Effects of Suspension Limiters on the Dynamic Load/Unload Process: Numerical Simulation[1]

Qing-Hua Zeng and David B. Bogy

Computer Mechanics Laboratory,
Department of Mechanical Engineering,
University of California at Berkeley, CA 94720, USA

Abstract

Specifically designed suspensions with limiters are currently used in disk drives with dynamic load/unload (L/UL) mechanisms. We simulate the L/UL process of air bearing sliders mounted on this kind of suspension. A simplified suspension model is presented, two pico-sliders are designed and simulated, and the effects of the suspension parameters related to the limiters are investigated. We find that the air bearing design, unload speed, and the limiter parameters (gap, offset and stiffness) significantly affect the unloading process. A smaller gap, medium stiffness and speed, and a properly designed offset are required for good unload performance. There is no effect of the limiters on the loading process.

---

[1] This report has been submitted for publication in *IEEE, Transaction on Magnatics*.

I. INTRODUCTION

Dynamic load/unload (L/UL) has been widely used in portable and removable drives. As the glide height continuously decreases to provide higher recording density, the implementation of effective landing zones for contact start stop (CSS) is becoming more difficult. As current CSS technologies are reaching their performance limits, L/UL is considered as one of the best alternatives to CSS. Therefore, the disk drive industry is showing an increased interest in L/UL for future desktop and server drives.

The main design objectives of the L/UL mechanisms are no slider-disk contact or no media damage even with contact during L/UL, and a smooth and short unloading process. Jeong, Fu and Bogy [1]-[3] studied L/UL systems by experiment and simulation to find the conditions for avoiding slider-disk contacts. Suk and Gillis [4] researched the effect of slider burnish on disk damage during L/UL. Zeng et. al. [5], Hu et. al. [6] and Peng [7] investigated the unloading process of negative pressure sliders, and showed that the suction forces result in severe problems for most current sliders during unload. To prevent these problems, Zeng and Bogy [8] designed sliders specifically for L/UL applications, and achieved the preferred performance. However, to easily combine all of the design requirements, such as shock resistance, altitude and normal load insensitivity, the industry currently employs another approach, specifically designed suspensions with limiters. In this paper, we study the L/UL simulation of air bearing sliders and suspensions with limiters. A simplified suspension model is presented, two pico-sliders are designed and simulated, and the effects of the suspension parameters related to the limiters are investigated. We find that the limiter design will greatly affect the unloading process.

II. MATHEMATICAL MODELS

The mathematical models used in this paper are similar to those used in our previous papers [6, 8] although there are some important differences. The air bearing pressure is governed by the generalized Reynolds equation. If the air bearing clearance is less than the glide height, the asperity contact force and moments are calculated by the Greenwood-Williamson method. If the clearance is less than or equal to *0*, the elastic-plastic model is used to approximately calculate impact force and moments. During the impact process, one cannot directly solve the Reynolds equation. An approximation is adopted in the simulation, whereby if the clearance at any grid is less that 0.1nm, the pressure is set to zero in agreement with results from DSMC studies [10].

The suspension is modeled as a spring/damper system, in which the suspension force and moments applied on the slider in the vertical, pitch and roll directions are

$$f_z = k_{zj}\left[z + x_{dj} * \sin(\theta) + y_{dj} * \sin(\beta) - vt - z_0\right] + c_{zj}\left[\dot{z} + x_{dj} * \dot{\theta} + y_{dj} * \dot{\beta} - v\right] \tag{1}$$

$$M_\theta = k_{\theta j}\theta + c_{\theta j}\dot{\theta} + x_{dj} f_z \tag{2}$$

$$M_\beta = k_{\beta j}\beta + c_{\beta j}\dot{\beta} + y_{dj} f_z \text{, } j=1,2\text{ ,}\ldots\text{,}Ns \tag{3}$$

where z is the vertical displacement at the slider's center, and θ and β are the slider's pitch and roll. v is the L/UL speed (a positive v for UL). *Ns* is the number that possible suspension states. The number is determined by the combinations of the contact states at the L/UL tab, dimple and limiters. In each state, the suspension has different stiffness k_{zj}, damping coefficient c_{zj}, and offset in the pitch and roll directions x_{dj} and y_{dj}. The state is changed during the L/UL process depending upon the slider's attitude or suspension force and moments. The effects of suspension inertia are included in the slider's inertia moments. The effective inertia moments are calculated by combining the calculated stiffness values and the measured modal frequencies of the pitch and roll modes of the slider.

III. SIMULATION RESULTS

Two 30% sliders (A and B) with air bearings as shown in Fig. 1, are assumed to be mounted on suspensions with a dimple and two limiters and simulated to investigate the L/UL process. Slider A was specially designed for L/UL applications based on our recent paper [8]. Slider B was designed with a cavity near the leading edge of the slider, which creates a large lift-off force and hence a worse L/UL performance, as shown in [8]. These are two extreme designs, and the L/UL performances of most current slider designs are expected to be between them. The two sliders have almost a uniform 30 nm flying height from the ID (21.2 mm, -7.5^o) to the OD (45 mm, 16^o) at 7200 RPM. A wireless suspension with limiters was used in the simulation. The suspension is similar to the HTI 2030 TSA, but a L/UL tab and two limiters were added for the L/UL application. The two limiters are located at the two sides of the slider and near the slider's center. In the base case, the suspension parameters were obtained from a FE model that was verified by modal experiment.

The loading process was simulated first. It is found that there are no effects of the limiters even when the sliders have strong oscillations during the loading process. Slider A has better loading performance than slider B. Both sliders have smooth loading processes at low RPMs, such as 3000 RPM. Then, the UL performances without the limiters were simulated, in which case the suspension has three states. In the third state, the dimple is open, and we used 25 N/m for k_{z3} and –0.8 mm for x_{d3} (from the slider's center to its leading edge). The air bearing and suspension force histories are shown in Fig. 2, where we see that slider A can be smoothly unloaded in a short time, but slider B generates a large lift-off force (the minimum amplitude of the air bearing force) that causes dimple separation, and it takes a longer time to unload. So, the limiters are required to satisfactorily unload slider B. All of the following results are for slider B with limiters.

If the two limiters have different gaps or the slider has a significant roll, the two limiters engage at different times, and then the suspension has at least five states. We find that the fourth state, in which only one limiter engages, is very short, even when one limiter gap is 0.025 mm and the other is 0.075 mm. This is because after one limiter closes the suspension force increases quickly due to a larger stiffness associated with this state, and the roll changes rapidly due to a larger offset in the Y direction. Therefore, a difference of the limiter gaps doesn't obviously affect the unloading process, and so the smaller gap can be used as the gap of the two limiters. This also explains why the fourth state is not observed in all experimental data of many measured samples [9]. In the following cases, we only simulate both limiters closed or open at the same time, and so the suspension has only four states. In the fourth state, the L/UL tab contacts the ramp, the dimple separates, and the two limiters engage. Because the suspension parameters in this state, such as the gap, k_{z4} and x_{d4}, can be easily changed by modifying the limiter design to achieve the preferred performances, we simulated the effects of the gap, k_{z4}, and x_{d4}. In the base case, the unload speed (vertical) is 254 mm/s, the gap is 0.05 mm, stiffness k_{z4} is 500 N/m, and offset x_{d4} is –0.2 mm.

Figure 3 shows that the limiter gap only affects the unload time. The smaller gap gives a shorter unloading process. Comparing Fig. 3 with Fig. 2 b), we see that the limiters greatly affect the unload process. The process has five stages, and the limiters engage in the third and fifth stages. The limiters increase the lift-off forces from 9.41 mN (without limiters) to 23.4 mN, and decrease the unload time from 1.8 ms to 0.55 ms. Because of the large lift-off forces, the slider strongly oscillates in the fifth stage as shown in Fig. 3b. This results in a high risk of slider/disk contacts.

Figures 4-6 show the resulting unload air bearing force histories and minimum clearances between the disk and the slider for different x_{d4}, k_{z4} and v. The non-smooth curves in the force histories and the negative minimum clearances indicate that the slider contacts the disk. From Fig. 4, we see that slider B can be smoothly unloaded only in a small range of x_{d4} when v=254 mm/s, k_{z4}=500 N/m. Figure 7 shows a small x_{d4} (-1.0 mm) results in the slider contacting the disk at the trailing edge for a large positive pitch, although it has smaller lift-off forces. A large x_{d4} results in the slider hitting the disk at the leading edge for a large negative pitch, and also results in a large lift-off force and strong slider oscillations during unload. As shown in Fig. 5, this range becomes wider and the lift-off forces become smaller when a smaller k_{z4} is specified. However, the unload processes become longer. Figure 6 shows that there are additional chances for the slider to contact the disk when it is unloaded at a lower speed. The severe impacts occur after the air bearing disappears when large or small offsets are used. A small or large offset results in strong slider pitch oscillation and thereby the slider hitting the disk.

IV. CONCLUSION

The dynamic L/UL simulation of air bearing sliders and suspensions with limiters is studied. A simplified suspension model is presented, two pico-sliders are designed and simulated, and the effects of the suspension parameters related to the limiters are investigated. We find that the air bearing design, unload speed, and suspension limiter parameters (gap, offset and stiffness) significantly affect the unloading process. A proper design of these five aspects is important for good unload performance. A smaller gap, a medium stiffness and unloading speed, a properly designed offset, and a strictly controlled offset tolerance are preferred. There is no effect of the limiters on the loading process.

ACKNOWLEDGMENTS

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

REFERENCES

[1] T. G. Jeong and D. B. Bogy, "An experimental study of the parameters that determine slider-disk contacts during dynamic Load-Unload," *ASME J. of Trib.*, Vol. 114,pp. 507-514, 1992.

[2] T. G. Jeong and D. B. Bogy, "Numerical simulation of dynamic loading in hard disk drives," *ASME J. of Trib.*, Vol. 115, pp. 307-375, 1993.

[3] T. C. Fu and D. B. Bogy, "Slider-disk contacts during the loading process in a ramp-load magnetic disk drive," *Adv. Info. Storage Syst.*, Vol. 6, pp. 41-54, 1995.

[4] M. Suk and D. Gillis, "Effects of slider burnish on disk damage during dynamic load/unload," *ASME J. of Trib.*, Vol. 120, pp.332-338, 1998.

[5] Q. H. Zeng, M. Chapin and D. B. Bogy, "Dynamics of the unload process for negative pressure sliders," *IEEE Trans. Magn.*, in press. [*Dig. of Asia-Pacific Magn. Recording Conf., Singapore*, July 29-31, 1998].

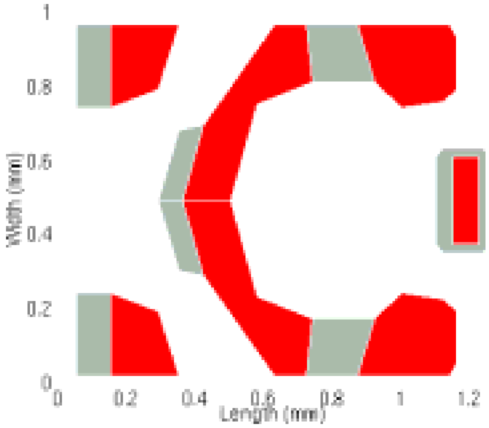
[6] Q. H. Zeng and D. B. Bogy, “Slider air bearing designs for load/unload applications,” *IEEE Trans. Magn.*, in press. [*Dig. The Magnetic Recording Conference (TMRC), Colorado*, Aug. 17-19, 1998].

[7] Y. Hu, P. M. Jones and K. Li, “Air bearing dynamics of sub-ambient pressure sliders during dynamic unload,” ASME/STLE, International Tribology Conference, Toronto, Canada, Oct. 25-28, 1998.

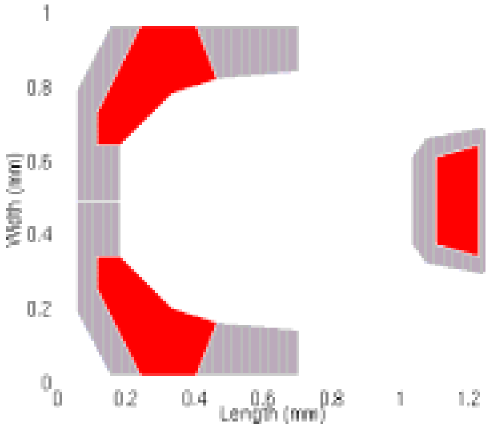
[8] J. P. Peng, “Theoretical prediction of ramp loading/unloading process in hard disk drives,” ASME/STLE, International Tribology Conference, Toronto, Canada, Oct. 25-28, 1998.

[9] M. Chapin and D. B. Bogy, “Air bearing force measurement of pico negative pressure sliders during dynamic unload,” unpublished.

[10] W. Huang and D. B. Bogy, “An investigation of a slider air bearing with an asperity contact by a three-dimensional Direct Simulation Monte Carlo (DSMC) method,” *IEEE Trans. Magn.*, Vol.34, 1810-1812, 1998.

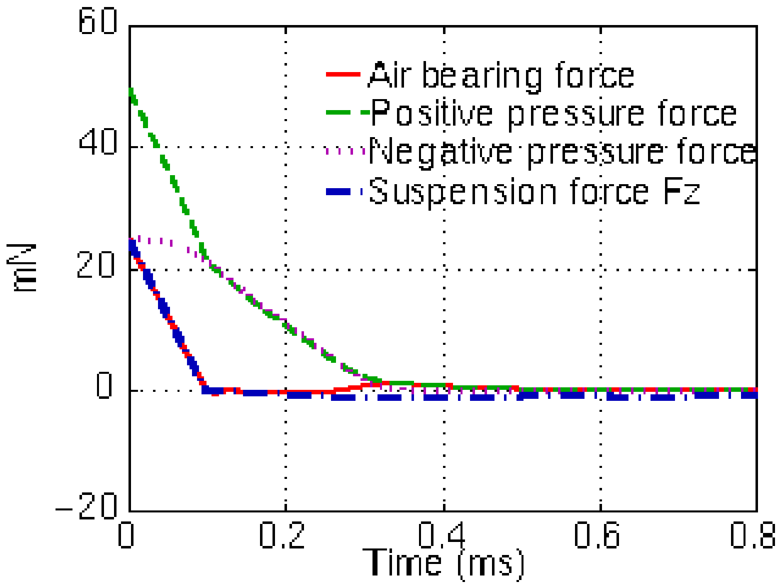


a) Slider A

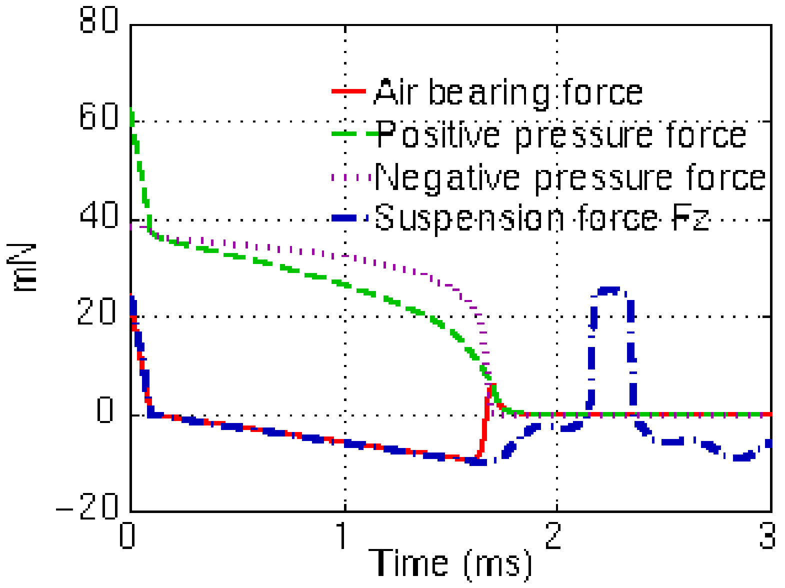


b) Slider B

Fig. 1 Two sliders used in the simulation

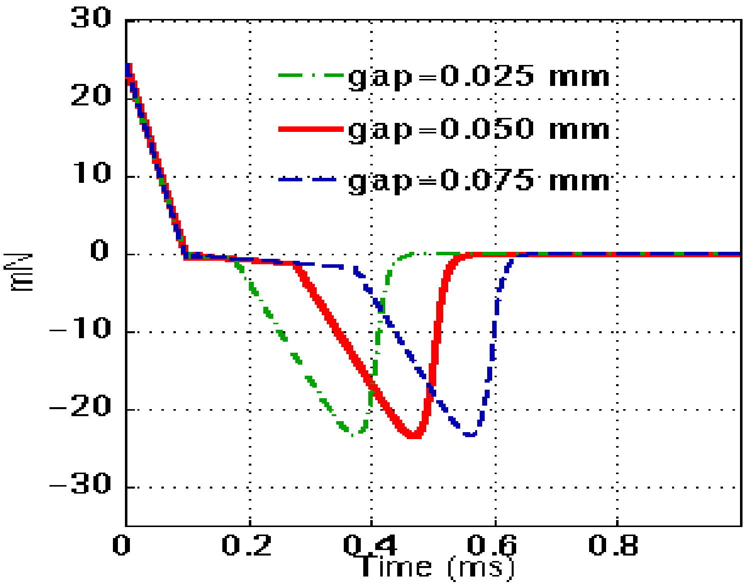


a) Slider A

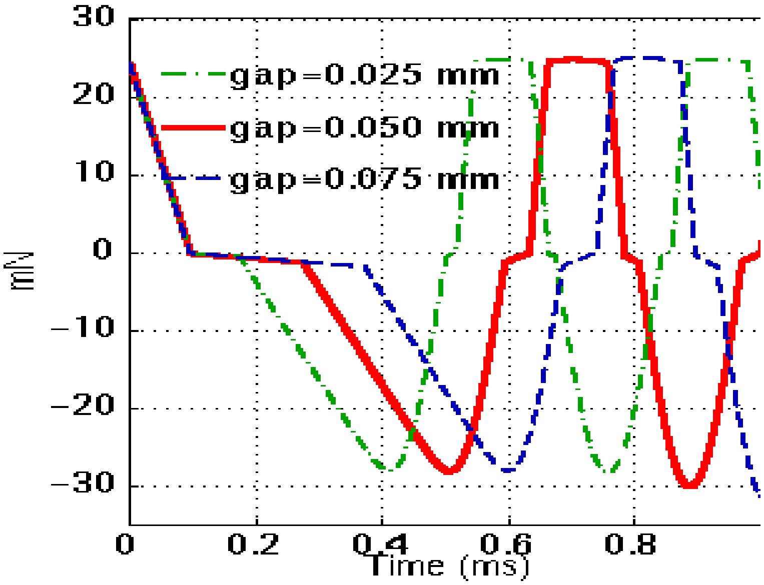


b) Slider B

Fig. 2 Unloading process without limiters (*v*=254 mm/s)



a) Air bearing forces



b) Suspension forces

Fig. 3 Force histories during the unloading process with different limiter gaps

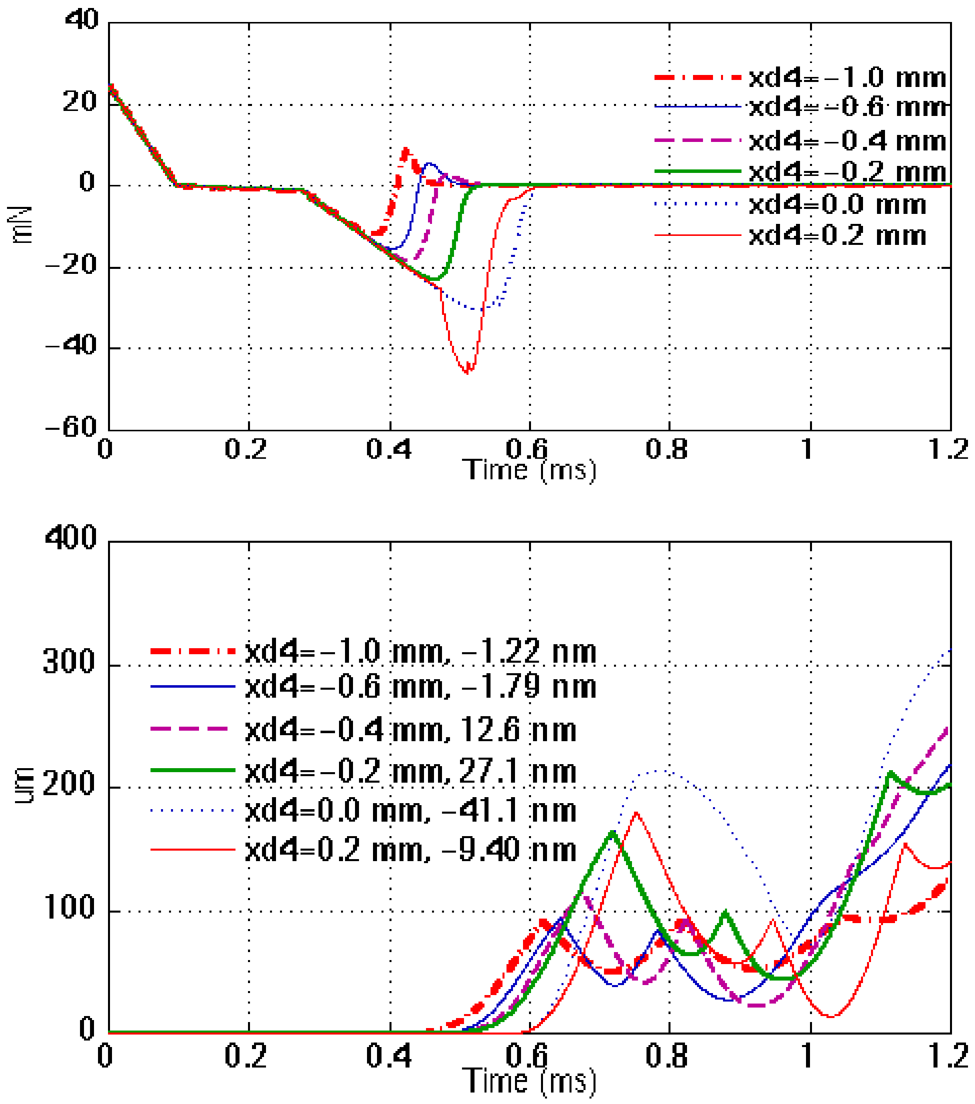


Fig. 4 Air bearing force histories and minimum clearances during the unloading process of slider B (*v*=254 mm/s, k_{z4}=500 N/m)

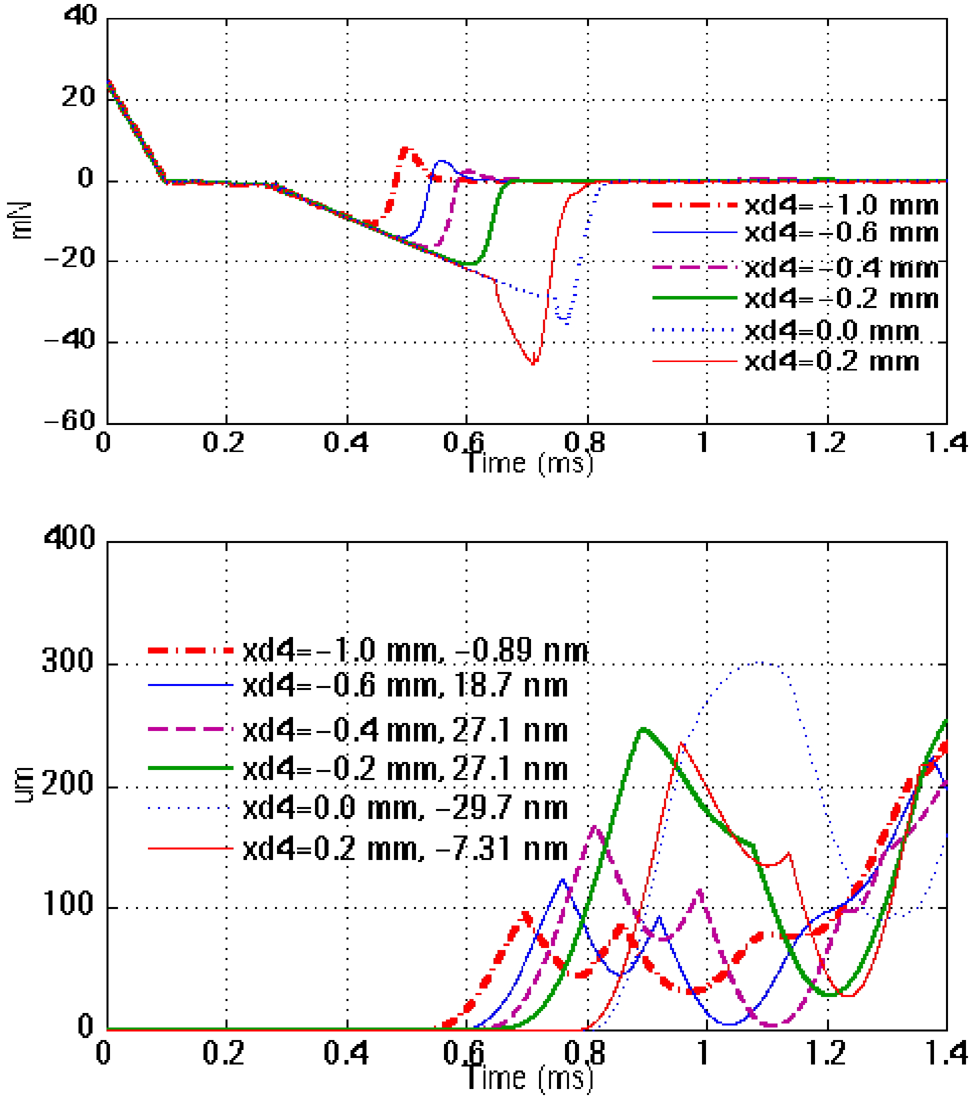


Fig. 5 Air bearing force histories and minimum clearances during the unloading process of slider B (*v*=254 mm/s, k_{z4}=250 N/m)

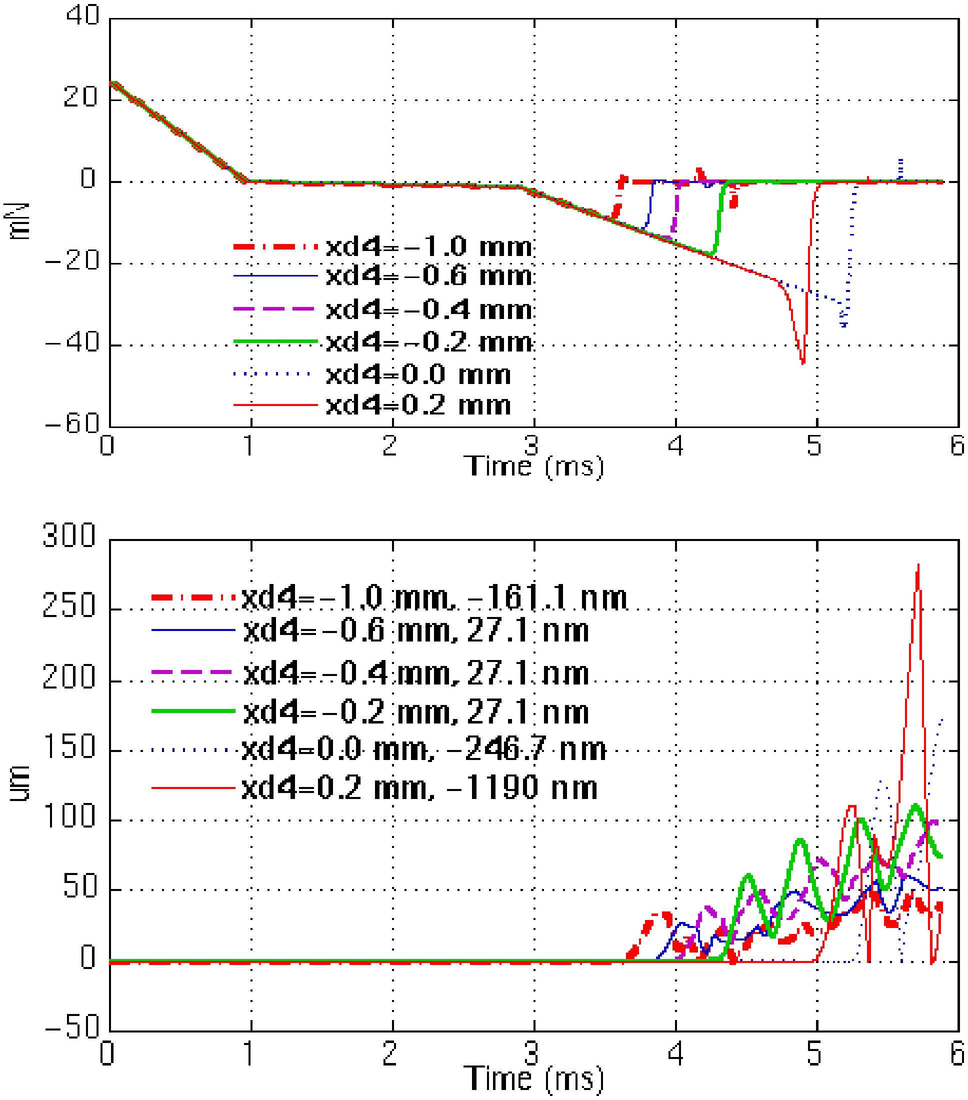
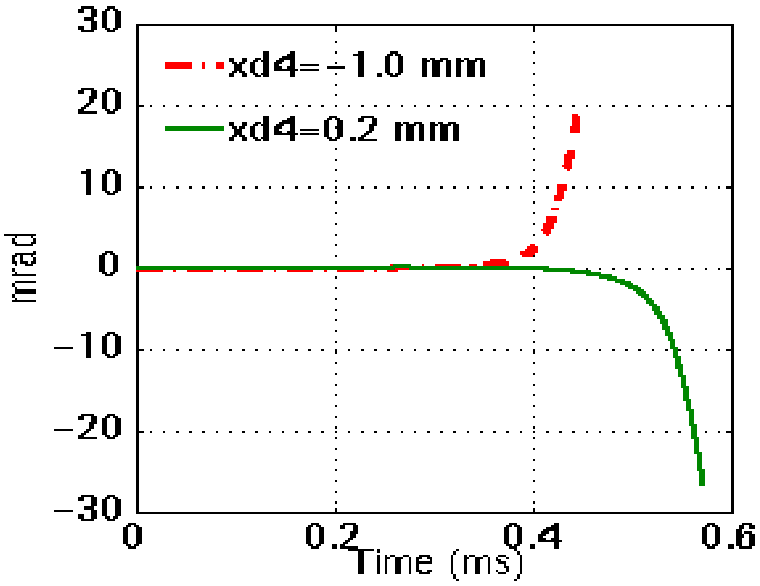
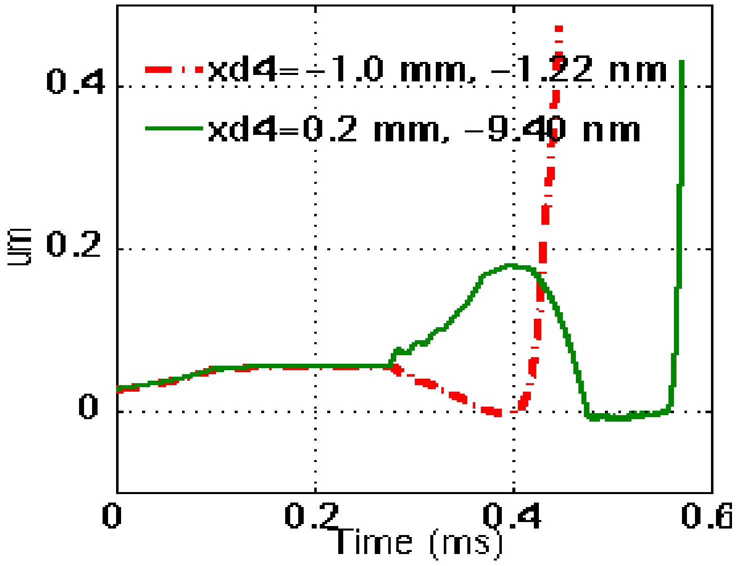


Fig. 6 Air bearing force histories and minimum clearances during the unloading process of slider B (*v*=25.4 mm/s, k_{z4}=500 N/m)



a) Sldier pitch



b) Minimum clearances

Fig. 7 Slider pitch and minimum clearances during the unloading process of slider B (v=254 mm/s, k_{z4}=500 N/m)