Magnetic force microscopy study on wide adjacent track erasure in perpendicular magnetic write heads

P Ruksasakchai¹, K Saengkaew², I Cheowanish² and B Damrongsak¹,*
¹ Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom, 73000, Thailand
² Western Digital (Thailand) Co. Ltd., Bang Pa-In, Ayutthaya, 13160

* E-mail: damrongsak_b@su.ac.th

Abstract. We used a phase-contrast magnetic force microscopy (MFM) to observe and analyze the failure of magnetic write heads due to the WATEr problem, which limits the off-track performance. During MFM imaging, the magnetic write head was energized by a DC current. The induced out-of-plane magnetic field was then detected by scanning a MFM probe across the surface of the magnetic write head. MFM images were then mapped with WATEr measured results from a spin stand method. Results showed that WATEr effect can be generated by several factors, i.e. the structure of magnetic domains and walls from material discontinuities and the magnetic field leakage at different locations on magnetic write heads. Understanding WATEr mechanisms is useful for design and process development engineers.

1. Introduction
Wide adjacent track erasure (WATEr) is one of major problems in hard disk drive. The problem occurs when out-of-plane magnetic fields from elements around a magnetic write head causes the erasure on both adjacent and wide-area tracks [1]-[3]. Previous studies reported that the WATEr can be measured by a spin-stand technique [4, 5]. A result of the spin-stand measurement is a delta bit error rate (BER) at each cross-track position [6], which obtained after multiple write cycles on a center track as shown in figure 1. A strong signal of delta BER represents high number of bit error, whereas a weak signal of delta BER is low number of bit error. For a typical write head, the strong signal can be seen at the center track as shown in figure 1(a). On the other side, for the write head with the WATEr problem, not only the strong signal can be observed at the center track but also at the other tracks; the strong signal due to adjacent track erasure (ATE) is shown on the side track close to the center track, whereas the strong signal due to wide-area track erasure (WTE) occurs on multiple tracks away from the center track as shown in figure 1(b) and 1(c), respectively. Although the spin-stand technique is able to inspect the WATEr issue in a fast and precise way, its results cannot identify the locations where the WATEr is occurred. Recently, a stationary footprint technique on a modified spin-stand was proposed for monitoring and characterizing the WATEr problem [7, 8]. A Result from this technique is a 2-dimension footprint image on media which accurately links to the magnetic field from the write head. The footprint image can disclose the mechanisms and locations of the WATEr problem on the write head. Nevertheless, this technique has complicated procedures and time consuming.

In this study, we present a different technique for identifying the sources and locations where the WATEr problem is occurred on the write head. This technique utilized a magnetic force microscopy
(MFM) in a phase-contrast mode to image the out-of-plane magnetic field on the surface of the write head. The MFM image was employed to observe and analyze the WATER effect occurred on the write head by comparing with results from the spin stand measurements.

Figure 1. Cross-track profile of normalized delta BER of the write heads (a) without WATER, (b) with ATE effect and (c) with WTE effect.

Figure 2. Schematic diagram of the MFM system for measuring the out-of-plane magnetic field on the write head. The scan size used in the experiment was 6 µm × 3 µm. The write head was biased with 30 mA AC current. The colour represents the measured phase data corresponding to the out-of-plane magnetic field intensity at each location.

2. Experimental setup
Samples were perpendicular magnetic write heads with a fully wrapped-around shield design [9]. The structure of these heads was composed of a main pole (MP) surrounded by magnetic shields, i.e. two side shields (SS), trailing shield (TS) and leading shield (LS) [10, 11]. A touch down sensor (TDS) was laid close to the leading shield. It was partly made by ferromagnetic materials and used for controlling the fly height of the write head.

MFM imaging was performed in a phase contrast mode as shown in figure 2. A soft magnetic coated MFM probe was used to ensure that magnetic moments within the write head were unaffected during probe scanning. The write head was vacuum hold in a static state and was biased with a 30 mA AC...
current or greater in order to make the main pole magnetically saturated. The MFM probe was driven close to its resonance frequency by a piezoelectric transducer. The probe scanned across the surface of the write head to measure the induced out-of-plane magnetic field. The phase shift of the probe oscillation corresponding to the out-of-plane magnetic field at each location was then used to generate the MFM image as shown in figure 3(a). The red colour represents the highest magnetic field intensity. The dark blue colour represents the lowest magnetic field intensity.

The Guzik spin stand system was employed to measure and inspect the WATEr problem resulting from the write head samples. Firstly, the recording media was prepared by AC erasure. Then, the center track was written by a square wave data at 10,000 cycles. The last step was the read back process. The magnetic read head moved across both sides of the center track, approximately 6 µm, and measured the BER losses for different cross track position. The normalized BER losses at each cross track position was used to form the WATEr profile as illustrated in figure 3(b). The measured WATEr profile was then mapped with the MFM image in order to reveal the sources and locations of the WATEr failure on the write head.

3. Results and discussions
MFM images of the write heads with the WTE failure are shown in figure 3(a). As can be seen, we observed the out-of-plane magnetic fields not only at the main pole but also at the shields. For the left figure, the magnetic flux leakage due to the magnetic domains was detected at the left side shield and the trailing shield, while, for the figure in the right-hand sided, the flux leaking was observed at the material interface between the right side shield and the trailing shield. When compared with those results from the spin stand measurement, it was found that the WTE peak positions in figure 3(b) were correlated to the positions of the magnetic domains. This can be concluded that the magnetic field leaking resulting from the material discontinuities can be one of the root causes of the WTE failure.

Figure 3. WTE results of the write heads with the magnetic flux leakage at shields: (a) MFM images and (b) cross-track profiles of normalized delta BER from the spin-stand testing.
In addition, for some samples of the magnetic write heads, the magnetic flux leakage was found at the touch down sensor as shown in figure 4. The MFM image revealed the relatively strong field intensity at the touch down sensor and its location was correlated to those found from the spin stand, which showed the ATE peak close to the center track.

4. Conclusion
In this work, the MFM in phase-contrast mode was used to inspect and analyze the WATEr failure on the magnetic write heads. The MFM image was mapped with the measurement results from the spin stand in order to reveal and identify the source and its location causing the WATEr effect. The results showed that the magnetic flux leakages at the material interface were observed on almost all writers with the WTE problem. For some write heads with the ATE effect, we observed the magnetic field leaking at the TDS which was induced by the applied write current.

Acknowledgment
The authors would like to sincerely appreciate and gratefully acknowledge Faculty of Science, Silpakorn University, Development and Promotion of Science and Technology Talents Project (DPST) and Western Digital (Thailand) Co. Ltd. for financial supports of this work. Special thanks to all WD engineers and technical staffs in department of test engineering and slider fabrication development for all technical contributions and helpful discussions.

References
[1] Kao A S, Lee H J, Bekkers G and Hong S 2005 J. Magn. Magn. Mater. 287 475-80
[2] Jiang W, Smith N, Williams M, Heresin W, Kuroki K, Ikeda Y, Takano K, Khera G and Wood R 2003 IEEE Trans. Magn. 39 1891-6
[3] Jiang W, Khera G, Wood R, Williams M, Smith N and Ikeda Y 2003 J. Appl. Phys. 93 6754-6
[4] Peng Q and Tang K X 2012 U.S. Patent Application US8094401B1
[5] Guarisco D and Li M L 2006 IEEE Trans. Magn. 42 3868-73
[6] Liu Y, Takano K, Bai D, Zhang X, Liu K, Wu Y and Dovel M 2009 IEEE Trans. Magn. 45 3660-3
[7] Tang Y, Song S and Guan L 2013 IEEE Trans. Magn. 49 744-50
[8] Li S, Lin E, George Z, Terrill D, Mendez H, Santucci J and Yie D 2014 J. Appl. Phys. 115 17B733.
[9] Okada T, Nunokawa I, Mochizuki M, Haratani M, Kimura H, Etoh K, Fuyama M and Nakamoto K 2005 IEEE Trans. Magn. 41 2899-901
[10] Mallary M, Torabi A and Benakli M 2002 IEEE Trans. Magn. 38 1719-24
[11] Hsu Y, Nikitin V, Hsiao D, Chen J, Zheng Y, Pentek A, Loo J, Jiang M, Yuan S, Alex M, Luo Y, Salo M, Okada T, Maruyama Y, Mitsuoka K 2007 IEEE Trans. Magn. 43 605-8

Figure 4. ATE results of the write heads with the magnetic flux leakage at the TDS: (a) MFM image and (b) cross-track profile of normalized delta BER from the spin-stand testing.