Micromagnetic recording model of writer geometry effects at skew

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The effects of the pole-tip geometry at the air-bearing surface on perpendicular recording at a skew angle are examined through modeling and spin-stand test data. Head fields generated by the finite element method were used to record transitions within our previously described micromagnetic recording model. Write-field contours for a variety of square, rectangular, and trapezoidal pole shapes were evaluated to determine the impact of geometry on field contours. Comparing results for recorded track width, transition width, and media signal to noise ratio at 0° and 15° skew demonstrate the benefits of trapezoidal and reduced aspect-ratio pole shapes. Consistency between these modeled results and test data is demonstrated. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2170046]

I. INTRODUCTION

A significant motivation for the rapid increase in interest given to perpendicular recording over the past several years has been the looming prospect of limitations imposed by the superparamagnetic effects. A recording system which incorporates a soft media underlayer (SUL) greatly increases the potential magnitude of the write head field, thereby enabling the required small-grain, high-coercivity record layer necessary to maintain adequate signal-to-noise ratio (SNR) and thermal stability with increasing areal density. However, details associated with geometrical aspects of the write-pole at the air-bearing-surface (ABS) play a crucial role in the structure of recorded media transitions. A "footprint" of the entire shape of the main write pole at the ABS is imprinted on the media. The geometry of the pole tip at the ABS thus has the potential to interact strongly with recording of transitions in regions of the disk where the trailing edge of the write pole is skewed with respect to the track direction.[1,2] This puts limitations on, for example, the length of the pole tip at the ABS in the down-track direction and thus the ability of the write head to deliver higher field strength. Trapezoidal pole shapes have been proposed to alleviate this problem.[3] All common solutions require a reduction in the cross-sectional area at the ABS and thus compromise the potential extendability of perpendicular recording.

This work addresses some of these issues through write fields calculated using the finite element method (FEM) and simulating the record and playback process with our micromagnetic recording model (MRM).[4,5] Fields were calculated using a common single-pole type write head design in the presence of a medium SUL. This field is added to a Landau–Lifshitz–Gilbert treatment of the medium hard layer to record transitions. Playback is then simulated using a micromagnetic model of a generic spin-valve sensor.

The focus of this work is an evaluation of four different ABS pole-tip shapes for recording at 0° and 15° skew. The shapes cover a variety of square, rectangular, and trapezoidal designs. These are evaluated through a comparison of FEM write field strengths and contours, as well as using the MRM to calculate transition profiles, effective magnetic track width, down-track pulse width, and media SNR. Finally, a brief comparison of modeled results with experimental data on track width versus skew for several pole-shape designs is made.

II. WRITE FIELDS

FEM software was used to generate magnetic fields for four different write-element geometries at the pole-tip ABS. These were: (1) a square pole (1:1 aspect ratio); (2) a trapezoidal pole with the same height and width but a 15° wall angle; (3) a rectangle with the same width in the cross-track direction but a 1.5:1 aspect ratio; and (4) a narrow rectangle with 20% reduction in the cross-track direction and 1.4:1 aspect ratio. The square and rectangular designs had a very slight 2° wall angle. All the models of the write elements were otherwise identical with 2.4 T materials in the pole tip and had a three-turn coil structure. The SUL was 200 nm thick, was located 35 nm from the ABS and had a saturation moment of 2.0 T.

Figure 1 shows the maximum total field magnitude of the head field, H_m, versus write current at the assumed location of the medium center, 18 nm from the ABS. The amount of relevant record field is strongly related to the pole-tip ABS cross-sectional area. Note in particular the decrease in field associated with the trapezoidal shape. Adequacy of these designs for recording is dependent on the medium coercivity at the designed product data transfer rate.

Head field contours for the square and trapezoidal designs are shown in Fig. 2. Recording occurs roughly in the regime where the field strength is slightly larger than the medium coercivity, 5–7 kOe. Note that for the square shape, the maximum width of the write bubble does not occur at the trailing edge (TE) but is closer to the center of the pole in the down-track direction. This maximum width occurs much

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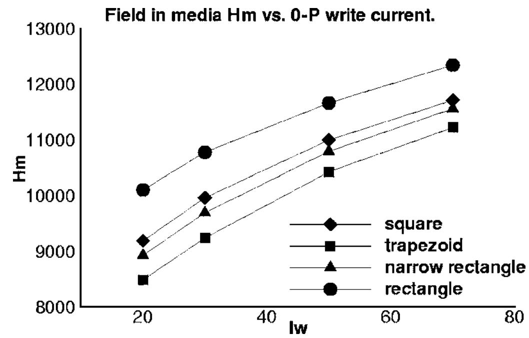

FIG. 1. FEM generated maximum magnitude of the head field as a function of current for the four ABS pole-tip shapes used in this study.

closer to the TE for the trapezoidal design, which has the additional benefit of showing the likelihood of skew insensitivity.

III. RECORDED TRACK AND TRANSITION WIDTHS

For recording transitions with the MRM, a medium with uniform $9\times9\times12\ \mathrm{nm}^3$ grains was used where $M_s = 350$ emu/cc, $H_k = 10$ kOe, and an exchange energy of $A_x = 0.05\times10^{-6}$ erg/cm giving a coercivity of 6.5 kOe (zero temperature). Fourth-order anisotropy was also added with a strength 10% of the primary second-order term, $K_2/K_1 = 0.1$. The anisotropy axis was given a Gaussian distribution with a standard deviation of 5° about the direction perpendicular to the medium plane. A Gaussian distribution in the magnitude of H_k was assumed to be 15% 1σ.

Figure 3 shows isolated transitions recorded with square and trapezoidal pole shapes at zero and 15° skew using a write current of 30 mA (*O-P*). The effective magnetic track width clearly increases significantly in the case of the square pole. This effect is absent for the trapezoidal design. Note, however, that there is some evidence that the trapezoidal design is producing poorer quality transitions due to overdriving the pole-tip with a concomitant degradation in downtrack field gradient.

The effective magnetic writer widths (WW) for all four designs at both skew angles are estimated from the media magnetization images and are plotted in Fig. 4. We chose to show these results as a function of the normalized head field strength, H_m/H_c, as this quantity is a useful indicator of optimal write current. All designs show a substantially larger effective magnetic width than the physical TE as well as

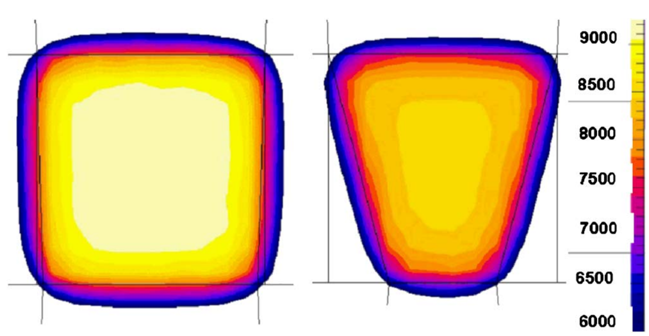

FIG. 2. Field contours corresponding to the square (left) and trapezoidal (right) pole-tip shapes.

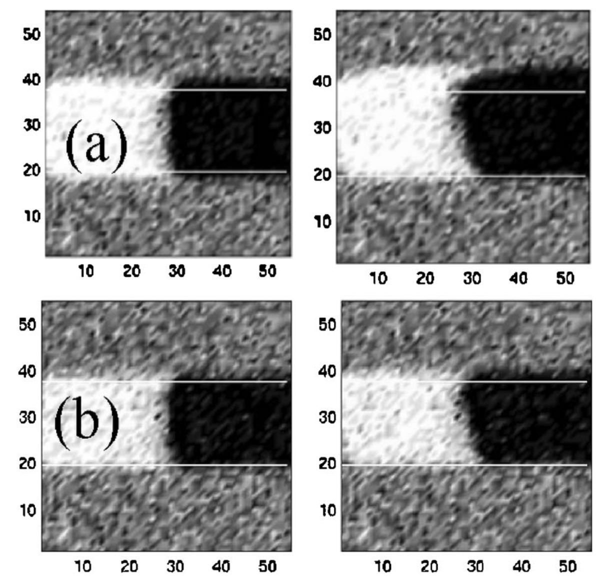

FIG. 3. Isolated transition recorded at 0° and 15° skew with the square pole (a) and trapezoidal design (b) using 30 mA write current. White lines indicate the edges of the pole-tip trailing edge.

significant widening as the write current increases. The square pole shows about a 20 nm larger WW than the trapezoidal design at zero skew. At 15° skew, the effective WW of the square pole increases by about 10 nm. The WW of the trapezoidal pole decreases slightly at 15° skew due purely to geometrical effects (as it should). The rectangular poles show large increases in effective WW as the skew is increased to 15°. The rectangular pole, although providing large recording fields, results in about a 40 nm increase in WW at skew. The narrow rectangle shape shows an overall reduction in

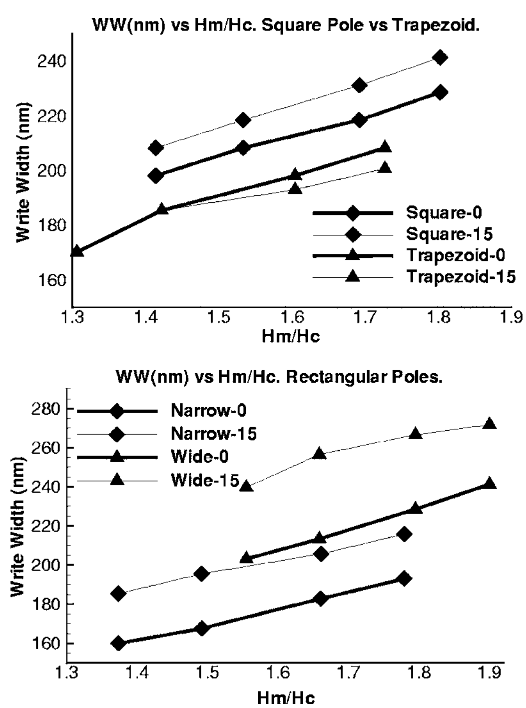

FIG. 4. Effective magnetic write width from isolated transition using the MRM for the square, trapezoidal pole shapes (top panel), and rectangular poles (bottom panel) as a function of write current at 0° (thick lines) and 15° (thin lines) skew.

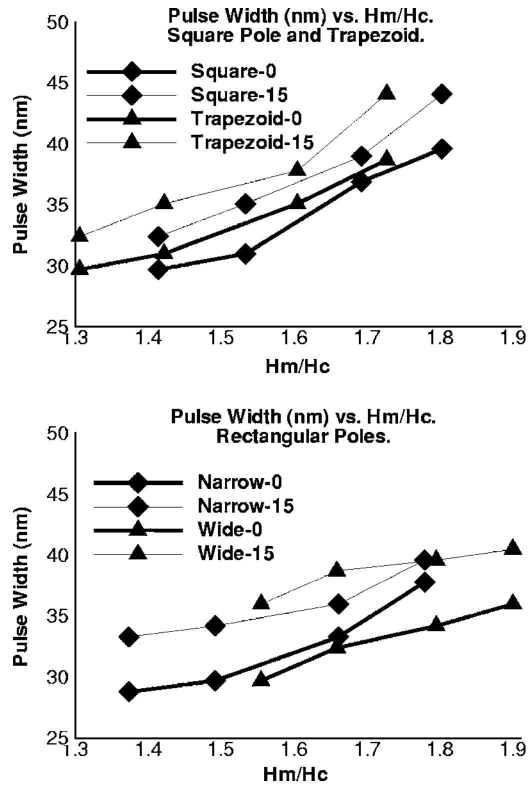

FIG. 5. Pulse width from isolated transition using the MRM for the square, trapezoidal pole shapes (top panel), and rectangular poles (bottom panel) as a function of write current at 0° and 15° skew.

WW (at both skew angles) by about 30 nm. However, it shows a larger increase at skew than the square pole design.

The MRM was also used to calculate the isolated pulse transition width at half maximum of the differentiated playback signal.[5] Figure 5 shows that for each of the four cases considered, the pulse width increases at skew and with increasing write current. For both square and trapezoidal designs, the skew-effect broadening is 3–4 nm. Note that the overall transitions widths are larger for the trapezoidal pole, likely due worse gradient as a result of tip saturation effects.[5–7] The small rectangular pole shows about the same skew-effect degradation in transition quality as the square

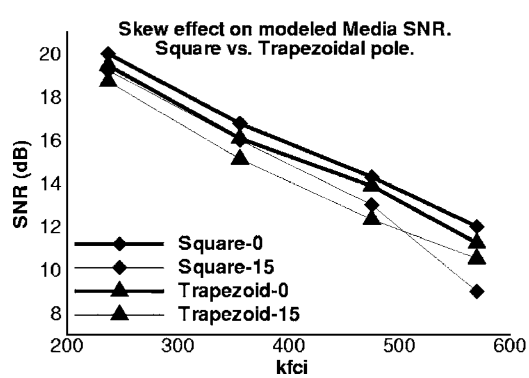

FIG. 6. Transition SNR vs kfci for both pole shapes at both skew angles.

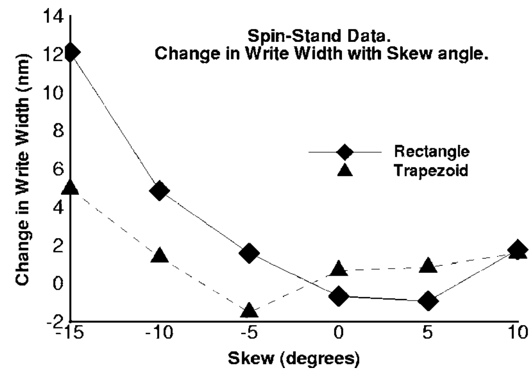

FIG. 7. Change in measured magnetic writer width vs skew angle for recording heads with rectangular and trapezoidal ABS pole-tip geometries.

and trapezoidal shapes. The larger rectangle shows a substantially bigger detrimental effect of skew on pulse width being about 6 nm.

The impact of skew on calculated media SNR[4] as a function of linear transition density is shown in Fig. 6 for the case of square and trapezoidal pole shapes. The number of transitions used to calculate SNR varies from ~300 at low kfci to 800 at high kfci, and that error bars on SNR are ~0.25 db, smaller than the differences shown in the figure. Both designs show the same detrimental impact on performance at low density. At high density, SNR for the square pole degrades much faster for the case of 15° skew.

IV. SPIN-STAND DATA

Figure 7 illustrates one example of the impact of ABS pole-tip geometry on measured magnetic writer width using a standard spin-stand technique. Two ABS pole-tip shapes were tested; rectangular and trapezoidal. Consistent with the modeled results, the rectangular case shows substantially larger skew sensitivity.

V. CONCLUSIONS

The full potential of SUL-based perpendicular recording is clearly limited by the necessity to accommodate head designs which provide adequate performance across the stroke of the disk. The interplay between field magnitude, gradient, and track width with skew considerations requires a nontrivial optimization of the pole-tip geometry at the ABS. The present work has demonstrated the utility of recording models in the further understanding of these issues.

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