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Thermomechanical finite element analysis of slider–disk impact in magnetic storage thin film disks

Ning Yu [a,1], Andreas A. Polycarpou [a,*], Jorge V. Hanchi [b]

[a] Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, 140 Mechanical Engineering Building, MC-244, 1206 W. Green Street, Urbana, IL 61801, USA
[b] Seagate Technology LLC, Minneapolis, MN 55416, USA

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ABSTRACT

Oblique impact of a slider with a rotating disk in a hard disk drive was analyzed using the finite element method. A three dimensional, thermomechanical, impact model was developed to study the mechanical and thermal response during the impact of a spherical slider corner with a rotating disk. The model was validated by comparing the finite element results with analytical solutions for a homogeneous glass substrate disk. Impact penetration, stress and incurred flash temperature were obtained for various normal impact velocities. The effects of material layers on the disk were also investigated by introducing layers with different material properties and thicknesses. It was found that for a rounded slider corner and a critical normal impact velocity of 0.03 m/s studied in this work, the layers have insignificant effects on the mechanical response and small but predictable effects on the flash temperature.

1. Introduction

Magnetic storage hard disk drives (HDDs) have been used widely to provide storage of digital information in modern computer systems and consumer electronic products. With the continuous reduction of the head (slider) disk interface spacing, and the usage of HDDs under hostile environments, the occasional impact between slider and disk during operation is a major reliability challenge. The high contact pressure and surface temperature that are usually associated with such impact may lead to the loss of data or even catastrophic failure of the disk or slider [1]. Impact between a slider corner with a disk is often observed in experiments [2], and is due to the large pitch and roll motion of the slider during impact events [3]. Moreover, the slider corners have certain degree of radius of curvature, which could be artificially increased to reduce the contact stresses and damage [4].

Various models have been proposed to describe the slider–disk impact behavior. The quasi-static Hertz impact theory has been used by several researchers [4,5] to estimate the contact forces and stresses. The Hertz impact theory is valid for quasi-static frictionless, normal impact of smooth, homogenous bodies and Yu et al. [6] extended the Hertz impact theory to include the effects of layers, adhesion and roughness. The impact between slider and disk during HDD operation is oblique impact, i.e., in addition to the normal velocity component there is also a lateral velocity component. In such oblique impacts, friction also exists between the slider and the high speed rotating disk. It is postulated that such impact could still be described using Hertz impact theory or a similar quasi-static approach [4,7]. When impacts involve plastic deformation, an elastic-plastic contact model could also be used instead of a Hertz elastic contact model [8]. For normal frictionless impact of spheres, the Hertz theory has been shown to favorably compare with finite element modeling results at relatively low impact velocities up to 0.2 m/s (to satisfy quasi-static conditions) [9]. However, no such comparison of finite element method (FEM) with frictional oblique impact with Hertz impact theory has been reported in the literature. Note that current magnetic storage slider–disk impacts could range from few mm/s to several m/s, where a normal impact velocity of 0.03 m/s is typically the maximum (threshold) velocity without permanent disk damage [8].

The temperature rise at the head disk interface during impact is also of great importance to the integrity of the magnetic data, as reported for example in the studies of [1,10–12]. Several modeling works have also been reported in predicting the temperature increase during slider–disk contact [13,14], and the maximum temperature increase is predicted to be up to 1000 °C. Yu et al. [6] showed via analytical modeling that the temperature increase during slider–disk impact depends on the impact mechanical response, i.e., contact area and contact pressure profile. In turn,

* Corresponding author. Tel.: +1 217 244 1970; fax: +1 217 244 6534.
E-mail address: polycarp@illinois.edu (A.A. Polycarpou).
[1] Currently with Zimmer Inc.

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the thermal response may cause thermal stresses and variation in the real contact area and contact pressure distribution due to thermal expansion.

To accurately determine the mechanical and thermal behavior at a slider–disk interface, it is necessary to perform a fully coupled thermomechanical analysis. Due to the complex nature of a fully coupled thermomechanical contact problem, the FEM is primarily used for such studies. Fully coupled thermomechanical analysis for normal and sliding contact has also been performed by Ye and Komvopoulos [15] for elastic-plastic layered media, and Gong and Komvopoulos [16] for layered media with patterned surfaces. To the best of our knowledge, as of today, fully coupled thermo-mechanical finite element analysis (FEA) of impact has not been reported in the literature.

When using the FEM to model the contact between slider and disk, one difficulty is the large difference in the magnitude of the contact area and the thickness of various layers on the disk and slider surfaces, which could only be few nanometers thick. This difference renders the implementation of an accurate FEA model to represent the actual contact problem and at the same time include all the layers very difficult. Therefore, the slider–disk contact FEM studies reported in the literature [15–17] focused on the contact behavior of submicron size asperities and slider geometries with a submicron sliding distance, in which case various nm thick layers could be modeled with sufficient accuracy. On the other hand, several researchers modeled the disk and slider as homogeneous materials, in which case they modeled the whole mm size slider, under severe contact, such as impact [18]. Based on the analysis in Yu et al. [6], it is seen that the impact is a severe contact and that the contact penetration is of the order of μm. Therefore, such a problem could not be modeled by considering only the nm size asperity contact. Similarly, it is not necessary to consider the whole mm size slider as only the slider corners come into contact with a contact size of the order of μm.

From the above discussion, it is seen that in order to correctly model the impact of slider–disk during operational shock, one needs a dynamic, thermomechanical, μm size model of the slider corner with some consideration of the multilayers on the disk and slider. In this paper, a three dimensional, thermomechanical finite element model is built to study the oblique impact of a slider corner with a rotating disk, using the multipurpose finite element code ABAQUS/Explicit [19]. The mechanical and thermal responses of slider corner impact with a homogeneous, smooth glass disk are first studied and compared with a contact mechanics-based model. Thereafter, the effect of layers on the mechanical and thermal impact response are discussed by including various layers in the finite element model. Note that in cases of general sliding conditions with no impact, no layers and no thermal effects, asperity-based models could be used to predict contact and friction forces, see for example Ref. [20]. Thermomechanical sliding analysis using fractal surfaces in an FEA framework has also been reported [21].

2. Finite element model

2.1. Finite element mesh

Fig. 1 shows a three dimensional finite element model of a sphere representing a slider corner, termed spherical slider, impacting an elastic-plastic layered medium. The spherical slider is modeled as a rigid body using an analytical rigid surface to ensure a smooth contact surface as well as to reduce computational time. Due to symmetry, only one-half of the layered medium was modeled, again to reduce computational time. The finite element mesh consists of 20,000 three dimensional, eight node trilinear coupled temperature-displacement elements (C3D8RT) with a total of 26,467 nodes. A reduced integration with hourglass control scheme [19] is used to reduce the computational time while maintaining the accuracy of the finite element analysis.

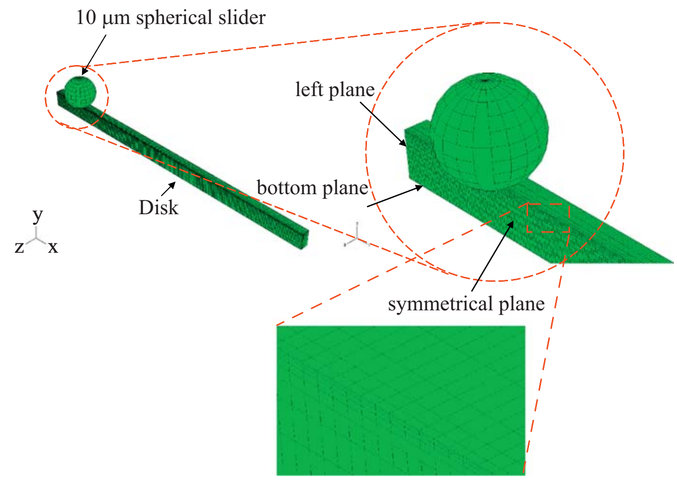

Fig. 1. Three dimensional finite element mesh of a 10 μm spherical slider impacting a moving disk.

The spherical slider is set to have a radius of 10 μm, which is typical for a "rounded" slider corner [22]. The slider has a mass of 1.5 mg, which is typical of the mass of a modern slider in a HDD. The mesh dimensions for the disc media are 10 μm in the impact *z*-direction, 200 μm in the sliding *x*-direction, and 5 μm in the lateral *y*-direction. The mesh dimensions are chosen to accommodate the sliding that occurs during oblique impact, as well as to contain the stress field. A biased mesh in the impact and lateral directions is also used, with finer mesh closer to the contact area. The smallest elements are underneath the center of the impacting sphere, along the sliding direction, as shown in the bottom inset of Fig. 1. The size of the smallest elements are 0.5 (*x*-direction) by 0.25 (*y*-direction) by 0.05 (*z*-direction) μm. The nodes on the left, bottom and symmetrical planes (also shown in Fig. 1) are constrained against displacements in the *x*-, *y*-, and *z*-directions, respectively. The temperature at the nodes on the left, right, bottom and back planes is set to 20 °C, the same as the initial temperature for all the nodes. Heat conduction is restricted only within the sphere/layered disk contact interface.

2.2. Material properties

The mechanical and thermal properties of the materials used in the simulations were obtained from various sources and are listed in Table 1 [1,5,15,16,23–26]. Glass or glass–ceramic substrate has been used predominately in mobile applications that require superior shock resistance and lower susceptibility to embedded particles. From the disk surface to disk substrate, there are usually a lubricant layer, a diamond-like-carbon (DLC) layer, magnetic layer(s), and chromium vanadium (CrV) underlayer(s). The 1–2 nm perfluoropolyether lubricant layer which includes both mobile and immobile/bonded portions is used to reduce friction and wear when contact occurs between slider and disk. Since the lubricant layer is very thin it is not expected to significantly affect the impact analysis, and is ignored. With high modulus and hardness, the 2–5 nm thick DLC layer serves to protect the magnetic layer(s) and also acts as a support structure for the lubricant. The recorded bits are saved in the magnetic layer(s), where a cobalt-based alloy is commonly used. An underlayer is also needed to help nucleate and grow microstructures thus giving appropriate magnetic properties, for