TRACKING SERVO CONTROL SYSTEMS FOR DISC MEMORIES

This invention relates to tracking servo control systems for disc memories or disc drive systems.

Recording density, and especially track density, measured in units of TPI (tracks per inch), has recently become a very important factor in the field of disc memory systems. To obtain higher track densities, more precise tracking systems are required. One proposed solution to this tracking system problem resides in the use of a tracking servo signal which is prerecorded on a disc. During operation, a closed loop tracking servo circuit controls the position of a head in accordance with the reproduced servo signal. This tracking servo technique is called fine tracking servo control, while coarse tracking servo control accomplishes only a rough positioning of the head with the mechanical precision of an actuator. Coarse tracking servo control uses an open loop servo circuit. Generally, a combination of fine and coarse tracking servo control is used for tracking control of the head in disc memory systems if they need precise tracking control.

However, the above-explained tracking control technique has several problems, especially when floppy discs are used as the disc medium. Since floppy discs are interchangeable on a disc drive, some eccentricity of tracks cannot be avoided. The amount of eccentricity changes in accordance with the condition of disc chucking onto the disc drive. Further, some expansion, contraction and deformation of the disc, due to a change of temperature or humidity, are inherent characteristics of floppy discs. Accordingly, the actual positions of tracks on the disc are different from the ideal or theoretical positions of the tracks. Thus, it is very hard to make the head follow the actual tracks by using tracking error data when the prerecorded tracking signal is reproduced from the disc, because the amount and the direction of track deviation from the ideal track positions is very large.

According to one aspect of the invention there is provided a tracking servo control system for a disc memory, the system comprising:

at least one disc medium on which a plurality of concentric data tracks are provided for recording and/or reproducing data signals and

on which servo sectors are provided for prerecording servo signals;

transducer means for recording and/or reproducing said data signals and for reproducing said servo signals;

actuator means for moving the transducer means radially of the disc medium;

first detecting means for detecting tracking error in accordance with said servo signals reproduced by the transducer means, said tracking error being representative of any difference between the position of the transducer means and the position of a desired data track on which the transducer means should be positioned;

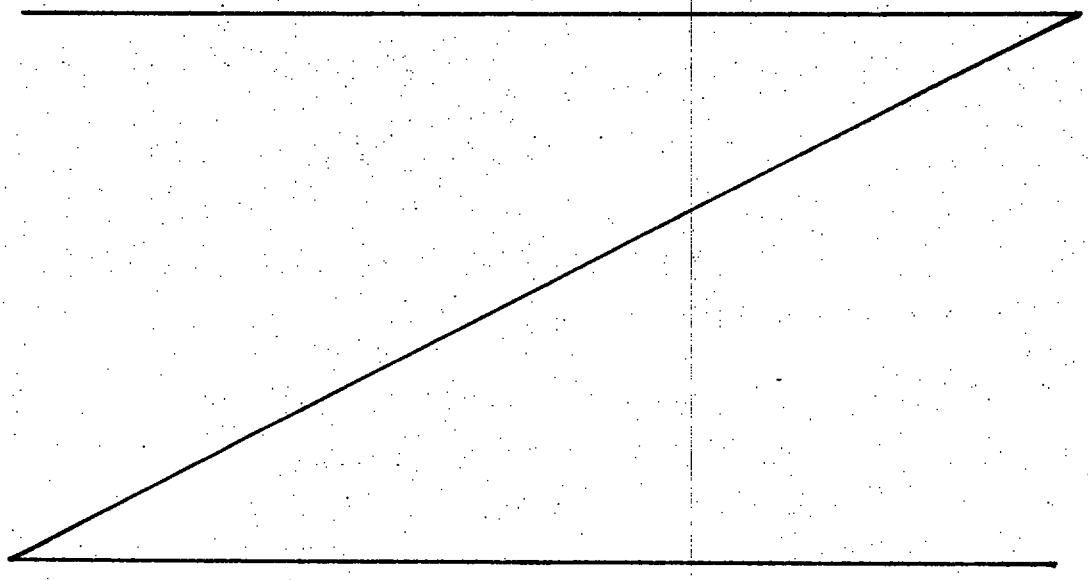
second detecting means for detecting a current position of the transducer means;

adding means for adding said tracking error detected by the first detecting means and said current position of the transducer means detected by the second detecting means to produce added data;

delay means for delaying said added data produced by the adding means for a period corresponding to at least one revolution of the disc medium to produce a delayed signal;

comparing means for comparing said current position of the transducer means detected by the second detecting means with said delayed signal produced by the delay means; and

tracking servo control means for controlling the actuator means in accordance with an output signal from the comparing means, whereby the transducer means is positioned on said desired data track.



A preferred embodiment of the invention described in detail below provides a precise tracking servo system for a disc drive system which overcomes at least partially the above-described problems of the previously proposed disc drive system. The preferred embodiment is particularly, though not exclusively, applicable to floppy disc drive systems and uses a servo signal prerecorded on servo sectors on a floppy disc to provide precise tracking control regardless of expansion, contraction or deformation of the disc caused by a change of temperature or humidity, and regardless of any eccentricity of tracks on the floppy disc caused by various conditions of chucking of the floppy disc onto the disc drive. In the preferred system, current tracking servo control is based on previous tracking error data developed in a previous cycle of the disc rotation, whereby precise tracking servo control for the disc drive is possible even in the event of a relatively large amount of eccentricity of the tracks, or expansion or contraction of the disc.

The invention will now be further described, by way of illustrative and non-limiting example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a tracking control system embodying the invention for a disc drive;

Figure 2 shows a plan view of a portion of a disc, and waveforms of signals developed when a head scans such portions, for explaining a detecting operation of a servo signal recorded on the disc;

Figure 3 is a diagram used for explaining a basic principle of tracking control for a disc drive;

Figure 4(A) shows a relationship between track position and head position in a previously proposed tracking control system;

Figure 4(B) shows a tracking error waveform of the previously proposed tracking control system;

Figure 5(A) shows a relationship between track position and head position in the tracking control system embodying the invention;

Figure 5(B) shows a tracking error waveform of the tracking control system embodying the invention;

Figure 6 is a diagram used for explaining a tracking control operation performed during a track jump; and

Figure 7 shows a plan view of an example of a recording format of a magnetic disc.

Figure 1 is a block diagram of a tracking control system or apparatus embodying the invention for a disc memory. In this embodiment, the invention is applied to a floppy disc system which utilises a recording format as, for example, shows in Figure 7.

Servo sectors S and data sectors D are intermittently provided on concentric tracks of a floppy disc 1 which has a central hub 6 by means of which the disc is mounted for rotation in a direction represented by an arrow R. Servo signals 2 having a recording width WS are prerecorded in the servo sectors and data signals 3 having a recording width WD are recorded in or reproduced from the data sectors D. Each servo signal 2 is prerecorded so that the centre line thereof is offset radially (in the direction of an arrow A) from the centre line T of a data signal 3 by half of a track pitch P. At the beginning portion of each servo sector S, a servo identification (ID) signal 2ID is prerecorded to identify a servo sector. Following the servo ID signal 2ID, two kinds of servo burst signal 2S are prerecorded.

Figure 2 is an enlarged illustration of the recording format. (Although the tracks on the disc are actually concentric, Figure 2 shows the tracks as if they were straight lines for explanation purposes.) As shown in Figure 2, the servo ID signals 2ID and the servo burst signals 2S are formed in the servo sector S, and tracks comprising a data signal 3 and a data sector ID signal 4 are formed in a data sector D. These patterns are repeatedly formed on the disc, as shown in Figure 7.

When a head scans a track (data track) of a data sector D, it may also scan, at the same time, a portion of each of a pair of servo burst signals 2S on opposite sides of the data track. Tracking position information is made available by comparing the envelope levels of the reproduced pair of servo burst signals.

As shown in Figure 1, signals reproduced by a magnetic head 11 are amplified and filtered by a recording /reproducing amplifier 12 and then supplied to an envelope detecting circuit 13 and a servo ID detecting circuit 14. A sample of the output signal EN of the envelope detecting circuit 13 is shown in Figure 2. The signal EN, which is an envelope waveform, is generated when the magnetic head 11 passes over

the servo sector S, and is supplied to an analog to digital (A/D) converter 15. A signal SID (Figure 2) generated at the output of the servo ID detecting circuit 14 comprises a pulse PSID when the detecting circuit 14 detects a servo ID signal 2ID and is supplied to a timing control circuit 16. The timing control circuit 16 then supplies sampling pulses PS1 and PS2 (Figure 2, line SP), derived in accordance with the timing of the pulse PSID, to the A/D converter 15 and a latching circuit 17. In response to the sampling pulses PS1 and PS2, the levels of the envelope waveform EN corresponding to the servo burst signals 2S are latched by the latching circuit 17. Referring to Figure 2, L1 and L2 represent the envelope level of the servo burst signals 2S, which are oppositely offset from the centre line of the track of a data signal 3. The latched levels L1 and L2 are supplied to a subtractor 18 where they are subtracted from each other. The resultant calculated tracking error data L1-L2 is supplied to a multiplier 19 in which the tracking error data L1-L2 is multiplied by a number (coefficient) a which is selected to be between 0 and 1. The result of the multiplication operation is supplied to an adder 21. Also, an output signal hpd of a head position detecting circuit 20 is supplied to the adder 21. The output signal a(L1-L2)+hpd of the adder 21 is delayed by a delay circuit 22 whose delay is equal to the rotation period of the disc. Since servo sectors S may be provided for every data sector D and the output signal of the adder 21 is updated after reading each sector, the delay circuit may comprise a shift register having a number of stages such that the number of shifting operations required to pass data through the shift register is as same as the number of the sectors during each rotation of the disc. A FIFO (first-in, first-out) memory may be used as a part of delay circuit 22.

A comparator 23 compares the output signal hpd of the head position detecting circuit 20 with the delayed output signal of the adder 21. An output signal of the comparator 23 is supplied to a phase control circuit 24 which effects a phase correction of the supplied signal and produces an output signal which is supplied to a fine tracking control circuit 25. The fine tracking servo control circuit 25 controls an actuator 26, which may be a stepping motor, a linear motor, etc., so that magnetic head 11 is positioned in alignment with the centre line of a track containing a data signal 3.

A basic principle underlying the operation of the present tracking control system is that the present or current tracking error data is used for head position control after at least one rotation or revolution of the disc. In other words, the head position control can be carried out with the previous tracking error data which was calculated during at least one prior disc rotation. Figure 3 shows an index pulse IXP which is generated once every rotation or revolution of the disc. Also, Figure 3 shows a change of track position which is caused by eccentricity or deformation of the disc itself. More particularly, the change of the track position as shown in Figure 3 is the change in the radial position of the centre line of the actual tracks with respect to the centre line of ideal or theoretical tracks, as the disc rotates. It is also assumed that such a change of track position is related only to the angular position of the rotating disc. Accordingly, it is also assumed that characteristics of the change are stable in the nth rotation or revolution and in the (n+1)th rotation or revolution. On the other hand, the difference between the position of the magnetic head 11 and the actual track, that is the tracking error, is detected every sector. The tracking error data in the ith sector during the nth rotation or revolution is shown as trp(i)-hpd(i,n), where trp(i) is the actual track position and hpd(i,n) is the position of the magnetic head 11 in the ith sector during the nth rotation or revolution with respect to the centre line of the ideal tracks. The magnetic head position hpd(i,n+1) in the ith sector during the (n+1)th rotation is controlled using the tracking error data obtained in the ith sector of the nth rotation. The relationship between hpd(i,n+1) and hpd(i,n) is given by:

$$(1)\quad hpd(i,n+1) = hpd(i,n) + a[trp(i)-hpd(i,n)]$$

where $0 < a \leq 1$.

Although the left hand side of Equation (1) represents the desired head position to which the magnetic head 11 will be positioned, it may be considered as the actual position of the magnetic head 11 if the operational characteristics of the fine tracking servo control circuit 25 and the actuator 26 are substantially fast and linear.

If (a) is equal to 1, hpd(i,n+1) has no tracking error. However, in actual practice, a number of rotations of the disc may be required to obtain final accurate placement of the magnetic head 11. The

present system is designed to perform only a partial correction (a) during each rotation, so as to avoid overshooting or a hysteresis effect. Equation (1) can be rewritten, to incorporate the function of the multiplier 19, as follows:

$$(2)\quad \begin{aligned} hpd(i,n+1) &= (1-a)hpd(i,n) + a \cdot trp(i) \\ &= (1-a)^2 hpd(i,n-1) + a[1+(1-a)]\, trp(i) \\ &= (1-a)^3 hpd(i,n-2) + a[1+(1-a)+(1-a)^2]trp(i) \\ &= (1-a)^{n+1} hpd(i,o) + a[1+(1-a)+(1-a)^2+\ldots \\ &\quad + (1-a)^n]trp(i). \end{aligned}$$

(3) If $n \to \infty$,

$$\begin{aligned} hpd(i,\infty) &= a \frac{1}{1-(1-a)} trp(i) \\ &= trp(i) \end{aligned}$$

because $o<a\leq 1$.

Therefore, if (a) is between 0 and 1, the fine tracking servo operation of the magnetic head 11 according to Equation (1) finally controls the magnetic head position hpd to be in alignment with the track position trp. In Equation (1), the first term on the right hand side represents the magnetic head position one rotation period ago and the second term represents the tracking error one rotation period ago. The magnetic head position hpd(i,n) in the ith sector during the nth rotation is also given by the following equation:

$$(4)\quad hpd(i,n) = hpd(i,n-1) + a[trp(i) - hpd(i,n-1)].$$

An explanation of the operation of the system when the magnetic head 11 is running on the ith sector during the nth rotation will now be given. The tracking error data a(L1-L2) derived from the multiplier 19 in Figure 1 corresponds to a[trp(i) - hpd(i,n)], as explained above. Since the magnetic head position detecting circuit 20 supplies the current position data hpd(i,n) of the magnetic head 11 to the adder 21, the adder 21 provides an output hpd(i,n) + a[trp(i) - hpd(i,n)], representing position data hpd(i,n+1), to which position the magnetic head 11 will be moved in the ith sector during the (n+1)th rotation. At the same time, the delay circuit 22 provides an output hpd(i+1,n-1) + a[trp(i+1) - hpd(i+1,n-1)] as position data hpd(i+1,n), to which position the magnetic head 11 will be moved in the (i+1)th sector during the nth rotation of the disc. Accordingly, when the magnetic head 11 reaches the (i+1)th sector, the data hpd(i+1,n) - hpd(i,n),

which corresponds to the difference between the current position hpd(i,n) of the magnetic head 11 and the next position hpd(i+1,n), is supplied from the comparator 23 to the phase control circuit 24 and then supplied to the fine tracking servo control circuit 25 so that the magnetic head 11 is positioned on the desired track in the (i+1)th sector.

The current position of the magnetic head 11 is provided by accumulating the distance over which the magnetic head 11 has been moved, taking into account the direction of movement.

When tracking control is initiated and no tracking error data is yet stored, usual tracking techniques may be used. For example, fine tracking control may be carried out according to the tracking error data based on the reproduced servo signal on the disc, without storing or delaying the tracking error data. Once the tracking error data comes within a predetermined range, the tracking error data is stored or delayed and used for head positioning during the next rotation of the disc. In this case, although the tracking control of this embodiment starts after one rotation of the disc, the tracking control is carried out according to the tracking error, without waiting for a one rotation delay.

An advantage of the present tracking control system will now be described with reference to Figures 4(A) to 5(B). Figure 4(A) shows the relationship between the track position and the magnetic head position for a previously proposed system and Figure 4(B) shows the amount of the tracking error encountered in the previously proposed system. Figures 5(A) and 5(B) show, respectively, the same data for the present tracking control system. In Figures 4(A) and 5(A), a broken line shows the changing of the actual track position on the disc with respect to the ideal track position, which has no eccentricity, and a solid line shows the position of the magnetic head which is tracking servo-controlled.

Comparison of Figures 4(A), 4(B) and 5(A), 5(B) shows that the tracking ability of the magnetic head in the previously proposed system begins with an imperfect position, and the amount of the tracking error is never improved after subsequent revolutions or rotations of the disc, whereas the tracking ability of the magnetic head in the present system is significantly improved after the second revolution or

rotation and, consequently, the tracking error also is significantly reduced.

In the above explanation, it was assumed for easier understanding that the magnetic head is scanning the same track continuously. However, the characteristic of the deviation of any actual track from the corresponding ideal track over various radial positions is very similar if the angular positions are the same. Accordingly, when a change in the selected track takes place, that is a track jump takes place, the tracking error data of the different tracks may be used. In this case, as shown in Figure 6, the difference d of the head positions in the ith sector before and after a track jump corresponds to the positioning error caused by the coarse tracking apparatus during the track jump, and the settling time of the tracking servo during the track jump can be shortened by adding the difference d as a biasing factor for other following sectors.

This invention is not limited to the above embodiment, but can also be applied to a hard magnetic disc system, an optical disc system or a magnetic-optical disc system, as well as to a flexible magnetic disc.

CLAIMS

1. A tracking servo control system for a disc memory, the system comprising:

at least one disc medium on which a plurality of concentric data tracks are provided for recording and/or reproducing data signals and on which servo sectors are provided for prerecording servo signals;

transducer means for recording and/or reproducing said data signals and for reproducing said servo signals;

actuator means for moving the transducer means radially of the disc medium;

first detecting means for detecting tracking error in accordance with said servo signals reproduced by the transducer means, said tracking error being representative of any difference between the position of the transducer means and the position of a desired data track on which the transducer means should be positioned;

second detecting means for detecting a current position of the transducer means;

adding means for adding said tracking error detected by the first detecting means and said current position of the transducer means detected by the second detecting means to produce added data;

delay means for delaying said added data produced by the adding means for a period corresponding to at least one revolution of the disc medium to produce a delayed signal;

comparing means for comparing said current position of the transducer means detected by the second detecting means with said delayed signal produced by the delay means; and

tracking servo control means for controlling the actuator means in accordance with an output signal from the comparing means, whereby the transducer means is positioned on said desired data track.

2. A system according to claim 1, wherein said servo signals comprise first and second servo signals on servo tracks in said servo sectors, which servo tracks are offset from said data tracks, radially of the disc medium, by half of the track pitch between said data tracks.

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3. A system according to claim 2, wherein the first detecting means comprises envelope detecting means for detecting envelope levels of said first and second servo signals reproduced by the transducer means, and second comparing means for comparing the envelope levels of said first and second servo signals.

4. A system according to claim 1, claim 2 or claim 3, comprising multiplying means for multiplying said tracking error detected by the first detecting means by a coefficient "a" and supplying the result of the multiplication to the adding means so that the adding means adds the result of the multiplication and said current position of the transducer means detected by the second detecting means, the coefficient "a" being selected to be between 0 and 1.

5. A system according to any one of claims 1 to 4, wherein the delay means is operative to delay the added data produced by the adding means for a period corresponding to multiple revolutions of the disc medium.

6. A system according to any one of claims 1 to 4, wherein the delay means is operative to delay the added data produced by the adding means for a period corresponding to one revolution of the disc medium.

7. A tracking servo control system for a disc memory, the system being substantially as herein described with reference to Figures 1 to 3, 5(A), 5(B) and 6 of the accompanying drawings.

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