Proc. 19th Magnetic Recording Conference
(TMRC), Singapore, 2008

Evaluation of Track Following Servo Performance of High Density Hard Disk Drives Using Patterned Media

Younghee Han†, Raymond A. de Callafon† and Paul H. Siegel*
†Department of Mechanical and Aerospace Engineering, *Center for Magnetic Recording Research
University of California San Diego, La Jolla, CA

In recent years, track densities of magnetic hard disks have continued to grow. A promising approach for ultrahigh storage density is the use of patterned media. Prediction of future products' performance becomes more crucial when new technology is introduced into HDD manufacturing. Much research has been conducted on improving PES quality for achieving higher recording density related to patterned media technology, but fails to address how an accurate estimate of the true actuator position is required to obtain a desired closed-loop track following servo performance. In this paper, we discuss how accurate estimates of PES are required to achieve a desired track following performance and what the important factors that affect PES quality are in HDDs. A PES simulation tool was developed to provide a realistic HDD track following simulation and to serve as a virtual drive to estimate PES quality and predict achievable track density for high density HDDs. Simulation results provide valuable information for enhancing performance of high density HDDs using patterned media.

In order to obtain a comprehensive understating of PES quality, we investigate what are the important factors that affect PES quality and show, through a PES simulation example, how those factors affect PES quality during closed-loop track following. Three important factors that affect PES quality (PES linearity, pattern timing jitter, and signal quantization) are characterized. First, PES linearity is considered. In order to investigate this nonlinearity effect on PES, a mathematical approximation of nonlinear PES for the ABCD amplitude servo pattern was developed by using a Gaussian-integral error function as a base function. In order to manipulate the linearity of an error function, the linearity constant is defined. By conducting servo track following simulations with PES decoders having different nonlinearities, the linearity requirement for PES for achieving a desired track following performance level can be estimated. This consideration can be expanded to various servo patterns by constructing different PES decoders for different servo patterns. In this way, the validity of new servo patterns and PES demodulation schemes can also be estimated. Second, pattern timing jitter is considered. The PES quality is also affected by the timing-jitter caused by misalignment of the servo burst pattern and head fabrication tolerances during HDD manufacturing. In order to account for the timing jitter effect on PES quality, probability distribution of PES data is introduced. The dispersion parameter δ is defined to specify the dispersion of the PES data distributed on a patterned disk. By conducting servo track following simulations with different dispersion parameters, required maximum timing jitter tolerance satisfying a desired track following performance level can be estimated. Third, signal quantization is considered. In HDD servo control systems, quantization errors, caused by the finite precision of these converters, affect PES quality and servo tracking performance significantly. Considering these quantization errors, the proper number of quantization bits for the PES and control signals must be chosen. Correct quantization levels that satisfy a desired PES quality can be estimated by conducting servo track following simulations.

In order to evaluate the closed-loop track following performance, a closed-loop track following simulation tool is developed as a stand-alone Matlab function. This simulation tool can serve as a virtual HDD that allows us to estimate the effects of the parameters, defined previousely, on PES quality and their optimal values for achieving required PES quality, and to predict achievable track densities for high density HDDs using patterned media. The approach for the track-following simulation at the track density of 400ktpi is defining, with acceptable physical properties, a speculative HDD system operating at the track density of 400ktpi and disturbance models based on speculations, research and experimental results available in the literature. PES simulation at the track density of 400kti is conducted with the speculative HDD system and disturbance models by using the developd PES simulation tool. The simulation results show that PES nonlinearity does not greatly affect track following performance. However, the pattern timing-jitter and quantization errors degrade PES quality dramatically.

The importance of advance evaluation of PES quality and track following performance for future product planning and the evaluation approach are presented. Three important factors that affect PES quality (PES nonlinearity, pattern timing jitter, and signal quantization) are characterized. An advanced PES simulation tool is developed to provide realistic simulation of HDD track following to evaluate PES quality and track following performance at

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Younghee Han and Raymond A. de Callafon
University of California at San Diego, Mechanical and Aerospace Engineering,
La Jolla, CA 92093, USA
Tel: 858-5343166, Fax: 858-8223107, E-mail: callafon@ucsd.edu

higher track densities. Simulation for the track density of 400ktpi was conducted with speculative plant and disturbance models defined based on research available in the literature using the developed simulation tool. The evaluation of PES quality and track following performance at higher track densities and how those factors affect PES quality during closed-loop track following has been presented. From the simulation results, we conclude that PES nonlinearity does not greatly affect track following performance. However, the pattern timing-jitter resulting and quantization errors degrade PES quality dramatically. It has been shown that the simulation tool is able to predict valuable information, such as PES linearity requirement, the maximum allowable dispersion parameter, the minimum PES quantization bits, and the minimum control signal quantization bits for desired recording density. The feasibility of servo patterns and demodulation schemes can be also tested by the track following simulation. The estimation will provide valuable information that directly affects servo pattern design, PES demodulation schemes, MR head design, and manufacturing efficiency of HDD using patterned media and allow reduced total production cost. More accurate plant and disturbances models for higher track densities are required in future development work to provide more realistic simulation results.

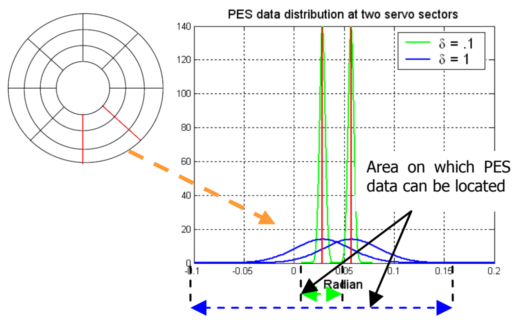

Fig. 1. The dispersion parameter δ (δ specifies the dispersion of the PES data distributed on a patterned disk).

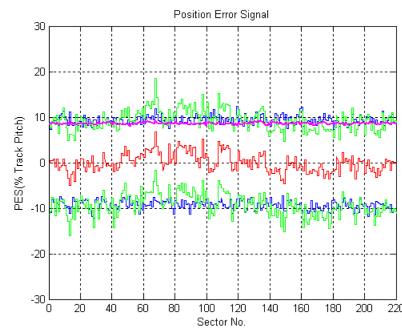

Fig. 2. PES of a speculative HDD (400ktpi) with δ is 0.

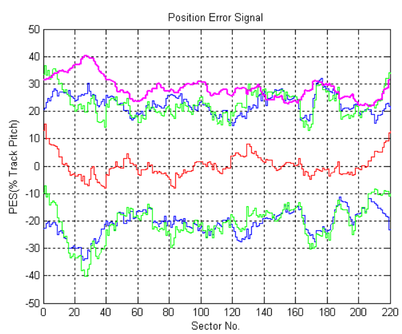

Fig. 3. PES of speculative HDD (400ktpi) with δ is 1.

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Younghee Han and Raymond A. de Callafon
University of California at San Diego, Mechanical and Aerospace Engineering,
La Jolla, CA 92093, USA
Tel: 858-5343166, Fax: 858-8223107, E-mail: callafon@ucsd.edu