Friction Effect on Loading Process and Multiple Stable Flying States of Air Bearing Sliders

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Abstract
One reason to use load/unload (L/UL) technology in hard disk drives is to avoid friction and stiction between sliders and disks during a start and stop process. However, friction between sliders and disks can still exist and has a strong effect on loading because sliders may contact disks during loading. In this paper, a new simplified friction model was proposed and implemented into the L/UL simulation code. Then, we studied two cases: A 10000 rpm server drive and A 1.0 inch Microdrive. It was found that the friction effect is smaller in the server drive case, while it is dramatic in the Microdrive case. Simulation with the proposed friction model shows that sliders will load to the third stable state if PSA is negative and the friction is big enough. In the third stable state, the slider has a negative pitch angle, and its leading edge continuously drags on the disk. In this state, we cannot do any reading/writing, and disks and sliders can be damaged.

1. Introduction
It was found that when the friction is big and PSA is not in the preferred range, the loading process will fail. There are many published papers on L/UL related studies [1-3]. However, there is no any paper describing the friction effect on the loading process. When a slider flies on a spinning disk, the self-generated air bearing force will balance with the suspension gramload and moments. As a result, the slider flies in a stable state – normal state. However, if parameters are in the right range, such PSA is too big, the sliders might load to another stable state – high flying state or HP state (about 1 um flying height, a very high pitch) described in [3]. At the HP state, we could not do any reading/writing operation. Recently, we observed that sliders can have a third stable flying state when the friction exists. In the third stable state, the slider has a negative pitch angle, and the slider trailing edge is higher than the leading edge, then we definitely cannot do any reading/writing, and disks and sliders can be damaged because the slider continuously drags on the disk.

2. Theoretical Background
The slider dynamics model, suspension model and numerical solutions are very similar to those used in paper [1], but we used a different friction model. Based on experimental observations, we proposed a simplified friction model

\[ F_c = u_n F_c + u_a A_c \times 10^6 \]  

where \( F_c \) is the normal contact force, \( u_n \) is the normal friction coefficient, and \( u_a \) is the constant area friction coefficient (N/m²). \( A_c \) is the “contact area” (m²). If \( u_n = 0.1 \), \( u_a \) should be in the range between 0.5 and 2.0 N/m² normally. \( u_n \) and \( u_a \) are determined by many factors, such as slider/disk surfaces, lubricant, humidity, overcoats, etc. Practically, we cannot control the slider/disk friction very well, so we should design the slider/disk interface to be reliable in a wide range of \( u_n \) and \( u_a \) values. Drives will fail if they are larger than those values. Following simulation will find these critical values.

3. Case Studies

3.1 Two cases. We studies two extreme cases: a 10k RPM/84 mm disk server drive with a Pico slider and a 3600 RPM/1.0 inch Microdrive with a Femto slider. We focused on the PSA and friction coefficient effects on the loading process, and fixed all other parameters.

3.2 Loading process of the server drive. If PSA = -0.2°, the slider contacts the disk strongly in a short period of time. It could damage the disk, but the slider did quickly load to the normal state or LP state with a low FH and pitch angle after the contact as shown Fig. 1. The friction effect is shown in Fig. 2. As \( u_a \) increases from 0.5 to 1.5, its effect is small. However, when \( u_a = 1.7 \), its effect becomes very significant. The slider’s leading edge keeps contacting to the disk for more than 1.0 ms. When \( u_a \geq 1.8 \), the slider cannot be fully loaded as shown Fig. 3. It has a negative pitch and a very large FH. The leading edge keeps contacting to the disk. It reaches a quasi “balanced” state. We call this state as a “negative pitch state” or NP state. The critical friction coefficient is 1.8 in this case.

3.3 Loading process of the Microdrive. If PSA = -0.2°,
and $u_a=0.1$ and $u_b<1.0$, the slider loads to the LP state. However, if $u_a\geq 1.0$, the slider loads to the NP state as shown in Fig. 4. In this case, the critical friction coefficient is 1.0 that is much smaller than the server drive case. The suspension force is balanced with the suction force and the contact force. There is no lift force. The NP state is a balanced state. Is it stable? In the NP state, let the slider fly over a bump on the disk to see if the slider can stay at this state or change to other states. When the slider hits the bump with a 15.0 nm bump height (and 30x30 um area), it still settles to the NP state, so it is a stable state. After it hits the bump with a 30 nm height, it settles to the LP state.

4. Discussions and summary

The slider air bearings with a sub-ambient pressure have lift force $F_{al}$ and suction force $F_{as}$. Logically, it could have three combinations:

a) $F_{al}>0$, $F_{as}>0$; b) $F_{al}>0$, $F_{as}=0$; c) $F_{al}=0$, $F_{as}>0$

Then, we could have three balanced states that are shown in the cases studies. However, whether they would occur in the drives practically is highly depended on the design parameters. If sliders load to the HP or NP states, the drives fails because they cannot operate properly and reliably.

One of most obvious solutions is controlling PSA. If PSA=0, the slider wouldn’t load at the NP state theoretically. However, if there is any disturbance during loading or even in the normal frying state, the pitch angle can be negative, and the leading edge can contact the disk instantly. Then, the slider would stay at the NP state if the friction is big enough. Therefore, only controlling PSA might not be reliable enough.

In summary, we successful predicted the NP state with the proposed friction model. The main parameters that determine if the slider would load on the NP state are PSA, the friction force between slider and the disk, ABS design and the disk speed. The friction force is determined by many other parameters. The low disk speed drives have a much higher risk to have the NP state than the high disk speed drives.

Fig. 1 Loading process of a server drive (PSA=-0.2°)

Fig. 2 Loading of the server drive ($u_a=0.1$, PSA=-0.2°)

Fig. 3 Loading process of a server drive (PSA=-0.2°)

Fig. 4 Loading process of a micro drive (PSA=-0.2°)

