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Head Instability Detection for Testing Process in Perpendicular Magnetic Recording System

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Keywords: Baseline popping, Head instability, Perpendicular magnetic recording, Testing process

Abstract. During hard disk drive (HDD) testing process, the magneto-resistive read (MR) head is analyzed and checked if the head is defective or not. Baseline popping (BLP) is one of the crucial problems caused by head instability, whose effect can distort the readback signal to the extent of causing possible sector read failure. Without BLP detection algorithm, the defective read head might pass through HDD assembling process, thus producing an unreliable HDD. This situation must be prevented so as to retain customer satisfaction. This paper proposes a simple (but efficient) BLP detection algorithm for perpendicular magnetic recording systems. Results show that the proposed algorithm outperforms the conventional one in terms of both the percentage of detection and the percentage of false alarm, when operating at high signal-to-noise ratio.

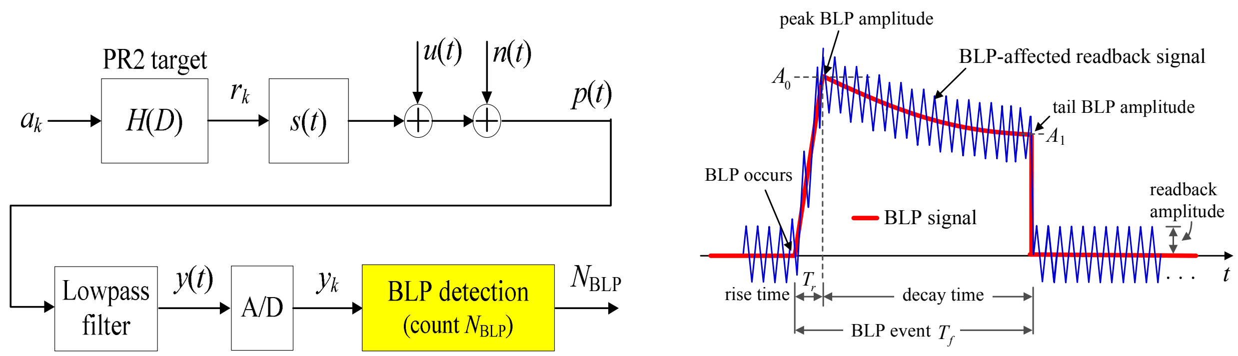
Introduction

High-density perpendicular magnetic recording systems employ the MR head to sense the change in a magnetic flux via the transitions of the magnetization pattern, producing an induced voltage pulse called a transition pulse. Hence, a read channel transforms this transition pulse into the readback signal. If the head has some defects, it will function unstably, thus lowering the quality of the readback signal, especially at high recording densities. Practically, head instability causes many problems, including BLP, writer induced instability, permanent magnet reversal instability, spiking noise, and random telegraph noise [1-3]. However, this paper focuses on the BLP because it is often found in testing process.

During testing process, several parameters are optimized to improve HDD performance and reliability, but this paper considers only the head stability. To test the head stability, a square-wave signal of $4T$ pattern, where T is a bit period, is written into the disk. Then, the tested head reads out that stored data to obtain the readback signal, which will be used to detect the number of BLP events. Basically, the read head is said to be defective if the number of BLP events (N_{BLP}) exceeds a given threshold. Once the defective head is detected, it will be discarded from the assembling process so as to avoid the defective HDD reaches a customer. Accordingly, an efficient BLP detection algorithm is important to ensure that all HDDs contain good heads.

Several works have studied the BLP effect. Chen *et al*. [1] proposed an averaging filter used in conjunction with a threshold detector to detect the BLP. Ottesen *et al*. [4] employed a bandpass filter to find the envelope of the readback signal before sending it to a threshold detector to determine the BLP. Zafer [5] passed the readback signal through a digital filter and computed the absolute value of the resulting signal before feeding it to a threshold detector to detect the BLP. Moreover, Li *et al*. [6] proposed to use track average amplitude and a threshold detector to find both the BLP and an unstable baseline of the read head.

This paper proposes a simple BLP detection algorithm and compares its performance with the conventional algorithm in perpendicular recording channels in terms of the percentage of detection and the percentage of false alarm.



(a) (b)

Fig. 1. (a) A channel model with BLP effect and (b) A BLP signal.

Channel Model

Fig. 1 (a) illustrates the perpendicular magnetic recording model with the BLP effect, where $H(D) = \sum_k h_k D^k = 1 + 2D + D^2$ is a PR2 channel [7], where D is a unit delay operator. A data input sequence $a_k \in \{-1,1\}$ with bit period T passes through the PR2 channel. The BLP-affected readback signal, $p(t)$, can be expressed as

$$p(t) = \sum_k r_k s(t - kT) + n(t) + u(t), \tag{1}$$

where $r_k = a_k * h_k \in \{0,\pm2,\pm4\}$ is a noiseless channel output, $*$ is a convolution operator, $s(t)$ is an ideal zero-excess bandwidth Nyquist pulse, $n(t)$ is additive white Gaussian noise with two-side power spectral density $N_0/2$, and $u(t)$ is the BLP signal shown in Fig. 1 (b).

Typically, the BLP is a low-frequency signal with a short rise time and a moderate exponentially decay time [1], and its peak amplitude is less than 1.5 times the peak of the normal readback signal. If precautions are not taken, the BLP effect can cause an error burst in data detection, which could exceed the correction capability of error-correction codes, thus resulting in a sector read failure. Note that the severity of the BLP effect depends on the BLP duration and its peak amplitude. In this paper, the BLP signal in Fig. 1(b) is modeled as

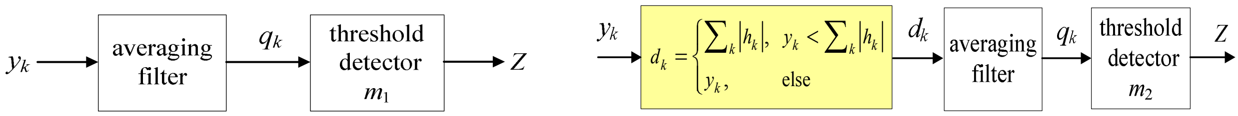
$$u(t) = \begin{cases} A_0 t / T_r, & 0 \le t \le T_r \\ A_0 \exp\left(-(t - T_r)/T_d\right), & T_r < t \le T_f \end{cases}, \tag{2}$$

where $A_0 = \alpha \sum_k |h_k|$ is a peak BLP amplitude, $\alpha \ge 0$ is the peak factor (in percentage), T_f is a BLP duration, T_r is a rise time of $5T$, and T_d is a decay constant depending on a tail BLP amplitude A_1. In this paper, we assume that A_1 is 40% of the peak amplitude of the normal readback signal (i.e., $\sum_k |h_k|$), which corresponds to $T_f = T_r + \ln(A_1/A_0) T_d$, where $\ln(x)$ is a natural logarithm of x.

At the receiver, the readback signal $p(t)$ is filtered by an ideal lowpass filter whose impulse response is $s(t)/T$, to eliminate the out-of-band noise. The filtered signal $y(t)$ is sampled at time kT by an analog-to-digital (A/D) converter, assuming perfect synchronization. The sample $\{y_k\}$ is fed to the BLP detection block to count the number of BLP events (N_{BLP}) to indicate the head instability. Specifically, the BLP is detected if N_{BLP} is larger than a given threshold.

Conventional BLP Detection Algorithm

Fig. 2 (a) displays the conventional BLP detection algorithm, which consists of an averaging filter and a threshold detector. Specifically, the sample $\{y_k\}$ is sent to an averaging filter with a window length of L bits to obtain a sequence q_k according to $q_k = \sum_{i=k-\beta}^{k+\beta} y_i$ where $L = 2\beta + 1$ and β



(a) (b)

Fig. 2. (a) Conventional and (b) Proposed BLP detection schemes.

is a positive integer. Then, a sequence q_k is fed to a threshold detector to determine the presence of BLP. Clearly, the BLP is detected if $q_k > m_1$.

Proposed BLP Detection Algorithm

The proposed BLP detection algorithm is given in Fig. 2 (b). To easily detect the BLP event, we first adjust a sequence y_k according to

$$d_k = \begin{cases} \sum_k |h_k|, & y_k < \sum_k |h_k| \\ y_k, & \text{else} \end{cases}, \tag{3}$$

where $|x|$ is an absolute of x. A sequence d_k is sent to an averaging filter with a window length of L bits according to Eq. 3 to obtain a sequence q_k. Then, a sequence q_k is fed to a threshold detector with a threshold m_2. Specifically, the BLP event is detected if $q_k > m_2$ for three consecutive samples so as to make it more robust to false alarm.

Numerical Results

Consider the perpendicular recording channel model in Fig. 1 (a). We define a signal-to-noise ratio (SNR) as $E_b/N_0 = 10\log_{10}(\sum_k |h_k|^2 / 2\sigma^2)$ in decibel (dB). In simulation, the BLP event is randomly occurred (some 4096-bit data sector contains one BLP event, but some does not), and the tail BLP amplitude $A_1 = 0.4\sum_k |h_k|$, where the BLP location, amplitude and duration are all random. Then, we measure the percentage of detection and the percentage of false alarm of each BLP detection algorithm based on a minimum number of 10000 4T-pattern data sectors. For a PR2 channel, the conventional BLP detection algorithm uses $L = 251$ bits and $m_1 = 1.14$, whereas the proposed one employs $L = 101$ bits and $m_2 = 4.12$ (the smaller the L, the lower the complexity). Note that all parameters are designed by maximizing the percentage of detection and minimizing the percentage of false alarm at E_b/N_0 = 12 dB, where the system without a BLP event yields bit-error rate (BER) of 10^{-5}.

Fig. 3 (a) compares the percentage of detection of both BLP detection algorithms as a function of peak factors at E_b/N_0 = 12 dB when the BLP event is of length 500 bits. Apparently, the proposed algorithm can detect the BLP event faster than the conventional one. We also plot the percentage of detection as a function of BLP duration in Fig. 3 (b) at E_b/N_0 = 12 dB when the BLP peak factor is α = 40%. Again, the proposed algorithm can detect the BLP event better than the conventional one. For the percentage of false alarm, we found that both conventional and proposed algorithms have nearly 0% false alarm (not shown here) for all BLP peak amplitudes and BLP durations.

Furthermore, we also compare the performance of different algorithms by plotting the percentage of detection as a function of SNRs in Fig. 4, when the BLP length of 500 bits and α = 40%. In this case, we found that both algorithms show 0% false alarm (not shown here). Additionally, the proposed algorithm performs better than the conventional one only when SNR is high enough (more than 11 dB). This is because the proposed scheme is quite *sensitive* to the noise; therefore, it does not perform well at low SNRs. Nevertheless, it should be pointed out that HDD practically operates at high SNR (e.g., more than 12 dB) to guarantee customer satisfaction, which in this case the proposed algorithm outperforms the conventional one (see Fig. 3). Therefore, it might be worth utilizing the proposed BLP detection algorithm in the real testing process where the operating SNR is high enough to obtain high percentage of detection and low percentage of false alarm.

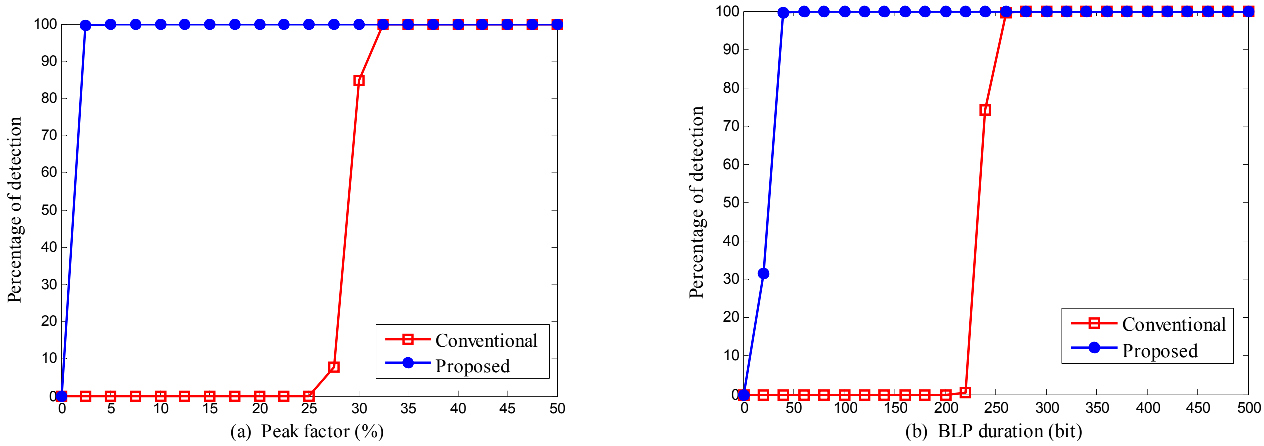


Fig. 3. Percentage of detection with (a) different BLP peak amplitudes and (b) different BLP durations.

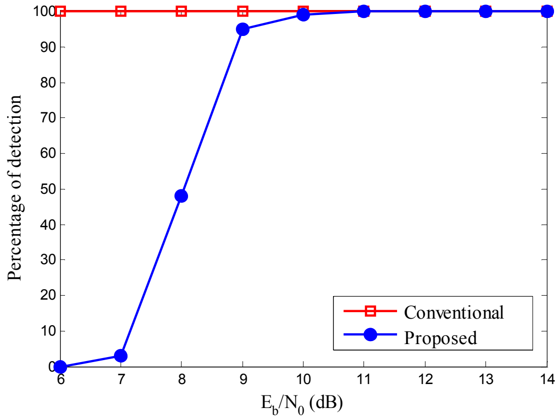


Fig. 4. Percentage of detection at different SNRs, when the BLP peak factor is 40%.

Summary

Baseline popping is one of the problems caused by head instability, which can degrade the system performance significantly. This paper proposed a simple BLP detection algorithm for perpendicular recording systems. Simulation results indicated that the proposed algorithm is superior to the conventional one in terms of the percentage of detection and the percentage of false alarm when operating at high SNR, where an actual HDD practically operates.

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