IEEE THAILAND SECTION

DST-CON Proceeding 2010

A New Thermal Response Model Induced by Head/Disk Interaction in Current TGMR Head

S. Thamakam, K. Powers, P. Kovintavewat, and P. Supnithi

***Abstract*— The tunneling giant magneto-resistive (TGMR) head technology incorporating an MgO barrier is currently the most promising candidate for replacing a GMR head. As the areal density increases, the actual flying clearance of the head above the media surface during read/write operations is reduced to less than 10 nm. The head/disk interaction under such conditions results in a thermal response, which causes a shift in the baseline of the readback signal and also exhibits bi-polar magneto-striction on opposing DC (positive and negative) backgrounds. This magneto-striction causes the thermal response to look different from the classical thermal response that could distort the readback signal to the extent of causing a sector read failure. This paper proposes a mathematical model for the thermal response induced by the head/disk interaction in the TGMR head with an MgO barrier. Results show that the proposed mathematical model coincides with the actual thermal response occurred in today's hard disk drives.**

***Index Terms*— MgO barrier; Perpendicular recording; TGMR head; Thermal response, Corrupted duration**

I. Introduction

TUNNELING giant magneto-resistive (TGMR) sensors have many advantages over the classical GMR sensors when implemented as a read element in a hard disk drive (HDD). These advantages include increasing magneto-resistive ratio (MR ratio) [1], and reducing areal resistance (RA) value [1] and head noise. These advantages allow for an increase in storage capacity.

Current designs continuously reduce the head-disk clearance in today's disk in an effort to gain write/read performance. Recent drives are built with the head-disk clearance close to 10 nm [2] as shown in Fig. 1. In addition, the head-disk clearance can become even less with decreased ambient air pressure. The reduction in the head-disk clearance causes an increased sensitivity in the air bearing surface (ABS) altitude, resulting in variations in head flying characteristics. Therefore, in real disk drive environments, the head-disk interaction often occurs. As the amount of pole-tip protrusion increases, the gap between the head and the disk surface narrows. Consequently, HDDs become more susceptible to shock and vibration during manufacturing and normal operation [3, 4]. The reduction in an effective fly height could cause the media surface and the read head to interact and become heated easily. This heat will cause the resistive properties of the read head to change, resulting in a *thermal response* (TR) (or, equivalently, *thermal transient*) in the readback signal. This thermal response affects the performances of both recording and disk drive reliability. If precautions are not carefully taken, the string of errors in the detected data caused by the thermal response could easily exceed the correction capability of error-control code (ECCs), resulting in unrecoverable data. Hence, the thermal response is a crucial problem in perpendicular recording systems.

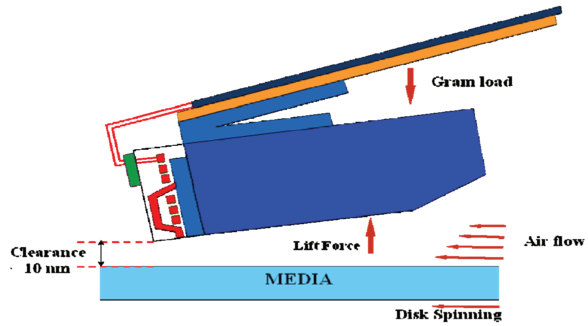

Fig.1. A schematic of the mechanical model of the media-slider contact

With the current TGMR read head (using an MgO barrier), the thermal response no longer looks like the classical thermal response proposed by Stupp *et al*. [5]. Thus, the characteristic of the thermal response introduced by the current TGMR head is of importance, as studied in [6]. This paper proposes a mathematical model for the thermal response induced by the head/disk interaction in the TGMR head with an MgO barrier.

This paper organizes as follows. After describing the mechanism of the TGMR read head and proposing the TR signal model in a mathematical equation in Section II, Section III explains the experiment setup in the laboratory to verify the proposed TR model. Section IV briefly describes a free-

Manuscript received February 28, 2010.
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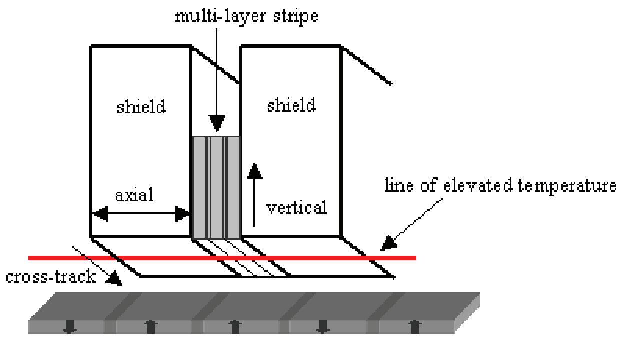

Fig. 2. A schematic of the line around the read element that is heated during head/disk interaction.

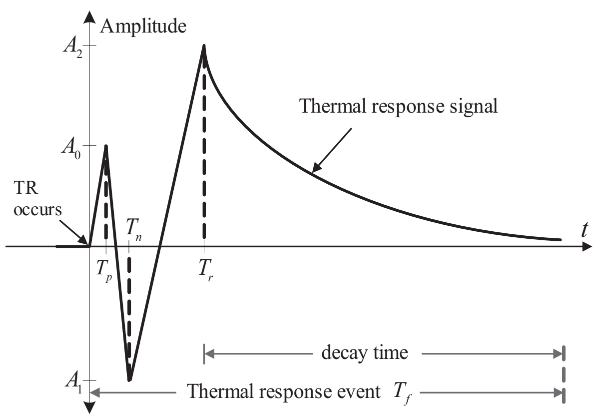

Fig. 3. The thermal response model induced by head/disk interaction.

layer magneto-striction mechanism. Eventually, Section V concludes this paper.

II. TGMR Heads With Thermal Response Model

In general, the contact between the slider and the medium surface does not begin at the read element. Instead, the initial contact occurs along the slider rail. As the medium moves towards the trailing edge of the slider, an interaction between the medium and the slider will occur, resulting in the medium heating to a high temperature. This abrupt change to high temperature will cause the slider surface to have high temperature as well as the medium which passes by. Then, the heat will diffuse through the read element.

The mechanism of thermal diffusion can be explained according to Mallary's realization [7]. As the medium passes by, not only the surface of the read element is heated, but the line around the read element is also heated as shown in Fig. 2. From the geometric viewpoint, we find that the line of elevated temperature of the heat move towards the head will have cylindrical in two dimensions. Practically, the heat will start flowing in cross-track and vertical directions. However, there is no heat difussion in the axial direction (across the stripe) at the beginning of the TR process because there is no

Table 1. Parameters for the experiment to verify the proposed TR model.

Parameters	
Product Name	Bxx, Pxx, Gxx, Mxx
Recording system	Perpendicular
Heads	2-8 heads
Rotation	Speed 7200 RPM
Interface	S-ATA
Capacity (GB/Disc)	320Gb (1D) – 1TB (4D)
Areal Density (max in drive)	219 (1D) – 228 (4D) Gb/in
Avg Format Efficiency (%)	77.8
Track Density (0-skew)	191.0 kTPI
Linear Density (max in drive)	1250 (1D) – 1300 (4D) kBPI
Data Rate (max in drive)	1460 (1D) – 1520 (4D) Mb/s

thermal gradient in that direction. This situation will cause the temperature to linearly increase. Next, when the heat diffussion arrives at the stripe edges, the heat passing through the stripe will be slower than that through the shield because of low thermal conductivity of the materials around the stripe in cross-track and vertical directions. This results in a gradient temperature across the stripe. Given such a geometry, this is a preferred thermal relaxation mechanism for the stripe. Once the head and medium interact, the average temperature in the stripe will reach the highest temperature and then exhibit an exponential decay.

Based on the thermal diffusion mechanism when there is head/medium interaction, we propose the TR model as shown in Fig. 3. This simplified TR model can decribe the TR event in *four regions*, namely, a linear positive magneto-striction rise-time, a linear negative magneto-striction fall-time, a linear TR rise-time, and an exponential TR decay-time. In other words, this TR signal can be mathematically expressed as

$$u(t)=\begin{cases} A_0\dfrac{t}{T_p}, & 0\le t\le T_p \\ A_0+\left(A_1-A_0\right)\dfrac{t-T_p}{T_n-T_p}, & T_p\le t\le T_n \\ A_1+\left(A_2-A_1\right)\dfrac{t-T_n}{T_r-T_n}, & T_n\le t\le T_r \\ A_2\exp\left(\dfrac{t-T_r}{T_d}\right) & T_r\le t\le T_f \end{cases}, \qquad (1)$$

where A_0 and A_1 are the positive and negative peak of magneto-striction, respectively, A_2 is the peak amplitude of TR signal, T_p and T_n are the positive and negative time of magneto-striction, T_r is a rise time, T_d is a decay constant, and $T_f = T_r + 3T_d$ because it matches the actual TR signal occurred in real disk drives as explained in Section III.

III. Spin-stand Experiment

In this section, we characterize the behavior of the TR signal induced by head/disk interaction in the current TGMR head when head/disk spacing is zero during contact. To achieve this,

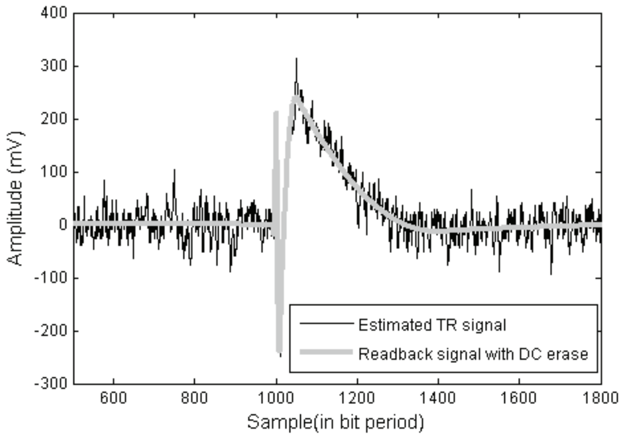

Fig. 4. The readback signal with TR based on a DC Erase pattern (black line) and the estimated TR signal based on a 2nd-order polynomial curve fitting technique (gray line).

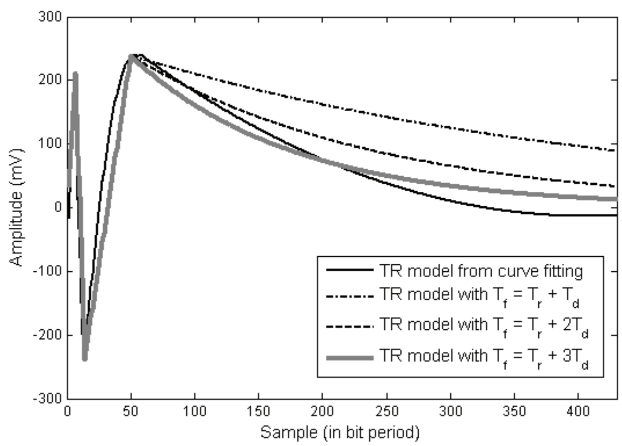

Fig. 5. The estimated TR signal from (1) with different T_f's.

we perform an experiment in the laboratory by setting several parameters as listed in Table 1.

To obtain a large and severe TR signal during read process, the head/disk spacing is set to zero (all heads are set at the same level), and the pole-tip protrusion is also set to a maximum value. We use Seagate's internal software to sends a command via serial port to a HDD to do this task. Then, we measure the readback signal from the RDx/y test points on the printed circuit board (PCB) of the HDD with a differential probe connected to an oscilloscope. Clearly, the measured TR signal shows a shift in the baseline of the readback signal and also exhibits bi-polar magneto-striction on opposing DC (positive and negative) backgrounds as shown in Fig. 4.

To verify the TR model in (1), we first estimate the TR signal for four regions in Fig. 4 based on a 2nd-order polynomial curve fitting technique according to

$$y(t) = p_1 t^2 + p_2 t + p_3, \qquad (2)$$

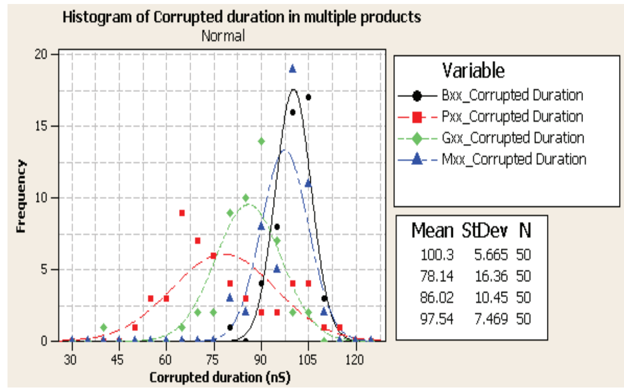

Fig.6. Histogram plot of the corrupted duration of the TR signal in various products.

where $y(t)$ is the estimated TR signal, and p_1, p_2, and p_3 are polynomial coefficients. Fig. 4 also depicts the estimated TR signal obtained from (2). Then, we compare the TR model in (1) with that in (2) for different T_f values as shown in Fig. 5. The result reveals that the TR model in (1) matches the estimated TR signal in Fig. 4, where the TR model in (1) with $T_f = T_r + 3T_d$ give the best estimate of the TR signal in Fig. 4.

We also verify the proposed TR model in (1) by comparing it with 200 samples of the actual TR signal obtained from four current Seagate products (50 samples/product). First, we find the time duration that the actual TR signal occurs in real disk drives. To do so, we collect the TR signal from 200 samples and plot the histogram of the corrupted duration (starting from when the TR occurs until T_f) caused by the TR signal as illustrated in Fig. 6. Based on different products, it implies that the corrupted duration of the actual TR signal ranges from 40.7 ns to 114.2 ns (with 5 Giga samples/second). In other words, the corrupted duration of the TR signal is about 203 – 571 bit periods.

Next, we find the time duration of the actual TR signal during magneto-striction mechanism, i.e. a magneto-striction duration T_n. Again, based on 200 samples, we plot the histogram of the magneto-striction duration (starting from when the TR occurs until T_n) as displayed in Fig. 7. It can be implied that the magneto-striction duration of the TR signal ranges from 1.8 ns to 5.2 ns (with 5 Giga samples/second). In other words, the corrupted duration of the TR signal is about 10 – 26 bit periods.

Furthermore, we also measure and analyze other parameters that matches the actual TR signal in various products as given in Table 2. Based on our experiment, we found that the average peak amplitude of the normal readback signal is about 55 mV (zero-to-peak voltage). As a consequence, when using (1) to generate the TR signal in the simulated channel model, the possible range of values of each parameter in (1) are, depending on how severe the TR signal as follows: A_0 is about 0.36 to 5.22 times, A_1 is about 0.51 to 6.7 times, and A_2 is about 2.2 to 6.33 times the peak of the normal readback signal.

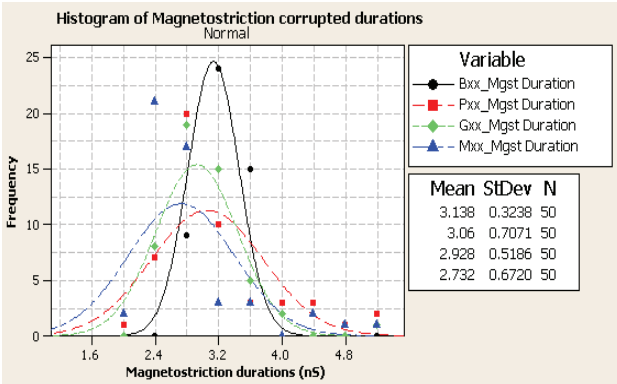

Fig. 7. Histogram plot of the magneto-striction duration in various products..

Table 2. Typical parameters of the TR model based on 200 sample in various products, where the sampling rate is 5Giga sample/second.

Parameter	Minimum	Maximum
Magneto-striction duration (T_n)	1.8 ns	5.2 ns
Positive magneto-striction amplitude (A_0)	20 mV	287 mV
Negative magneto-striction amplitude (A_1)	-28 mV	-368 mV
TR rise-time duration	3.2 ns	16 ns
TR decay-time duration	27.5 ns	100.8 ns
TR peak amplitude (A_2)	120 mV	348 mV
Total TR corrupted duration	40.7 ns	114.2 ns

IV. FREE LAYER MAGNETO-STRICTION

Practically, the thermal response occurred in the current TGMR read heads (using an MgO barrier) exhibits bi-polar magneto-striction on opposing DC backgrounds, which was induced from the free layer [8]. It is typically a property of ferromagnetic materials that change physically in response to changing its magnetization. James Joule first identified this effect in 1842 [9] when observing a sample of nickel that changed in length when it was magnetized. Fig. 8 briefly explains the phenomenon of magneto-striction.

The mechanism of magneto-striction at an atomic level is relatively complex. Internally, the structure of a ferromagnetic material can be divided into several domains, each of which is a region of uniform magnetic polarization. When an external magnetic field is applied or changing magnetization (H) is applied, the boundaries between the domains will be shifted and the domains will start rotating. As a result, the physical shape of the material ($\delta\lambda$) will also be changed.

V. CONCLUSION

To achieve ultra high recording densities, the TGMR head design is used in place of the GMR head. As the flying height is reduced, head/disk interaction in real disk drive environments frequently occurs, which can distort the readback signal to the extent of causing possible sector read failures. The head/disk interaction phenomenon seen on the readback signal is referred to as the *thermal response* (TR). It is important to note that the TR differs from the TA in a sense that the TA phenomenon

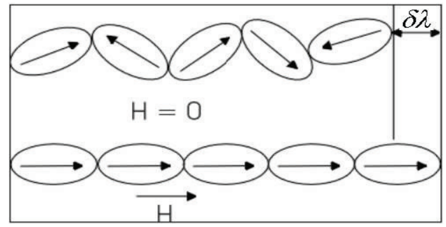

Fig. 8. Magneto-striction phenomenon [9].

induced from media asperity on the disk comes into contact with the slider, whereas the TR phenomenon induced from head/disk interaction (no media asperity).

Practically, the TR causes a shift in the baseline of the readback signal and exhibits bi-polar magneto-striction on opposing DC (positive and negative) backgrounds. This magneto-striction causes the TR to look different from the classical thermal response introduced by the MR sensors. This paper proposes the TR model. Experimental results based on 200 samples in HDDs indicate that the proposed TR model coincides with the actual TR occurred in real HDDs. This TR model can enable the development of new algorithms for detecting and correcting this TR, which will in turn improve the performance of the current HDDs.

ACKNOWLEDGMENT

This work was financially supported by I/U CRC in Data Storage Technology and Applications (D*STAR), KMITL, and National Electronics and Computer Technology Center (NECTEC), NSTDA, under grant HDD-01-51-06M.

REFERENCES

[1] T. Zhao, K. Zhang, H. Wang, Y. Chen, M. Li, "Low resistance tunneling magnetoresistive sensor with natural oxidized double MgO barrier,"
U.S Patent no. 0111332A1, May 2007

[2] R. Wang, U. V. Nayak, "Head-Disk Interface Considerations at 10-nm Flying Height," *IEEE Trans. Magn.*, vol. 38, no. 5, pp. 2132–2134, Sept 2002.

[3] A. N. Murthy, B. Feliss, D. Gillis, F. E. Talke, "Experimental and numerical investigation of shock response in 3.5 and 2.5 in. form factor hard disk drives," *Microsyst Design 2006*, pp. 1110-1116, June 2006.

[4] E. M. Jayson, J. Murphy, P. W. Smith, Frank E. Talke, "Effects of air bearing stiffness on a hard disk drive subject to shock and vibration," *J. of Tribology*, vol. 125, pp. 343–345, April 2003.

[5] S. E. Stupp, M. A. Baldwinson, P. McEwen, T. M. Crawford, C. T. Rogers, "Thermal asperity trends," *IEEE Trans. Magn.,* vol. 35, no. 2, pp. 752–757, Mar 1999.

[6] S. Thamakam, P. Kovintavewat, S. Nuanprasert, P. Supnithi, "Characterization of Thermal Response Induced by Head/Disk Interaction in Current TGMR Head," in *Proc. of DST-CON 2009*, DST-CON 2009, Bangkok, Thailand, May 13 – 15, 2009.

[7] M. Mallary, Quantum, Shrewsbury, MA, private communication, 1995.

[8] Z. Gao, B. W. Karr, S. Xue, E. L. Granstrom, K. T. Tran, Y. X. Li, "Magnetic sensing device including a sense enhancing layer," U.S Patent no. 0139827A1, June 2007.

[9] S. Chikazumi, "Physics of Magnetism", John Wiley & Sons, 1964.