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Effect of Heat Source Sliding Contact on the CoPtCr-based Magnetic Recording Disk

Yang Lei, Mu Ke, Zhan Wenjing, Diao Dongfeng

Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, China;

Abstract: Effect of heat source sliding contact on the CoPtCr-based magnetic recording disk was investigated. A tribo-test of the disk with low load heat source and the scan of disk with magnetic head were sequentially carried out. Then disk samples in the contact area were observed by atomic force microscopy (AFM) and magnetic force microscopy (MFM). A finite element model using thermomechanical coupling was developed to calculate the mechanical and thermal response of the disk under heat source sliding contact based on the experimental results. It was found that data loss load under sliding contact with a heat source was far less than that without a heat source, and mechanical scratches and demagnetization did not occur in the data loss area under the experimental conditions. The finite element analysis (FEA) results indicate that the thin surface DLC coating has more significant effect on the mechanical response than the thermal response of the magnetic layer.

Key words: heat source; sliding contact; data loss; mechanical scratches; demagnetization; finite element analysis

As the slider to disk spacing is decreasing, sliding contacts in the head/disk interface are of great concern since they may lead to loss of data as well as tribological failure of the magnetic disk [1]. Fu and Bogy [2] found read back signal amplitude reduced after multiple load/unload cycles. Suk and Jen [3] studied the effect of head/disk contacts during load/unload in terms of magnetic data loss. Liew and Wu [4] found that large surface and subsurface damage from heavy indentation and scratching resulted in large magnetization changes and loss. In Katta and Polycarpou's recent research [5], they believed that the magnetic recording layer could be damaged without observable damage to the protective top surface carbon overcoat. Therefore, study on the effect of magnetic recording disk under sliding contact is important in practical applications.

High temperature and contact pressure could be generated during the sliding contact [6-8]. There are many researches using numerical methods to calculate the contact temperature and stress at head/disk interface [9-12]. These studies are useful for knowing about the thermomechanical analysis under head/disk sliding contact. It is believed that friction heat and contact stress occur simultaneously in head/disk contact. So, comprehensive study of both is necessary.

In our previous work, the critical stress and temperature for the occurrence of data loss in CoPtCr-based magnetic recording disk under sliding contact were investigated [13]. However, the experiments were carried out at room temperature, while the high speed rotating disks driven by the motor will heat up during the practical work. The effect of thermo field on the magnetic disk is further concerned in this paper. Thus, in this study, a tribo-test apparatus with a heat source is designed to simulate the practical temperatures of head actual working condition. In order to further investigate the tribological effect on the disk under the experimental conditions, the disk in the contact area is observed by AFM and MFM. Then a finite element model with thermomechanical coupling is developed to calculate the mechanical and thermal response during the heat source sliding contact.

1 Experiment

Controlled tribo-test is performed on the CoPtCr-based magnetic recording disk. The disk used in the test has the recording density of 101 Gb/ in.^{2}. It is composed of several material layers, including an Al-Mg substrate, Ni-P adhesive layer, soft underlayer, intermediate layer, CoPtCr magnetic layer and DLC protective layer. The recorded bits are saved in the magnetic layer [14].

1.1 Experimental apparatus

Fig.1 shows the schematic sketch of ball-on-disk tribo-test apparatus. The apparatus includes a ball-on-disk loading system with a heat source and a magnetic disk scanning system.

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Corresponding author: Diao Dongfeng, Ph.D., Professor, Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, P. R. China, Tel: 0086-29-82669151, E-mail: dfdiao@mail.xjtu.edu.cn

The ball-on-disk loading system is illustrated in Fig.1(a). A temperature controllable heat source is designed in the loading system, as shown schematically in Fig.1(c). The heating resistor is used to heat the Al_2O_3 ball (R=4 mm) which is fixed on the end of the force sensor. Fig.1(d) depicts the heating process of the Al_2O_3 ball at different voltages. We can clearly notice that the ball temperatures keep steady after 30 minutes heating. Therefore, temperatures after 30 minutes heating are used in the test. In order to simulate the seek motion of magnetic head, a linear stage driven by the step motor is used to make the Al_2O_3 ball move radially on the disk. Computer B will record signal from the force sensor, as well as control the linear stage (shown in Fig.1(b)).

The magnetic disk scanning system is introduced to record the contact sectors in the tribo-test, as shown in Fig.1(b). The magnetic data of the hard disk are detected by head/disk system, and computer A scans the sectors in the contact area by using the software MHDD 4.0, which records the number of damaged sectors. Observation of the disk samples is done by using AFM and MFM produced by Vecco in America.

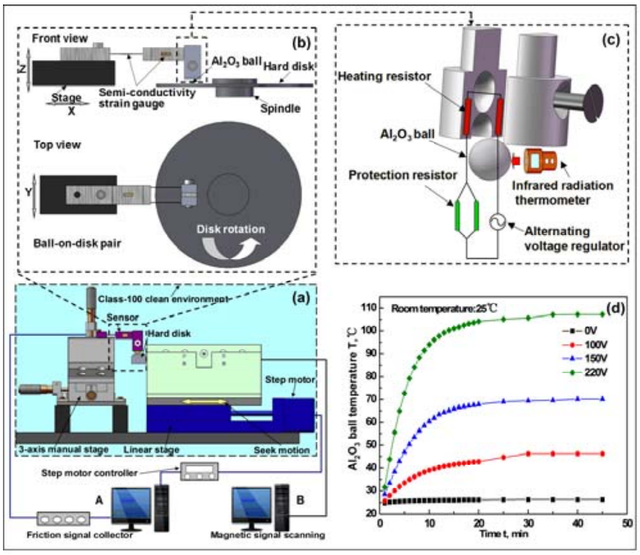

Fig.1 Schematic sketch of ball-on-disk tribo-test apparatus: (a) ball-on-disk loading system; (b) magnetic disk scanning system; (c) heat source system; (d) Al_2O_3 ball temperature versus time at different voltages

1.2 Experimental procedure

Prior to the test, the Al_2O_3 ball was cleaned with acetone to remove all impurities from the surface. The test was performed at room temperature (25 °C) and with a constant relative humidity of 50%, under class-100 clean environment. The whole magnetic disk should be scanned before loading the normal force in order to make sure that there are no damaged sectors in the disk. Then the Al_2O_3 ball was heated to the required temperature (25 °C, 40 °C, 60 °C and 80 °C). A normal force of 0.025 mN was loaded on the radius of 23 mm (sliding velocity V= 17.34 m/s). And the linear stage was started to do the reciprocating motion. After a total of 10 reciprocating times, the normal force was unloaded. The sectors in the contact area of the magnetic disk were then scanned by the head with the software MHDD 4.0. Finally, disk samples with the size of 5 mm×5 mm were observed with AFM and MFM.

2 Results and Discussion

2.1 Magnetic disk scanning results

Fig.2 summarizes the number of damaged sectors induced by sliding contact at different Al_2O_3 ball temperatures with the normal force W= 0.025 mN, sliding velocity V= 17.34 m/s. We can see that there is no sector damaged by the ball-on-disk sliding contact with the Al_2O_3 ball at room temperature (25 °C). However, as the temperature of the Al_2O_3 ball increases, the number of damaged sectors increases obviously.

We define in this paper that data loss occurred only if the damaged sectors in the tribo-test are more than one sector, based on the areal recording density of the magnetic recording disk used in the experiment. Therefore, data loss does not occur with the Al_2O_3 ball at room temperature, while data loss occurs with the Al_2O_3 ball temperatures of 40 °C, 60 °C, 80 °C under the normal force W=0.025 mN and sliding velocity V= 17.34 m/s. Compared with our previous work, the critical normal force under sliding velocity V= 17.34 m/s is 0.47 mN [13], it is clear that data loss load under sliding contact with a heat source is far less than that without a heat source.

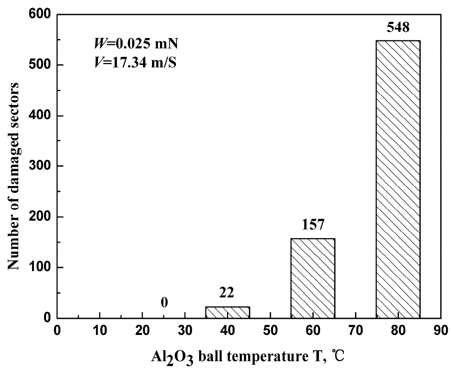

Fig.2 The number of damaged sectors induced by tribo-test at different Al_2O_3 ball temperatures

2.2 AFM and MFM results

Typical AFM and MFM images of the contact area after the tribo-test (V= 17.34 m/s, W= 0.025 mN, T= 80 °C) are shown in Fig.3. Fig.3(a) shows the 3D AFM image of the disk surface in the contact area. It is clear that there are not obvious mechanical scratches observed. Fig.3(b) and (c) show the MFM images in and outside the contact area. We can observe the magnetic domains in the contact area are the same as those outside the contact area, which indicates demagnetization does not happen in the contact area. Results of AFM and MFM under other conditions are similar. Therefore, we can conclude that mechanical scratches and demagnetization do not occur in the data loss area under the experimental conditions.

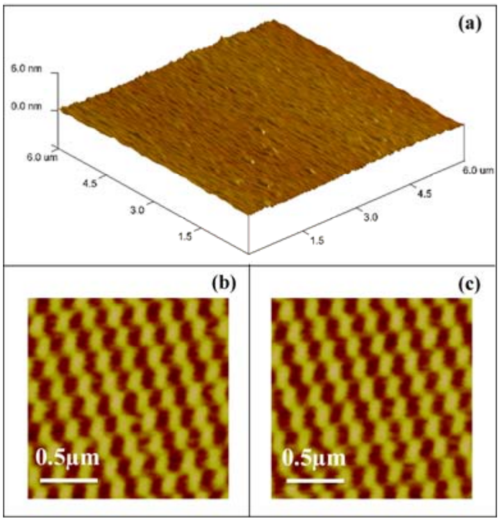

Fig.3 Typical AFM and MFM images of the disk in the contact area after tribo-test (V= 17.34 m/s, W= 0.025 mN, T= 80 °C): (a) 3D AFM image of the disk surface in the contact area; (b) MFM image in the contact area; (c) MFM image outside the contact area

3 Finite element analysis and discussion

To obtain the mechanical and thermal response in the magnetic recording disk under the experimental conditions, the heat source sliding contact was simulated using finite element analysis. For the development of the finite element model, a ball-on-disk contact model combined with equivalent roughness was introduced to calculate the contact width 2a and contact diameter of asperity D under the normal force [13, 15].

3.1 Finite element modeling

The finite element model simulated the effect of hard asperity (Al_2O_3 ball) loaded against a softer surface (magnetic disk) under sliding contact. Analysis was conducted under the plane strain condition. The lower surface was assumed to be a 2D, elastic, isotropic, and semi-infinite half-space. As shown in Fig.4, the finite element model of the magnetic disk size was 960 nm long by 120 nm thick to represent the semi-infinite body with 2 nm thick DLC layer, 36 nm thick CoPtCr layer, 72 nm soft magnetic underlayer, and 10 nm thick NiP layer. The contact width 2a equals 1.75 μm and the contact diameter of asperity D equals 120 nm under the normal force W= 0.025 mN, sliding velocity V= 17.34 m/s. The mesh was composed of a 2D four-nodded coupled area element (PLANE 13) with the finest mesh close to the contact region and coarsest mesh away from the region of interest. The minimum size and the maximum size of quadratic elements used in the model were 2 nm long by 2 nm deep and 8 nm long by 10 nm deep. Sliding was taken along the positive x direction. Material properties used in the present simulation were taken from Ref. [9.16].

For the boundary conditions, the displacement of elements in the x direction of the borderlines (AD, BC), as well as the y direction of the borderline (CD) of the lower surface were fixed, and the borderlines (AB, BC, CD) were thermally insulated. The heat temperature T was applied to the entire asperity, namely the temperature of the Al_2O_3 ball, and the contact pressure Pr(x) was applied on the top of the asperity, which can be estimated by Ref. [13].

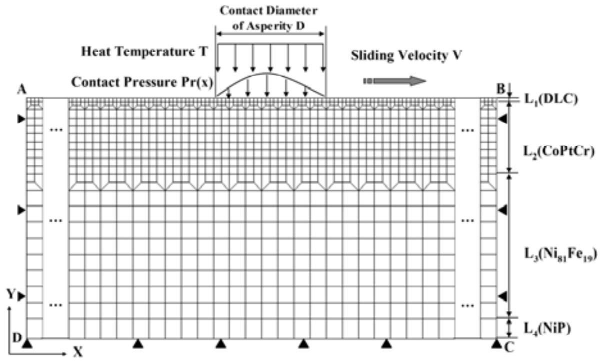

Fig.4 Illustration of finite element model

3.2 Finite element analysis results

Fig.5 depicts the contours of the temperature and stress in the semi-infinite medium of the CoPtCr-based magnetic recording disk under heat source sliding contact (V= 17.34 m/s, W= 0.025 mN, T= 80 °C).

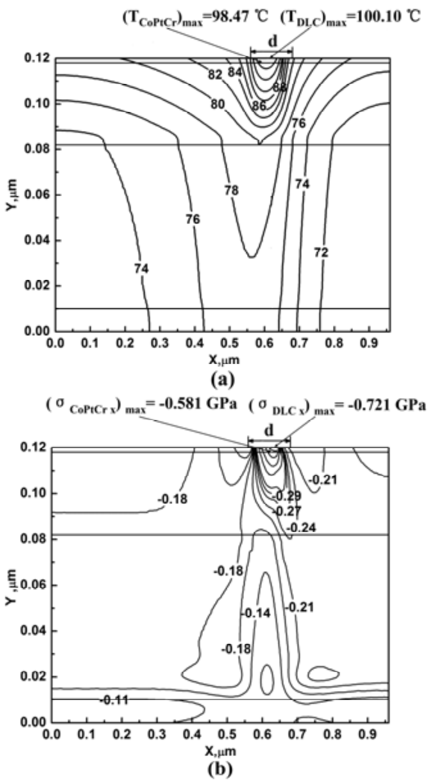

Fig.5 (a) contours of temperature and (b) contours of σ_x in the semi-infinite medium of the disk under heat source sliding contact (V= 17.34 m/s, W= 0.025 mN, T= 80 °C)

We can see, the maximum temperature T_{max}= 100.10 °C and maximum x-component stress $(\sigma_x)_{max}$= -0.721 GPa occur in the DLC coating surface The maximum temperature and x-component stress in the magnetic layer are $(T_{CoPtCr})_{max}$= 98.47 °C，$(\sigma_{CoPtCr\,x})_{max}$= -0.581 GPa. They occur at the interface between the DLC coating and the magnetic layer. It is clear that the maximum x-component stress in the DLC coating is 24.1% larger than that in the magnetic layer, while the maximum temperature in the DLC coating is only 1.7% higher than that in the magnetic layer. This implies that the DLC coating has a more significant effect on the mechanical response of the magnetic layer, compared with the effect on thermal response of the magnetic layer.

3.3 Discussion

In the present study, data loss load of the CoPtCr-based magnetic recording disk under heat source sliding contact was found through the tribo-test. And the mechanical and thermal response of the disk was calculated using FEA. Fig.6 summarizes the maximum temperature and stress in the magnetic layer under the experimental conditions.

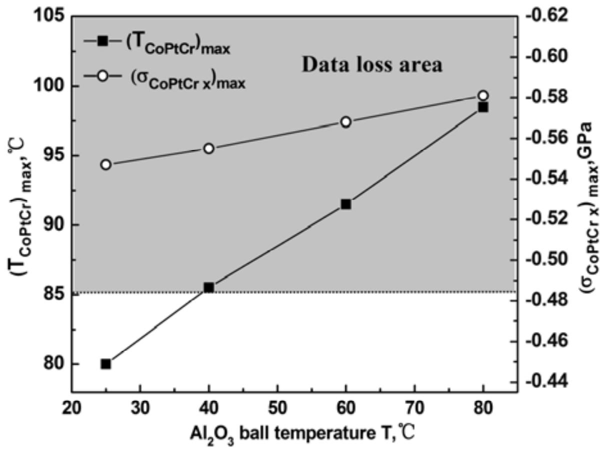

Fig.6 Al_2O_3 ball temperature versus maximum temperature and stress at different temperatures in disk under heat source sliding contact (*V*= 17.34 m/s, *W*= 0.025 mN)

As shown in Fig. 6, the maximum temperature and stress in the magnetic layer increase with the rising of the Al_2O_3 ball temperature. The dashed line represents the critical temperature and stress for data loss of the disk [13]. When the Al_2O_3 ball temperature *T*= 40 °C, 60 °C, 80 °C, both of the maximum temperature and stress in the magnetic layer are greater than than the critical temperature and stress, which are coincide with the tribo-test results. However, when the Al_2O_3 ball temperature *T*= 25 °C, the tribo-test results show that the data loss does not happen. But from the FEA results, it is found that the maximum temperature in the magnetic layer is below the critical temperature while the maximum stress in the magnetic layer is greater than the critical stress. Thus, it can be concluded that the data loss of the disk is the couple effect of temperature and stress.

4 Conclusions

Effect of heat source sliding contact on the CoPtCr-based magnetic recording disk was studied. The mechanical and thermal response was calculated by a finite element model using thermomechanical coupling. The following conclusions can be drawn from the present work.

1) The experimental and FEA results demonstrate that temperature of the CoPtCr-based magnetic recording disk has great influence on the data loss of the disk.

2) Mechanical scratches on surface of the disk and demagnetization of the magnetic layer do not occur in the data loss area under the experimental conditions.

3) According to the FEA results, the DLC coating has more significant effect on the mechanical response of the magnetic layer, compared with the effect on thermal response of the magnetic layer.

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