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TITLE OF THE INVENTION

METHOD AND APPARATUS FOR POSITIONING A HEAD IN A DISK
DRIVE WITH SERVO WRITING FUNCTION

BACKGROUND OF THE INVENTION

5 The present invention generally relates to a
head positioning system and, more particularly, to a
head positioning system of a disk drive with a servo
writing function.

10 In general, a disk drive that represents a hard
disk drive incorporates a head positioning system.
The head positioning system positions a head in a
target position on a disk medium (simply referred to
as a disk hereinafter) based on servo data recorded
on the disk.

15 As a servo writing method of recording servo
data on a disk, there is a self-servo writing method
that is executed using a mechanism incorporated into
a disk drive (see Jpn. Pat. Appln. KOKAI Publication
No. 8-212733, for example).

20 In the self-servo writing method, a head is
positioned using servo data written to a disk and the
next servo data is written thereto. The servo data
contains position error components that are synchro-
nized with the rotation of the disk, or repeatable
25 run-out (referred to as RRO hereinafter). If the
RRO increases, the distortion of old servo data in
the radial direction of the disk affects that of



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subsequent servo data.

The prior art self-servo writing method described above has the technique of suppressing the increase of RRO by a correction function of inputting a correction value by feed forward (FF) (which may be referred to as FF correction hereinafter).

The correction function employs a linear filter (FF filter) operation that corresponds to the inverse function of the sensitivity function of a head positioning system. The sensitivity function of a feedback control system is a transfer function $1/(1+G)$ where G means a open-loop transfer function of the feedback control system.

In the correction function, a correction value computed by the FF filter operation is added to the input value of a controller (follow-up control element) of the head positioning system. The correction value is computed based on RRO included in position errors of the head (relative to a target position), which are sensed before the correction.

In the above correction function, however, the RRO caused after a correction value is input cannot be corrected. It is thus difficult to correct the distortion of servo data to be recorded with high precision.

BRIEF SUMMARY OF THE INVENTION

In accordance with one embodiment of the present

invention, there is provided a head positioning system capable of suppressing the increase of RRO effectively and correcting the distortion of servo data with high efficiency.

5 The head positioning system comprises a positioning unit to position a head in a target position on a disk medium that is rotating, a unit which senses a position error of the head relative to the target position, a controller which outputs
10 an amount of control operation of the positioning unit based on the position error, and a correction unit which computes a position error component that is synchronized with rotation of the disk medium based on an input value of the controller, computes
15 a correction value to eliminate the position error component from the position error, and adds the correction value to the input value.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

20 The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

25 FIG. 1 is a block diagram of the main part of a disk drive according to an embodiment of the present invention;

FIG. 2 is a block diagram illustrating the main part of a head positioning system of the disk drive according to the embodiment of the present invention;

FIG. 3 is a diagram showing the amount of distortion in the head positioning system of the disk drive according to the embodiment of the present invention;

FIGS. 4 to 7 are diagrams of variations of input values of a controller of the head positioning system of the disk drive according to the embodiment of the present invention; and

FIG. 8 is a flowchart showing a procedure of a self-servo writing operation according to the embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment of the present invention will now be described with reference to the accompanying drawings.

FIG. 1 is a block diagram of the main part of a disk drive having a self-servo writing function. FIG. 2 is a block diagram illustrating a head positioning system incorporated into the disk drive. (Configuration of Disk Drive)

The disk drive according to the embodiment of the present invention includes a disk 1 serving as a data recording medium, a head 2 mounted on an actuator 3, and a servo system having a self-servo writing function, as shown in FIG. 1.

The disk 1 is attached to a spindle motor (SPM) 10 and rotates at high speed. The disk 1 has a number of tracks (cylinders) 100 that are formed concentrically around the rotation axis of the disk 1. Each
5 of the tracks 100 is divided into servo sectors 130. Each of the servo sectors 130 includes a leading servo area 110 and its subsequent data recording area 120. On the servo area 110, items of servo data (positional information) are recorded at regular intervals in the
10 circumferential direction by a servo writing operation described later.

The head 2 includes a write head 20 and a read head 21. The write head 20 performs a write operation to write servo data or user data onto the disk 1.
15 The read head 21 performs a read operation to read servo data or user data out of the disk 1. The actuator 3 moves the head 2 over the disk 1 in its radial direction by the driving force of a voice coil motor (VCM) 4.

20 The servo system includes a signal processing unit 5, a position sensing unit 6, a controller 7, a VCM driver 8 and a servo writing unit 9.

The signal processing unit 5 is a read/write channel that performs a decoding operation and an
25 error-correcting operation for read signals output from the read head 21. The position sensing unit 6 separates servo data from the read data processed by

the signal processing unit 5 to generate positional information of the head 2 (which is broadly divided into a cylinder address and a servo burst signal).

The controller 7 includes a microprocessor (CPU) 5 70 that serves as a main element to execute programs stored in a ROM 71 and configures a head positioning system, which will be described later. The CPU 70 computes the amount of control operation (control input value) to drive the VCM 4 in accordance with a 10 head position sensed every fixed time period by the position sensing unit 6, control parameters stored in the ROM 71, program processing time measured by a timer, and the like.

The VCM driver 8 generates a driving current 15 corresponding to the amount of control operation output from the CPU 70 and supplies it to the VCM 4. The servo writing unit 9 generates servo data to be recorded in the servo area 110 in response to an instruction from the CPU 70 and supplies it to the 20 write head 20. The servo writing unit 9 achieves a self-servo writing function together with the CPU 70. (Head Positioning Control System)

Referring to FIG. 2, the head positioning system includes a feedback control system having a controller 25 (transfer function C) 200 as a main element and a feed forward control system for generating a correction value (FF) to eliminate RRO (position error components

that are synchronized with the rotation of the disk). This system is configured by software including programs and control parameters stored in the CPU 70 and ROM 71 shown in FIG. 1.

5 The controller 200 receives a result of addition of a position error (PES) of a plant (target for control) 210 and a correction value (FF) (as an input value 250 to the input terminal) and performs sample value control to determine the amount of control
10 operation for controlling the plant 210 at regular time intervals.

 The plant 210 is the actuator including the head 2 in a broad sense and the VCM 4 in a narrow sense. Specifically, the VCM driver 8 converts the amount of
15 control operation output from the controller 200 into a driving current and supplies it to the VCM 4.

 The feed forward control system includes a RRO measuring unit 220, an FF filter 230 and an FF input generating unit 240.

20 The RRO measuring unit 220 measures an RRO residual component from the input value 250 of the controller 200. The FF filter 230 is a linear filter operating unit that is associated with the inverse function of the sensitivity function of the feedback
25 control system, and computes correction values (FF) from the measurement results (integration values of respective servo sectors) of the RRO measuring unit

220. The FF input generating unit 240 outputs the correction value (FF) for each of the servo sectors. (Self-Servo Writing Operation)

5 A self-servo writing operation according to the present embodiment will now be described with reference to FIGS. 3 to 8 as well as FIGS. 1 and 2.

First, the SPM 10 rotates the disk 1 at a constant angular velocity in the disk drive. In the self-servo writing method, the CPU 70 instructs the
10 read head 21 to read old servo data from the disk 1 at regular time intervals, as shown in FIG. 8 (step S1). The positional information indicating the current position of the head 2 is synchronized with the rotation angle of the disk 1 and obtained from the leading
15 servo area 110 of each of the servo sectors 130. The CPU 70 positions the write head 20 in a position to which the next servo data is written in accordance with the positional information obtained from the servo area 110 (step S2).

20 Referring here to FIG. 1, the write head 20 and read head 21 of the head 2 are displaced in the radial direction of the disk 1. More specifically, the write head 20 is located at the inner radius more than the read head 21.

25 The CPU 70 writes servo data to the servo area 110 of each servo sector of each cylinder (track) from the outer radius of the disk 1 (step S3). Then, the

head 2 seeks (is positioned) for each cylinder toward the inner radius of the disk 1. The CPU 70 repeats the servo write operation to write servo data to the entire surface of the disk 1 (step S4).

5 When the write head 20 is located at the outer radius of the disk 1 more than the read head 21, it writes servo data from the inner radius thereof.

 The positioning operation of the write head 20 in step S2 will now be described with reference
10 to FIG. 2.

 In self-servo writing operation, the CPU 70 positions the write head 20 by the head positioning control shown in FIG. 2. The controller 200 computes the amount of control operation to eliminate a position error (PES) between the position of old servo
15 data read by the read head 21 and a position to which the next servo data is written, and supplies it to the plant 210. The result of addition of the position error (PES) and the correction value (FF) from the FF
20 input generating unit 240 is regarded as the input value 250 of the controller 200.

 The old servo data includes distortion SD1 due to RRO, while the next servo data includes distortion SD2 due to RRO. The feed forward control system
25 computes a correction value (FF) such that the distortion SD1 has no influence on the writing of the next servo data. In other words, the correction value

(FF) is computed such that the input value 250 of the controller 200 includes no RRO components.

The operation of the feed forward control system will be described below.

5 The RRO measuring unit 220 has memories that are equal in number to the servo sectors and measures an RRO residual component from the input value 250 of the controller 200. Specifically, the measurement is given by the following equation (1):

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$$RRO(k) = RRO(k) + G \times (PES(t) + FF(k)) \quad \dots (1)$$

where k is the number of a servo sector, RRO(k) is a result of measurement of RRO corresponding to the servo sector k, which is stored in a memory of the RRO measuring unit 220, PES(t) is a position error (PES) including the distortion of servo data, FF(k) is a correction value output from the FF input generating unit 240 and corresponding to the servo sector k, and G is a gain constant of 0 through 1, which is selected to converge the generation of a correction value (FF) stably and quickly.

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In the above equation (1), RRO(k) in the right term represents a value measured when old servo data is written.

The FF filter 230 computes a correction value (FF) from the measurement result (an integration value of each of the servo sectors) stored in the memory of the RRO measuring unit 220. The FF input generating

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unit 240 outputs the correction value (FF) for each of the servo sectors.

As described above, the FF filter 230 included in the feed forward control system computes a correction
5 value (FF) to correct a distortion due to RRO caused when old servo data is written. In other words, the RRO measuring unit 220 estimates a residual RRO component that corresponds to the amount of distortion due to the RRO. The FF filter 230 adds the estimated
10 amount of distortion to the correction value (FF) to eliminate the distortion due to the RRO that was caused before the old servo data was written. Thus, the distortion SD1 caused when old servo data is written can suppress the increase of RRO that has
15 an influence on the distortion SD2 caused when the next servo data is written. It is therefore possible to correct a distortion due to RRO in servo data recorded on the disk 1 with high precision in self-servo writing operation.

20 FIG. 3 shows simulation results (gain constant G is 0.3) of the amount of distortion of servo data (servo distortion amount) measured for each servo sector in self-servo writing operation using the head positioning system according to the present embodiment.
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In FIG. 3, reference numeral 300 indicates the servo distortion amount at the time of writing of the

preceding (old) servo data. Reference numeral 310 denotes the servo distortion amount corrected by the prior art feed forward control. Reference numeral 320 represents the servo distortion amount corrected by the feed forward control of the present embodiment.

FIGS. 4 to 7 show simulation results of time variations in the input value 250 of the controller 200 according to a change in gain constant G in the head positioning system according to the present embodiment.

When the gain constant G is 0.1, the convergence speed becomes relatively low as shown FIG. 4. When the gain constant G is 0.3 as shown in FIG. 5, the convergence speed is improved. When the gain constant G is 0.6 as shown in FIG. 6, the convergence speed is noticeably improved. However, when the gain constant G is 0.8 as shown in FIG. 7, the convergence speed is not improved but varies somewhat widely in a steady state. It is thus desirable that the gain constant G should fall within a range of 0.3 through 0.6.

In the self-servo writing method using the head positioning system according to the present embodiment, when servo data is written to a disk based on the preceding servo data recorded on the disk, the RRO component that is synchronized with the rotation of the disk can effectively be inhibited from increasing. Specifically, the RRO component can be deleted from

the input value 250 of the controller 200. Consequently, the distortion of old servo data in the radial direction of the disk can inhibit RRO, which has an influence on the distortion of the subsequent
5 servo data, from increasing.

The head positioning system according to the present embodiment is applied to the self-servo writing operation in the hard disk drive. However, it can be applied to, for example, a process of
10 manufacturing a master of a digital versatile disk (DVD).

According to the head positioning system described above, a correction value is corrected by feeding back the RRO after the FF correction to
15 inhibit the RRO from increasing effectively and thus correct the distortion of servo data with high efficiency.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore,
20 the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as
25 defined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A head positioning system comprising:

a positioning unit to position a head in a target position on a disk medium that is rotating;

5 a unit which senses a position error of the head relative to the target position;

a controller which outputs an amount of control operation of the positioning unit based on the position error; and

10 a correction unit which computes a position error component that is synchronized with rotation of the disk medium based on an input value of the controller, computes a correction value to eliminate the position error component from the position error, and adds the
15 correction value to the input value, wherein the correction unit includes a linear filter that is associated with an inverse function of a sensitivity function of the head positioning system, and obtains the position error component from the input value of
20 the controller as an input value of the linear filter, the sensitivity function of a feedback control system being a transfer function $1/(1+G)$ where G means a open-loop transfer function of the feedback control system.

25 2. A disk drive comprising:

a head to read/write data from/to a disk medium that is rotating;

a unit which supplies the head with servo data to be recorded on the disk medium;

a positioning unit to position the head in a target position on the disk medium;

5 a unit which senses a position error of the head relative to the target position;

a controller which outputs a control value of the positioning unit based on the position error when the servo data is written to the disk medium to perform head positioning control; and

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a correction unit which computes a position error component that is synchronized with rotation of the disk medium based on an input value of the controller to obtain a correction value to eliminate the position error component from the position error, wherein the correction unit includes a linear filter that is associated with an inverse function of a sensitivity function of a head positioning system including the controller, and obtains the position error component from input values integrated for each of servo sectors as an input value of the linear filter, the sensitivity function of a feedback control system being a transfer function $1/(1+G)$ where G means a open-loop transfer function of the feedback control system.

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25 3. A method of servo writing for a disk drive including a head to read/write data from/to a disk medium that is rotating, the method comprising:

reading servo data from the disk medium by the head;

computing a position error component, which is synchronized with rotation of the disk medium, when
5 the head is positioned in a target position on the disk medium based on the servo data;

performing a positioning operation including a correcting operation to eliminate the position error component from a position error of the head relative
10 to the target position, wherein the correction operation includes a linear filter operation that is associated with an inverse function of a sensitivity function of the head positioning system including a controller, the sensitivity function of a feedback
15 control system being a transfer function $1/(1+G)$ where G means a open-loop transfer function of the feedback control system.; and

writing the servo data to the target position on the disk medium by the head.

20 4. The method according to claim 3, wherein the positioning operation is performed to position the head for each of cylinders formed on the disk medium, and the correcting operation is performed to compute a correction value to eliminate the position error
25 component for each of servo sectors included in each of the cylinders.