A Track Mis-Registration Estimation Method Based on a Ratio Value of Readback Signals in Bit-Patterned Media Recording Systems

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Abstract

Track mis-registration (TMR) or off-track condition is a problem in high-density magnetic recording systems. In a practical system, the servo system is employed to handle the TMR limitation. Additionally, in some works, the TMR level can be estimated and mitigated based on the readback signals; however, these techniques have high complexity. To reduce its complexity, this paper proposes a TMR mitigation method based on the ratio value of readback signals in bit-patterned magnetic recording (BPMR) systems. To do so, we first find the relationship between the ratio value of the readback signal and a TMR level. Then, the TMR level is estimated by utilizing this relationship information before selecting the equalizer coefficients used in the detector that match the TMR level. In simulation, the proposed TMR mitigation method can provide the performance gain better than the conventional system, especially when the TMR is high.

Keywords: bit-patterned media recording; track mis-registration; ratio value of readback signal.

1. Introduction

Bit-patterned magnetic recording (BPMR) is expected to be the innovative technology that can overcome the superparamagnetic limitation that encountered in a perpendicular magnetic recording (PMR) system. Because the PMR is approaching the storage capacity limit shortly, the BPMR system can help extend an areal density (AD) up to 4 Tera-bit per square inch (Tb/in^2) [1-2]. However, when the AD is increased, the intertrack interference (ITI) is also increased, which is considered to be the main problem to deteriorate the system performance. Moreover, the track mis-registration (TMR) easily occurred when the center of the readhead and the center track are misaligned as shown in Fig. 1(b), can also increase the ITI, which is a serious problem in magnetic recording system [3]. In a practical system, the vibration of the readhead is controlled by the servo system. Nevertheless, the servo system needs some area in a magnetic medium to storage the redundancy bits [4].

Alternatively, the TMR estimation methods based on the readback signal have been proposed in the literatures [5-7]. Nonetheless, these methods have high complexity to estimate TMR levels because it must estimate the signal-to-noise ratio (SNR) level in decibel (dB) before performing the TMR estimation [5]. In [6], the multi readheads are employed to estimate TMR levels; however, it loses the performance of the track position while the readhead is moved.

Therefore, to reduce and improve the system performance when faced with TMR, this paper proposes the TMR mitigation method based on the readback signals by utilizing the ratio value of the readback signals from the center track. To do so, we first find the ratio value of the readback signals from only the center track.

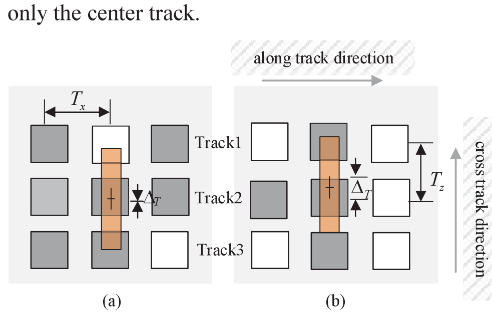

Fig. 1: Illustration of a BPMR system (a) without TMR or head offset, Δ_T, and (b) with TMR.

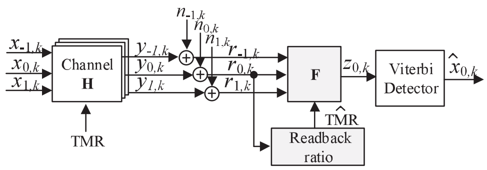

Fig. 2: A block diagram of a BPMR system with the proposed TMR mitigation method.

Then, the relationship between the ratio value and the TMR level is used to estimate a TMR level. Next, we mitigate the TMR effect by adjusting the equalizer's coefficients used in the receiver.

This paper is organized as follows. Section 2 describes the BPMR channel model and Section 3 explains the proposed TMR estimation and mitigation method. The simulation results are given in Section 4. Finally, Section 5 concludes this paper.

2. Channel Model

Here, we consider a discrete BPMR channel model [1] and the readback signal from the k-th data bit on the l-th track, $r_{l,k}$, can be determined by

$$r_{l,k} = \sum_n \sum_m h_{m,n} x_{l-m,k-n} + n_{l,k}, \quad (1)$$

where $x_{l,k}$'s are recorded bits, $n_{l,k}$'s are electronic noises modeled as an additive white Gaussian noise (AWGN), and $h_{m,n}$'s are the channel coefficients, which can be obtained by sampling the isolated island pulse response at integer multiples of the bit period T_x and the track pitch T_z, i.e.,

$$h_{m,n} = P(mT_x, nT_z + \Delta_T), \quad (2)$$

where $P(x,z)$ is the 2-D Gaussian pulse response, x and z are the time indices in along- and across-track directions, and Δ_T is the head offset or the distance between the center head and the center of the main track [3]. In this paper, the sign of Δ_T is assumed to be positive for an upward offset, where the TMR level is defined as

$$\text{TMR}(\%) = (\Delta_T / T_z) \times 100. \quad (3)$$

At the receiver, the readback sequence is equalized by a 2D equalizer and are fed to a Viterbi detector to produce the most likely estimated data input sequence as shown in Fig. 2. It is very important to note that there is only one 2D equalizer was employed to equalize three data sequences from the upper, center, and lower tracks.

3. Proposed Method

The proposed method performs as follows. Firstly, the 2D equalizer coefficients with the fixed 2D target for each TMR level (0%, 5%, 10%, 15%, 20%, and 25%) are designed and kept in a look-up table, which is stored in a data buffer. Then, the ratio value of the readback signal from the center track, V_r, is calculated by

$$V_r = V_p / V_a, \quad (4)$$

where V_p is the peak amplitude of the readback signal form the center track, and V_a is the average value of the readback signal from the center track whose amplitude is less than -2. Then, we found the relationship between the V_r and the TMR level as shown in Fig. 3. In Fig.3, we can ignore low SNR region, i.e., less than 10 decibel (dB), for TMR estimation because the system noise is too high. In addition, we found that the relationship curves at high SNR region are close to one another.

Therefore, in this paper, we use the relationship curve at SNR of 20 dB to estimate the TMR level. Moreover, we employ a curve fitting technique [5] to obtain a polynomial function that provides the best fit line (at SNR = 20 dB) from Fig. 3. This polynomial function can be utilized to approximate the TMR level according to the following equation

$$\hat{\text{TMR}} = b_0 + b_1 V_r + b_2 V_r^2 + \ldots + b_N V_r^N, \quad (5)$$

where $\hat{\text{TMR}}$ is an estimated TMR, b_i and N are the coefficient and a degree of the polynomial equation in (5), respectively, and $i \in \{0, 1, ..., N\}$. Here, we found that $N = 3$ provides the best fit between the actual and the estimated TMR levels. Note that the value less than -2, it can provide the best relation to estimate TMR level as Fig. 3, it is stable more than if we use the single value of minimum value from center track readback signal.

However, the proposed TMR estimation method cannot offer a high accuracy at low TMR levels (i.e., less than 10%). Although the accuracy of low TMR levels estimation may be not correct but the BER performances at low TMR levels can be improved by using properly equalizer from look-up table.

4. Simulation Result

We test the proposed TMR mitigation approach in the BPMR system given in Fig. 2 at AD of 3.0 Tb/in^2, where both the bit period and the track pitch are $T_x = T_z = 14.5$ nm, the along-track PW_{50} is 19.4 nm, and the across-track PW_{50} is 24.8 nm. The SNR is defined as SNR = $20\log_{10}(1/\sigma)$ in dB, where σ is a standard deviation of AWGN.

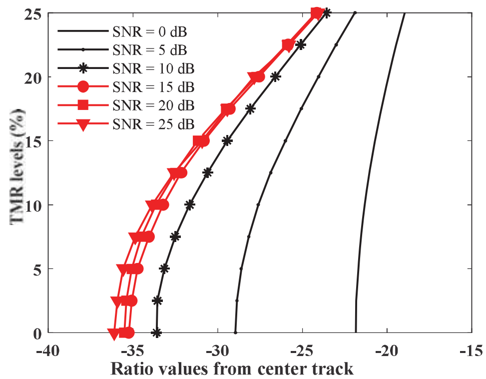

Fig. 3: The relationship between the TMR level (%) and the ratio value from the readback signal of the center track.

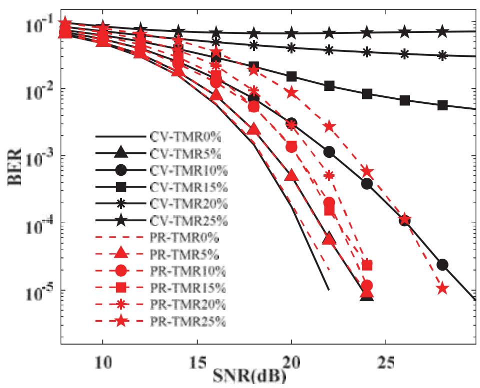

Fig. 4: The BER performance comparison between the proposed system (with the TMR mitigation method) and the conventional system.

Additionally, the accuracy of TMR estimation is measured by

$$\text{accuracy (\%)} = 100 - \frac{|\hat{\text{TMR}}\text{-TMR}|}{\text{TMR}} \times 100, \quad (6)$$

where $\hat{\text{TMR}}$ is the estimated TMR obtained from the proposed TMR mitigation method.

Clearly, the proposed method can offer good estimation of TMR level, especially when TMR is large. The proposed method provides the TMR estimation accuracy of more than 80% when TMR is larger than 15%, whereas it yields the TMR estimation accuracy of less than 50% when TMR is less than 15%.

We also compare the bit-error rate (BER) performance of the proposed systems and the conventional system, as illustrated in Fig. 4, where the conventional system performs without any TMR mitigation method. Note that the conventional system is labeled as "CV-TMRυ%," where υ% represents the TMR effect of υ%. The one labeled as "PR-TMR υ%" is the system with the proposed TMR mitigation method. Apparently, the proposed system performs better than the conventional system for all TMR levels, especially when TMR is high.

5. Conclusion

This paper proposes the TMR mitigation method by utilizing the relationship between the ratio value of the readback signal from the center track and the TMR level for the BPMR system corrupted by AWGN and 2-D interference. Specifically, the estimated TMR level will be employed to choose the proper 2-D equalizer coefficients used in data detection process. The experiment results indicate that the proposed method can effectively estimate large TMR levels and it can offer the BER performance gain over the conventional system at high AD and high TMR level.

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