# THE EFFECTS OF STRAY FIELD IN DIFFERENCE OF BIT PATTERNS EXPOSURE ON READ HEAD PERFORMANCE

**Ploybussara Gomasang and Rardchawadee Silapunt**

**Department of Electronic and Telecommunication Engineering,**

**King Mongkut's University of Technology Thonburi**

**ploybussara.bussee@mail.kmutt.ac.th, rardchawadee.sil@kmutt.ac.th**

**ABSTRACT**

The areal density enhancement in hard disk drive (HDD) is usually achieved by increasing bit density (number of bits per unit length along the track direction) and/or track density (number of tracks per unit length along the radial direction). As a result, bit dimension needs to be decreased to maintain the overall disk size and reading efficiency may be affected by adjacent bits' magnetizations or stray fields. In this paper, we focus on the effects of stray field (magnetic distortion) on reading performance of the Tunneling Magneto-Resistance (TMR) read head. The change in magnetizations of the free layer (FL) is investigated using simulation in different reading scenarios, *i.e.*, over transition regions, cross-track, down-track, and varied bit patterns. In addition, by the micromagnetic analysis is used to simulate detailed variation of magnetizations in FL. Results are then manipulated mathematically to obtain profiles of reader resistance. We found that the reader resistance is definitely affected by bit pattern and reader position over the media. The magnetic field induced over the transition region, whose magnetization is opposite to that of FL causes a rapid change in the reader resistance. The proposed research will help understand read head behavior which will lead to the improvement of HDD performance.

## 1. INTRODUCTION

HDD is an important device used for storing digital information with electromagnetic and mechanical processes. When the demand of storage technologies increases, many researchers have spent much more effort to improve magnetic recording technology to increasing data storage capacity (Das & Mochizuki, 2014). Associated with smaller bit dimension is a decrease in the read sensor dimension. The read head is then more sensitive to interferences from neighborhood fields (Das & Mochizuki, 2014), (Guzik Tech., 2005), and (Zeng, et al., 2012).

TMR is currently the most mature read sensor technology extensively adopted by all HDD manufacturers. Its resistance depends on the alignment of FL magnetization with respect to that of the pinned layer. The FL magnetization responds to the external magnetic field detected from media. We believe that the difference in bit pattern is one of the significant factors to evaluate the performance of read head and magnetic medium (Guzik Tech., 2005).

In this paper, we will determine the variation of magnetization vectors, and in turn, the resistances of FL due to the effects of stray fields when the read head flies over different bit patterns. Hypothetically, the magnetization vectors of FL will try to align themselves to the direction of external magnetic fields and that change of FL magnetization will potentially affect the resistance of the read sensor.

## 2. SIMULATION

### 2.1 Simulation setup

Fig.1 shows the main composition of TMR read head and the perpendicular magnetic recording (PMR) media. Both permanent magnet (PM) layers are 10 nm thick, 60 nm width, and 35 nm height. The saturation magnetization ($M_s$) is 590 kA/m (Liu, et al., 2014). The distance between PMs is 19 nm. The FL is 5 nm thick, 30 nm width, and 35 nm height. Both shields (SH) are 20 nm thick, 154 nm width, and 80 nm height. The SH to SH spacing is 14 nm. The recorded media is 60 nm track width, 10 nm height, and $M_s$ is 500 kA/m. The soft underlayer (SUL) is 192 nm height.

The initial magnetization of FL lies in the positive x-direction, forced by the magnetic field from both PM layers. In this study, FL magnetization vectors and resistances are simulated by assuming that the read head flies over different bit patterns or different stray field patterns. The read head is assumed to move from left to right in every case. In particular, to present the magnetization changing in FL, the volume of FL is divided into 42 cells and assumed to be homogeneous. All magnetization vectors in local cell are carefully considered to calculate the variation of resistance. The results will indicate that the FL resistance is varied by its properties and volume of each cell.

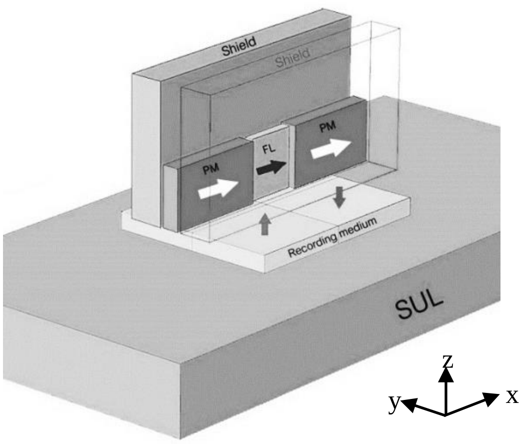


Fig. 1. The simulation model of TMR read head

### 2.2 Numerical method

The changing of magnetization vector can be determined by considering the variation of resistance from the micromagnetic analysis (Masuko, et al., 2008), as shown in Eq. (1)

$$r_{ij} = \left(\frac{R_{max}+R_{min}}{2}\right) - \left[\left(\frac{R_{max}-R_{min}}{2}\right)\cdot \hat{F}\cdot \widehat{M}_{ij}\right], \qquad (1)$$

where $r_{ij}$ is the resistance of each cell. $\widehat{M}_{ij}$ is the unit vector of magnetization vector in each cell. $\hat{F}$ is the unit vector of reference vector that is fixed in positive z-direction. $R_{max}$ and $R_{min}$ are the maximum and minimum resistance of the read sensor. We use the value of $R_{max}$ and $R_{min}$ from the TMR ratio (Uemura, et al., 2007). The total resistance of read sensor can be calculated by

$$R = \left(\sum_i \sum_j \frac{1}{r_{ij}}\right)^{-1}. \qquad (2)$$

### 2.3 Case Studies

In this paper, 3 case studies are performed. Each contains 2 cases. We begin the first study by setting the read head to move in down track direction over two different bits, as shown in Fig. 2. In case 1, the bit magnetizations are oriented upward (U) and downward (D) in negative y-region and positive y-region, respectively. In case 2, the bit magnetizations are oriented oppositely to those of case 1.

In the second study, the read head moves in cross track direction, as shown in Fig.3. In case 1, the bit magnetizations are oriented upward in the negative x-region and downward in the positive x-region. Case 2 setup is opposite to that of case 1.

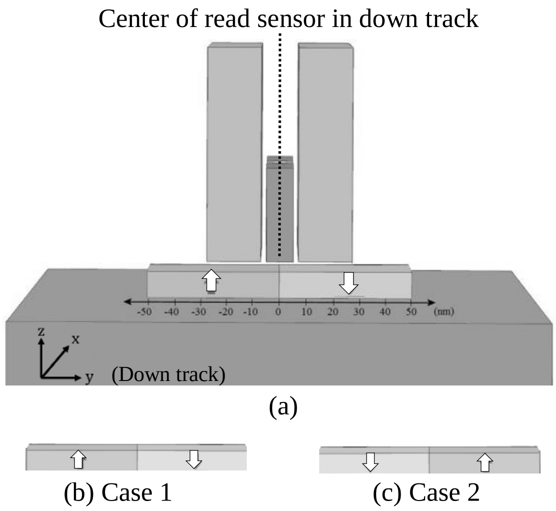


Fig. 2. (a) Study 1, the read head moves in down track direction over 2 different bits. Figs. 2(b) and 2(c) show bit patterns in case 1 and case 2, respectively.

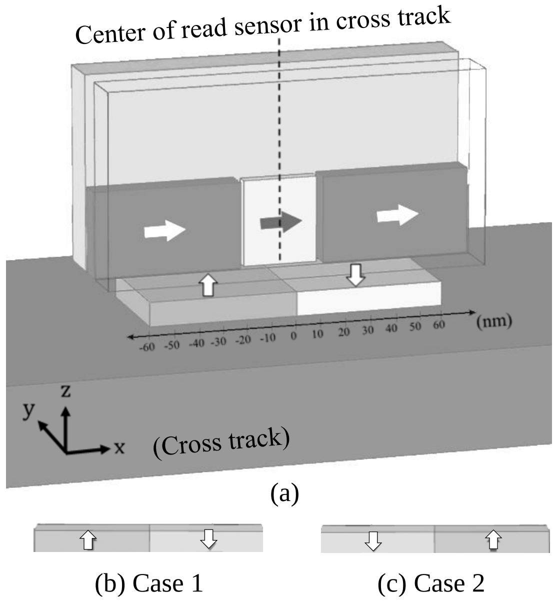


Fig. 3. (a) Study 2, read head moves in cross track direction over the track transition. Figs. 3(b) and 3(c) show bit patterns in case 1 and case 2, respectively.

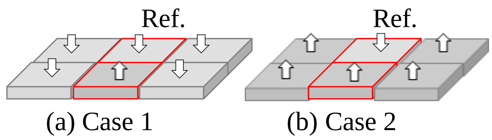


Fig. 4. Study 3, adding the adjacent tracks on both sides of the reference (Ref.) track. The read head moves in down track direction over the reference track. Figs. 4(a) and 4(b) show bit patterns in case 1 and 2, respectively.

The last study is performed on more number of bits. The reference track as shown in Fig. 2(b), is connected with additional tracks on both sides, as shown in Fig. 4. The magnetizations of adjacent tracks lie upward and downward for case 1 and 2, respectively.

## 3. RESULTS AND DISCUSSION

### 3.1 Study 1: Read head flies in down track direction.

Fig. 5. shows FL magnetizations induced by the external magnetic fields from the media in case 1. Fig. 5(b) implies that the magnetic field reversal at the bit transition region unlikely affects the magnetization change of FL in x-z plane. FL magnetization vectors appear to align themselves with that of PM.

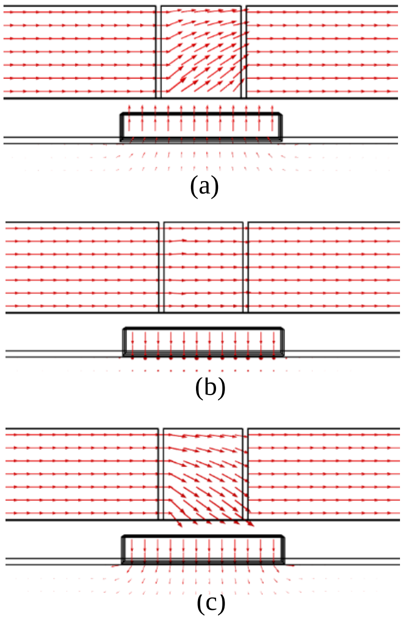


Fig. 5. FL magnetization vectors from the study 1-case 1 in x-z plane. The center of read sensor (referred to Fig. 2) is at (a) -10 nm, (b) 0, and (c) 10 nm, respectively.

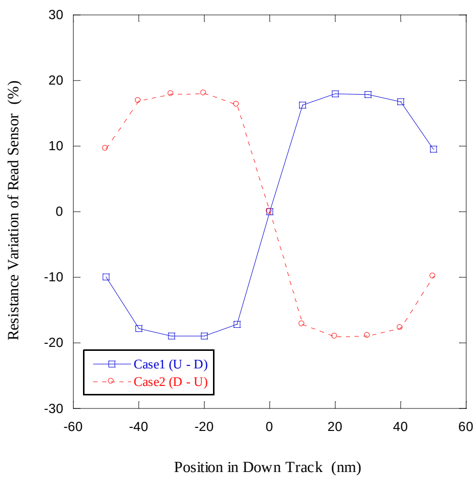


Fig.6. The relationship between the resistance variation in read sensor (%) and the position of read head from study 1.

The result of the study 1-case 2 is similar to case 1. The profile of the FL resistance variation in case 1 is opposite to that in case 2, as shown in Fig.6

### 3.2 Study 2: Read head flies in cross track direction

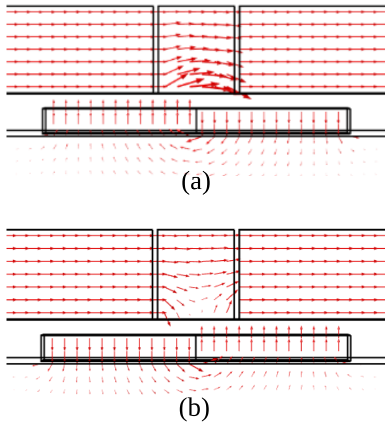


Fig.7. FL magnetization vectors from the study 2, (a) case 1 and (b) case 2. The center of reader sensor is at 0 nm.

Figs. 7(a) and 7(b) shows that the magnetic field reversal at the bit transition region clearly affects the magnetization of FL in x-z plane. The profile of FL resistance variation as shown in Fig. 8, shows higher magnitude of slope for case 2 (1.7) than case 1 (0.8). It could be explained that the external field induced over the bit transition region in case 2, whose magnetic field is opposite to the magnetization of FL causes a rapid change in the reader resistance.

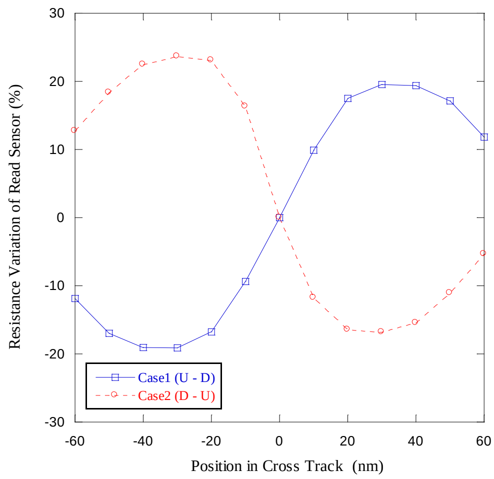


Fig.8. The relationship between the resistance variation in read sensor (%) and the position of read head from study 2.

### 3.3 Study 3: Adding the adjacent tracks and read head flies in down track direction

From Fig. 9, it can be seen that the magnitude of resistance variation over the first and second bits in case 1 is smaller and higher than that of the reference case, respectively. It could be explained that the net magnetization detected by the FL is probably low due to opposite magnetizing effect of the adjacent tracks. On the other hand, the enormous flux reversal takes place when the read head moves to the second reference bit since both adjacent bits possess the same magnetization direction as the reference one. Case 2 exhibits the opposite result but similar analysis can still apply. The higher net magnetization induced by the first bit and its adjacent tracks results in more flux reversal that results is slightly higher resistance variation. The effect of adjacent tracks substantially subsides the resistance variation when the read head moves to the second bit, again due to collectively lower magnetization in that region. Note that, smaller deviation from the reference is observed over the first bit region. It appears like the FL magnetization is preferentially induced downward.

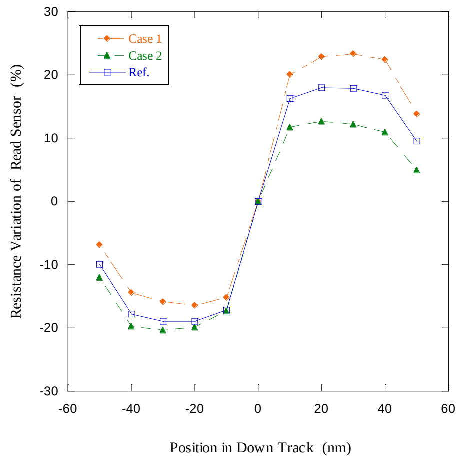


Fig.9. The relationship between the resistance variation in read sensor (%) and the position of read head from study 3, compared to the reference case.

## CONCLUSION

The simulation results clearly explain the effects of stray field from the different bit patterns. The stray field is an important factor that causes the distortion direction of magnetic fields over the media and influences the magnetization in FL. Rapid change of the resistance variation is observed in the cross track direction. Moreover, the influence of flux reversal in cross track direction is an important cause of the resistance change in read head. Finally, the collective impact from adjacent bits strongly affect the FL resistance variation. Future works include read out experiments using actual media with designed bit patterns.

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## REFERENCES

Das, S., and Mochizuki, M. , Magnetic head having a planar hall effect read sensor, U.S. Patent 8 760 801 B2, 2014.

Guzik Technical Enterprises, Perpendicular recording principles, [Online], Available: http://www.guzik.com /solutions_chapter7.asp, 2005.

Zeng, D., Lee, K., Chung, K., and Bae, S., Effects of media stray field on electromigration characteristics in current-perpendicular-to-plane giant magnetoresistance spin-valve read sensors, *J. Appl. Phys.*, 2012.

Liu, Z., Yuan, Z., Ong, C., and Ang, S., Influence of Data Patterns on Reader Performance at Off-Track Reading, *IEEE Trans. Magn.*, vol. 50, no. 11, p. 3002804, 2014.

Masuko, J., Akimoto, H., Matsumoto, M., Kanai, H., and Uehara, Y., Amplitude and Phase Distributions of Magnetization in Tunneling Magnetoresistive Head, *IEEE Trans. Magn.*, vol. 44, no. 7, pp. 1856-1860, 2008.

Uemura, T., Marukame, Takao., Matsuda, K., and Yamamoto, M., Four State Magnetoresistance in Epitaxial CoFe-Based Magnetic Tunnel Junctions, *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2791-2793, 2007.

**Ploybussara Gomasang** received the B.E. (2013) degree in electronic and telecommunication engineering from King Mongkut's University of Technology Thonburi (KMUTT), Thailand.

She is now a graduate student in Department of electronic and telecommunication engineering, KMUTT. Her current interests include read head technology and stray magnetic field.

**Rardchawadee Silapunt** received the B.E. (1992) from Chulalongkorn University, Thailand. She received the M.S. (1998) and Ph.D. (2004) degrees in Electrical and Computer Engineering from University of Wisconsin-Madison, USA.

She is now a lecturer at Department of Electronic and Telecommunication Engineering, KMUTT. Her current interests include recording head technology, plasmonic devices, and nano electromagnetics.