Numerical Simulation of

Slider Dynamics over Patterned Media with Servo Zones

Liping Li and David B. Bogy

Computer Mechanics Laboratory

Department of Mechanical Engineering

University of California

Berkeley, CA 94720

Abstract

Bit Patterned Media (BPM) recording is one of the potential means of reaching areal densities of 4 $T\text{bit}/in^2$ in hard disk drives. However the non-planarity of bit patterns on a disk can lead to a change of the slider's flying performance compare to that on a traditional "smooth" disk, especially when the bit pattern types on the data zones and servo zones are different. In this investigation, the bit aspect ratio (BAR) and pattern arrangement effects are studied and found to be minimal. A slider's dynamics across a servo zone with various kinds of pattern designs are also studied. The simulation results indicate that the slider's flying attitude depends on the servo pattern area ratio, pattern height, servo zone circumferential length and servo pattern array.

Keywords: Bit Patterned Media, Bit Aspect Ratio, pattern arrangement, servo zone, flying attitude.

Introduction

In BPM recording an individual recorded bit is stored on distinct nano-scale magnetic islands in order to overcome the thermal stability problems caused by continuously increasing the areal density in hard disk drives. Several numerical techniques have been proposed to solve the slider's flying attitude on small-scale surface textures. Mitsuya et al. [1-3] studied the effects of two-dimensional roughness on the slider's flying characteristics using an averaged Reynolds equation. Jai [4] and Buscaglia et al. [5] used a homogenization method based on a double-scale approach to solve the hard disk problem with a rough slider and a rough disk.

Several works have been reported on the slider's flying characteristics over a BPM disk. Gupta et al. [6] applied the Homogenization method to simulate the static problem of the head disk interface (HDI) with a BPM disk. Li et al. [7] investigated the flying characteristics of air bearing sliders over BPM disk using direct simulation. Li et al. [8] used the direct simulation Monte Carlo method to study the head/disk interface with BPM. Knigge et al. [9] performed experiments on a disk with a half flat zone and a half patterned zone.

Recently, some works have been reported considering the pattern type difference on data and servo zones. Li et al. [10] identified the Taylor Expansion Homogenization to be an economical and accurate method for studying a slider dynamics on a BPM disk with identical or different pattern types on the data and servo zones. Hanchi et al. [11] investigated the impact of discrete track pattern orientation shift at data-servo transitions on air bearing dynamic flying stability. The dynamic characteristics of a slider flying over various servo patterns were studied in Li et al. [12].

In this work the Bit Aspect Ratio (BAR) and bit pattern arrangement orientation effects on a slider's flying attitude are investigated numerically. The impacts of the bit pattern types that define the configuration of the servo zone are also studied, including the pattern area ratio, pattern height, servo zone circumferential length and servo pattern array.

Numerical Modeling

The model of a slider flying on a BPM disk which is defined as uniformly distributed cylinders on a flat disk is show in Fig.1. The bit pattern parameters are shown in Fig.2, in which h is the pattern height, p is the wavelength and d is the diameter. So the area of one bit island is $\pi d^2/4$.

Bit aspect ratio (BAR) is defined as the ratio of the track pitch W and bit cell length L. Fig.3 is a regular BPM model with a BAR of one. For higher BAR, there are two kinds of models: one has a fixed bit pattern size (Fig.4) which is the same as BAR of one and the other has a fixed bit cell ratio in the width and length directions (Fig.5). For the pattern arrangement effects we study two kinds of pattern arrangement models: the first one is shown in Fig.6, and the second one has a parallelogram pattern arrangement (Fig.7).

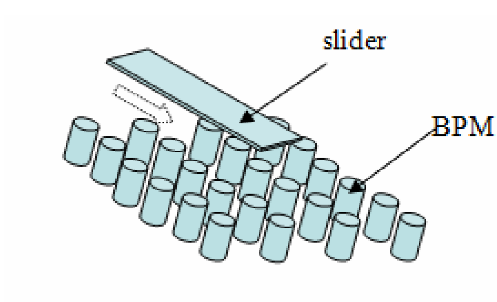


Fig. 1 Model of a slider flying on a BPM disk

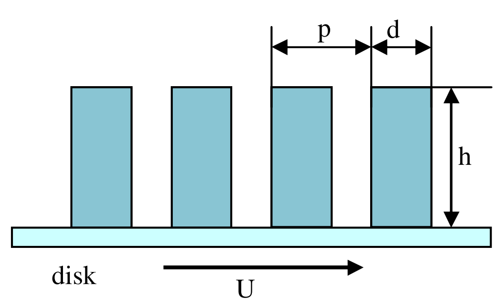


Fig. 2 Parameters of BPM

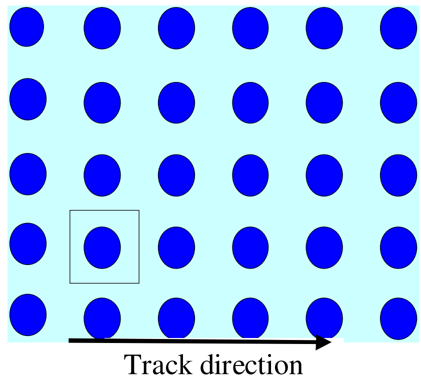


Fig. 3 Regular BPM model with BAR=1

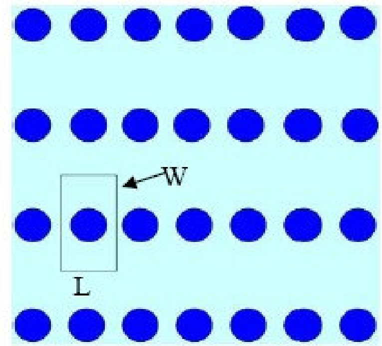


Fig.4 BAR model I

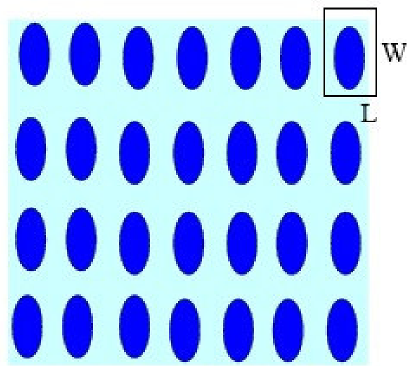


Fig.5 BAR model II

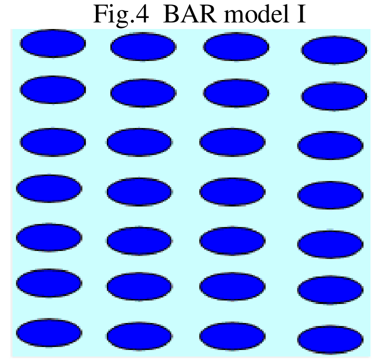


Fig.6 pattern arrangement model I

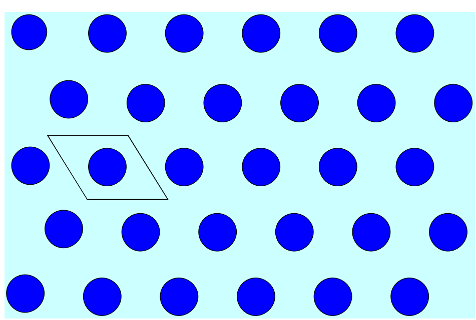


Fig.7 Parallelogram pattern arrangement (model II)

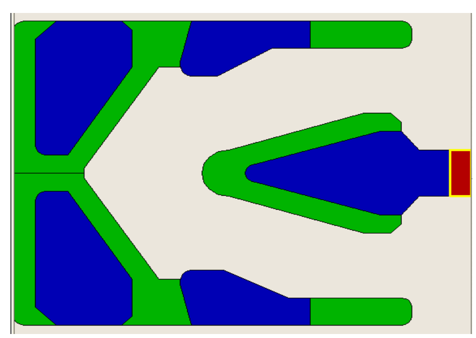


Fig. 8 Femto slider design used in this investigation

The femto-sized slider (0.85mm×0.7mm×0.23mm) used in this study is shown in Fig.8. The minimum flying height of this slider flying over a smooth disk is about 11.5 nm.

In the next section we first investigate the bit aspect ratio and bit pattern arrangement effects on a slider's flying attitude using the Taylor Expansion Homogenization method

[10]. After that the slider's flying condition when experiencing transitions between data zones and servo zones is also studied.

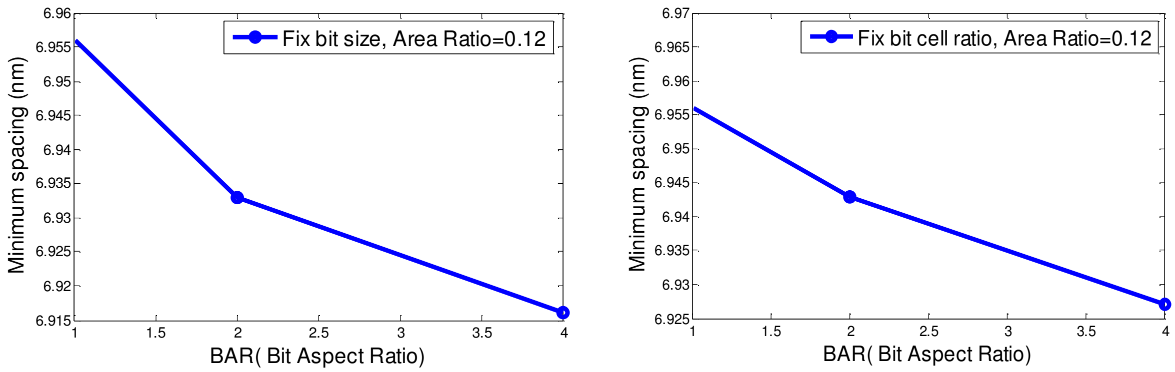
Simulation results and analysis

Bit aspect ratio and bit pattern arrangement effects

The slider's flying attitude on BPM disks with the above two different bit aspect ratio models (Fig.4 and Fig.5) is shown in Fig.9. In Fig.9(a), we increased the BAR but fixed the bit size (BAR Model I) while in Fig.9(b), we fixed the bit cell ratio (BAR Model II), but the pattern area ratio was kept the same for both cases. It shows that the minimum spacing decreases slightly as the BAR increases for the slider we studied. But the decreases are very small for both cases.

Fig.10 shows a comparison of the slider's flying height when it flies on two different bit pattern types, which were shown in Fig.5 and Fig.6. It indicates a negligible difference when the slider is flying on these two patterned model disks. Fig.11 is a comparison of the slider's flying heights on a rectangular pattern (Fig.3) and a parallelogram pattern (Fig.7) at three different radial positions. It shows that the two pattern types lead to almost the same result.

From these results we conclude that the BAR and bit pattern arrangement effects are very small on the slider's flying attitude. So these pattern designs can be the choices for the pattern type on data zones or servo zones in order to reduce the transition oscillation. The result of one of these applications can be found in Fig.12 which shows the slider's minimum flying height response when it experiences transitions between data zones and servo zones. These two zones have different pattern arrangements but the same pattern height. The pattern types on the data zones are rectangular (Fig.3) and parallelogram (Fig.7) on the servo zones. Fig. 12 shows that the oscillations are negligible during transitions.



(a) (b)

Fig.9 Slider's minimum spacing from disk top surface as a function of the BAR

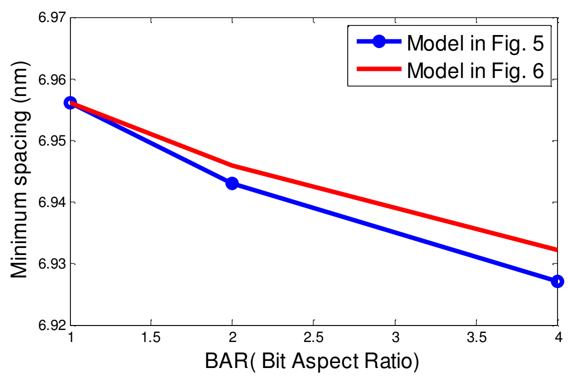


Fig.10 Slider's flying height on two bit pattern types shown in Fig.5 and Fig. 6

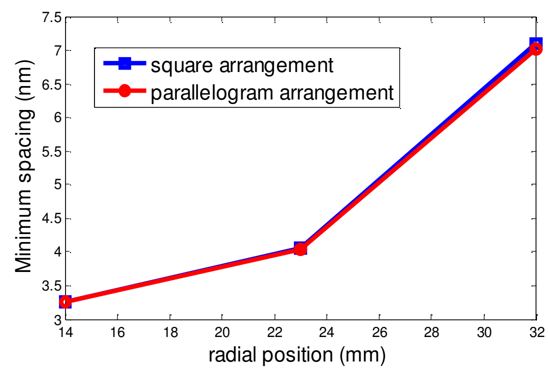


Fig.11 Slider's flying height on two bit pattern types shown in Fig.3 and Fig. 7

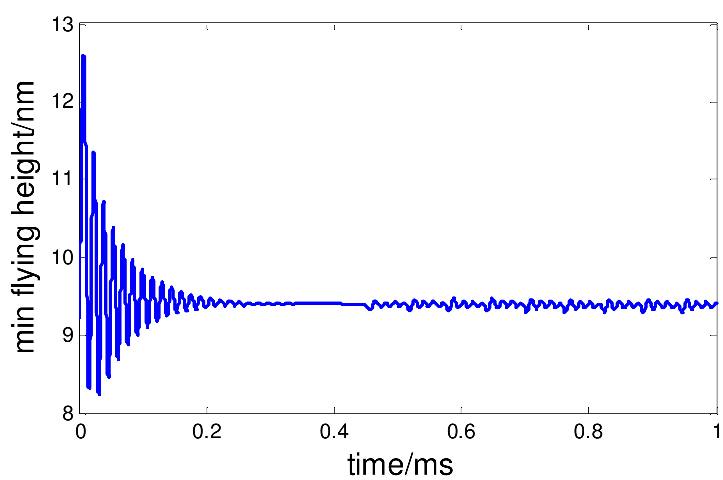


Fig.12 Slider's transitions between data zones and servo zones which have different pattern arrangements

Transition between data zones and servo zones

Fig.13 is a schematic diagram of a slider flying at the transition between a data zone and servo zone. We assume the servo zone is composed of six blocks (listed in Table 1): sync/ automatic gain control, servo address mark (SAM), cylinder (gray), sector, bursts and post amble. The cycles of bit pattern and degrees for each block are also listed in the table.

In our previous study [10] we investigated the slider's flying attitude when it experiences transitions between data zones and servo zones which have different pattern heights or pattern area ratios, and we found the slider-disk spacing increased and decreased periodically. Here the slider's flying height response when flying from a data zone to a servo zone and then back to a data zone is simulated in order to study the slider's flying attitude change in more detail when the servo zone bit patterns are different, for example, different pattern area ratio, pattern height, and servo zone length.

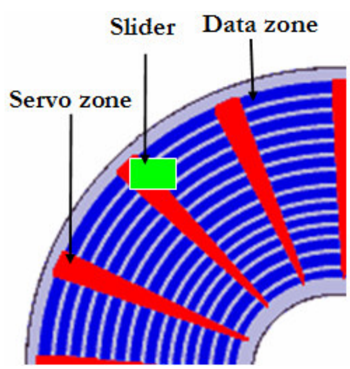


Fig.13 A slider flying at transition between data zone and servo zone

Table1. Servo zone configuration (6 blocks)

Index of block	1	2	3	4	5	6
Servo zone configuration	Sync/Automatic gain control	Servo address mark (SAM)	Cylinder (gray)	Sector	bursts A B C D	Post amble
Cycles of bit pattern	53	21	10	5	192	11
Degrees	0.0858	0.0340	0.0162	0.0081	0.3111	0.01782

Fig.14 shows the slider's flying height response on servo zones with pattern height 3 nm and pattern area ratios of 0.25 and 0.5. The pattern area ratio is 0.1 on the data zones for all the following cases. One sees that the maximum flying height, which is defined as the flying height at the peak point, as well as the flying height oscillation during the transition increase with the increase of the pattern area ratio. This is easy to understand since the slider's flying height increases with the increase of pattern area ratio according to [10]. Fig.15 shows the slider's flying height response on servo zones with pattern heights 3 and 6 nm and pattern area ratio 0.5. It shows that the maximum flying height decreases with the increase of the pattern height, but the flying height oscillation increases as the pattern height increases. Fig.16 shows the slider's flying height response over two servo zones with different circumferential lengths (one is twice the other). From this result one can see that both the maximum flying height and flying height oscillation increase with the increase of servo zone length.

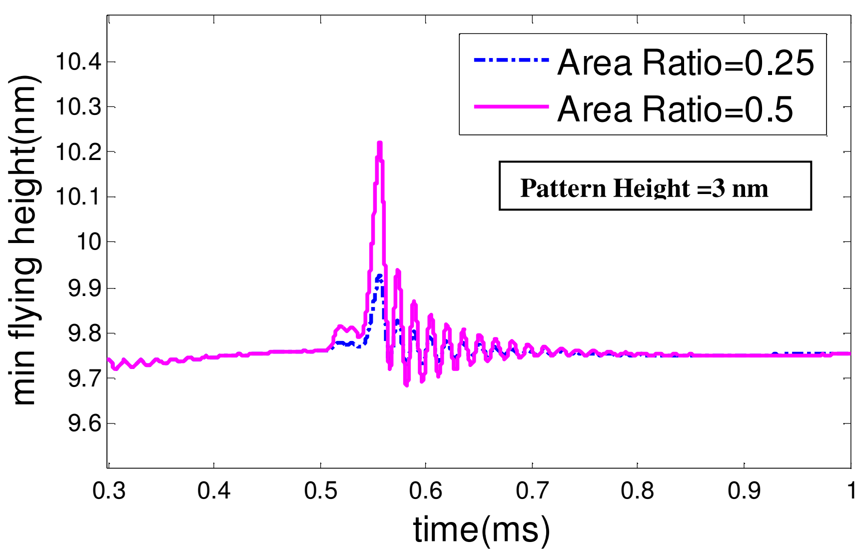


Fig.14 Comparison of minimum flying height when servo zones have pattern area ratios 0.25 and 0.5

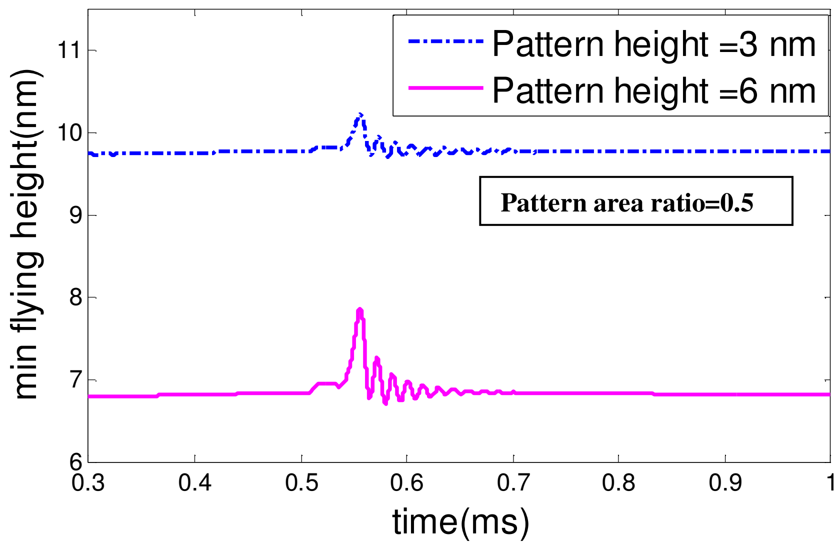


Fig.15 Comparison of minimum flying height when servo zones have pattern heights 3 and 6 nm

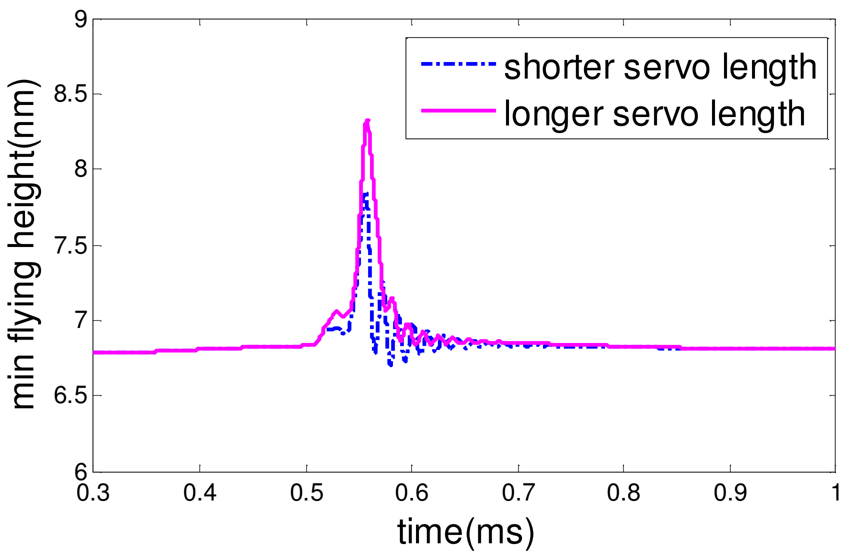
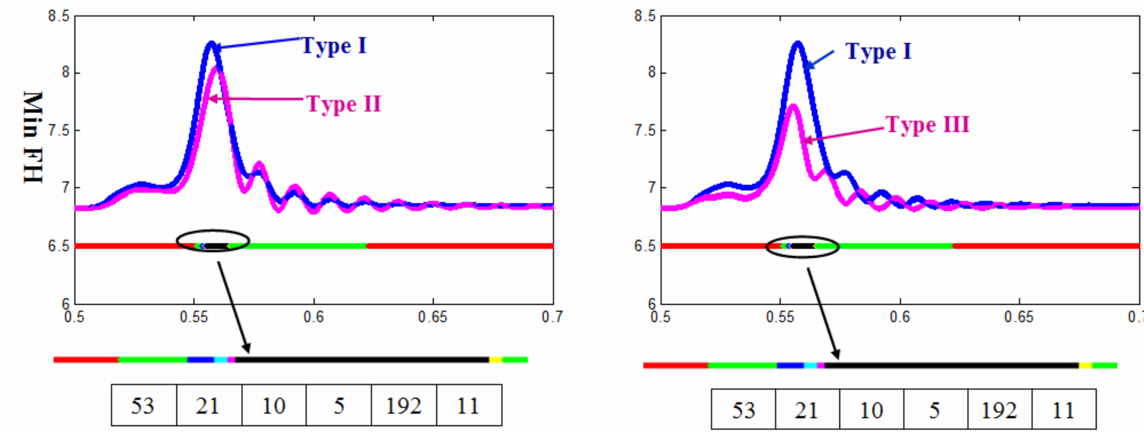


Fig.16 Comparison of minimum flying height over two servo zones with different circumferential lengths

For all the above cases we assumed the pattern types on the six blocks of the servo zone are the same. We also investigated cases when the pattern types are not the same for the six blocks. The three servo zone designs we studied are shown in Table 2. The slider's flying height responses on these servo zones are shown in Fig.17. Fig.17(a) compares the results for the first two cases. The color bars under the flying height response curves show the position of the slider's trailing edge: red indicates the slider's trailing edge is on the data zone; green means it is transferring between a data zone and servo zone; the other colors indicate the transitions between different blocks of the servo zone. The numbers under the amplified color bar are the cycles of bit pattern for each block. From Fig.17(a) one can see that the minimum flying heights begin to show a difference when the slider's trailing edge is still on the data zone. That's because at this moment the other part of the slider has already transferred to the servo zone and the pattern area ratios are different for these two cases. The flying height difference increases as the slider moves more to the servo zone until the slider's trailing edge has transferred to the fifth block since the pattern area ratio is the same on this block for the first two cases. Oscillation occurs when the slider is transferring from the servo zone back to data zone. Fig.17(b) shows the comparison of the first and third cases. The minimum flying height difference is very small when the slider's trailing edge is on the first four blocks, while the difference begins to increase when it transfers to the fifth block since the pattern area ratios are different on the last two blocks for these two cases.

Table 2. Three servo zone designs

Block index	1	2	3	4	5	6
Type I	AR=0.5	AR=0.5	AR=0.5	AR=0.5	AR=0.5	AR=0.5
Type II	**AR=0.25**	**AR=0.25**	**AR=0.25**	**AR=0.25**	AR=0.5	AR=0.5
Type III	AR=0.5	AR=0.5	AR=0.5	AR=0.5	**AR=0.25**	**AR=0.25**



(a) (b)

Fig.17 Minimum flying height responses over three servo zone designs

Conclusion

In this paper we investigated the BAR and bit pattern arrangement effects on the slider's flying attitude and found that both of them have very small effects. So the bit pattern designs with different BAR or bit pattern arrangement can be used on different zones of the disk in order to reduce the transition oscillations.

The slider's flying height response is different when the servo pattern area ratio, pattern height, circumferential length or pattern array on six blocks are different. The maximum flying height on the servo zone increases with increases of the servo pattern area ratio and servo zone length, but decreases with the increase of pattern height. The flying height oscillation increases with increases of the servo pattern area ratio, pattern height or servo zone length.

Acknowledgments

This research was supported by the Information Storage Industry Consortium (INSIC) and the Computer Mechanics Laboratory (CML) at University of California at Berkeley.

References

1. Mitsuya Y., 1984, "A Simulation Method for Hydrodynamic Lubrication of Surfaces with Two-Dimensional Isotropic or Anisotropic Roughness Using Mixed Average Film Thickness", *Bulletin of JSME,* 27(231):2036-2044.
2. Mitsuya Y., Ohkubo T., Ota H., 1989, "Averaged Reynolds equation extended to gas lubrication processing surface roughness in the slip flow regime: approximate method and confirmation experiments", *ASME J. Tribol,* 111:495–503
3. Mitsuya Y. and Koumura T., 1995, "Transient-Response Solution Applying ADI Scheme to Boltzmann Flow-Modified Reynolds-Equation Averaged with Respect to Surface-Roughness", *ASME J. Tribol*, 117(3): 430-436.
4. Jai M., 1995, "Homogenization and 2-Scale Convergence of the Compressible Reynolds Lubrication Equation Modeling the Flying Characteristics of a Rough Magnetic Head Over a Rough Rigid-Disk Surface", *Mathematical Modeling and Numerical Analysis,* 29 (2), pg 199-233.
5. Buscaglia G., Ciuperca I. and Jai M., 2002, "Homogenization of the Transient Reynolds Equation", *Asymptotic Analysis*, 32(2):131-152.
6. Gupta V., 2007, "Air Bearing Slider Dynamics and Stability in Hard Disk Drives", *Ph.D. Dissertation,* Department of Mechanical Engineering, University of California – Berkeley.
7. Li H., Zheng H., Yoon Y. and Talke F. E., 2009, "Air Bearing Simulation for Bit Patterned Media", *Tribol. Lett.,* 33:199-204.

8. Li H., Amemiya K. and Talke F. E., 2010, “ Slider Flying Characteristics over Bit Patterned Media Using the Direct Simulation Monte Carlo Method”, *Journal of Advanced Mechanical Design, Systems, and Manufacturing,* 4(1):49-55.
9. Knigge B. E., Bandic Z.Z., Kercher D., 2008, “Flying Characteristics on Discrete Track and Bit-Patterned Media With a Thermal Protrusion Slider”, *IEEE Trans. Magn.,* 44: 3656-3662.
10. Li L. and Bogy D. B., 2011, “Dynamics of air bearing sliders flying on partially planarized bit patterned media in hard disk drives”, *Microsyst Technol*, Online First
11. Hanchi J., Sonda P. and Crone R., 2011, “Dynamic Fly Performance of Air Bearing Sliders on Patterned Media”, *IEEE Trans. Magn.,* 47(1): 46-50.
12. Li J., Xu J., and Kobayashi M., 2010, “ Slider Dynamics over a Discrete Track Medium with Servo Patterns”, Presented on the STLE/ASME 2010 International Joint Tribology Conference, San Francisco, CA.