Magnetic force microscopy characterization of write field profiles of magnetic recording heads having a pole-tip protrusion

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Abstract. Almost all previous studies on a thermal-induced pole-tip protrusion (PTP) were mainly focused on the extension of the main pole which in turn affects the flying height of magnetic recording heads and the hard-disk drive reliability. None was reported the PTP effect on a variation of write filed profiles that is directly related to the track width of the magnetic data. In this work, a method to characterize the magnetic field distribution of perpendicular recording heads with a protrusion in a pole-tip region was proposed and implemented. A magnetic head under test was biased with two current sources, one for the write coil and the other for the heater. The write field was then observed by magnetic force microscopy (MFM). MFM images were post-processed in order to investigate the field profiles. Two models of magnetic write heads having different heater designs were employed as test samples. We observed the variations in the area of the write field for the write heads having the protrusion of the pole tip, while the magnitude of the field intensity was almost constant.

1. Introduction

As there is a demand to increase the data storage density in hard disk drives (HDDs) in order to make them competitive to the rapid growth of solid state drives, the physical spacing, or the so-called flying height (FH), between the main pole and the surface of the recording media tends to be decreased [1],[2]. A FH adjustment is typically controlled by thermal heating by applying the DC current to the heater element or by Joule heating due to the biased write current during writing of data on recording media [3],[4]. The heat generated by the FH adjustment causes thermal expansion of the main write pole, referring to as the pole-tip protrusion (PTP) that in turn reduces the spacing gap between the recording head and the magnetic disk. Both thermal-induced and write current-induced PTPs have extensively been studied by many researchers, by either finite element modeling (FEMs) [5] or experimental analysis [6],[7]. Almost all works are mainly focused on thermal expansion of the main pole and the effects of the PTPs on the disk stability. There is no previous work reporting the effects of the PTP on the writing performance.

In our previous work, we employed magnetic force microscopy (MFM) to observe the write field [8] as well as the remanent field on the write element [9]. In this study, we developed additional function for imaging the magnetic write field generated from a thermally protruded main pole of
magnetic recording heads. This can be used to study the effects of the pole-tip protrusion on the intensity and width of the write field. Moreover, the image of the write field profiles can be further utilized to analyze the failure in the magnetic writer fabrication. In the next section, we will discuss the experiment setup and results of two different models of magnetic write heads.

2. Experimental Setup

The MFM setup used for the characterization of the write field profile was illustrated in Figure 1. Magnetic write heads in a form of sliders or rowbars were equipped on the xyz piezoelectric positioner. A 4-pin probe fixture was used as the interconnection between the write heads and two current sources (Keithley SMU2400), one is for the write coil and the other is for the heater. During MFM imaging, the write coil was biased by a DC current in order to generate the magnetic write field from the tip of the main pole. The DC current can be applied to the heater to activate the pole-tip protrusion. A soft magnetic coated MFM probe, scanning at 10 nm height across the slider surface, was employed to detect the magnetic stray field. The scan size is 800 nm x 800 nm with a resolution of 256 pixels x 256 pixels.

A MFM image of the write field generated by magnetic head samples as shown in Figure 2(a) was constructed from a phase shift between the piezoelectric driving force and the oscillation of the MFM probe. The area shown in red represents large phase shift corresponding to the high intensity of the magnetic write field; on the other hand, the area shown in blue represents the low magnitude in the phase shift, implying that there is no magnetic field in the area. Figure 2(b) shows the post-processed contour plot of the MFM image for a comparison of the write fields between the protruded and unprotruded main pole.

![Figure 1. Schematic diagram of MFM system for the characterization of the magnetic write field.](image)

![Figure 2. Write field profile observed at a main pole tip of magnetic write heads when the write coil is biased with a DC current. (a) MFM phase contrast image and (b) post-processed contour plot of the MFM image.](image)
3. Results and discussions

Perpendicular magnetic write heads with a fully wrap around shield were used as test samples for the experiment. Two head designs, i.e. model A and B, were investigated. These samples have different pole and heater designs. For the model A, the write heads have shorter main pole and larger gap spacing between the pole and the side shields. The pole width of the model A is in a range of 40 – 70 nm. On the other hand, the main pole of the model B is longer but the gap is significantly narrower. The pole width of the model B is relatively larger, ranging from 60 – 80 nm, approximately. The view of the write heads on the air-bearing surface (ABS) are illustrated in Figure 3. In addition, the heater design of the model A is a dual heater in order to make the protrusion in both the writer and the reader regions simultaneously. For the write head in model B, the heater can cause the protrusion only on the main writer pole. Those model A and B are required different magnitudes of the biased DC current to make the pole fully saturated, i.e. 40 mA for model A and 30 mA for model B. The MFM images of the write field profile for the writer having model A and B are shown in Figure 4. No DC current was applied to the thermal heater yet. As can be seen, the shape of the write field profiles was similar to the physical geometry of the main pole.

For the sake of demonstration, the write coil was biased with the required DC current and the pole-tip protrusion (PTP) was activated by applying the DC currents to the heater coil. DC currents ranging from 10 – 40 mA, which are equivalent to the heater power of 60 mW to 100 mW, were applied to the heater.

![Figure 3](image-url)

**Figure 3.** Drawing showing the ABS view of magnetic write heads (a) Model A and (b) Model B. MP is stand for a main pole and PW is for a pole width.

![Figure 4](image-url)

**Figure 4.** MFM images of the magnetic write field for the writer with (a) model A and (b) model B.

Figure 5 shows MFM images and contour plots of the write field generated from the model A write heads having 3 different values of magnetic write width (MWW), i.e. 58.8, 65.5 and 68.7 nm.
For the sake of comparison, the area of the write field profiles was calculated at 5 and 15 degree phase shifts. We then compared the area for the writer with different heater currents from 0 to 40 mA. It was found that the area of the write field for the model A write heads was narrower when the heater element was biased and the area was independent to the amount of applied heater currents. For the model B, on the other hand, the area of the write field profile of the protruded writers was relatively wider than ones without the PTP. We also observed the changes of the write profile area when the heater current increases. Results for the model B are shown in Figure 6. This finding can lead to the further investigation on the effects of the PTP on the writing performance as well as the effects of heater designs on the device stability and reliability.

![Figure 5. MFM images contour plots of the write field of model A having 3 different values of MWW. (a) MWW = 58.8 nm (b) MWW = 65.5 nm and (c) MWW = 68.7 nm. (d) Calculated area of the write field profiles corresponding to different heater currents at 5 degree (▲) and 15 degree (■) phase shifts.](image-url)
Figure 6. MFM images contour plots of the write field of model B having 3 different values of MWW (a) MWW = 67.8 nm (b) MWW = 74.7 nm and (c) MWW = 80.6 nm. (d) Calculated area of the write field profiles corresponding to different heater currents at 5 degree (▲) and 15 degree (■) phase shifts.

4. Conclusions
MFM images of the write field for magnetic heads having the PTP were demonstrated in this study. A given DC current as high as 30 – 40 mA was applied to the write coil to generate the saturated magnetic field on the main pole. The pole protrusion was activated by applying the DC current to the heater element. Results of the demonstration revealed that the profiles of the write field were altered when the protrusion was present. Moreover, we observed the variation of the write field profile between the model A and model B writers. This can lead to further investigation of the PTP effects on the write field distribution in the future development of magnetic write heads.
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Acknowledgments
Authors would like to thank Western Digital (Thailand) Co., Ltd. and Department of Physics, Faculty of Science, Silpakorn University for financially supports of this work. Special thanks to WD engineers and technical staffs in test engineering department for all technical contributions and helpful discussions.