Control Design for Self Servo Track Writer using Estimation of the Head Position

Norihito Nakamura, Nobutaka Bando and Yoichi Hori
University of Tokyo
Department of Electrical Engineering
4-6-1 Komaba, Meguro
Tokyo153-8505, Japan
n-nakamura@horilab.iis.u-tokyo.ac.jp
bando@horilab.iis.u-tokyo.ac.jp
hori@iis.u-tokyo.ac.jp

Abstract— **In the production process of Hard Disk Drive (HDD), there is a process of writing servo signals on magnetic disks to move the head to target address. However, such a servo track writer takes longer time to draw servo signals because of recent increase of the capacity of HDD. Therefore, they desire a low-cost method to draw servo signals. In order to resolve the problems, SSTW method (Self Servo Track Writing) which draws servo signals with its own head was already suggested. In SSTW method, there are two problems to realize it. One is how to know where the absolute position of head is. The other is that written servo tracks diverge because gain of the feedback controller is higher than 0[dB] in high frequency domain.**

In this paper, we try to summarize the problems of SSTW and introduce our past work proposed by Bando and Hori [1][2]. This method is essentially different from other methods, and performance is dramatically improved. Main ideas of this method, namely the estimation of the head position and the design of feedforward input, are introduced and simulation results are shown.

I. INTRODUCTION

Recent years, Hard Disk Drive (HDD) becomes more important for our society. HDD is now used widely for many ways. Depending on these demands, the capacity of HDD is increasing very rapidly [3].

In the production process of HDD, there is a process to write servo tracks using Servo Track Writer (STW). Servo tracks include a servo sync mark, a track address, and offset information. HDD servo controller uses them to move the actuator with magnetic heads to a target track address. Therefore, it is important to improve accuracy of servo patterns. At the same time, we should consider the efficiency of production cost and time for writing.

The conventional STW, the pushpin STW (Fig.2), has been used for servo track writing for many years. This apparatus writes servo tracks using encorder which measures the head's absolute position on the disk from outside. However, there are following problems in this system at present.

- Width of servo track is getting much narrower than before. Therefore, we should consider disturbances which were ignored in the past.

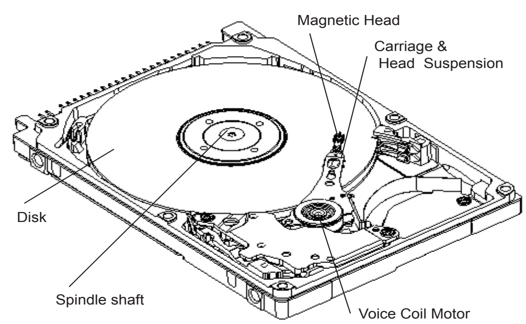


Fig. 1. Overview of hard disk drive

- It takes too much time to write servo tracks because of high density of servo track, which increases the cost.
- Servo track should be written in a clean room. However, to maintain a clean room is too costly. Then, we want to eliminate it.

In order to solve these problems, new methods have already been suggested [4][5][6][7][8]. In this paper, we aim to realize Self Servo Track Writer (SSTW). SSTW writes servo tracks using its own write head and position control system which is installed in any HDD. However, until now, it has been difficult to realize this. In this paper, we propose the method to estimate the head position and design the feedforward input. Simulation results are shown to verify them.

II. SERVO TRACK AND PROBLEMS OF SSTW

A. Explanation of Servo Track

Image of servo track patterns of HDD is shown in Fig.3. When we use HDD, track data consist of two kinds of data, namely servo data and user data. In the production process of HDD, servo data was written on blank disks as circles. HDD needs these servo data to move its head to target address because its head can't know the absolute position by itself. The reason of using relative postion is that there are some disturbances in HDD. Therefore, if we want to control the head precisely, it is important to use relative coordinate. In the next section, we will discuss the SSTW in detail.

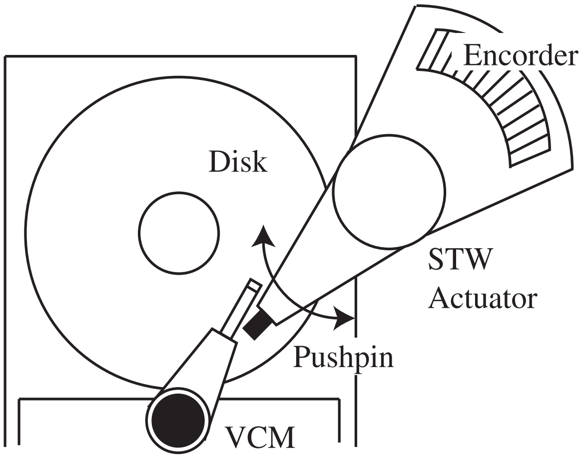


Fig. 2. Pushpin servo track writing method

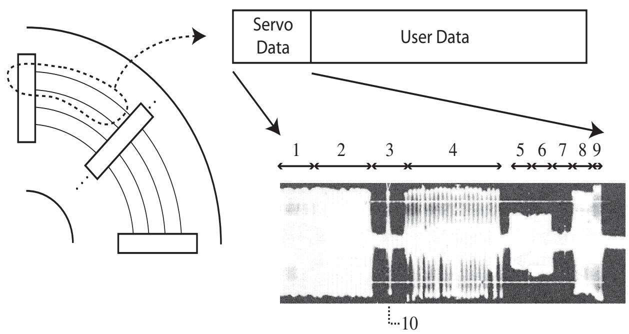


Fig. 3. Image of servo track

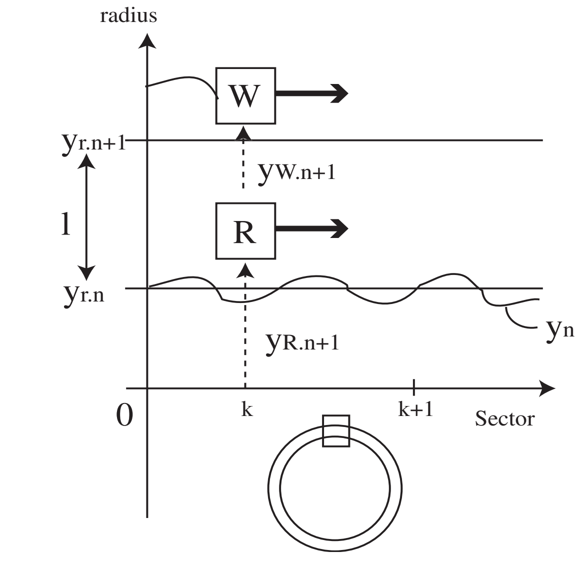


Fig. 4. Coordinates of servo track

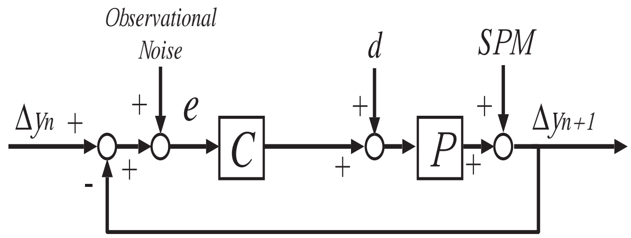


Fig. 5. Block diagram of SSTW with error coordinates

B. Block Diagram and Conditions of SSTW

In the SSTW method, we use read and write head of HDD to write servo tracks. In order to simplify problems, we suppose that the distance between read head and write head is equal to width of track (Fig.4) and servo track which is located in the most inner circle has already written by some ways.

We explain procedure of servo track writing concretely in the SSTW method. First, when the read head follows first track, the write head writes next track. In next step, the write head writes third track when the read head follows the second track. By repeating these steps, we can write servo tracks one by one. Coordinates of servo track are shown in Fig.4.

In this paper, each variable is defined as below.

- $y_{R,n+1}$:absolute position of the read head when head writes (n+1)th servo track
- $y_{W,n+1}$:absolute position of the write head when head writes (n+1)th servo track
- $y_{r,n}$:ideal (n)th servo track
- $y_{r,n+1}$:ideal (n+1)th servo track
- y_n :written servo track in (n)th track(=$y_{W,n}$)
- l :distance between the tracks
- N :the number of sectors in one track
- Δy_n : the error between written (n)th servo track and ideal (n)th servo track

By using these variables, eqs. (1) and (2) are obtained. In these equations, $\Delta y_n[k]$ means the error between written (n)th track and ideal (n)th track. Therefore, the block diagram of SSTW is shown in Fig.5. In this figure, C is the controller which is well tuned for following mode of HDD. In addition, d and SPM are distrubances. "d" is caused by wind and "SPM" is caused by rotation of the disk. Observational noise is expressed by ζ in equations. The gain of feedback controller is higher than 0[dB] in high frequency domain. Therefore, those disturbances make servo tracks divergent as servo track writing proceeds.

$$y_n[k] = y_{r,n}[k] + \Delta y_n[k] \quad (1)$$

$$y_{n+1}[k] = y_{r,n+1}[k] + \Delta y_{n+1}[k] \quad (2)$$

Transfer function from reference input to output is described as eq. (3).

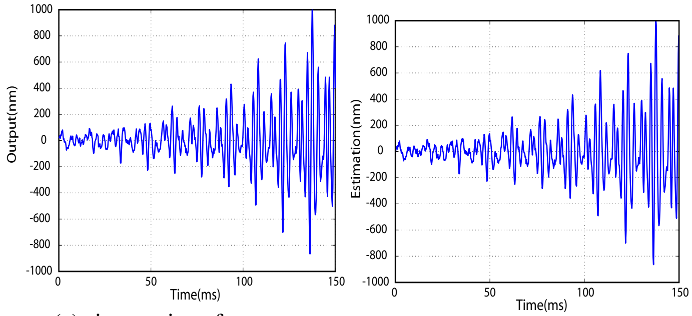
$$\Delta y_{n+1}[k] = \frac{CP}{1+CP}\Delta y_n[k] + \frac{CP}{1+CP}\xi_{n+1} + \frac{P}{1+CP}d_{n+1}[k] + \frac{1}{1+CP}SPM_{n+1}[k] \quad (3)$$

This is the basic equation to express the system of SSTW.

C. Problems of SSTW

It is difficult to realize SSTW because of three major problems as following.

- Gain of complementary sensitivity function of the control system is higher than 0[dB] in high frequency domain.



(a) time series of output calculated in simulation

(b) time series of estimated output

Fig. 6. Time series of output

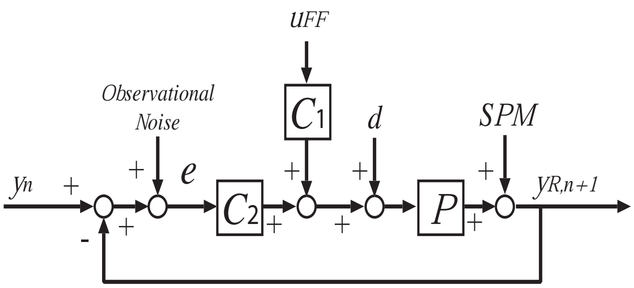


Fig. 7. Block diagram with feedforward input(1)

Hence, disturbances in those frequencies are easily amplified.

- There are some kinds of disturbance, such as wind disturbance caused by disk, sensor noise and repeatable runout (RRO).
- The number of observable signals is limited. In this system, only the position error signals (PES) expressed as symbol "e" is observable.

In the next section, we introduce a new method to solve these problems.

III. Estimation of the Head Position and Design of Feedforward Input

A. Estimation of the Head Position

One problem of SSTW is that we can't know the absolute position of head as it is pointed in section II. In this section, we propose a drastic idea to estimate it.

In this system, the observable signal is position error signal (e) described in section II. Position error signal of each track is expressed by eqs. (4)∼(6). By taking the summation in left and right terms respectively, eq. (11) is finally obtained.

$$e_{n+1}[k] = y_n[k] - y_{R,n+1}[k] + \zeta_{n+1}[k] \quad (4)$$

$$e_n[k] = y_{n-1}[k] - y_{R,n}[k] + \zeta_n[k] \quad (5)$$

$$\vdots$$

$$e_2[k] = y_1[k] - y_{R,2}[k] + \zeta_2[k] \quad (6)$$

$$e_{n+1}[k] + e_n[k] + \cdots + e_2[k]$$

$$= y_1[k] + (n-1)l - y_{R,n+1}[k] + \sum_{m=2}^{n+1} \zeta_m[k] \quad (7)$$

$$= y_1[k] + nl - y_{W,n+1}[k] \quad (8)$$

$$= y_1[k] - \Delta y_{n+1}[k] \quad (9)$$

$$(10)$$

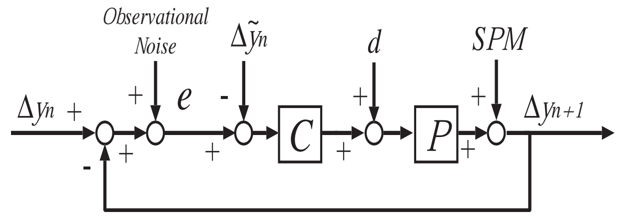


Fig. 8. Block diagram with feedforward input(2)

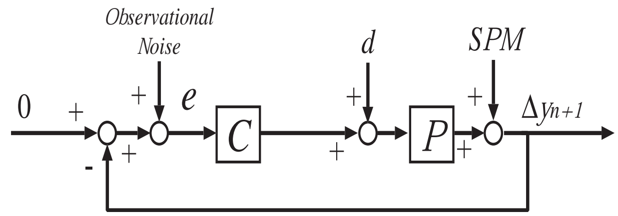


Fig. 9. Block diagram with reference 0

therefore

$$\Delta y_{n+1} = y_1 - \sum_{m=2}^{n+1} e_m[k] \quad (11)$$

In eq. (11), Δy_{n+1} means the error between written servo track and ideal servo track. Therefore, we add Δy_{n+1} to $y_{r,n+1}$, and then get the absolute position of head. In order to verify this estimation, time series of output are shown in Fig.6. According to this figure, the accuracy of estimation is clearly verified.

It enable us to solve the problems which have been difficult for previous researches. By using this estimated absolute position, we can design a feedforward input. In the next section, we introduce the actual design of feedforward input.

B. Design of Feedforward Input

1) Design(1): Using the proposed method, we design a feedforward controller. Fig.7 shows the block diagram, where the feedforward input is added to Fig.5. Transfer function is expressed by eq. (12).

$$\Delta y_{n+1}[k] = \frac{C_2 P}{1 + C_2 P}\Delta y_n[k] + \frac{C_1 P}{1 + C_2 P} u_{FF}[k] \quad (12)$$

In eq. (12), we design the feedforward input so that $\Delta y_{n+1}[k]$ becomes 0. In order to realize this, we define the controller and the feedforward input as $C_1 = C_2, u_{FF}[k] = -\Delta y_n[k]$. Then, eq. (13) is obtained.

$$\Delta y_{n+1}[k] = \frac{C_2 P}{1 + C_2 P}\Delta y_n[k] - \frac{C_2 P}{1 + C_2 P}\Delta y_n[k]$$

$$= 0 \quad (13)$$

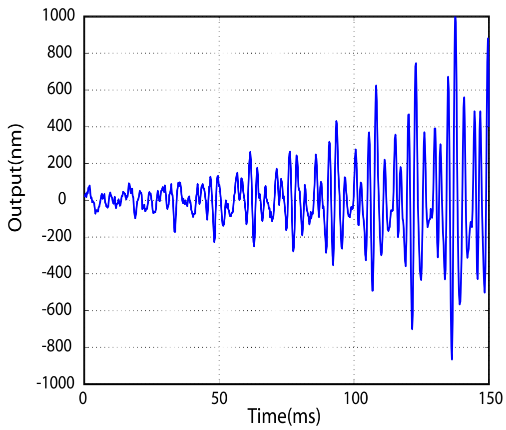


Fig. 10. Time series of output without FF input

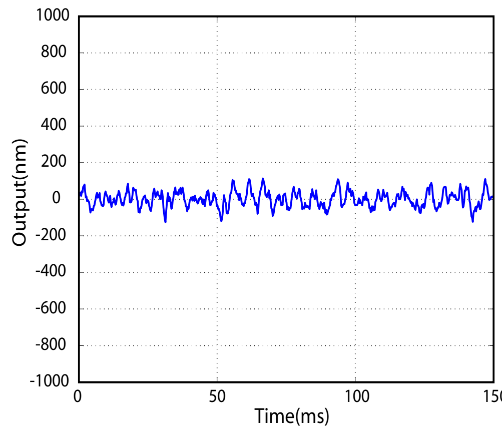


Fig. 11. Time series of output with FF input

Therefore, using this feedforward input, we can suppress the error $\Delta y_{n+1}[k]$. Furthermore, block diagram (Fig.7) can be changed into Fig.8. Fig.8 equals to Fig.9. Fig.9 shows that this system follows reference=0, namely ideal servo track.

Simulation results are shown in Figs.10 and 11. According to the results, servo track becomes more stable clearly by adding the feedforward input.

2) Design(2): In previous section, we designed the feedforward input to satisfy the conditions and finally got Fig.9. However, relative position between tracks is important to realize SSTW. Therefore, some information of previous track should be inputted as reference input. Block diagram of this system is shown in Fig.12. Naturally, if κ is larger than its specific value, servo tracks will diverge. Consequently, we should select proper κ.

Table. III-B.2 Simulation results 3σ of output and track width

reference	3σ of output	3σ of track width
κ =0	138[nm]	705 $\pm$ 197[nm]
κ =0.4	153[nm]	705 $\pm$ 173[nm]
κ =0.6	190[nm]	705 $\pm$ 178[nm]

Using this input, another simulation results are shown in Table.III-B.2. According to Table.III-B.2, 3σ of output gets worse gradually if κ becomes larger. However, 3σ of track width is improved. When κ=0, 3σ of track width is 705±197. On the other hand, when κ=0.4, 3σ of track width is 705±173. Therefore, it is shown that 3σ of track width is improved by inputting $\kappa\Delta y$ as reference.

IV. Conclusion and Future Work

In this paper, we introduced the method of estimation of head position and designed the feedforward input using it to realize Self Servo Track Writer. Also, we summarized some problems for realization of Self Servo Track Writer.

According to the simulation results, 3σ of each written servo track is almost the same if servo track writing proceeds. It

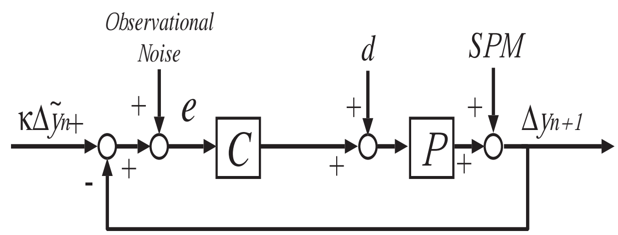


Fig. 12. Block diagram of SSTW with reference $\kappa\Delta y_n$

means that the problems in SSTW are completely improved, and it seems that SSTW can be realized easily. However, in actuality servo tracks diverge gradually if we apply this method to real product. Probably, one of reasons is that disturbances in high frequency domain cause this phenomenon.

Our future work is to find out the reason why servo tracks diverge gradually and to propose new method to resolve it.

References

[1] Nobutaka Bando , Yoichi Hori: "Estimation of the Head Position for Self Servo Track Writer and Consideration of Feedforward Control" Technical Meeting on Industrial Instrumentation and Control, IEE Japan,IIC-04-72,pp. 531-534,2004

[2] Nobutaka Bando , Yoichi Hori: "Estimation of the Head Position for Self Servo Track Writer and the Application of PTC" Technical Meeting on Industrial Instrumentation and Control, IEE Japan,IIC-05-68, 2005

[3] Takahiro Inoue, Makoto Horisaki, Yousuke Seo, and Shizuo Yamazaki: "Improvement of RRO Using Hybrid-Type STW for Hard Disk Drives" *IEEE Trans.Magnetics*,Vol.37,No.2,2001

[4] K.Miyata, T.Hamada, H.Hayashi, Y.Ban, K.Taniguchi and A.Saito: "Magnetic Printing Technology -Application to HDD" *IEEE Trans.Magnetics*,Vol.39,No.2,2003

[5] Hiroyuki Suzuki, Hitoshi Komoriya, Yutaka Nakamura, Takao Hirahara, Tadashi Yasunaga, Masakazu Nishikawa and Makoto Nagao: "Magnetic Duplication for Precise Servo Writing on Magnetic Disks" *IEEE Trans.Magnetics*,Vol.40,No.4,2004

[6] Kazuhiko Takashi, et. al:"Hard Disk Drive Servo Technology for Media-Level Servo Track Writing", *IEEE Trans.Magnetics*,Vol.39,No.2,2003

[7] Yukihiro Uematsu, Masanori Fukushi, and Kayoko Taniguchi:"Development of the Pushpin Free STW", *IEEE Trans.Magnetics*,Vol.37,No.2,2001

[8] Haibei Ye,Vincent Sng,Chunling Du,Jingliang Zhang and Guoxiao Guo: "Radial Error Propagation Issues in Self-Servo Track Writing Technology ", *IEEE Trans.Magnetics*,Vol.38,No.5,2002