A TA SUPPRESSION METHOD BASED ON WAVELET PACKET FOR PERPENDICULAR RECORDING CHANNELS

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ABSTRACT

This paper proposes a thermal asperity (TA) suppression method based on wavelet packet for perpendicular recording channels. The proposed method consists of two channels working concurrently, one for a target $H(D)$, and the other for a target $G(D)H(D)$ equipped with a bandpass filter $G(D) = 1 - D^2$. The Viterbi detector (VD) in the $H(D)$ channel has lower bit-error rate (BER) in absence of the TA, while that in the $G(D)H(D)$ channel has lower BER in presence of the TA. The wavelet packet transform is used to determine the TA location embedded in the readback signal. Then, the overall decoded bit stream is chosen from these two VDs depending on whether the TA is detected. Experimental results show that the proposed method is superior to the other methods and is also robust to changes in the peak TA amplitude.

***Index Terms*—** Bandpass filter, perpendicular recording channel, thermal asperity suppression, wavelet packet transform

1. INTRODUCTION

During read process in hard disk drives, when a magneto-resistive (MR) read head comes in contact with an asperity (or surface roughness) on magnetic media, the voltage transient known as the *thermal asperity* (TA) [1] is generated. As the storage capacity increases and the flying height decreases, there is a high possibility that the read head would contact with the asperity. Therefore, a method to mitigate the TA effect is essential, especially in perpendicular recording channels. In general, the TA signal has a short rise time (50 – 160 ns) with a long decay time (1 – 5 μs), and its peak TA amplitude is 2 – 3 times the peak of the normal readback signal. Practically, the TA effect can cause an error burst in data detection that could easily exceed the correction capability of the error-control code (ECC) and thus resulting in a sector read failure.

Most of TA suppression methods proposed in the literature [2 – 5] attempt to filter out the TA, lessen its duration, or employ a suitable equalization target to reduce the TA at the detector input. Because the TA causes a shift in the baseline of the readback signal, the average value of the normal readback signal is zero, whereas that of the TA-affected readback signal is not. Thus, Klaassen and van Peppen [2] proposed the TA detection by looking at the baseline of the averaged readback signal, while the TA correction was performed by use of a high-pass filter. Dorfman and Wolf [3] proposed to use a filter $(1 - D)$ to eliminate a TA effect in readback signal in a longitudinal recording channel. However, this method does not perform well in a perpendicular recording channel because this channel contains a d.c. component.

For perpendicular recording channels, Mathew and Tjhia [4] proposed a simple threshold-based approach to detect and suppress the TA effect in the readback signal. Kovintavewat and Koonkarnkhai [5] manipulated the wavelet transform to detect a TA signal, which performs well only when the TA event occurs at the location close to the 2^n-th bit, where n is a positive integer. Specifically, this method is not suitable when the TA event is randomly occurred in the readback signal. Therefore, this paper proposes a new method based on the wavelet packet [6] to mitigate the TA effect in the readback signal for perpendicular recording channels.

This paper is organized as follows. After explaining the channel model in Section 2, Section 3 describes the proposed TA suppression method. Simulation results are given in Section 4. Finally, Section 5 concludes this paper.

2. CHANNEL MODEL

Consider a perpendicular recording channel model shown in Fig. 1, where an input data sequence $a_k \in \{\pm1\}$ with bit period T is filtered by an ideal differentiator $(1 - D)/2$, where D is a unit delay operator to form a transition sequence $b_k \in \{0, \pm1\}$, where $b_k = \pm1$ corresponds to a positive and a negative transition, and $b_k = 0$ corresponds to the absence of a transition. The sequence b_k passes through a magnetic recording channel represented by the transition response $g(t)$,

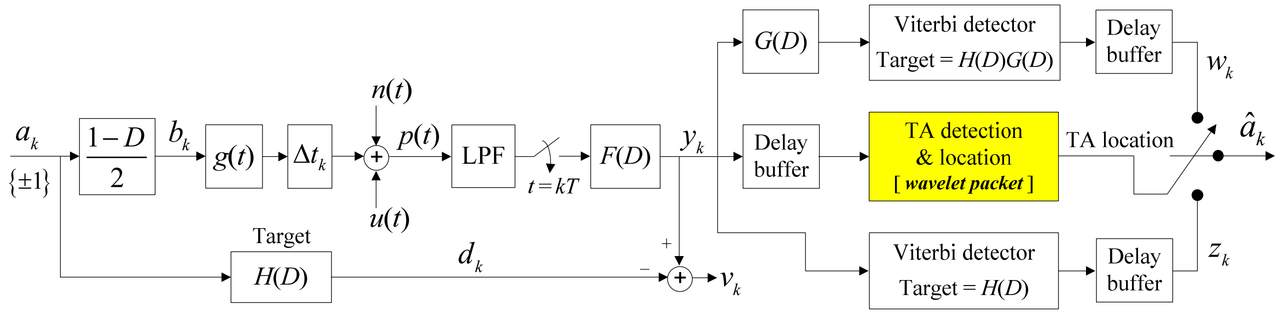

Fig. 1. Channel model with the proposed TA suppression method.

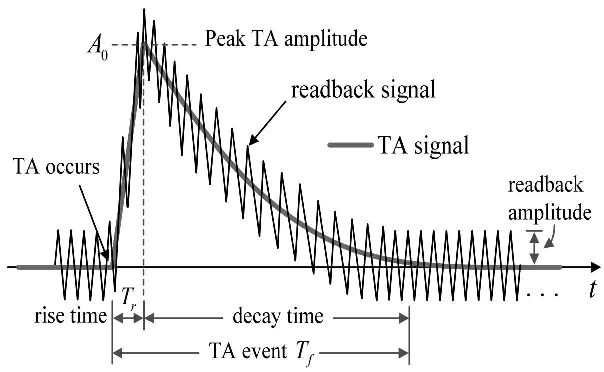

Fig. 2. The TA signal $u(t)$ associated with the MR sensor head.

which is given by

$$g(t) = \text{erf}\left(\frac{2t\sqrt{\ln 2}}{\text{PW}_{50}}\right), \quad (1)$$

where $\text{erf}(y) = \left(2/\sqrt{\pi}\right)\int_0^y e^{-z^2}dz$ is an error function and PW_{50} determines the width of the derivative of $g(t)$ at half of its maximum. The TA-affected readback signal, $p(t)$, can be written as

$$p(t) = \sum_k b_k g(t - kT - \Delta t_k) + n(t) + u(t), \quad (2)$$

where $n(t)$ is additive white Gaussian noise (AWGN) with two-sided power spectral density $N_0/2$, Δt_k is media jitter noise modeled as a random shift in the transition position [5] with Gaussian probability distribution function with zero mean and variance $|b_k|\sigma_j^2$ truncated to $T/2$. Thus, when we specify that jitter equals x%, it mean σ_j is x% of T. The $u(t)$ is a TA signal. In this paper, we consider a widely used TA model described by Stupp *et al.* [1] as shown in Fig. 2 because it fits the captured spin stand data and the drive data very well. This TA signal can be expressed as

$$u(t) = \begin{cases} A_0 t / T_r, & 0 \le t \le T_r \\ A_0 \exp\left(-\left(t - T_r\right)/T_d\right), & T_r < t \le T_f \end{cases}, \quad (3)$$

where A_0 is a peak TA amplitude, T_r is a rise time, T_d is a decay constant, and T_f is a TA duration. The TA duration is assumed to be $T_f = T_r + 4T_d$, where a decay time of $4T_d$ is sufficient because it will reduce the amplitude of the TA signal to approximately 1.8% of its peak amplitude.

In conventional setting, the signal $p(t)$ is filtered by the 7th-order Butterworth lowpass filter (LPF) and is sampled at time $t = kT$, assuming perfect synchronization with a sampling rate of 500 Mbps. The sampler output is equalized by an equalizer $F(D)$ such that a sequence y_k resembles a desired sequence d_k. Thus, the sequence y_k is fed to the TA detection and location block followed by the VD to determine the most likely input sequence.

3. PROPOSED TA SUPRRESSION METHOD

The structure of the proposed method is similar to that in [3, 4]. Specifically, the proposed method consists of two VDs running in parallel, one for the target $H(D)$, and the other for the target $G(D)H(D)$ equipped with a bandpass filter $G(D) = 1 - D^2$ to eliminate the TA effect in readback signal. Furthermore, we use the wavelet packet to determine the TA location, which will then be used to select the output from these two VDs.

The TA detection and location block is shown in Fig. 3. To find the TA location, a sequence y_k is filtered by an LPF $F_1(D)$ to smoothen the signal, whose transfer function is

$$F_1(D) = \frac{1}{n_1 + (1 - n_1)D}, \quad (4)$$

when n_1 determines a cutoff frequency. Then, the filtered sequence $\{c_k\}$ is normalized to have its maximum amplitude equal to one (so that the proposed method can be used for all channels). The normalized sequence $\{r_k\}$ is transformed using the wavelet packet [9], where a *Harr* wavelet is chosen as a mother wavelet because of its simplicity for detection.

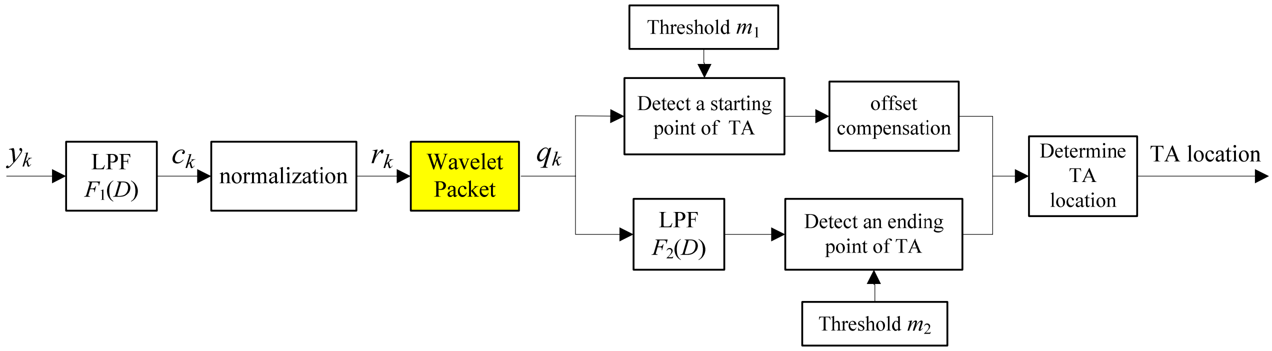

Fig. 3. The diagram of the TA detection and location block.

Then, the output sequence from the wavelet packet, q_k, is sent to a peak detector to determine the starting point of TA. The TA is detected if $q_k \geq m_1$ for few consecutive samples, where $m_1 > 0$ is a threshold value. Based on extensive simulation, we found that the detected location of the TA starting point is lagging the actual TA location for this system about 35 samples. Therefore, to make the proposed method robust to the TA effect, we need to compensate 35 samples prior to the detected location of the TA starting point.

To detect the location of the TA ending point, we feed the sequence q_k to another LPF $F_2(D)$, whose transfer function is given by

$$F_2(D) = \frac{1}{n_2 + (1 - n_2)D}, \tag{5}$$

where n_2 determines a cutoff frequency. Then, the filtered output is passed to another peak detector to find the ending point of TA. Specifically, the ending point is detected when $q_k > m_2$, where $m_2 > 0$ is a threshold value. Finally, the information about the starting and the ending points will determine the location of the TA signal. This TA location will be employed to select the output from the two VDs according to

$$\hat{a}_k = \begin{cases} w_k, & \text{if TA is present} \\ z_k, & \text{if TA is absent} \end{cases}. \tag{6}$$

4. EXPERIMENTAL RESULTS

Consider a perpendicular recording channel at ND = 2.5 with 3% media jitter noise (σ_j/T = 3%). The signal-to-noise ratio (SNR) is defined as SNR = $\log_{10}(E_i/N_0)$ in decibel (dB), where E_i is the energy of the channel impulse response (the derivative of the transition response scaled by 2). The 11-tap equalizer and the 4-tap target were designed based on the minimum mean-squared error (MMSE) approach [7] at the SNR required to achieve BER = 10^{-4} when the TA is absent and without the media jitter noise. The 4-tap target is given by $H(D) = 1 + 1.28D + 0.88D^2 + 0.27D^3$. In simulation, every 4096-bit data sector is corrupted by one TA signal with a peak TA amplitude of $A_0 = 2$, a rise time of $30T$, and a decay time of $1000T$ (i.e. a TA duration of $1030T$). This TA event can be considered as a worst case. Note that in this paper, we assume that the TA is occurred *randomly* in data packet.

We compute the BER of the system based on a minimum number of 1000 data sectors and 500 error bits, and call that number as "BER given TA." We use $n_1 = 12$, $n_2 = 235$, $m_1 = 0.15$, and $m_2 = 0.01$ for detecting the TA location. We compare the performance of the proposed TA suppression method with that of the "M1" and "M2" methods, where the method M1 was presented in [3], and the method M2 was presented in [5]. It should be pointed out that the proposed method is similar to the method M2, except that the proposed method uses the wavelet packet to detect the TA, whereas the method M2 employs the wavelet transform [6] to detect the TA.

Fig. 4 compares the BER performance of different TA suppression methods as a function of SNRs. It is clear that without a TA suppression method; the system performance is unacceptable (denoted as "With TA"). The proposed method performs better than M1 and M2. In addition, we observed that the proposed method performs comparably to M2 only when the TA is occurred at the position close to the 2^n-th bit, where n is a positive integer. Therefore, it can be implied that the wavelet packet is more robust to detect the TA than the wavelet transform used in M2.

Also, Fig. 5 compares the performance of different TA suppression method as a function of peak TA amplitudes at SNR = 27.4 dB, where the system without a TA event yields BER ≈ 10^{-4}. Apparently, the proposed TA suppression method performs better than other methods and it is also robust to changes in the peak TA amplitudes.

5. CONCLUSION

The TA effect can distort the readback signal. Without the TA detection and correction method, it could cause sector

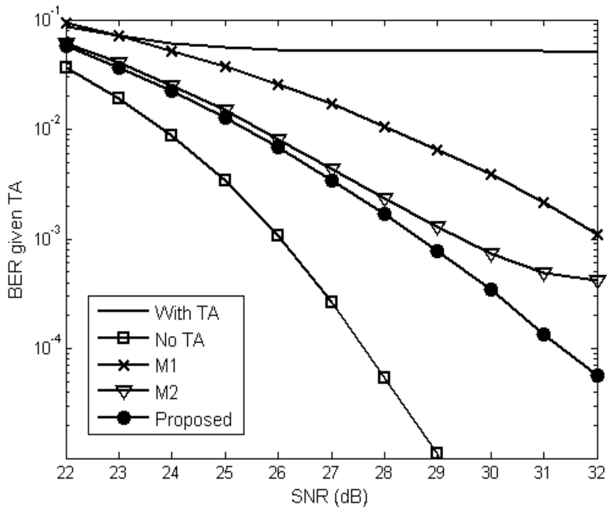

Fig. 4. Performance comparison for ND = 2.5 and σ_j/T = 3%.

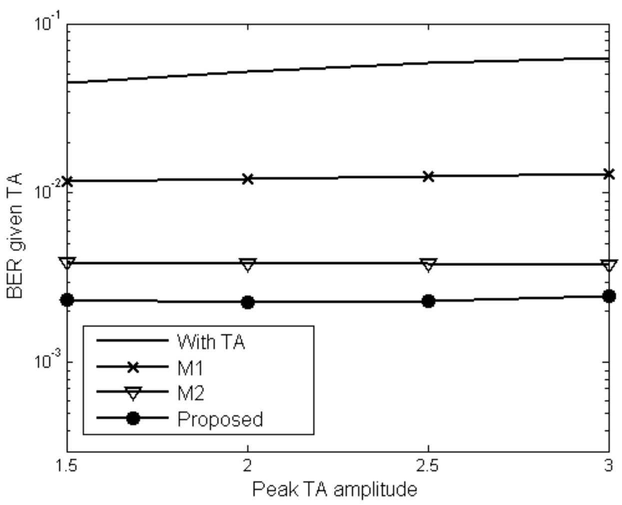

Fig. 5. BER performance with different peak TA amplitudes.

read failure. This paper proposes a new TA suppression method for perpendicular recording channels, which consists of two channels running in parallel, one for the target $H(D)$ and the other for the target $H(D)G(D)$, where $G(D) = 1 - D^2$ is a bandpass filter. Then, the wavelet packet is applied to detect the TA location. This TA location will be used to choose the output from the two Viterbi detectors. It is apparent from the simulation that the proposed method performs better than the other methods and is also robust to changes in the peak TA amplitudes.

6. ACKNOWLEDGMENT

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