EXPERIMENTAL STUDY OF
HIGH-SPEED CONTACT AT HEAD-DISK INTERFACE IN A MAGNETIC HARD DISK

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ABSTRACT

Tribological performance of the head-disk interface will have significant impact on the performance and durability of the hard disk drive. A high-speed contact test method has been developed for the purpose of evaluating nanometer-thick lubricant film/carbon overcoats materials on hard-disk surfaces. Four different thickness overcoats were used in high speed contact experiments. High speed contact force was calculated based on the calibration of acoustic emission signal by proposed ball dropping tests. Acoustic emission analysis, frequency spectrum analysis, and surface morphology imaging were used to analyze the deformation and fracture at high speed contacted area. The availability of an experimental technique enables effective screening of different material chemistries and lubricant combinations to improve the level of protection for hard disk technology.

1. INTRODUCTION

Development of newer generations of hard disk drives with higher data storage capacity poses many technological challenges. The continuing pursuit of ever-increasing recording areal density has targeted to 1 Tb/in² with head-media spacing of about 6.5 nm. It only allocates 1 nm each for disk overcoat, head overcoat, and disk lubricant film, leaving 3.5 nm for head disk mechanical separation. The combination of such super low flight height (~2 nm) and high speed rotation (15000 rpm, ~45 m/s) makes occasional contacts inevitable due to disk waviness, spindle wobble, disk surface roughness, and even environmental vibration or impact. However, if the head disk interface (HDI) contact lost stability, catastrophic collisions, namely avalanche, will result in the loss of data. Besides improving the spindle and surface roughness, new overcoats and lubricants are being investigated to improve protection of the disk towards such high-speed collisions. Actual durability field trials to evaluate new materials under such conditions are time-consuming and expensive as well as the information obtained is statistical-based. There is an urgent need to develop an accelerated test methodology to evaluate materials under controlled conditions. The experimental research includes development of a one-pass, high-speed contact test instrumentation and test method to evaluate materials on a hard disk surface. The basic concept is to artificially create a ridge on the disk surface by a controlled scratching at the substrate side of the disk to create a ridge on the top surface with its multilayer intact. A 3.18 mm (1/8”) diameter ruby ball is used to collide with the ridge. The contact force is measured with an acoustic emission (AE) sensor and the deformation volume is obtained with an AFM and optical profiling system. The experiment was conducted in a commercial instrument with major modification. A special load and unload ramp was designed so the positioning of contact can be controlled in nano meter scale by application of a pair of capacitive sensors with a nominal resolution of 0.1 nanometer. Commercial hard disk with carbon film thickness of 3.5 nm, 5 nm, 7.5 nm, and 10 nm were used in this experiment. No lubricant was applied on the as-received disks. A ridge was formed on disk surface by scratching the opposite disk surface with a diamond stylus installed on a special designed apparatus with angel and load adjustable.

2. RESULTS AND DISCUSSION

AE calibration was done by pencil break method and by ball dropping method. The ball dropping method for AE calibration is based on the principle of energy balance, namely the change in kinetic energy equals to work done by contact force on contact area, AE voltage in sensor equals to contact force on the contact area, and it also equals to total energy transmitted to the surface substrate. We have deduced following equation

\[ k = mA\sqrt{2\eta g} \int_0^T V(t) \, dt \]

AE calibration was done by free falling of a ball in a copper tube. The ball was centered in a guide ring cylinder. It was designed to contact the disk in an indented area exactly. So in all free falling tests, the contact area as well as contact pressure are the same for the same falling height. Four different dropping heights of 10, 20, 30, and 40 mm respectively were used in the test. The resulting calibration curve indicates a sensor constant to be 3.2±0.4 N/V. Fig 1 shows the raw AE signals and their frequency spectrum of films with thickness of 3.5 nm, 7.5 nm, and 10 nm respectively.
Because the AE sensor was installed in the nearest position of ruby ball, at the moment of contact, the AE in ruby ball is identical to the AE in the ridge; after that, the AE is only those transferred in ruby ball. So the first AE peak is meaningful to explain the disk surface response against high speed contact. The number and height of peaks around 400 KHz and 600 KHz reflects the degree of high speed contact. It is clearly that the 3.5 nm films fail both at 10 and 20 m/s and exhibited strong random peaks around 600 kHz. In comparison, the 5.0 nm films did not failed even at the linear speed of 20 m/s. The 7.5 nm thickness film also did not fail and the elastic and plastic deformation is the main mechanism of high speed contact. However, the 10 nm thickness films exhibited strong peaks around 650 KHz, indicating fracture occurred at the disk interface. Further more, from the number and height of peaks between 300 to 450 KHz, 7.5 nm and 10 nm thickness film both exhibited increased elastic and plastic deformation, and even fracture as shown. Meanwhile peaks strength increased as velocity increased from 10 to 20, 30, and 40 m/s. It means the degree of deformation increased also. Hence the thicker film has better resistance to severe contact. It is may be concluded that the regular frequency peaks show the deformation of films, and the peak height reflect the degree of deformation. In comparison, random frequency peaks stands for the fracture of films, and its strength stands for the degree of damage.

In comparison with blank carbon film coated disk, the application of one nanometer thickness lubricant significantly improves the robustness of films on the disk. Fig 2 shows the AE raw signals and its frequency spectrum of 1 nanometer thickness Z-Dol dip-coated disk under the high speed contact at linear speed of 10 m/s. The frequency spectrum between 300 and 1000 KHz did not appear and the frequency strength decreased in the frequency range of 50 and 300 KHz, this is because that localized stress re-distributed and maximum stress decreased due to exists of film. In addition, the application of 1 nanometer of Z-Dol plus 5% XIP enhanced the robustness of the films further, the frequency peaks ranging from 50 to 400 KHz did not appear and the peaks ranging from 500 to 900 KHz shows a connected and wide peak. It is possible that the addition of XIP decreased the adhesion between ruby ball and disk and increased the bonding strength between lubricant and disk due to existence of immobile XIP, and the application of lubricant greatly change the frequency characterization.

AFM image (Fig. 3) shows high speed contacted area of disk with 5.0 nm CH\textsubscript{3}N\textsubscript{2} at 5 m/s. The crater has diameter of about 50 µm and depth of 120 nm. It clearly indicates existence of plastic deformation after elastic deformation recovery and also it indicates no fracture or wear occurrence. If the ruby ball is taken as rigid, it can be deduced the crater depth before elastic recovery. With increasing contact speed, the severity of contact increased. In Fig 3, a typical optical microscope of disk ridge with three craters after three high speed contacts for disk with 10 nm CN\textsubscript{15} at 30 m/s, nearly 10, 1000 rotation per minute (rpm). The crater has diameter of about 200 µm at short axis and depth of 40 nm. Although the three craters were not in the same radial straight line due to axial vibration of disk on such high speed rotation, they were still on the ridge which has semi-width of about 19 mm. When further increased the speed, the fracture of film occurred. In this case, the frequency spectrum shows random peaks, Contact mechanics was used to conduct the relationship between elastic deformation and impact velocity at normal direction and tangential direction

$$\delta_{\text{max}} = \left( \frac{15mv_z^2}{16R^{1/2}E} \right)^{2/5}$$

$$\beta = \frac{Q}{8}\left( \frac{2-v_y}{G_1} + \frac{2-v_z}{G_2} \right)$$

According to work from Maw et al and Johnson, the elastic deformation was numerical simulated based on the theory from Mindlin and Maw et al.

3. CONCLUSIONS

The AE and spectrum analysis can be used to determine the effect of thickness on the robustness of nano meter scale film at high speed contacting, and thicker film can withstand higher speed contact. Primary results show that the lubricant on the carbon coating prevented the coating from plastic deformation and even micro fracture.