Springer

Journal of Mechanical Science and Technology 23 (2009) 2679~2685

Journal of Mechanical Science and Technology

www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-0521-2

# Simulation of a head slider considering a discrete track recording technology †

Sang-Joon Yoon[1], Seok-Ho Son[2], Jihoon Kang[3], Hyunki Kim[3], Jingyoo Yoo[3] and Dong-Hoon Choi[1,*]

[1]*Department of Mechanical Engineering, Hanyang University, Seoul, 133-791, Korea*
[2]*Graduate School of Mechanical Engineering, Hanyang University, Seoul, 133-791, Korea*
[3]*Samsung Electronics Co., Ltd., Suwon 443-742, Korea*

(Manuscript Received December 3, 2008; Revised May 6, 2009; Accepted May 14, 2009)

**Abstract**

Discrete track recording (DTR) is a new application technology that utilizes a separate physical storage disk with grooves and ridges comprised of radial and circumferential direction in order to achieve higher data transfer rates and storage densities on a hard disk drive (HDD). However, the grooves and ridges on the DTR media cause flying stability issues. Therefore, we analyze and compare the dynamic performance of a head slider with three types of DTR media in which different DTR parameters are defined, such as groove width and pitch. Prior to simulations, we propose the DTR flying height (FH) loss equation which estimates a loss of FH on the DTR media using the defined DTR parameters. The accuracy and creditability of this equation is then predicted by comparing the results of the equation to those of the simulation. Consequently, we propose a method for designing the air bearing surface (ABS) on the DTR media using the static performance of the ABS on a continuous track recording (CTR) along with the proposed DTR FH loss equation.

***Keywords***: DTR (Discrete Track Recording); DTR FH loss; Flying stability

## 1. Introduction

A hard disk drive (HDD) constantly requires higher storage densities and data transfer. It is possible for a higher track density to make narrow write/read head elements because it depends on the write/read head width. However, the decrease in the width of the write/read head elements causes critical issues to occur, such as the side-fringe effect of the write head, cross-talk from adjacent tracks, and difficulty fabricating the narrow write/head. It may be possible to overcome these drawbacks using discrete track recording (DTR) technology because the bits are stored on single tracks that are physically separated by grooves and ridges [1-3].

However, even though DTR technology offers many advantages, there are still design difficulties to consider. The flying behavior of a slider on the DTR media is different from that on continuous track recording (CTR) media due to the grooves and ridges covering the entire recording band. The loss of flying height (FH) and the fluctuation of a head slider when it is in steady-state with the DTR media and that of a head slider with the CTR media were comparatively investigated [4-6].

In this study, we analyzed the performance of a head slider on three types of DTR media modeled via defined parameters using the CML air bearing simulator. We determined the effect of the groove size and area ratio on the flying attitudes of a head slider from these results. In addition, we checked the empirical

† This paper was recommended for publication in revised form by Associate Editor Jeonghoon Yoo

*Corresponding author. Tel.: +82 2 2220 0443, Fax.: +82 2 2291 4070
E-mail address: dhchoi@hanyang.ac.kr

equation to estimate the FH loss on the DTR media [6] and proposed an equation for the loss of FH on the embossed pattern. Specifically, we proposed an efficient simulation method which makes it possible to check the performance of a head slider on the DTR media. According to this proposed method, we can design the head slider's efficiency to improve and satisfy the suitable range of a slider's performance on the DTR media.

## 2. Numerical methods

### *2.1 DTR pattern modeling*

In this paper, the DTR pattern is modeled using five parameters as a function of discrete track media parameters, where *wamp* is the depth of the groove, *wthx* and *wpdx* are the pitch and width of the groove in the circumferential direction, respectively, and *wthy* and *wpdy* are the pitch and width of the groove in the radial direction, respectively, as shown in Fig. 1 below.

Fig. 2 shows a schematic of the three different types of discrete track media. We call them the Circumferential Infinite Groove (CIG), where the groove only occurs in the circumferential direction as shown in Fig. 2(a), the Radial Infinite Groove (RIG), where the groove only occurs in the radial direction as shown in Fig. 2(b), and the Embossed Groove (EG), where the groove is both in the circumferential and radial directions as shown in Fig. 2(c). Fig. 3 shows the Pemto slider (measuring 1.235×0.7×0.23mm) used in this investigation.

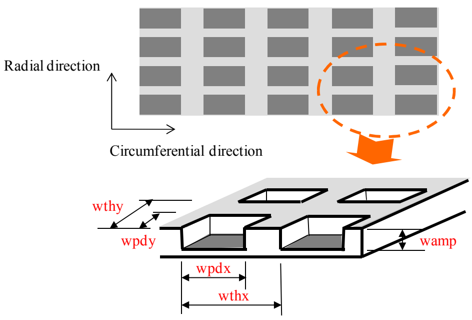



Fig. 1. Parameters for defining the disk model.

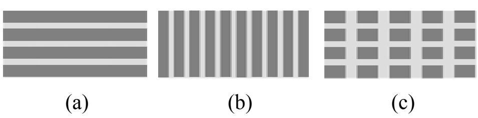



Fig. 2. A variety of DTR patterns.

### *2.2 Effect of the groove scale*

In this study, we determined that the groove scale has an effect on the dynamic performance of a head slider. We modeled the DTR pattern by changing the normalized scale of the groove width and groove pitch from 1 to 100 for numerical convenience, with the fixed groove area ratio comprised of a defined groove width and pitch. In addition, the normalized average value was calculated as the ratio of the average flying attitudes on the DTR to the average value of the flying attitudes on the CTR. That is, the normalized average value "1" represents the average flying attitudes on CTR.

There are three cases of groove scales for each type of DTR pattern, as shown Table 1. The normalized groove scale "1" represents the nanoscale, which signifies a realistic DTR pattern, and "100" represents the centuple scale.

Fig. 4(a) shows the normalized values for flying attitudes on each DTR pattern in comparison to those on the CTR media.

In the case of the CIG, if the groove area ratio and the groove depth are uniform, then a slider has a similar loss of FH with a different groove scale. This means that the groove scale has no effect on the loss of FH. Even with pitch and roll angle, there is no change over CIG when compared to the CTR media.

Next, we simulated a head slider on RIG while keeping the groove area ratio fixed at 1:2. Fig. 4(a) shows that if the resulting groove area ratio and the groove depth are uniform, the loss of FH is approximately the same.

The third type, EG, also gives the same result as that of CIG and RIG. The loss of FH is nearly uniform, with a variety of EG fixed at the same groove depth and groove area ratio. Once again, the pitch and roll angle remain nearly constant.

We likewise checked the fluctuation of a head slider for the flying stability, as shown in Fig. 4(b). There is no effect on the fluctuation of FH, pitch, and

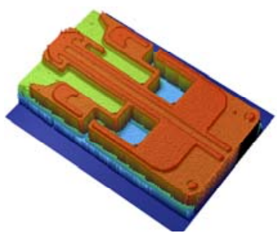


Fig. 3. ABS model for simulation.

Table 1. DTR patterns for the effect of groove scale.

| Pattern | Normalized groove scale | Groove area ratio |
|---|---|---|
| CIG | *1* | 2/3 |
| | *10* | |
| | *100* | |
| RIG | *1* | 1/2 |
| | *10* | |
| | *100* | |
| EG | *1* | 1/2 & 1/2 |
| | *10* | |
| | *100* | |

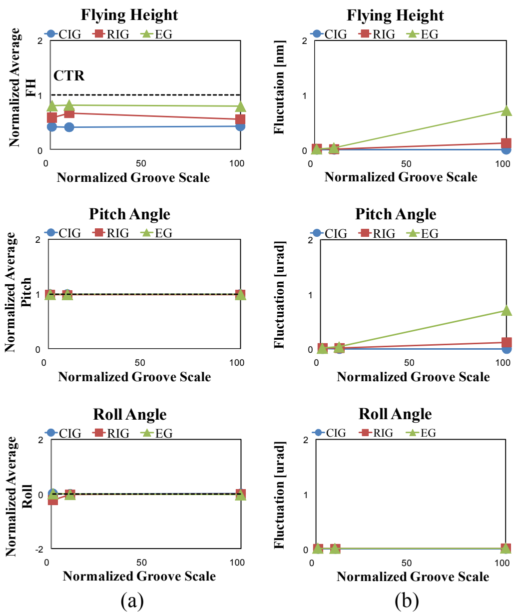



Fig. 4. Effect of the groove scale.

roll angle over CIG and RIG as the groove scale changes. The largest possible variation of FH and pitch angle occurs at them "100" scale in EG. However, as the groove scale decreases to a realistic DTR pattern, the variation of the head slider decreases dramatically.

### *2.3 Effect of the groove area ratio*

This study has determined the effect of the groove area ratio on the change of groove width and fixed groove pitch. The groove depth is also uniform. We likewise compared the flying attitudes of a head slider on CIG and RIG, as shown Table 2.

Table 2. CIG and RIG for the effect of groove area ratio.

| Pattern | Normalized groove scale | Groove area ratio |
|---|---|---|
| CIG | 100 | *1/3* |
| | | *1/2* |
| | | *2/3* |
| RIG | 100 | *1/4* |
| | | *1/2* |
| | | *3/4* |

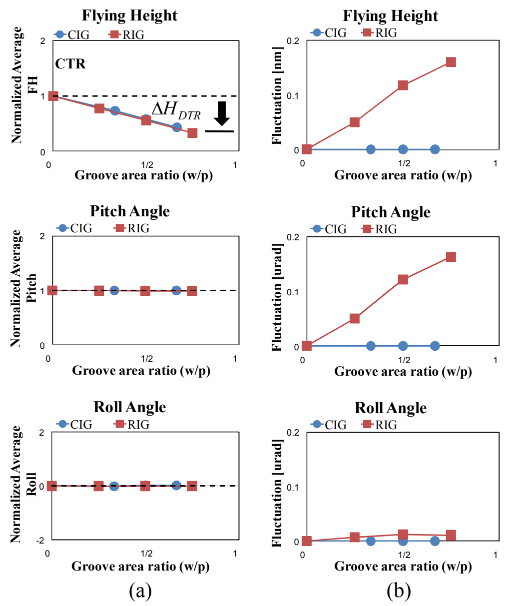



Fig. 5. Effect of the groove area ratio on CIG and RIG.

Fig. 5(a) shows the normalized values for flying attitudes on CIG and RIG in comparison to those on the CTR media. With CIG, the patterns were defined to have a variety of groove area ratios of 1:3, 1:2, and 2:3, as shown in Table 2. These results were then used to compare the flying attitudes of a head slider, as shown in Fig. 5(a). The FH of a head slider decreases as the groove area ratio linearly increases. The groove area ratio has no effect on pitch or roll angle. In addition, the groove area ratio has an insignificant influence on the variation of a head slider with the CIG in Fig. 5(b).

With RIG, we also modeled DTR patterns with a variety of groove area ratios. Fig. 5(b) shows that, as the groove area ratio increases, the FH of a head slider linearly decreases, and there is no effect on the pitch or roll angle. However, the variation of flying attitudes over RIG is different than that over CIG.

There is a small amount of linear variation according to the change in groove area ratio. Since the direction of RIG is perpendicular to the flying direction of a head slider, RIG has a greater effect on the performance of a head slider.

EG is considered in Table 3. We have defined the groove area ratio, $(wpdx/wthx)$ or $(wpdy/wthy)$, in RIG and CIG. When these groove area ratios are applied, the loss of FH and the ensuing variation is compared. The result is shown in Fig. 6 (a) . In the figure, the loss of FH and the variation change nonlinearly according to the variations in the groove area ratio. Therefore, we propose a new groove area ratio for EG as follows in Eq. (1):

$$(wpdx/wthx)\times(wpdy/wthy) \tag{1}$$

We recognized that the loss of FH and the fluctuation of a head slider linearly changes according to the proposed groove area ratio, as shown in Fig. 6(b).

Table 3. EG for the effect of groove area ratio.

| Pattern | Normalized Groove Scale | *Groove Area Ratio* | |
|---|---|---|---|
| | | *wpdx/wthx* | *wpdy/wthy* |
| EG | 100 | *1/2* | *1/2* |
| | | *3/4* | *3/4* |
| | | *1/4* | *1/4* |

## 2.4 Application of the DTR FH loss equation

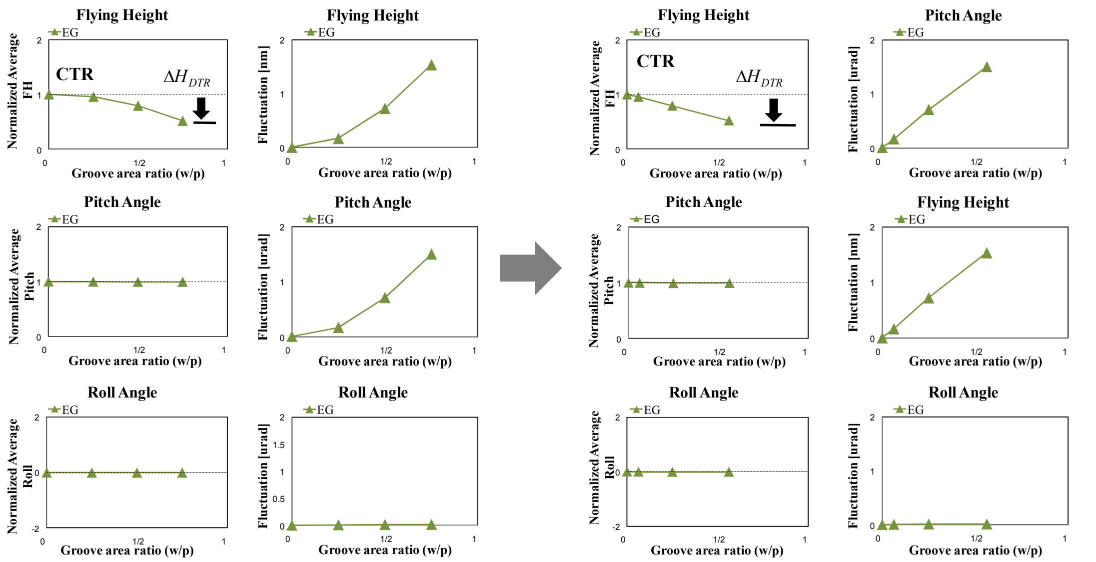
As discussed above, the FH of a head slider on the DTR media is affected by the groove. Therefore, we pre-estimate the loss of FH through the following empirical Eq. [6]:

$$\Delta H_{DTR} = \left(\frac{w}{p}\right)\cdot d \tag{2}$$

where w/p is the groove area ratio and d is the groove depth.

In order to determine the application of this DTR FH loss equation, we simulated a head slider with a variety of DTR patterns which have a uniform groove depth as shown in Table 4. We compared the results between the DTR FH loss equation and the real simulation results. As shown in Fig. 7, the investigated case of CIG shows that the result from the DTR FH loss equation matches the real simulation in five cases of the DTR patterns. Similar to CIG, we checked the application against RIG. As shown in Fig. 8, the result of FH loss from the equation nearly matches the result of the simulation.

Finally, we simulated a head slider on each of the five cases of EG. The DTR FH loss equation must be updated to define the new groove area ratios for EG. The DTR FH loss equation for EG is as follows in Eq. (3):




(a) (b)

Fig. 6. Effect of groove area ratio on EG.

Table 4. DTR patterns for the DTR FH loss equation.

| Pattern | *Normalized Groove Scale* | Groove Area Ratio |
|---|---|---|
| CIG | *1* | 2/3 |
| | *10* | 2/3 |
| | *100* | 2/3 |
| | *100* | 1/2 |
| | *100* | 1/3 |
| RIG | *1* | 1/2 |
| | *10* | 1/2 |
| | *100* | 1/2 |
| | *100* | 3/4 |
| | *100* | 1/4 |
| EG | *1* | 1/4 (*1/2 & 1/2)* |
| | *10* | 1/4 (*1/2 & 1/2)* |
| | *100* | 1/4 (*1/2 & 1/2)* |
| | *100* | 9/16 (*3/4 & 3/4)* |
| | *100* | 1/16 (*1/4 & 1/4)* |

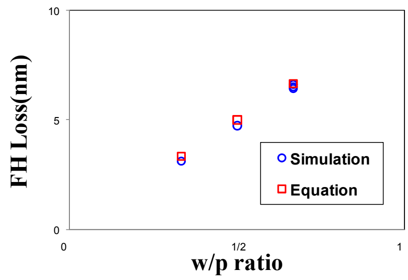



Fig. 7. Simulation results on CIG.

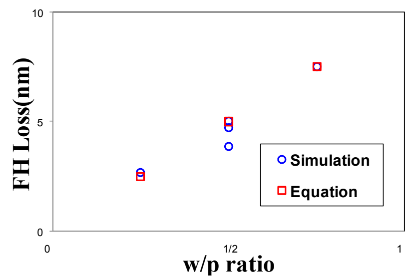



Fig. 8. Simulation results on RIG.

$$\Delta H_{DTR} = \left(\frac{w_x}{p_x}\right)\cdot\left(\frac{w_y}{p_y}\right)\cdot d \quad (3)$$

When we applied the new equation for EG, the results are similar to both the DTR FH loss equation and the simulation shown in Fig. 9.

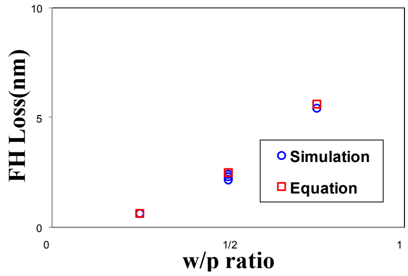



Fig. 9. Simulation results on EG.

## *2.5 Effective simulation*

The proposed loss of FH equation is very efficient in predicting the dynamic performance of a head slider on the DTR by using those on the CTR.

However, the CTR slider simulation still requires a lengthy computation time. Therefore, in order to find a more efficient analysis method, we compared the dynamic simulation, which takes a long CPU time, and the static simulation, which has a shorter calculation time. We analyzed the FH of a head slider at both the sea level and the altitude, as shown in Fig. 10(a). The FH is nearly the same from both the static simulation and the dynamic simulation with CTR.

Previously, we examined the relation of FH with CTR and DTR. Therefore, we can define the relation of FH with the static simulation results of CTR and the dynamic simulation results of DTR, as shown in Eq. (4).

$$\begin{aligned} FH_{DTR} &= FH_{S\cdot CTR} - \Delta H_{DTR} \\ FH_{DTR\,@alt} &= FH_{S\cdot CTR\,@alt} - \Delta H_{DTR} \end{aligned} \quad (4)$$

The subscript $S \cdot CTR$ indicates the static simulation on CTR. Similarly, we have given recognition to the fact that the pitch and roll angle are the same as the results of both CTR and DTR, as shown in Figs. 10(b) and (c). Consequently, we define an equation with both the pitch and roll angle, as shown in Eq. (5) and (6).

$$\begin{aligned} Pitch_{DTR} &= Pitch_{S\cdot CTR} \\ Pitch_{DTR\,@alt} &= Pitch_{S\cdot CTR\,@alt} \end{aligned} \quad (5)$$

$$\begin{aligned} Roll_{DTR} &= Roll_{S\cdot CTR} \\ Roll_{DTR\,@alt} &= Roll_{S\cdot CTR\,@alt} \end{aligned} \quad (6)$$

Simply by using the static simulation, a good estimate can be reached for the flying attitudes of a head slider on the DTR media, both at sea level and at

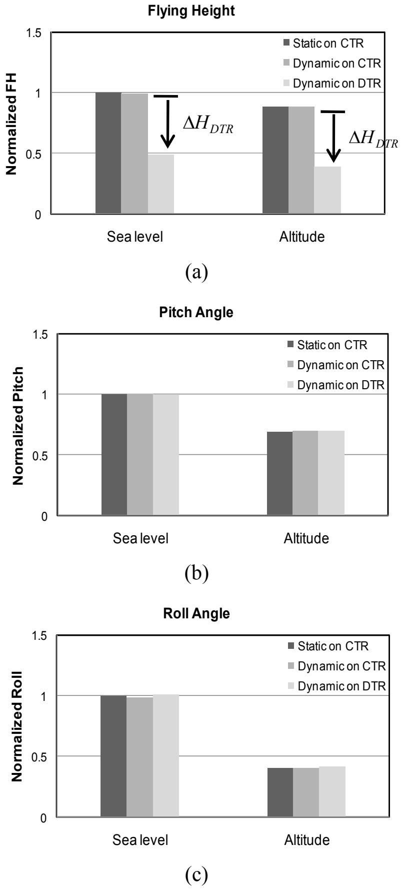



Fig. 10. Relation between the static simulation and the dynamic simulation.

higher altitudes.

## 3. Conclusions

We simulated the dynamic performance of a slider on three types of DTR media as follows: the circumferential infinite groove along the track, the radial infinite groove across the track, and the embossed groove both along and across the track.

We demonstrated that with a uniform groove area ratio and groove depth, the groove scale has no effect on the loss of flying attitudes for a head slider. Even if the variation is increased via a larger groove scale, the true scale of a DTR pattern has little influence on the variation.

The loss of FH changes linearly as the groove area ratio changes on CIG and RIG. In addition, the loss of FH changes linearly on EG if the proposed groove area ratio is applied.

Finally, with the proposed simulation technique, we can evaluate the flying attitudes of a slider on the DTR media without using the dynamic simulation, which takes a long time. Instead, we can use the static simulation, which requires a shorter computation time at both sea level and at higher altitudes. In conclusion, our results will allow the optimal head slider to be utilized more efficiently in order to improve the slider's performance on the DTR media.

## Acknowledgments

This work was supported by Brain Korea 21, Samsung Electronics Co., Ltd., and the Center of Innovative Design Optimization Technology (iDOT).

## References

[1] D. Wachenschwanz, W. Jing and E. Roddick et al., Design of a Manufacturable Discrete Track Recording Medium, *IEEE Transactions on Magnetics,* 41 (2) (2005) 670-675.

[2] Y. Soneo, M. Moriya and A. Kaizu et al., Performance Evaluation of Discrete Track Perpendicular Media for High Recording Density, *IEEE Transactions on Magnetics,* 41 (10) (2005) 3220-3222.

[3] J. Li, J. Xu and Y. Shimizu, Performance of sliders flying over discrete-track media, *Journal of Tribology Transactions of the ASME,* 129 (4) (2007) 71-719.

[4] J. P. Peng, G. Wang and S. Thrivani et al, Numerical and Experimental Evaluation of Discrete Track Recording Technology, *IEEE Transactions on Magnetics,* 42 (10) (2006) 2462-2464.

[5] K. Kawazoe, M. Yotsuya and T. Shimamura et al., Dynamics of Flying Head Slider for Groove Discrete Track Disk, *Advance in Information Storage Systems,* 6 (1995) 97-106.

[6] M. Duwensee, S. Suzuki and J. Lin et al., Air Bearing Simulation of Discrete Track Recording Media, *IEEE Transactions on Magnetics,* 42 (10) (2006) 2489-2491.

**Sang-Joon Yoon** received a B.S., M.S. and Ph. D. degrees in Mechanical Design & Production Engineering from Hanyang University in 1989, 1992 and 1997, respectively. He worked for the technical research center at DAEWOO Motors Co. for four years. He visited Georgia Institute of Technology in Atlanta, USA for around 3 years as a visiting scholar. He is currently a Research Professor at Hanyang University and a director at FRAMAX Inc. in Seoul, Korea. Dr. Yoon's research interests are in the area of product designs using practical optimization techniques such as DOE, Meta-Modeling, RA, RBDO, etc.

**Seok-Ho Son** received a B.S. degree in Mechanical Engineering from Hannam University in 2005 and then he went on to receive his M.S. from Hanyang University in 2007. He is currently a Ph. D. student in Hanyang Universiy. Mr. Son's research interests are in the area of optimization, approximation techniques, and design of experiments.

**Dong-Hoon Choi** received a B.S. degree in Mechanical Engineering from Seoul National University in 1975. He then went on to receive his M.S. from KAIST in 1977 and Ph. D. degree from University of Wisconsin-Madison in 1986, respectively. Dr. Choi is currently a Professor at the School of Mechanical Engineering at Hanyang University in Seoul, Korea. He is currently the director of iDOT (the center of innovative design optimization technology). Prof. Choi's research interests are in the area of optimization techniques: developing MDO methodology, developing optimization techniques to ensure a reliability of optimum solution, and developing approximation optimization technique, etc.