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High-Rate Skew Estimation for Tape Systems

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Abstract: In several recent magnetic tape drive designs, an actuator with two degrees of freedom has been adopted for joint skew- and track-following control. This enables the removal of flanges from guide rollers in the tape path, thus avoiding debris build-up, tape-edge damage, and high-frequency lateral tape motion. Skew compensation is needed to keep the head perpendicular to the direction of tape motion to enable read-while-write functionality in the presence of large lateral tape excursions originating from the removal of roller flanges. In this paper, we present a novel skew estimator that generates skew estimates at a high rate for an extended range of allowable tape-to-head skew values. A skew estimate is given by the sum of a fractional and an integer part, extracted from information provided by two parallel synchronous servo channels operating on timing-based servo patterns. The fractional part is obtained from the accurate measure of timing intervals between dibit correlation peaks, whereas the integer part is derived from longitudinal position information. The new method was implemented in an FPGA and verified experimentally using a commercial tape drive.

Keywords: Skew estimation, skew-following control, tape systems.

1. INTRODUCTION

In modern magnetic tape drives, the system reliability is enhanced by performing a read operation simultaneously with write operations to verify that the data has been correctly written. This verification is performed using a second head module with read elements, which is positioned adjacent to the head module writing the data. This second head module is typically physically attached to the first head module, with the read elements of the second module aligned with the write elements of the first module. Data is written as the tape is streamed over the first head module and then read back and verified as the written data passes over the second head module. If too many raw errors are detected in this verification step, the data can be rewritten immediately without stopping the tape. For this verification process to function properly, the tape motion must be essentially perpendicular to the axis of the arrays of writers and readers in the two modules, such that the read elements remain in the shadows of the write elements.

Tape skew is a measure of the deviation from perpendicularity of the angle of the tape relative to the read/write head. In previous generations of tape drives, tape skew was constrained by flanged roller guides that limit the lateral motion of the tape that causes tape skew. When the tape comes into contact with these flanges, high-frequency lateral tape motion can result that is difficult for the track-following actuator to follow and can also cause tape-edge damage. To alleviate these problems, the flanges have been removed from the guide rollers of more recent tape drives. Unfortunately, removing the flanges from the guide rollers results in a significant increase in lateral tape motion and hence in dynamic tape skew. This, in turn results in larger and more frequent misalignment of the read elements relative to the written tracks during read-while-write verification. To address this issue, flangeless tape drives use an actuator with two degrees of freedom for joint skew- and track-following control. The skew servo controller ensures that the read elements are aligned with the freshly written tracks during read-while-write verification and hence is a key enabler for achieving the very high reliability of tape systems.

2. TAPE-TO-HEAD SKEW AND TRACK FOLLOWING

Figure 1 illustrates the head modules of a tape drive, including the servo readers and the data read and write elements, and a skew θ between the tape head and the tape medium, while the tape is being transported from a supply reel to a take-up reel at a nominal velocity. Servo bands, which straddle the data bands, are prewritten on tape media during tape manufacturing to allow simultaneous reading of servo signals from two adjacent servo bands. Each servo band contains timing-based servo (TBS) frames (Barrett *et al.* (1998)), from which servo parameters, such as the tape velocity, lateral head position, and longitudinal tape position (LPOS), are extracted. The TBS servo frames are written with two different azimuth angles and consist of four servo bursts, i.e., two bursts with four servo stripes followed by two bursts with five stripes. Therefore a servo frame consists of 18 stripes arranged in a sequence of [4 4 5 5] bursts. During tape-drive operation, a servo reader reads the magnetic transitions associated with the servo stripes, resulting in pulses usually called dibits (Furrer et al. (2012)). The tape velocity and the lateral head position are estimated from the relative arrival time of dibits associated with servo stripes. TBS patterns also allow 1 bit of additional LPOS information

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to be encoded per frame using pulse-position modulation (PPM) on selected stripes, without affecting the generation of the transversal position estimates. In LTO-7 drives, the latest drive of the LTO* family, LPOS information is comprised within an LPOS word consisting of 36 servo frames. Each 36-bit LPOS word starts with a known 8-bit synchronization word, followed by 24 information bits. Sync words are periodically embedded into the LPOS data stream such that a sync word is always repeated after a distance of 36 servo frames. Detection of the servo patterns and extraction of the servo information parameters are achieved by a synchronous servo channel using a matched-filter interpolator/correlator, which turns out to be optimal in the presence of additive white Gaussian noise, and considerably increases both system robustness and measurement accuracy in the presence of media noise and other disturbances (Cherubini et al. (2015)).

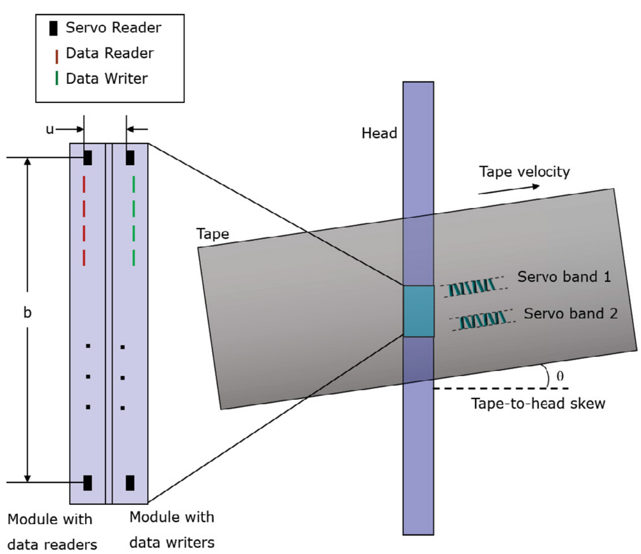

Fig. 1. Illustration of head modules and tape-to-head skew.

The block diagram of a skew- and track-following control system is shown in Fig. 2. Dual synchronous servo channels ch1 and ch2 receive servo signals $r_1(t)$ and $r_2(t)$, respectively, from the two servo readers reading servo patterns on adjacent servo bands. They provide estimates $\hat{y}_1$ and $\hat{y}_2$ of the lateral head position, and estimates $\hat{\tau}_1$ and $\hat{\tau}_2$ of the times at which peaks of the correlator output signals are observed at the servo channels, indicating the arrival times of the dibits in the servo bursts with high precision, as illustrated in Fig. 3. By defining b as the distance between servo readers in the same head module and assuming that the shift between servo frames in adjacent servo bands is zero, an estimate of the skew-error signal (SES) is given by

$$\hat{\theta} = \arctan\left(\frac{v(\hat{\tau}_2 - \hat{\tau}_1)}{b}\right) \approx \frac{\Delta x}{b} \ ,$$

where v is the tape velocity in the longitudinal direction, the function arctan(x) is approximated by its argument, assuming small values of x, and $\Delta x = v(\hat{\tau}_2 - \hat{\tau}_1)$ corresponds to the distance travelled by the tape in the time interval.

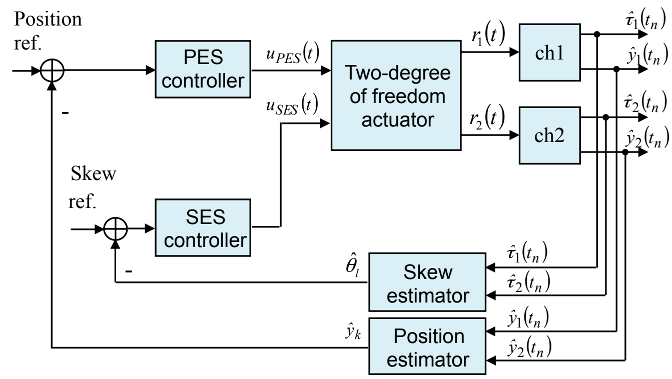

Fig. 2. Skew- (SES = skew error signal) and track-following (PES = position error signal) control system.

3. HIGH-RATE SKEW ESTIMATION

In the method described in Cherubini et al. (2015), there is an inherent ambiguity equivalent to the length $2d$ of a servo frame, e.g., 200 μm for the TBS servo format adopted for LTO-1 to 6 tape drives.

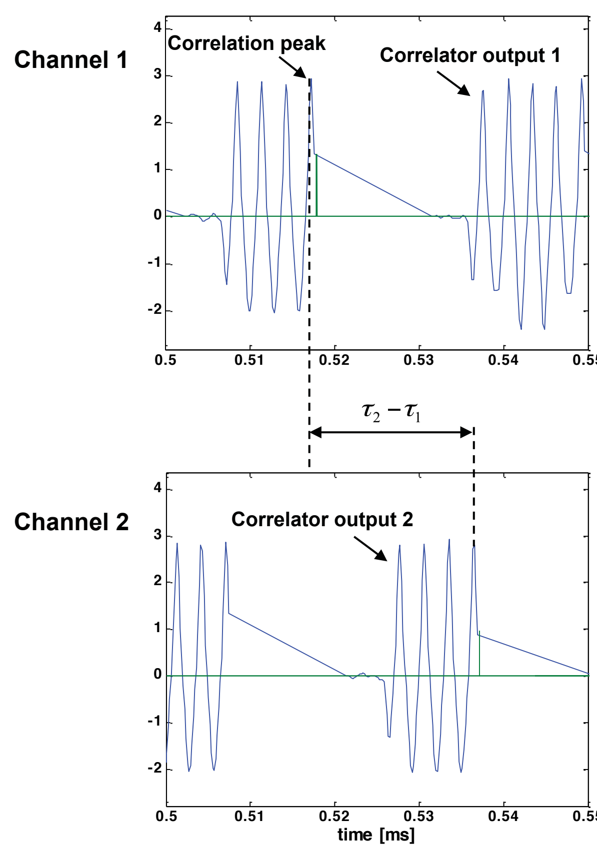

Fig. 3. Skew estimation using correlation signal peaks.

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