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Lubrication effects on head–disk spacing loss

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Abstract

As flying heights are reduced to 10 nm or less, maintaining good flyability becomes critical to ensuring the robustness of the head–disk interface. One way to reduce the head–disk interference during low flying is to minimize the media portion of the head–disk spacing loss. In this work, both Touchdown RPM and Pump down Pressure tests were used to measure this parameter. Experimental results from this study show that the free lubricant thickness is a major contributor to the loss and results in the observed hysteresis between the Touchdown and Take off Pressures (or RPM).

Keywords: Head–disk interface (HDI); Head–disk spacing loss (HDSL); Touchdown (TD); Take off (TO); Fly height (FH); Flyability

1. Introduction

In the pursuit of 1 Tb/in.^{2} magnetic recording areal density, the clearance between the head and media surface in the hard disk drive is becoming critically small (<10 nm). At such low flying heights, intermittent head–disk contact, which induces unstable interface flyability, is inevitable. At high RPM, the large air bearing pressure leads to increased lubricant pick-up on the head surface, resulting in degraded flyability. Therefore, optimization through media design is necessary in reducing the head–disk spacing. To understand the effects of media variables on flyability, precise measurement of the head–disk spacing loss (HDSL) is critical. Both Touch Down RPM [1–3] and Pump Down Pressure [4] tests have been employed for measuring the HDSL by several groups. Herein we compare both methods for measuring the head–disk spacing under various RPM and vacuum dropping rate conditions. In addition, the spacing data are compared with Air-Bearing Simulations (ABS). It has been proposed that the HDSL results from the attractive van der Waals force between the slider and the disk lubricant layer [1,2]. Here we study the effects of lubricant thickness on the HDSL through Pump Down Pressure testing. Concurrently, adhesion and friction measurements are made on sister disks by atomic force microscopy (AFM).

2. Experimental

Samples consisted of 95 mm diameter NiP-plated Al substrates with a 3 nm plasma-enhanced vapor deposited (PECVD) carbon overcoat. Disks with an AFM roughness value of 0.3 nm (5 μm×5 μm scans) were lubed with up to 40 Å of Zdol/additive by a dipping process. Relative adhesion curves were collected on a Veeco Dimension 3000 AFM, operating in the contact mode. More detailed adhesion and friction measurements were undertaken on a ND-MDT 'Solver' AFM[1]. Touch Down RPM and Pump Down Pressure tests were made with a Vena tester, mounted with an acoustic emission (AE) sensor. In these tests, as the RPM or pressure is continuously reduced, the head comes into contact with the disk, giving rise to a large AE signal. Conversely, as RPM or pressure is increased, the head lifts away from the disk and the AE signal drops to zero, indicating that the head is flying once again. Hysteresis between the touchdown (TD) and takeoff (TO) pressures

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[1] Courtesy, Dr V. Gitis, CETR, Campbell, CA.

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(or RPM) is present, as has been described by Thornton and Bogy [2]. This work examines the effect of lubricant thickness on this phenomenon.

3. Results and discussions

3.1. Test method comparison

Although TD RPM measurements on the same disk, using the same head were found to be very reproducible for a given change rate, test results indicate that is very sensitive to the rate, itself (Table 1). TD Pressure, however, is independent of changes in pressure drop (Fig. 1).

To relate these results to Fly Height (FH) differences, a simulation study was done for each test method. Fig. 2 illustrates the FH simulation results for both Touch Down RPM and Pump Down Pressure tests. The FH is seen to increase linearly with RPM up to ∼2000 rpm after which it remains approximately constant (Fig. 2a). This may indicate that the negative and positive air bearing forces do not release simultaneously. In contrast, the FH is seen to decrease linearly with pump down pressure over the full range of pressures investigated (Fig. 2b). Consequently, prediction of FH changes is more straightforward with the latter method.

3.2. Lubricant effect

To investigate lubricant effects on the HDSL, disks of identical AFM roughness (0.3 nm) were used to minimize

Table 1
Touch down RPM data with different dropping RPM rate

Sample disk same head	40 rpm/s	80 rpm/s	1160 rpm/s
Trial 1 (RPM)	1197	1324	1860
Trial 2 (RPM)	1220	1220	1940
Trial 3 (RPM)	1191	1300	1780

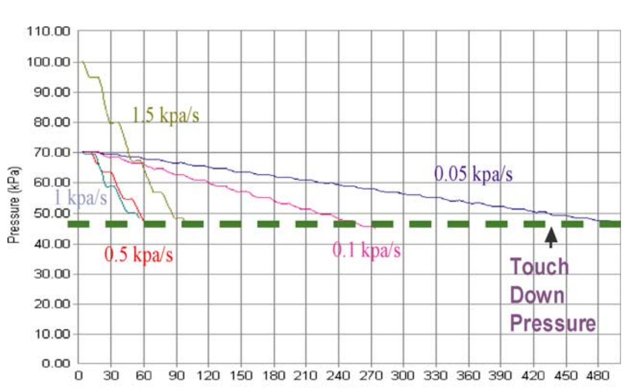

Fig. 1. Dependence of touch down pressure with drop rate.

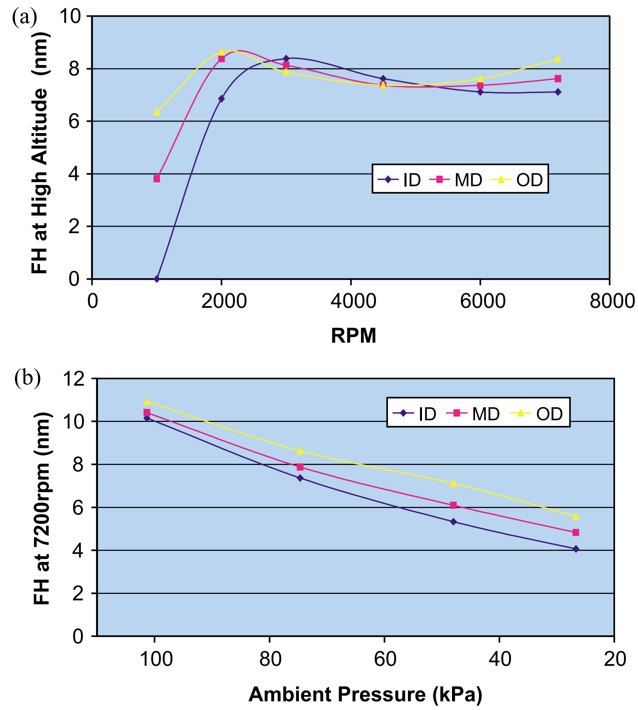

Fig. 2. Fly Height simulation curves for (a) Touch down RPM and (b) pump down pressure tests.

the effect of texture, which was observed by He [5]. Bogy et al. [3] had previously reported that the HDSL was less with thicker lubricant. In this study, both unlubed disks and those with (7 Å) 100% bonded lubricant repeatedly crashed during testing, indicating that some free lubricant is necessary for flying. Fig. 3 depicts measured TD and TO pressure values for the 15 and 40 Å lubricant thickness samples. Two features are noteworthy. First, both TD and TO pressures are lower in the 40 Å lubricant thickness sample, relative to the than 15 Å case. Second, the pressure increase required for takeoff (i.e. hysteresis) decreases as the lubricant thickness increases.

Fig. 4 shows the relation between free lubricant thickness and TO pressure. As shown, the lubricant adhesive effect decreases linearly with the free lubricant thickness.

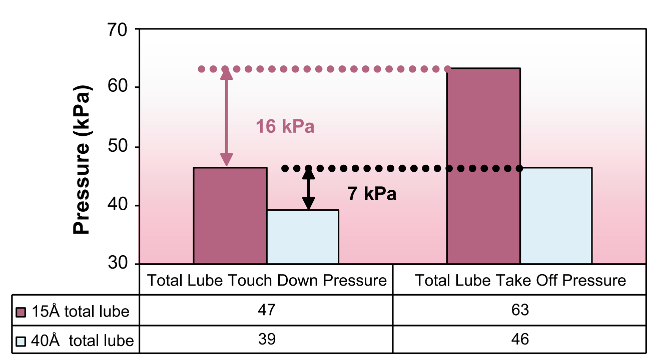

Fig. 3. Touch down and take off pressure of 15 and 40 Å disks.

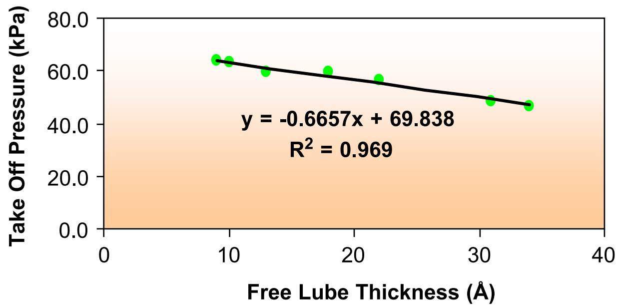

Fig. 4. Correlation between take off pressure and free lube thickness.

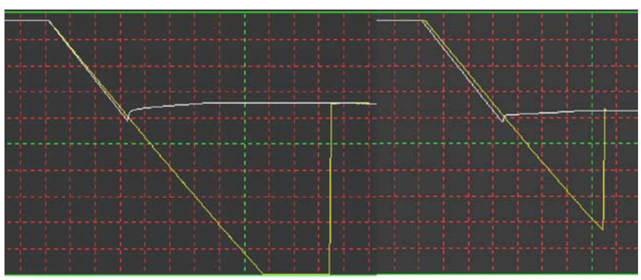

Fig. 5. AFM force distance curves for 15 Å (left plot) and 40 Å (right plot) lubricant layer disk surfaces (upper curve is approach, lower, retraction), Zpiscale = 22nm/div.

To further investigate this apparently non-intuitive result, force curves were measured by atomic force microscopy. In this test, a ∼15 nm radius, 'ultra sharp' cantilever probetip was extended toward the disk surface until contact was established and subsequently retracted. The resulting force–extension curves are depicted in Fig. 5, for disks containing 15 and 40 Å of total lubricant.

As shown, the extension portions of the curves are similar, indication that similar meniscus forces are at work on the tip as it approaches the surface. The retraction portions differ significantly, however. The thinner (15 Å) lubricant layer gives rise to a noticeably larger pull off (i.e. adhesive) force than its 40 Å thick lubricant counterpart. Fig. 6 shows lateral force images for the 15 and 40 Å lubricant cases. As shown, the 15 Å sample (Fig. 6a)

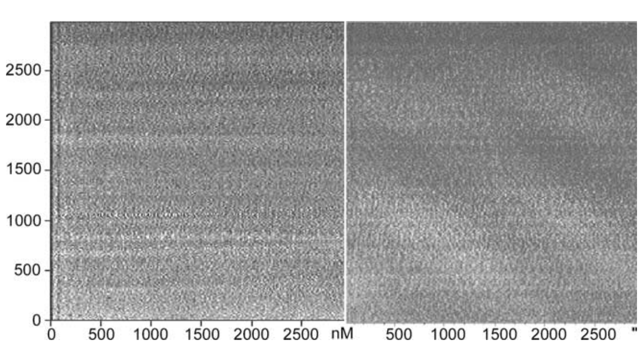

Fig. 6. AFM lateral force images for 15 Å (left) and 40 Å (right) lubricant layer disk surfaces.

Table 2
AFM Lateral and adhesive force measurements

t (Å)	Lat. for., rel. units	Adh. for. nN
15	0.047	7.67
15	0.054	6.72
40	0.014	4.77
40	0.031	5.58

exhibits a greater degree of 'ripple' in the image, indicating greater in-plane friction, as compared to the 40 Å case (Fig. 6b). Table 2 summarizes the elastic measurements for these two cases.

Independent Fourier Transform Infrared (FTIR) spectrometry measurements have shown that both of these lubricant layers contain a similar bonded fraction (∼5.5 and 7.5 Å for the 15 and 40 Å cases, respectively). Since the tip extension is identical in each case, one can conclude that it is the bonded lubricant fraction and not the total lubricant thickness that determines the adhesive force. Therefore, in this regime, intermolecular rather than meniscus forces are controlling. Conceptually, one can envision the probetip to be immersed in primarily bonded lubricant in the thinner lubricant sample and in mainly free lubricant in the thicker lubrication layer case. These results are consistent with the reduced take off time (i.e. lower HDSL) observed for the thicker lubricant layer samples.

Although the results show that thicker free lubricant gives rise to a reduced HDSL, tests also suggest that repeatability and head pick up are compromised. Thus optimization is necessary in designing the lubricant thickness for a given media.

4. Conclusions

The linear relationship between pump down pressure and fly height renders this method preferable to touch down RRM testing in predicting the HDSL. Results show that both the HDSL and the hysteresis decrease as the free lubricant thickness increases, due to the smaller adhesive and frictional forces associated with increased free lubricant. Therefore the free lubricant thickness is the major contributor to HDSL and the hysteresis between the touch down and take off pressures.

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