Head-Disk Interface : Migration from Contact-Start-Stop to Load/Unload

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1. Contact-Start-Stop

In the computer information storage technology of magnetic recording rigid disk drives, an important issue related to increased storage densities is the tribological problem of the head-disk interface. An air-bearing slider carries the magnetic read/write transducer and positions it at designed spacing above the disk surface when the disk is rotating at full speed. The flying height in current drives is about 25 to 50 nm. When the drive is switched off, the disk slows below a speed at which the air bearing will support the load applied to the slider by its suspension, which causes the slider to rub in contact with the disk. The process of starting and stopping is called contact-start-stop (CSS) and usually takes place in a dedicated start-stop zone on the disk. The contact between the two surfaces results in wear of the mating surfaces, and it is the wear that presents one of the greatest challenges for increasing the storage densities in future products using this technology.

The problem of the static and sliding contact that takes place in disk drives, where the surfaces must be considered as statistically rough, is more complicated than it first appears. It is not a matter of one smooth surface sliding in one dimensional motion next to another one. The static contact of statistically rough and non-planar surfaces is already formidable. If one imagines a slider being loaded gently against a non-rotating disk, the following sequence would be predicted. First, the surfaces would touch in as few as three isolated spots that would determine the initial relative orientation of the surfaces. These three points would be determined by the distribution of asperities and the planarity of the two surfaces, and the three locations would be different if either of the surfaces were changed or even if the position on the disk were to change. This is because of the statistical nature of the surface roughness and of the manufacturing tolerances involved. If the load on the slider were increased until the design load of the suspension is reached then the situation would be even more complicated. The initial asperities would become deformed, possibly even to their yield points, and other asperities would come into contact and assume some of the load. When the slider is fully loaded, the number of contacting

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asperities and the magnitude of the load on each asperity are related to the profiles of the mating surfaces and the material properties of the slider and disk. This is the situation during static contact, and it is quite difficult to analyze quantitatively, requiring a statistical approach.

Now imagine that after this static loading process is completed, the drive is turned on and the disk begins to rotate at increasing speeds until it reaches its design speed. In the initial stages, when the surfaces are rubbing, a surface profile on the disk that is continuously changing passes by the slider and the contact condition, including the contact points and the severity of loading at these points, must change. This means that impacts and rebounds will take place which will excite the vibrations of the structural components of the system. These include the slider, disk, suspension, actuator, and possibly other parts. These components all have their own structural resonances and the entire assembly may have additional ones. The dynamical contact condition, with its contact and impact stresses, may be fundamental to the failure and associated wear of the material. It is conceivable that the severity of the contact and impact stresses in this dynamical process depend on the structural response of all the assembly components as well as on the materials that make up the slider and disk.

One method of increasing the durability of the disk is to reduce the roughness of the disk. Reducing the roughness of the disk also allows the head to fly closer to the disk surface which is required for increasing the storage density. However, with smoother disks, the tendency for the mating surfaces to stick increases when they are left in static contact during the off periods of the drive. Hence, the roughness of the disk surface must be chosen as to balance the two opposing problems: durability and stiction (static friction).

Controlling the roughness of the start-stop zone while ensuring acceptable level of head-disk interface stiction and durability performances remains a formidable task. To overcome some of the difficulties, the disk drive industry has been and continues to investigate new lubricants, tougher carbon overcoats, and non-mechanical texturing processes like the laser texturing process. (1) In the laser texturing process, a series of small bumps are created on the substrate by pulsing with a high-energy laser. The typical size of the bumps is about 20~30 um in diameter and 15~30 nm in height. The bumps are separated by 10~50 um radially and tangentially. Figure 1 shows a series of laser bumps on a disk in the start stop zone. An atomic force microscope image (AFM) of a single bump is shown in Fig. 2 .

There is no deterministic approach to quantifying the quality of the head/disk interface because of significant variability in tribological properties between one set of heads and disks to another. Therefore, all the testing are statistical in nature,

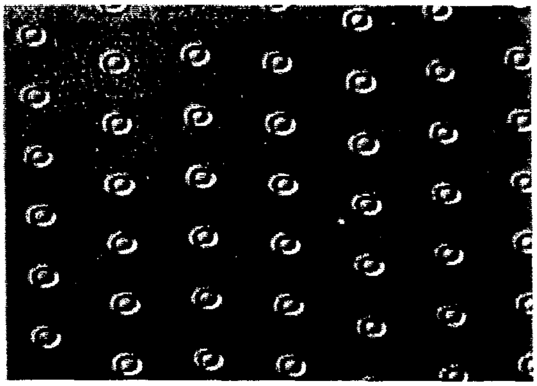


Fig. 1 A series of leaser bumps in the start/stop zone of an Al-Mg disk

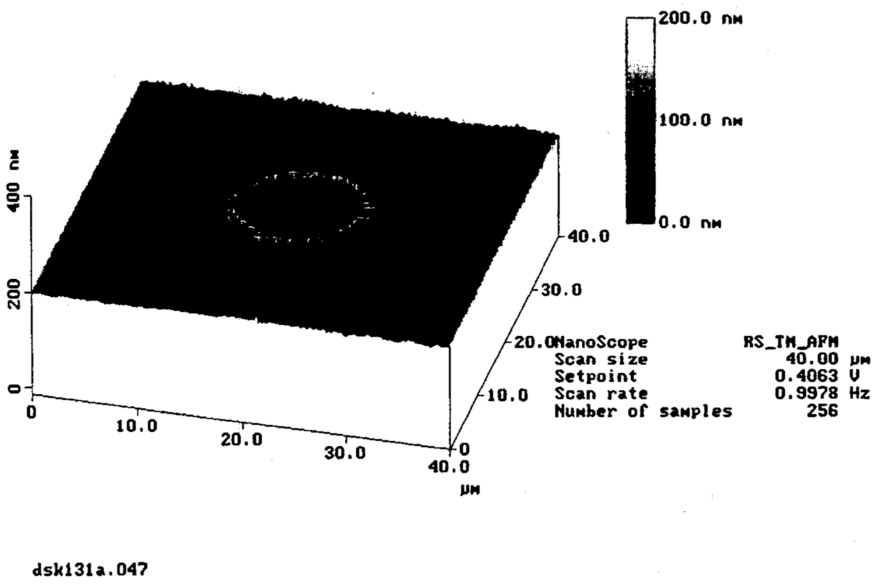


Fig. 2 An AFM image of a single laser bump

i.e., many parts are tested to determine the average life and standard deviation. Due to many unknown parameters, it is nearly impossible to design and then manufacture a set of heads and disks that can survive a preset number of start/stop cycles with stiction values within an acceptable range. Hence, many sets of statistical tests are run while varying several parameters, such as, the disk and head carbon thicknesses, disk lubricant thickness, disk surface roughness, etc. In essence, the interface is designed, more or less, by trial and error consuming significant amount of resources and time.

The methods used in evaluating the quality of the head/disk interface or durability are quite common across the disk drive industry. The typical test employed is called start/stop test which uses strain gauges to measure stiction and kinetic friction as the disk spins up from rest to the design speed. A typical output of the strain gauge is shown in Fig. 3 where the vertical axis is in grams which is the accepted unit used for force in the disk drive industry. The curve shown is Fig. 3 is called a Stribeck diagram and represents the change in the friction force as the slider moves from boundary lubrication to hydrodynamic lubrication regime where the slider is flying on a cushion of compressed air. Frequently, an acoustic emission (AE) sensor is also used to make similar measurements. Since AE sensors are much more sensitive, they are more commonly used to determine the disk speed at which the slider clears the disk. The test is usually run until a

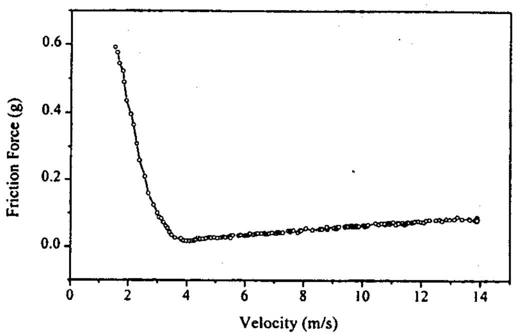


Fig. 3 Striebeck diagram showing the change in the friction force as a function of disk liner velocity

visible scratch is shown on the disk or the friction rises over a certain value.

2. Load/Unload

An alternative technology that can circumvent the undesirable issues related to wear durability and stiction problems is called load/unload(L/UL), which has been implemented since early disk drives with 14 inch removable drives. In the pure mechanical sense, the first hard drive ever designed and sold by IBM in 1956 also had L/UL technology as the heads were moved from one disk surface to another by a vertically moving actuator. In the middle of 1980's, L/UL was reintroduced into large and small form factor files to avoid head/disk stiction and durability problems all together. The system is designed so that the slider does not touch the disk surface at any phase of the disk drive operation this is not always true, however, since the slider does tend to contact the disk momentarily during the L/UL process. When the drive is not in operation, the slider carrying suspension sits on top of a ramp which lifts the slider completely off the disk surface. During the drive start phase, the suspension slides off the ramp at a controlled speed and the slider loads onto the disk surface while the disk is spinning at some designed speed. The average loading velocity of the slider is servo controlled by monitoring the back-emf of the actuator voice coil motor. When the drive is turned off, the slider is moved off the disk surface before the disk comes to a full stop. Figure 4 shows the typical layout of a ramp L/UL system.

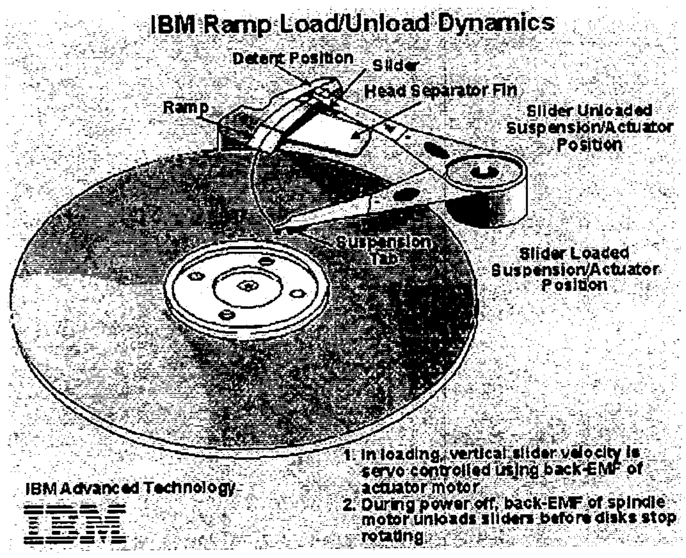


Fig. 4 The ramp load/unload mechanism

Most of the published research on L/UL technology has been carried out by Yamada and Bogy(2), Tagawa and Hashimoto(3), Kajitani et al.(4), Jeong and Bogy(5~7), and Fu and Bogy.(8) Although testers used by the above authors had some differences, the general theme was usually similar. Perhaps one of the most important conclusions made by their research is that the actual landing velocity of the slider can be much greater that the designed average loading velocity due to flexure vibration.(6) This revealed that merely controlling the average loading/unloading velocity was usually insufficient to prevent head/disk contacts. Recent works by Suk and Gillis(9) and Suk and Jen(10) showed that the slider does hit the disk during L/UL and can cause damage to both the slider and the disk. This is perhaps the most significant drawback of the systems utilizing L/UL since the head/disk contacts occur at high horizontal velocities during the loading and unloading processes.

2.1 Disk Damage Due to L/UL

Data loss can result from head/disk contacts if the slider loads or unloads onto a zone occupied by data. There are

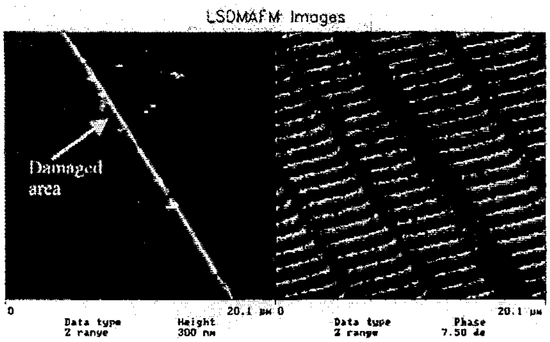


Fig. 5 AFM/MFM images of a disk scratch resulting in disk damage and erasure of data over a potion of a track

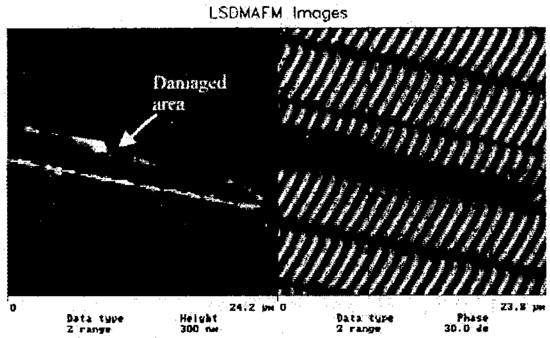


Fig. 6 Another AFM/MFM images of a disk scratch. Over 50% of data is lost over on track. This level of data loss is virtually impossible to overcome with signal processing

at least four potential mechanisms for data loss due to head/disk contacts: (1) physical damage to the magnetic layer, (2) magnetostriction effects that arise during elastic contacts, (3) flash temperature induced erasure resulting from frictional heating between the slider and the disk$^{(11)}$, and (4) the combination of the three.

Figures 5 and 6 show an image of the disk scratch on an aluminum-magnesium (Al-Mg) alloy substrate disk caused by head/disk contact during loading. The left side of each figure is an AFM image and the right side is the corresponding magnetic force microscope (MFM) image. The dark narrow and long regions in the AFM images are the areas of disk damage where the depth is on the order of microns. The MFM images show the corresponding damaged regions and data (bit transitions) on about four data tracks. The damaged regions show loss of data (no bit transitions) due to the physical damage to the magnetic layer. Moreover, since the transition from data to lost-data regions is very distinct, no significant portion of data loss is attributable to magnetostriction effects. Otherwise, the transition lines would be broader and not as sharp as shown.

2.2 Slider Damage Due to L/UL

In Figs. 5 and 6, the disk damage is caused by the slider. However, the same contact events also cause damage to the slider, i.e., the disk surface tends to round the sharp corners of the slider that causes disk damage. Figure 7 shows a picture of a worn slider after numerous number of L/UL cycles. An

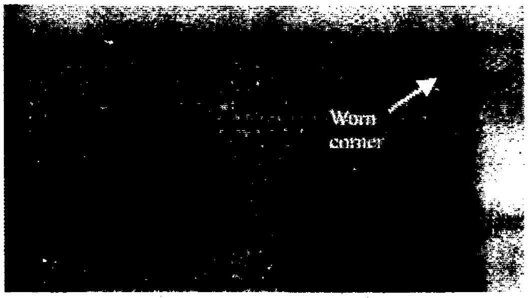


Fig. 7 Optical picture of a negative pressure slider with the leading edge worn away due to head/disk contacts during load/unload

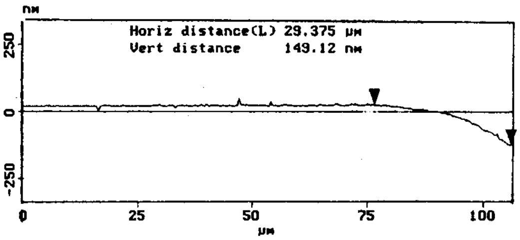


Fig. 8 Cross section of an AFM image of a worn area of a slider

AFM image cross section of the worn slider shown in Fig. 7 is shown in Fig. 8. As the slider corners become rounder with usage, the probability of disk damage also decreases with usage since the contact stress also decreases.

2.3 Eliminating Disk Damage Due to L/UL

The potential for disk damage can be eliminated by rounding the corners of the slider. This is shown by the following experimental results. Figure 9 show disk damage results as a function of slider pitch and roll static attitudes for 22 different negative pressure sliders after 20 k L/UL cycles on 95 mm diameter Al-Mg disks rotating at 7200 rpm. Tests that resulted in any disk damage are represented by cross symbols, while circles show tests that did not cause any disk damage as observed under an optical microscope. Under these test conditions, it appears that no reasonable range of pitch-static-attitude and roll-static-attitude can be used to consistently avoid damaging the disk surface. The next figure (Fig. 10) shows the result of running over 60 corner rounded sliders for 20 k cycles at 7200 rpm none of the sliders caused any disk damage. It is clear that the rounding process dramatically improves the reliability of the interface.

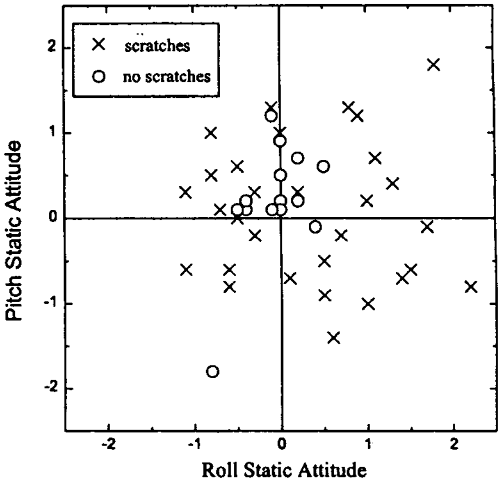


Fig. 9 Test results for negative pressure sliders at 7200 rpm after 20k L/UL cycles

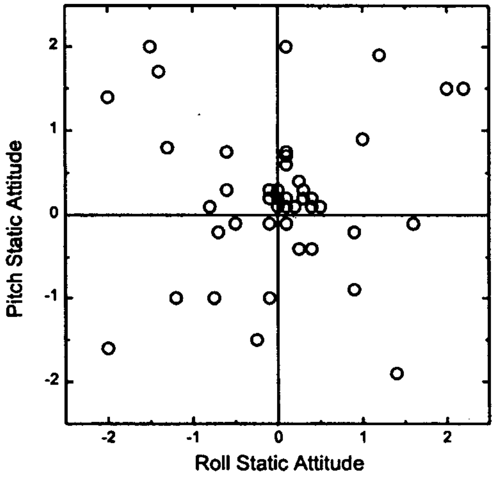


Fig. 10 Corner rounded sliders run at 7200 rpm for 20K L/UL cycles

One disadvantage of rounding the corners of sliders is lack of control of the flying height. In the above tests, the rounding actually occurred on the air-bearing surface. Any changes to this surface also alter the flying height, pitch and roll of the slider. The rounding process itself at the leading edge, for example, can increase the flying height by as much as 50% resulting in a significant manufacturing challenge. This problem can be overcome by using negative pressure bobsled(12) designs which have three small air-bearing surfaces that support more than 95% of the load (Fig. 11). The perimeter surfaces around these pads are about 200 nm lower and support very small of amount of the applied load. Therefore, the corner of these sliders can be rounded without significantly affecting the flying height, pitch or roll. For this class of sliders, the change in the flying height due to

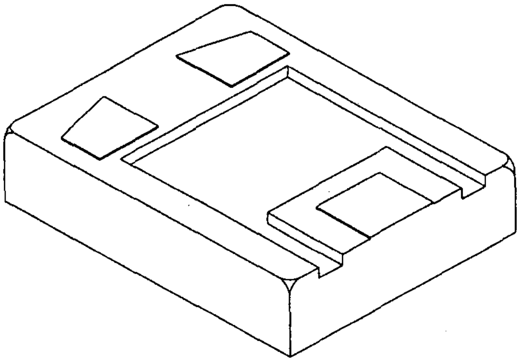


Fig. 11 A negative pressure bobsled air-bearing design with rounded corners

rounding will result in about 1 nm which is well within the flying height tolerance.

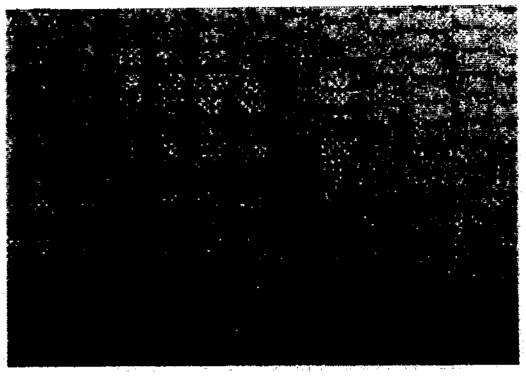
2.4 Glass Substrates and Potential for Data Loss

The substrate material used in most of today's disk drives is an Al-Mg alloy. The other well known substrate is glass, although not as commonly used. One significant advantage of glass is that it is easier to produce smooth surfaces allowing lower flying height. In addition, because glass has higher hardness, it offers greater resistance to disk damage during shock events.(13) For this reason, glass substrates have been used more frequently in mobile disk drives rather than desktop or server drives. Recently, however, glass disks have become more widely used because smoother surfaces are required for reduced magnetic spacing. Furthermore, recently announced hard drives with L/UL technology all use glass disks since the increased hardness of the material offers greater resistance to disk damage resulting from head/disk contacts during L/UL process (in May 1999, IBM announced 10 k rpm server class drive which uses both glass disks and L/UL technology).

For L/UL systems that can experience slider/disk contacts, advantages offered by glass substrates may be outweighed by potential for data loss due to thermal heating if the system is not robustly designed. In general, slider-disk contacts at high velocities may lead to extremely high flash temperatures due to frictional heating. If the flash temperature approaches the Curie temperature, then any purposely oriented magnetic patterns may become incoherent resulting in potentially unrecoverable data loss. These events may occur even at lower temperatures if the coercivity of the disk is reduced by magnetostriction effects caused by shear stress generated during slider/disk contacts.

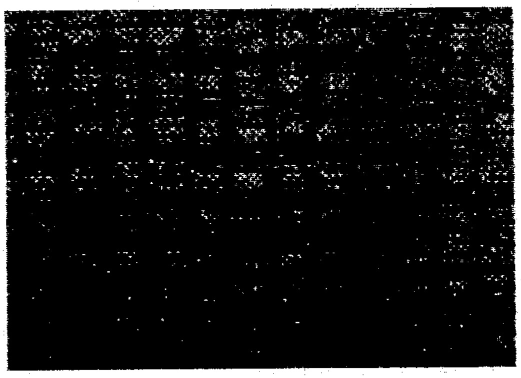
A primitive but simple and effective method is used to demonstrate that data can be lost due to high temperatures on glass and to approximate the temperature at which erasure occurs -- an in depth discussion can be found in Suk et al.(11) A heat source with a small tip set at a specified temperature is moved across the disk in contact along an area already written with magnetic flux patterns. The disk is then dipped in ferrofluidic bath to reveal the magnetic pattern. Figure 12 shows the results on a glass disk at 315C and 420C. The onset of erasure occurs at about 315C, and below it, no significant erasure is observed. At 420C, all the information is completely lost. Therefore, the flash temperature on glass disk must exceed about 315C for erasure to occur. In contrast, a similar experiment on an Al-Mg disk show no erasure, even at 420C (Fig. 13). The heat source has no noticeable effect on the magnetic pattern. This is expected since the thermal conductivity of Al-Mg disks is more than two orders of magnitude higher than glass disks.

(a) T=315C



(b) T=420C

Fig. 12 Data erasure due to a heat source scanned over a glass substrate disk



T=420C

Fig. 13 No data erasure is seen even when a heat source at 420C is scanned over an Al-Mg disk

3. Summary

A brief description of the current technology (contact-start-stop) employed in most of today's hard disk drive is presented. The dynamics and head/disk interactions during a start/stop process are very complicated and no one has been able to accurately model the interactions. Thus, the head/disk interface that meets the start/stop durability and stiction requirements are always developed statistically. In arriving at a solution, many sets of statistical tests are run by varying several parameters, such as, the carbon overcoat thickness, lubricant thickness, disk surface roughness, etc. Consequently, the cost associated in developing an interface could be significant since the outcome is difficult to predict.

An alternative method known as Load/Unload technology alters the problem set, such that, the start/stop performance can be designed in a predictable manner. Although this technology offers superior performance and significantly reduces statistical testing time, it also has some potential problems. However, contrary to the CSS technology, most of the problems can be solved by design and not by trial and error. One critical problem is that of head/disk contacts during the loading and unloading processes. These contact can cause disk and slider damage because the contacts are likely to occur at high disk speeds resulting in large friction forces. Use of glass substrate disks also may present problems if not managed correctly. Due to the low thermal conductivity of glass substrates, any head/disk contacts may result in erasure due to frictional heating of the head/disk interface. In spite of these and other potential problems, the advantage with L/UL system is that these events can be understood, analyzed, and solved in a deterministic manner.

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