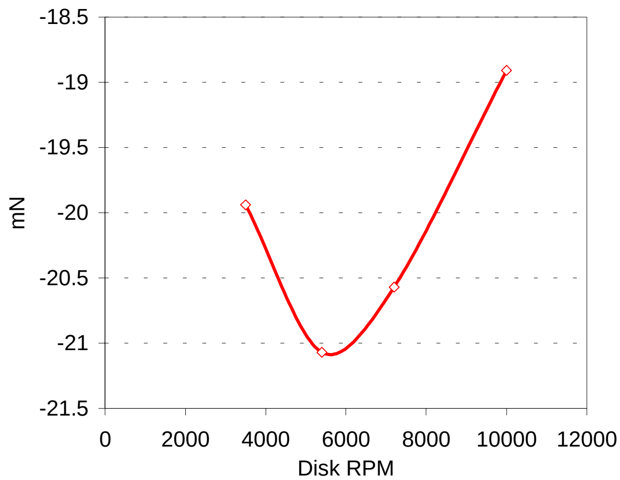
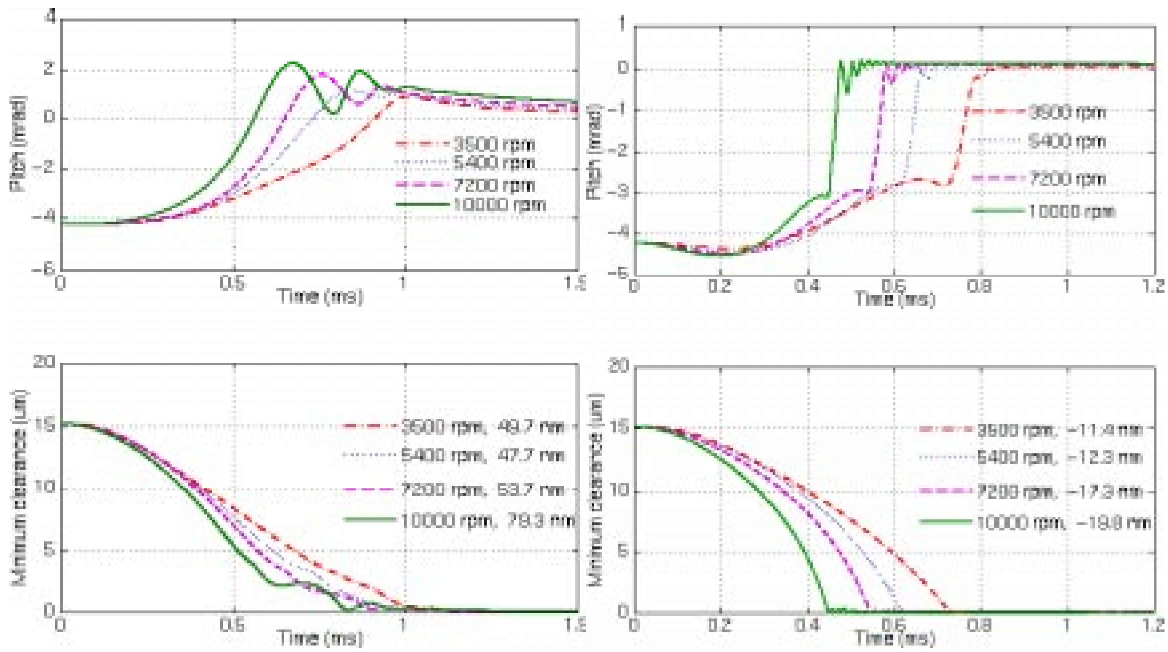


Fig. 10 Lift-off force of slider B for different disk rpm



a) Slider A b) Slider B

Fig. 11 Pitch and minimum clearance history during the loading process at different disk rpm (PSA=0 degree).

2.5 L/UL velocity

Figure 12 shows the lift-off force of slider B as a function of unloading velocity. The trend is very clear; a smaller velocity gives a smaller lift-off force because of smaller squeeze effects of the air bearing. The loading processes of the two sliders were simulated for different vertical loading velocities at 7200 rpm, 0 PSA. Higher acceleration (300 m/s^2) and initial flying height (30 μm) were used to achieve the given velocities, which are in a wide range of 12.7 to 101.6 mm/s, before the air bearing appears. The simulation results (Fig. 13) show that the velocity effects are not significant in this velocity range. Slider A doesn't contact the disk, and slider B contacts the disk in all five cases. Slider B strongly hits the disk twice at the loading speed of 12.7 mm/s and three times at 101.6 mm/s, and it lightly touches the disk at 50.8 mm/s. Therefore, slider B has better loading performance at the medium velocity, such as 50.8 mm/, while slider A has a smoother loading process at the higher velocity, as shown in Fig. 13 a).

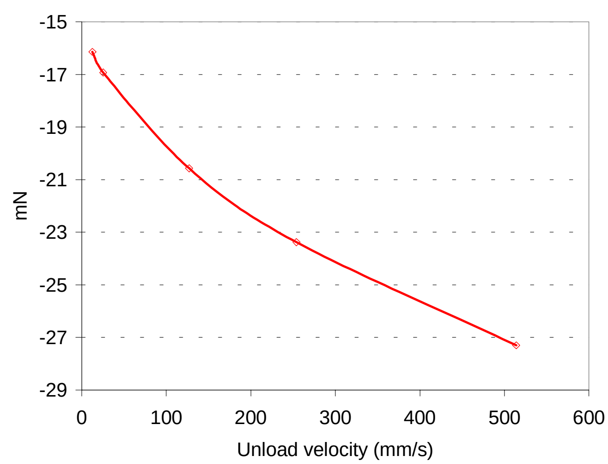
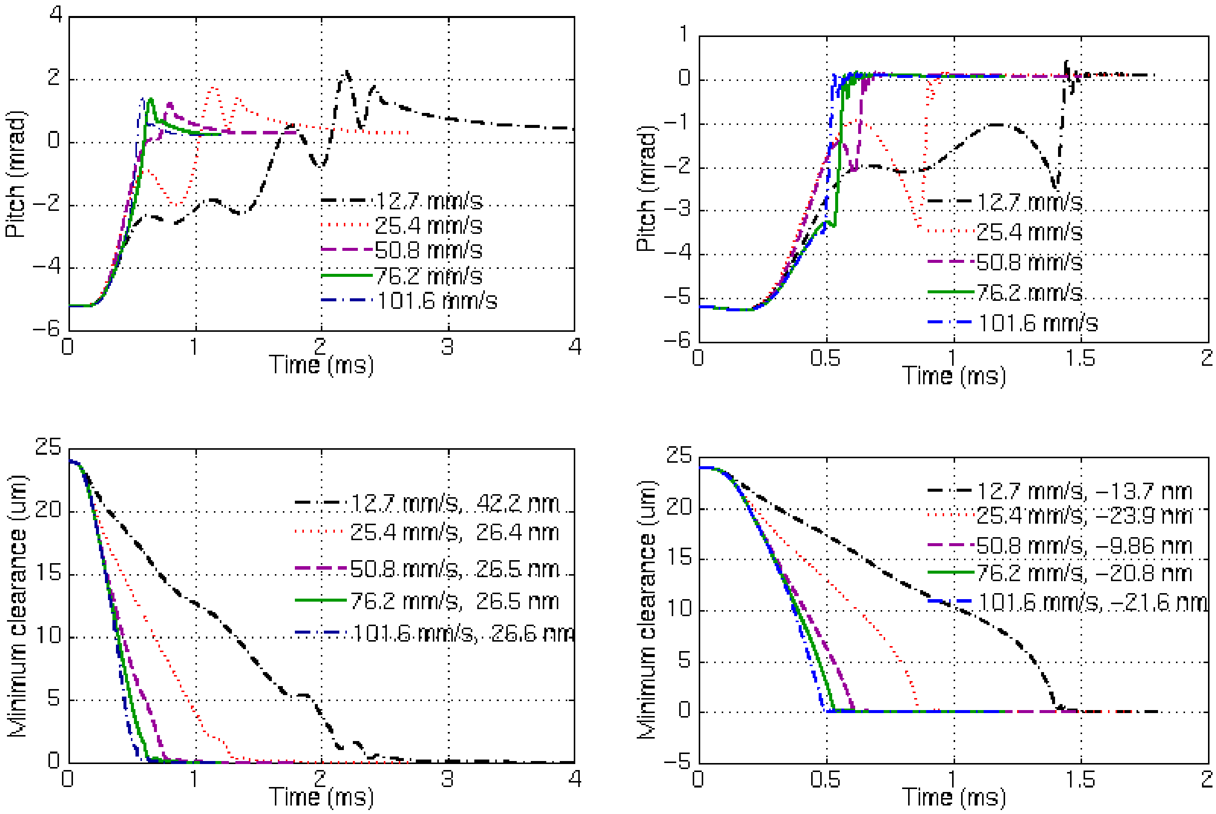


Fig. 12 Lift-off force of slider B for different unloading velocities



a) Slider A b) Slider B

Fig. 13 Effects of the loading velocity (7200 rpm, 0 PSA, 30 μm initial FH)

2.6 Ramp profile

If the actuator velocity is constant in the track seeking direction, then the vertical L/UL velocity is changed proportionally by changing the ramp profile. Slider A has good L/UL performance, and so it doesn't need a special ramp profile. We therefore designed ramp profiles to improve slider B's L/UL performance. Avoiding slider/disk contact, decreasing the ramp force, and shortening the unloading process are preferred for slider B. When the negative pressure sliders are unloaded contact may occur at two stages. The first stage is when the air bearing exists and the suspension dimple separates if the ABS and/or suspension are not properly designed, or the vertical unloading velocity is very large. This can be avoided by changing the ABS and/or suspension design, and limiting the velocity. The second stage is after the air bearing disappears, the dimple closes, and the slider strongly rebounds and then hits the disk. This can be avoided by decreasing the lift-off forces and increasing the unloading velocity. However, increasing the velocity will increase the lift-off force. This conflicted requirement can be satisfied if the ramp profile is properly designed. We designed the ramps, as shown in Fig. 14, to have a small slope at the low height, at which the air bearing exists. We achieve a low velocity and thereby a small lift-off force. The ramps have a larger slope at the higher height, at which the air bearing disappears, which provides a high unloading velocity to move the slider away. Slider B is unloaded at an 80 mm/s horizontal velocity with ramp A that has a 15 degrees uniform slope. The slider almost hits the disk at about 4.8 ms after the air bearing disappears and the slider rebounds. However, we can prevent the contacts by using any of the other three ramps as shown in Fig. 14. There are only small differences in the loading performance for the four ramp profiles. That is because the ramp profiles change the loading velocity, but the loading velocity has no significant effect on the loading process in a wide velocity range as shown in Fig. 13. We can also specially design the ramp profiles to improve the loading performance at high speed loading. Figure 15 shows another ramp profile that is designed to improve both loading and unloading performances. This ramp has a similar unloading performance as ramp D, and a better loading performance than ramps A-D.

2.7 Dimple pre-load.

Figure 15 also shows the effect of dimple pre-load on the loading process of slider B with ramp F. There is a large pitch oscillation. That is because the change of the slope of the ramp from 0 degree to 30 degrees causes a small excitation to be applied to the slider. The slider oscillates, and the dimple separates. After the dimple separates, the suspension force moves to the leading edge, and it generates a larger pitch moment [4]. This moment results in the pitch oscillation. If the dimple pre-load is increased from 0.1 mN to 1.5 mN, the dimple separation is prevented, and the pitch oscillation is significantly decreased, as shown in Fig. 15. Therefore, a larger dimple pre-load smoothens the loading process. Smoothing the ramp can also decrease the oscillation. A larger dimple pre-load can also decrease the dimple separation during unloading, and shorten the unloading process.

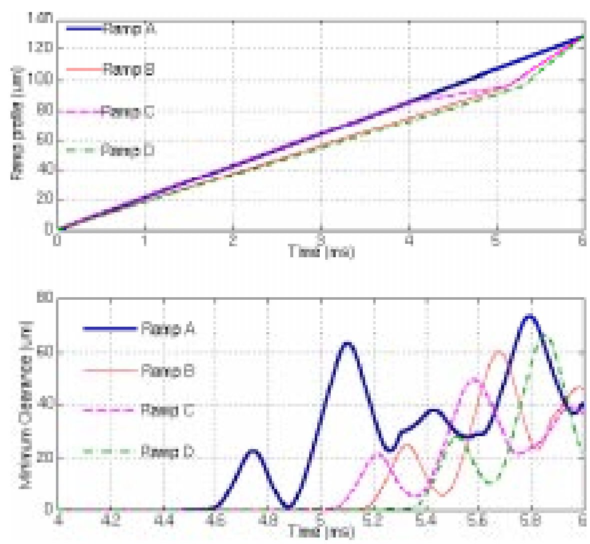


Fig. 14 Effects of ramp profile (unloading at the 80 mm/s horizotal velocity)

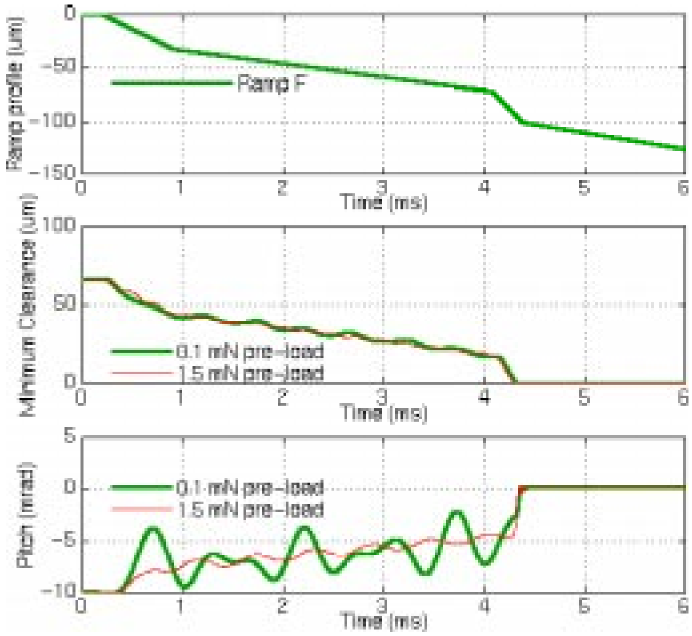


Fig. 15 Effects of dimple pre-load

3. Summary

Based on our recent research, we can summarize the desirable design features for dynamic load/unload as follows.

A) To achieve good unload performance, the key is to control the suction force, and thereby the lift-off force. A large lift-off force results in many problems, such as

- A large dimple separation that can cause gimbal damage.
- Slider/disk contacts may occur before the lift-off or after the air bearing disappears causing strong oscillations.
- A longer unload process that reduces the recordable area and/or requires a steeper L/UL ramp.
- A large ramp pressure that increases the ramp wear and unload torque.

B) The ABS design significantly affects the L/UL performance of the sliders.

- Properly designed ABS's, like slider A, can almost entirely prevent dimple separation.
- The negative pressure sliders that have good unloading performance usually have the good loading performance.
- The design guide for sliders having good L/UL performance is to keep the negative pressure regions (not only the cavities) near the center line and trailing edge during the L/UL processes while considering the worst conditions.
- Slider A can meet most of the design and fabrication requirements. The major trade-off is worse normal load sensitivity, operating shock performance, and altitude sensitivity.

C) There are many parameters that affect the unload process, such as:

- ABS design- as mentioned above.
- Disk rpm - different ABS designs show different relationships with rpm.
- Unload velocity - higher velocity gives larger lift-off force. A medium velocity is preferred for the sliders with large suction forces.
- Pitch static attitude - a positive PSA can significantly reduce the lift-off forces.
- Dimple pre-load - it can reduce the dimple separation.
- Suspension (or limiter) stiffness - smaller stiffness gives lower lift-of force and a longer unload process.
- Limiter location (offset x_{d4}) - it significantly affects the unload process.
- Limiter gap - it mainly affects the unload time. Larger gap gives a longer process.
- Ramp profile - Specially designed ramps can improve the unloading performance.

D) There are also many parameters that affect the load process, such as:

- ABS design- as mentioned above.

- PSA - a positive PSA can very effectively prevent slider/disk contact. Negative PSA should be prevented for all sliders.
- Roll static attitude (RSA) - a positive RSA can prevent contact.
- Disk rpm - the lower the RPM, the smoother the loading process. All negative pressure sliders have a better loading performance at lower RPM.
- Load velocity - different ABS designs show different relationships with the velocity. In a wide velocity range, there are no obvious effects on the loading process.
- Dimple pre-load - a proper dimple pre-load can smooth the load process.

Acknowledgments

This study is supported by the Computer Mechanics Laboratory at the University of California at Berkeley.

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