The Use of DSMC in HAMR Head-Disk Interface to Study Smear

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We simulate the gas bearing in the HAMR head-disk interface using the direct simulation Monte Carlo (DSMC) method and the consistent Boltzmann algorithm. We report two observed phenomena and comment upon their implications on smear formation on the head surface. First, we observe that in very low spacing, the gas particles are more likely to collide with the head and disk surfaces rather than with each other. Second, we observe the presence of a gas velocity component toward the head in the leading edge and trailing edge. These vertical drifts can carry airborne contaminant particles to the head surface forming smear.

***Index Terms*—Heat-assisted magnetic recording, Head-disk interface, Air-bearing, DSMC**

I. INTRODUCTION

THE GAS-BEARING in hard disk drives forms a critical component in the head-disk interface. A thin-film lubrication theory, along with the Fukui-Kaneko slip correction, is generally used to calculate the properties of the air-bearing surface [1]. This model, however, does not give insight into the molecular nature of the air-bearing. The minimum head-disk clearance under the near field transducer (NFT) is as low as 1 nm, which is roughly 3-4 helium atoms wide. Given the high-temperature gradient under the NFT, the molecular nature of the air-bearing can significantly impact the reliability of the head-disk interface. Direct Simulation Monte Carlo (DSMC) is a particle-based method that agrees well with the lubrication theory and has been used to study thin film bearings [2]. This study uses DSMC and the Consistent Boltzmann Algorithm modification for dense gases [3] to study the air-bearing effects of smear formation in the head-disk interface.

II. MODEL

We use a 2D channel to simulate the air-bearing, as shown in Fig. 1. The bottom plate is a smooth surface moving at 50 m/s and represents the disk. The top plate contains a protrusion, which is the head. The temperature hotspot is located at the minimum clearance (G_p). This area is referred to as the gap zone. Since DSMC relies on statistical averages to output macro quantities, the length of the gap zone is set at 2 μm to calculate the results reliably.

1.

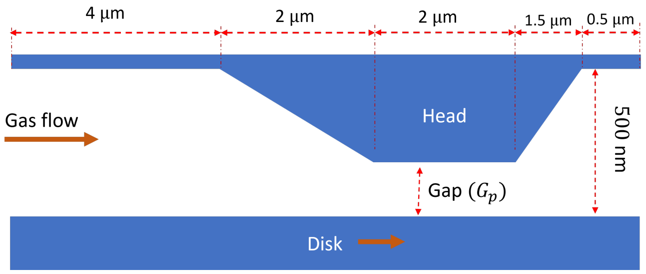

Fig. 1: Schematic of the 2D channel

The Gap value (G_p) varies between 1 and 200 nanometers. The disk temperature was maintained at 800 K at the gap zone, and the head temperature was 500 K. At the inflow and the outflow locations, the temperature was fixed at 300 K. The gas bearing consists of either helium atoms or nitrogen molecules. The properties of the simulation are listed in Table. I.

Parameter	Value
Nitrogen diameter	407 pm
Helium diameter	320 pm
Accommodation Factor	1.0
Time-step	10 ps
Simulation time	10 μs
Particle Count	$\approx 2 \times 10^6$

TABLE I: Simulation Properties

III. RESULTS

A. Collisions Ratio

We begin our analysis by considering the gas particle collisions at minimum clearance. There can be two kinds of collisions: gas-to-gas collision or gas-to-surface collision. In Fig 3, we plot each type of collision and their ratios at various spacings. The gas-to-gas collision increases with clearance due to the increase in volume and number of particles. The gas-to-surface collisions decrease with spacing as the density of the gas-bearing reduces, causing fewer particles to hit each surface. The ratio between the gas-to-gas collision exhibits interesting behavior at very low spacings (¡ 10 nm). The ratio is greater than 1, indicating that each gas particle collides with other particles after several surface collisions. At the lowest simulated spacing of 1 nm, a helium atom collides with a surface 50 times before collision with another gas particle. This shows that they follow a free molecular flow (collisionless trajectory) in these spacings, and the mean free path is limited by the head disk clearance. In other words, this regime resembles rarefied gas dynamics. Helium and Nitrogen exhibit different ratios due to their molecule's sizes and mass. The faster helium atoms collide with the surface at a faster rate than the slower nitrogen molecules. The free molecular flow has several implications for the reliability of gas-bearing, especially in the nature of the heat transfer mechanism [4],

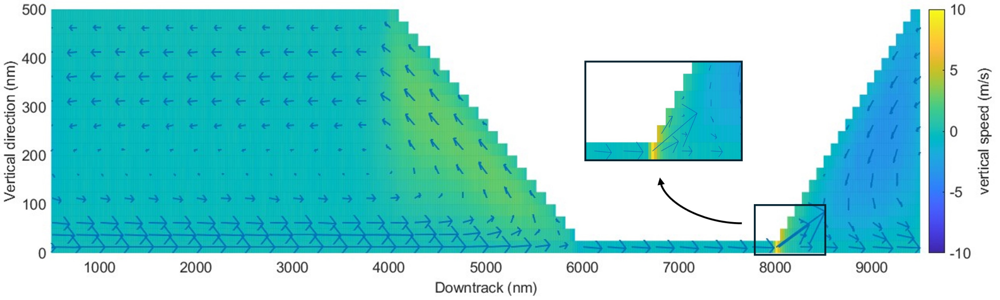

Fig. 2: Vertical component of the average gas velocity in the simulation domain for nitrogen bearings at 5 nm spacing

which may be enhanced due to the collisionless flow of particles. Further, it suggests that smear nanoparticles can travel largely unhindered by the moving gas in the head-disk spacings of HAMR drives.

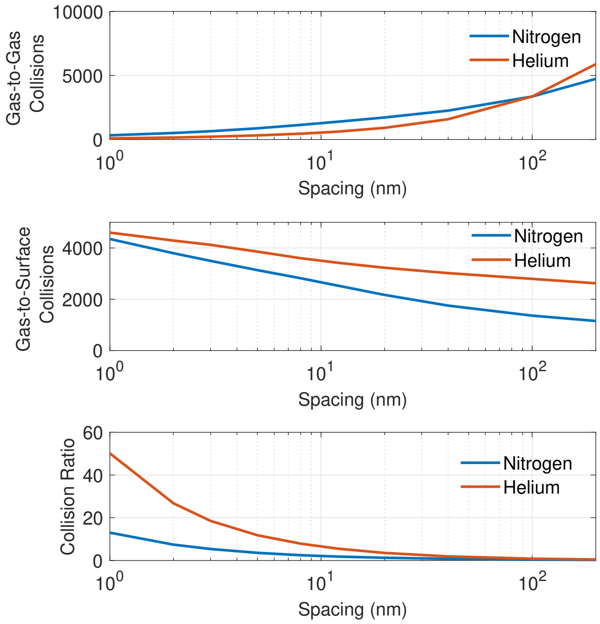

Fig. 3: (a) The gas-to-gas collision per timestep. (b) The gas-to-surface collision per timestep. (c) The ratio of gas-to-surface collisions and gas-to-gas collisions

B. Vertical drift

We plot the average vertical component of the velocity of the nitrogen-bearing at 5 nm spacing in Fig. 2. Since the inflow boundary inserts particles with only the horizontal component, any vertical component is due to the temperature difference and head protrusion. It shows two locations with positive vertical components of vertical velocity. First is a larger region at the leading slope of the head surface. The magnitude of which is around 3 m/s. Second, we observe another area at the beginning of the trailing slope (≈ 8000 nm down-track in Fig. 2). This area is significantly smaller but has a larger magnitude. The variation of their magnitudes with head-disk spacing is plotted in Fig. 4.

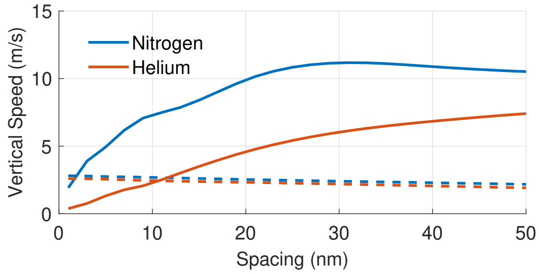

Fig. 4: Magnitude of the vertical drifts in nitrogen and helium at spacings less than 50 nm. Dashed lines represent the leading edge, and solid lines represent the trailing edge.

The vertical velocity in the leading side is weakly dependent on spacing, with values reducing from 3 m/s to 2 m/s over the range. On the other hand, for the vertical velocity near the trailing end, the magnitude increases with spacing till it reaches a maximum of 11 m/s at 30 nm spacing. This component of the gas velocity can impact the movement of contaminants in the gas-bearing by giving them a vertical drift. It would eventually lead to smear accumulating on the head surface.

C. Conclusions

The DSMC simulations revealed many interesting phenomena impacting the smear formation in the gas-bearing. We observed two effects: the large collision ratio and vertical drifts. A complete 3D model of the slider will be needed to uncover additional nano-scale effects in the head-disk interface. Subsequent simulations can then incorporate smear nanoparticles to study and control their transport under the influence of these nano-scale molecular phenomena.

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