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TITLE OF THE INVENTION

METHOD AND APPARATUS FOR SERVO CONTROL IN A DISK DRIVE

BACKGROUND OF THE INVENTION

5 The present invention generally relates to a disk drive including a servo control system and, more particularly, to a servo control system obtained by improving an off-track position detecting method.

10 In a conventional disk drive typified by a hard disk drive, a servo control system which controls a head to position the head at a target track (target cylinder) position by using servo information recorded on a disk medium is incorporated.

15 The servo control system uses servo information read by a read head to calculate a track address to identify a target track and an off-track position (PES) which is a positional error from a track center of the target track. The servo control system uses a servo burst pattern included in servo information to calculate an off-track position.

20 In this case, as a scheme which detects an off-track position of a read head, in addition to a burst detecting scheme which uses a servo burst pattern, a phase difference detecting scheme is known (for example, see Jpn. Pat. Appln. KOKAI Publication
25 No. 6-231552).

In this phase difference detecting scheme, schematically, a discrete Fourier transform (DFT)

process is performed to a servo reproduction signal read by a read head and reproduced by a signal processing circuit (read channel) to generate a sine component value and a cosine component value.

5 Furthermore, the ratio (tangent) of the sine to the cosine is subjected to arctangent transform to detect an off-track position corresponding to a phase difference from the track center.

10 In a conventional phase difference detecting scheme, a servo pattern different from a servo burst pattern of the burst detecting scheme is generally used. On the other hand, of burst values A, B, C, and D obtained from the servo burst pattern, a servo operation "A-B" is regarded as an almost sinusoidal component value, and servo operation "C-D" is regarded
15 as an almost cosinusoidal component value, so that an almost correct off-track position can be detected by an arctangent transform process performed by an inverse function approximate expression. More
20 specifically, the phase difference detecting scheme using a servo burst pattern can be applied.

However, in an actual disk drive, since off-track characteristics based on a burst pattern include a high-order distortion (or an asymmetrical distortion)
25 or an even function, an error over a tolerance probably occurs between an off-track position calculated by an arctangent transform process using a

simple inverse function approximate expression and a
genuine off-track position. Such deterioration in
detection accuracy of an off-track position
(positional error of a head with respect to a target
5 position) causes deterioration in servo performance of
a disk drive.

BRIEF SUMMARY OF THE INVENTION

It is an object of the present invention to
provide a disk drive having a servo control function
10 to which a phase difference detecting scheme using a
servo burst pattern is applied to make it possible to
detect a genuine off-track position at high accuracy.

An aspect of the present invention is a disk
drive including a servo control function which uses a
15 burst value obtained from a servo burst pattern to
generate a tangent-equivalent value (pseudo tangent)
and detects an almost correct track position by a
servo process which performs an arctangent transform
process using an inverse function approximate
20 expression structured on the basis of a relationship
between an off-track position and the tangent-
equivalent value.

A disk drive according to one aspect of the
present invention comprises: a head which reads data
25 recorded on a disk medium; an actuator which moves the
head in a radial direction on the disk medium; and
servo processor means for using servo information

recorded on the disk medium to drive and control the actuator and performing positioning control of the head to a target track position on the disk medium, wherein the servo processor means comprises: means for
5 acquiring a burst value from a servo burst pattern included in the servo information on the basis of a reproduced signal output from the head; tangent calculating means for calculating a tangent from the burst value; phase calculating means for using an
10 inverse function approximate expression structured on the basis of the characteristics of an off-track position of the head to calculate a phase-equivalent value from a tangent-equivalent value calculated by the tangent calculating means; and position
15 calculating means for using the phase-equivalent value calculated by the phase calculating means to calculate the off-track position with respect to the target track position.

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,
25 serve to explain the principles of the invention.

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

invention;

FIG. 2 is a block diagram for explaining a configuration of a servo processor according to the embodiment;

5 FIG. 3 is a block diagram for explaining a configuration of an off-track position calculating unit according to the embodiment;

FIG. 4 is a diagram showing an arrangement of servo burst patterns according to the embodiment;

10 FIG. 5 is a graph showing read signal waveforms of the servo burst patterns according to the embodiment;

FIG. 6 is a graph for explaining a method of deriving a coefficient of an inverse function approximate expression according to the embodiment;

15 FIG. 7 is a graph showing general burst off-track characteristics according to the embodiment;

FIG. 8 is a graph showing burst off-track characteristics having a large asymmetric diversity according to the embodiment;

20 FIG. 9 is a graph showing detection characteristics obtained by the off-track position calculating unit according to the embodiment;

FIG. 10 is a graph showing a relationship between an off-track position and a tangent-equivalent value according to the embodiment;

FIGS. 11A and 11B are graphs showing positioning

accuracy characteristics and loop transfer gain
characteristics obtained by a burst detecting scheme;

FIGS. 12A and 12B are graphs showing positioning
accuracy characteristics and loop transfer gain
5 characteristics obtained by a position detecting
scheme according to the embodiment;

FIGS. 13A and 13B are graphs showing positioning
accuracy characteristics and loop transfer gain
characteristics obtained before coefficient setting by
10 the position detecting scheme according to the
embodiment; and

FIGS. 14A and 14B are graphs showing positioning
accuracy characteristics and loop transfer gain
characteristics obtained after the coefficient setting
15 by the position detecting scheme according to the
embodiment.

DETAILED DESCRIPTION OF THE INVENTION

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

FIG. 1 is a block diagram showing a main part of
a hard disk drive (to be simply referred to as a disk
drive hereinafter) according to the embodiment.
FIG. 2 is a block diagram for explaining a
25 configuration of a servo processor according to the
embodiment. FIG. 3 is a block diagram for explaining
a configuration of an off-track position calculating

unit included in the servo processor according to the embodiment.

(Configuration of Disk Drive)

5 The disk drive, as shown in FIG. 1, has a disk medium 10 on which data is magnetically recorded, a spindle motor 11 which rotates the disk medium 10, and an actuator 13 on which a head 12 is mounted.

10 A large number of tracks (cylinders) 100 serving as data recording areas are formed on the disk medium 10. Each of the tracks 100, as will be described later, includes servo sectors on which servo information including servo burst patterns is recorded.

15 The head 12 has a read head (120) to read data (including servo information) from the disk medium 10 and a write head to write data on the disk medium 10. The actuator 13 moves the head 12 mounted at the distal end thereof in the radial direction on the disk medium 10 by driving a voice coil motor (VCM) 14.

20 Furthermore, the disk drive has a preamplifier 15, a signal processing unit 16, a hard disk controller (HDC) 17, a microprocessor (CPU) 19, a servo processor 20, and a VCM driver 21.

25 The preamplifier 15 amplifies a read signal read from the read head to transmit the read signal to the signal processing unit 16. In addition, the preamplifier 15 amplifies a write signal output from

the signal processing unit 16 to transmit the write signal to the write head. The signal processing unit 16 is a read/write channel which processes a read/write signal and has a function of reproducing servo information from the read signal. In addition, the signal processing unit 16 reproduces user data from the read signal to transmit the user data to the hard disk controller 17.

The hard disk controller 17 constitutes an interface between the drive and a host system 18 to execute data transfer control or the like of the read/write data (user data). The CPU 19 is a main control device of the drive which executes control or the like of a read/write operation.

The disk drive according to the embodiment has, besides the CPU 19, the servo processor 20 to execute a servo control process. Specifically, the servo processor 20 is constituted by a digital signal processor (DSP) and a logic circuit. The servo processor 20 drives and controls the actuator 13 through the VCM driver 21 on the basis of the servo information reproduced by the signal processing unit 16 to execute positioning control of the head 12.

The CPU 19 and the servo processor 20 need not be constituted by independent units. The CPU 19 and the servo processor 20 may be constituted by a microprocessor 22 which executes software for

realizing the functions of the CPU 19 and the servo processor 20. More specifically, the servo processor 20 may be software for realizing the servo control process.

5 (Servo Processor)

On the disk medium 10, as shown in FIG. 4, servo information including four-phase (A to D) servo burst patterns 410, 420, 430, and 440 and a track address (cylinder address) code 450 are recorded on servo sectors of each track. The track address code 450 is information to identify a track. The servo burst pattern is, as will be described later, information used to detect an off-track position of the read head 120.

15 In this case, the off-track position is a positional error of a target track identified by the track address code 450 with respect to the center of the tracks when the head 12 is positioned at a target track position. Burst signals obtained by reproducing the servo burst patterns may be represented by BST (A to D) or BST-A to BST-D, respectively. The burst values (amplitude values) may be represented by BstA to BstD, respectively.

25 The servo processor 20 includes, as shown in FIG. 2, an off-track position calculating unit 200 and a servo calculating unit 210. The off-track position calculating unit 200 uses, as will be described below,

a burst signal BST output from the signal processing unit 16 to detect an off-track position of the read head 120 and to output the off-track position data PES to the servo calculating unit 210.

5 The servo calculating unit 210 calculates a control value to position the head 12 (read head or write head) at a target track position on the basis of a track address CYL and an off-track position PES output from the signal processing unit 16.

10 The VCM driver 21 supplies a drive current depending on the control value calculated by the servo calculating unit 210 to the VCM 14 of the actuator 13. The actuator 13 is driven and controlled to position the read head 120 at the target track position.

15 (Off-track Position Calculating Unit)

 The off-track position calculating unit 200 includes, as shown in FIG. 3, a tangent calculating unit 220, an inverse function calculating unit 230, and a phase difference correcting unit 240.

20 The tangent calculating unit 220 receives burst values BstA, BstB, BstC, and BstD corresponding to the amplitude values of the burst signals BST (A to D) output from an A/D converter 160 included in the signal processing unit 16. The tangent calculating
25 unit 220 uses, as will be described later, the burst values BstA, BstB, BstC, and BstD to calculate a tangent-equivalent value (pseudo tangent) TAN.

The inverse function calculating unit 230 uses an inverse function approximate equation (including a coefficient) structured on the basis of the relationship between the off-track position and the tangent-equivalent value in advance to calculate a phase-equivalent value (phase angle) θ . The coefficient of the inverse function approximate expression is set on the basis of real off-track position characteristics measured for respective phase events (ph) (see FIG. 6). The phase events (ph) are event values obtained by dividing the same address section of a track address by four. Each phase event is information representing a specific section of $\pi/4$ of each burst sinusoidal cycle.

In this case, as shown in FIG. 1, the inverse function approximate expression and the coefficient are stored in a memory (flash EEPROM) 23 of the drive. The servo processor 20 extracts the inverse function approximate expression and the coefficient from the memory 23 to cause the inverse function calculating unit 230 to execute an inverse function calculation.

The phase difference correcting unit 240 calculates an off-track position (PES) from the phase-equivalent value θ and the phase event value (ph) to output the off-track position to the servo calculating unit 210. The phase difference correcting unit 240 has the same configuration as that of a phase

correcting unit used in a conventional phase detecting scheme.

(Operation)

5 An operation according to the embodiment will be described below with reference to FIGS. 4 to 14B.

In the disk drive, the head 12 is moved in the radial direction on the disk medium 10 by the actuator 13. At this time, as shown in FIG. 4, the read head 120 reads the servo burst patterns 410, 420, 430, and 440 and the track address code 450 from a track 10 (cylinder) passing immediately under the disk medium 10. In FIG. 4, reference symbol 400 denotes a rotating direction of the disk medium 10.

15 The signal processing unit 16 reproduces track address information and a burst signal for detecting an off-track quantity at a timing at which the read head 120 passes through the servo sector on the disk medium 10, and transmits the burst signal to the servo processor 20.

20 In the servo processor 20, as shown in FIG. 2, the off-track position calculating unit 200 converts the burst value of the burst signal BST from the signal processing unit 16 into an off-track position PES. The off-track position PES is a positional error 25 of a target track with respect to the center of the target track as described above.

The servo calculating unit 210 recognizes the

off-track position PES and the track address CYL as position information of the read head 120 at the present. The servo calculating unit 210 generates such a control value (VCM drive command) that the
5 present position of the read head 120 is positioned at the target track position.

The VCM driver 21 supplies a drive current depending on the control value calculated by the servo calculating unit 210 to the VCM 14 of the actuator 13,
10 so that the read head 120 is positioned at the target track position by driving and controlling the actuator 13.

In the servo control process described above, an operation of the off-track position calculating unit
15 200 will be described below.

FIG. 5 is a graph showing a read signal waveform 500 output from the read head 120 when the read head 120 travels at the centers of the burst patterns A and B as shown in FIG. 4.

20 The signal processing unit 16 reproduces the burst values BstA, BstB, BstC, and BstD corresponding to reproduced signal amplitude values of four sections (A to D) of a burst gate 510. FIG. 7 is a graph showing changes of the burst values BstA, BstB, BstC,
25 and BstD of the reproduced burst signals BST-A to BST-D with respect to the off-track position in the radial direction (vertical direction in FIG. 4). More

specifically, FIG. 7 is a graph showing general burst
off-track characteristics (sinusoidal-shaped
characteristics) held by four DC offsets having 90°
phase differences in the relationships between the
5 off-track position and the burst values. In contrast
to this, FIG. 8 is a graph showing burst track
characteristics having a large asymmetric diversity in
the relationships between the off-track position and
the burst values.

10 In FIGS. 7 and 8, the abscissa indicates a real
off-track position, and the ordinate indicates an
amplitude value of the burst signal BST.

In the off-track position calculating unit 200
according to the embodiment, the tangent calculating
15 unit 220 converts the acquired burst value into a
pseudo sine component value and a pseudo cosine
component value to calculate a tangent-equivalent
value (pseudo tangent) TAN which is a value equivalent
to the tangents.

20 As is apparent from FIG. 7, a difference signal
between the burst values BstA and BstB exhibits a
substantially sinusoidal waveform from which a DC
component is removed. In addition, a difference
signal between the burst values BstC and BstD exhibits
25 a substantially cosinusoidal waveform with a phase
shift of 90° . Therefore, the tangent calculating unit
220 calculates the tangent-equivalent value (pseudo

tangent) TAN equivalent to the tangent on the basis of a ratio of the pseudo sine component value to the pseudo cosine component.

More specifically, the tangent calculating unit
220 calculates the tangent-equivalent value TAN from
the following equations (1) and (2) by using the four
values, i.e., the burst values BstA, BstB, BstC, and
BstD. In this case, reference symbol BstAB means
"BstA to BstB". Reference symbol BstCD means "BstC to
BstD".

$$\text{TAN} = -\text{BstAB}/\text{BstCD} \quad \dots (1)$$

$$\text{TAN} = \text{BstCD}/\text{BstAB} \quad \dots (2)$$

where the equation (1) is established when the phase event value ph is 2 or 3, and the equation (2) is established when the phase event value ph is 1 or 4.

In this case, the following equations (3) to (6) are established for phase event values ($ph = 1$ to 4), respectively.

$$20 \quad \text{Ph} = 1 : |\text{BstAB}| \geq |\text{BstCD}|, \text{BstAB} * \text{BstCD} \geq 0 \quad \dots (3)$$

$$Ph = 2 : |B_{stAB}| < |B_{stCD}|, B_{stAB} * B_{stCD} \geq 0 \quad \dots (4)$$

$$\text{Ph} = 3 : |\text{BstAB}| < |\text{BstCD}|, \text{BstAB} * \text{BstCD} < 0 \quad \dots (5)$$

$$\text{Ph} = 4 : |\text{BstAB}| \geq |\text{BstCD}|, \text{BstAB} * \text{BstCD} < 0 \quad \dots (6)$$

The phase event values ph are event values obtained by dividing the same track address section by four as described above. Each phase event is a value representing a specific section of $\pi/4$ of each burst sinusoidal cycle.

Since the value $-BstAB/BstCD$ has an enormous value near the centers of the burst patterns C and D, as the tangent-equivalent value TAN, a tangent-equivalent value subjected to phase correction in each of divided events is calculated. As relationships between the off-track position and the tangent-equivalent values, characteristics 800 (see the equation (1)) and characteristics 810 and 820 (see the equation (2)) as shown in FIG. 10 are obtained. In FIG. 10, the abscissa indicates a real off-track position.

The inverse function calculating unit 230 executes inverse function calculation of the tangent-equivalent value TAN on the basis of the inverse function approximate expression and the coefficient stored in the memory 23 in advance to calculate a phase-equivalent value (phase angle) θ . More specifically, the inverse function calculating unit 230 calculates a cubic function expression shown as the following equation (7).

$$\theta = a_3 * TAN^3 + a_2 * TAN^2 + a_1 * TAN + a_0 \quad \dots (7)$$

The inverse function calculating unit 230

executes a process of switching coefficients depending on the polarity ($Ph = 1$ or 3 and $Ph = 2$ or 4) of the tangent-equivalent value TAN such that the inverse function calculating unit 230 can cope with burst off-track characteristics having a large asymmetrical diversity as shown in FIG. 8. When the symmetry is sufficiently high, the inverse function calculating unit 230 calculates a phase-equivalent value by a single inverse function approximate expression.

The phase difference correcting unit 240 divides the phase-equivalent value θ obtained by inverse function calculation of the inverse function calculating unit 230 depending on events to calculate an off-track position PES . More specifically, the phase difference correcting unit 240 executes calculation expressed by the following equations (8) to (10):

$$PES = T_p / \pi * (\theta - \pi/2), \text{ where } Ph = 1 \quad \dots (8)$$

$$PES = T_p / \pi * \theta, \text{ where } Ph = 2 \text{ or } 3 \quad \dots (9)$$

$$PES = T_p / \pi * (\theta + \pi/2), \text{ where } Ph = 4 \quad \dots (10)$$

In these equations, T_p is a track pitch, i.e., a value equivalent to a track width.

This process occurs since tangent-equivalent values are classified in two types to prevent a calculation error from expanding in the tangent calculating unit 220. As shown in FIG. 10, since there are two off-track positions corresponding to the

same phase-equivalent value, the off-track positions serve as indispensable processing elements.

By the off-track position calculating unit 200 according to the embodiment described above, as shown in FIG. 9, an off-track position 710 (characteristics represented by X) where a positional error is suppressed can be detected (estimated) to an ideal position (true value of target position) 700 as shown in FIG. 9. On the other hand, characteristics 720 (expressed by O) are off-track position characteristics obtained by a conventional detecting scheme.

In FIG. 9, the abscissa indicates a real off-track position, and the ordinate indicates an off-track position obtained by calculation (estimation). FIG. 9 shows detection characteristics in burst off-track characteristics having a large asymmetric diversity as shown in FIG. 8. In a conventional detecting scheme, a detection inclination (gain) change associated with a detected positional error causes deterioration in servo performance such as seek time or off-track positioning accuracy. In contrast to this, in the detecting scheme of the embodiment, extremely preferable servo performance can be achieved.

FIGS. 11A to 14B are graphs showing improvement factors of servo control (off-track position

detection) performance according to the embodiment.
In FIGS. 11A to 14B, FIGS. 11A, 12A, 13A, and 14A are
graphs showing 3σ positioning accuracy characteristics
in off-track positioning. FIGS. 11B, 12B, 13B, and
5 14B are graphs showing loop transfer gain variable
characteristics (corresponding to detection
inclination) in off-track positioning. In FIGS. 11A
to 14B, the abscissas indicate off-track positions.

FIGS. 11A and 11B are graphs showing
10 characteristics obtained by a general burst detecting
scheme. In contrast to this, FIGS. 12A and 12B are
graphs showing characteristics obtained by the
position detecting scheme according to the embodiment.
As is apparent from these comparisons, in the position
15 detecting scheme according to the embodiment, as shown
in FIG. 12B, a loop transfer gain (detection
inclination) is kept constant. As shown in FIG. 12A,
it is confirmed that the same positioning accuracy can
be assured in off-track positioning.

20 FIGS. 13A and 13B are graphs showing
characteristics (phase difference detecting
characteristics) obtained before a coefficient is set
by the position detecting scheme according to the
embodiment. FIGS. 14A and 14B are graphs showing
25 characteristics obtained after a coefficient is set by
the position detecting scheme according to the
embodiment.

As described above, in short, the position
detecting scheme according to the embodiment is an
off-track position detecting scheme using an inverse
function approximate expression of burst profile
5 characteristics. Furthermore, since position
detection is performed by the inverse function
approximate expression structured on the basis of the
relationship between the off-track position and the
tangent-equivalent value in advance, even though the
10 burst off-track characteristics have a asymmetrical
distortion, an almost genuine off-track position can
be estimated. Therefore, highly accurate head
positioning control can be performed, and servo
control performance can be improved in a disk drive.
15 (Coefficient Deriving Method of Inverse Function
Approximate Expression)

In the embodiment, as described above, the
inverse function calculating unit 230 executes inverse
function calculation of the tangent-equivalent value
20 TAN on the basis of the inverse function approximate
expression stored in the memory 23 in advance. A
coefficient of the inverse function approximate
expression is derived on the basis of the relationship
between the off-track position and the tangent-
25 equivalent value. The deriving method will be
described below mainly with reference to FIGS. 6
and 10.

In approximate expression coefficient derivation, a real positioning position must be estimated with respect to an off-track target value. Even though the off-track target position is set to perform
5 positioning, the position is not a genuine offset position. More specifically, the positioned position is a position derived by an off-track position detection calculating unit, an actual value and a true value are different from each other until calibration
10 setting of the unit is completed.

When the head 12 is positioned in a region near a certain target position, characteristic gains of the actuator 13 and the servo calculating unit 210 are equal to each other and do not vary. However, in
15 fact, when a loop transfer gain of a certain specific frequency in off-track positioning is monitored, for example, as shown in FIG. 11B, it is understood that the loop transfer gain changes. It can be estimated that, from the servo loop configuration in FIG. 2, the
20 change is caused by only a change in gain of the off-track position calculating unit 200. More specifically, when a change in loop transfer change in off-track positioning is monitored, the change consequently corresponds to a change in detection
25 inclination. A method of measuring a loop transfer gain can be achieved by a known method.

As a change in detection inclination of the

off-track position calculating unit 200, " dR/dP " is measured at a target position R_0 when a detection variation obtained by an actual variation dP is represented by dR . More specifically, when the
5 inverse number " dP/dR " of the detection inclination is integrated by dR , a real positioning position can be estimated with respect to the target position. Since the loop transfer gain includes a gain of a target to be controlled or a controller other than a detecting
10 system, the gain must be removed to calculate an inverse number " dP/dR " of the detection inclination.

In actual position transformation with respect to the target position, any off-track position detecting unit may be theoretically used. However, in fact,
15 when a change of a position detection inclination of the off-track position detection unit decreases, an error in real position estimation tends to be small. Therefore, until advance calibration is performed, as a coefficient of an inverse function calculating unit
20 in the off-track position detecting unit, a coefficient selected to satisfy an approximate expression of an arctangent function is used.

FIGS. 13A and 13B show changes in loop transfer gain at approximate functions of the arctangent function in
25 the embodiment. However, when this scheme is compared with the general burst detecting scheme shown in FIGS. 11A and 11B, it is understood that a variation

in detection inclination is small. The process using the approximate coefficient of the arctangent function is obtained by realizing a process close to a phase difference detecting process, and can achieve
5 relatively stable detection characteristics. From this point of view, the process is desirable.

The method of estimating a real positioning position (genuine off-track position) with respect to a target position is described above. When the
10 position is calculated, acquired information to the target position can be easily converted into acquired information to a genuine off-track position. The abscissas in FIGS. 7 to 10 are obtained by converting the target position into an estimated actual position
15 by the conversion.

Characteristics 800, 810, and 820 shown in FIG. 10 can be plotted by pseudo tangent calculation in the tangent calculating unit 220 on the basis of the burst values shown in FIGS. 7 and 8. However, in
20 inverse function approximation, a relationship except for a one-to-one relationship is inconvenient. For this reason, a one-to-one relationship is created by performing a process of phase-shifting the characteristics 810 and 820 to overlap the
25 characteristics 810 and 820 on the same event as that of the characteristics 800. A tangent function indicated by the curve in FIG. 10 is not always equal

to the actual characteristics 800. In particular, as shown in FIG. 8, in a pattern in which a strong asymmetric distortion is included in the burst characteristics, positions are positioned on the positive side of the tangent function on both the positive-value/negative-value sides. It is understood that positive and negative values should be approximated by different functions.

In FIG. 6, the plots are obtained by overwriting the map while reversing the abscissa and the ordinate to plot values in an inverse function relationship. A characteristic curve 610 is the cubic least squares approximate function. On the characteristic curve 610, the positive and negative values are approximated by different functions. With respect to fitting in least squares approximation, an error decreases when the order increases. However, since error quantity is sufficiently small in cubic approximation, the cubic approximation is preferably performed in consideration of a calculation amount. In the cubic approximate expression shown in FIG. 6, PES means a phase-equivalent value θ , and x means a tangent-equivalent value TAN.

With the above method, the coefficient of the inverse function approximate expression can be derived. In this case, in fact, detection characteristics of the off-track position calculating

unit 200 changes depending on radial positions of the disk medium 10. This is caused by a skew angle of the head generated when servo information is recorded.

However, also in consideration of an influence of a characteristic change of positions of inner and outer circumferences, a coefficient of an approximate inverse function must be set.

In the embodiment, for example, coefficients of an inverse function approximate expression are derived at nine points on the inner and outer circumferences on the disk medium 10. An average of the coefficients is set in the memory 23 as a coefficient of the inverse function approximate expression of the off-track position calculating unit 200.

Even though the same coefficient is determined by averaging on the inner and outer circumferences on the disk medium 10, detection inclination changes in off-track positioning are rarely observed on the intermediate/inner circumference. However, on the outer circumference on the disk medium 10, as shown in FIG. 14, a change in loop transfer gain appears.

In the embodiment, it is supposed that the same coefficient is employed over the entire circumference of the disk medium 10. The present invention is not limited to the configuration. That is, coefficients may be switched depending on radial positions on the disk medium 10, or respective coefficients may be

expressed as functions of radial positions and serialized.

In this case, in a conventional off-track position detecting system, it is assumed that burst
5 detection characteristics have a symmetrical shape. For this reason, in a drive which exhibits, for example, the burst detection characteristics as shown in FIG. 8, servo performance cannot be easily assured, so that a yield decreases. In this case, as a factor
10 of an asymmetrical system, the degree of deviation of a burst pattern in servo track write (recording of servo information), a setting angle error of a head, and the like are known. When the position detecting scheme according to the embodiment is applied,
15 preferable servo performance can be assured for the disk drive having such an asymmetrical system.

Even though burst detection characteristics has a small asymmetrical diversity, in a conventional
scheme, only a coefficient gain to a burst difference
20 signal is corrected. For this reason, a variation in servo gain occurs in off-track positioning. When the degree of variation is large, off-track positioning accuracy is deteriorated. With a recent decrease in track pitch, deterioration in off-track positioning
25 accuracy is posed as a problem. In contrast to this, in the scheme according to the embodiment, since a change in servo characteristics depending on off-track

positions can be suppressed, the scheme is effective as a countermeasure against a variation in servo gain in off-track positioning.

5 In the disk drive, a seek operation which moves the head 12 to a position near a target track is performed. The position detecting scheme according to the embodiment also contributes to improvement of the seek operation performance. In general, in the final stage of the seek operation, a change in moving speed
10 of the head 12 must be smooth. However, when a detection inclination of the detection system varies, even though an actual variation in speed is small, an apparent variation in detection speed is large. This causes deterioration of track stability when the head
15 is positioned at the target track position. When the position detecting scheme according to the embodiment is applied, it can be realized not only that servo characteristics is kept constant but also that an apparent variation in detection speed is suppressed.
20 For this reason, the track stability can be improved. Therefore, as a result, seek operation time can be shortened.

(First Modification)

25 As a off-track position detecting method according to the embodiment, a method using a burst value which is an amplitude value obtained from a servo burst pattern for detecting a positional error

(deviation) is applied. In contrast to this, in a scheme according to the modification, a servo burst pattern is an inclined pattern for detecting a phase difference, pieces of position information of two types, i.e., a sine component value and a cosine component value are used in place of amplitude information obtained by the signal processing unit 16.

5 In the scheme according to the modification, the configuration of the tangent calculating unit 220 in the off-track position calculating unit 200 can be simplified. In this case, processing is performed on the assumption that values corresponding to servo calculation results BstAB and BstCD obtained by using four values, i.e., burst values BstA to BstD are
10 determined. The other processing is the same as that in the embodiment.

A difference between the detecting method according to the modification and a conventional phase difference detecting method will be briefly described
15 below.

In the conventional phase difference detecting method, a process of converting ± 90 degrees (both the ends of the abscissa in FIG. 10) into phase-equivalent values by an arctangent transform (atan) process is
20 performed. In contrast to this, in the method according to the modification, phase events are exactly divided by 45 degrees, and a process using the
25

inverse function approximate expression is executed without using the arctangent transform (atan) process itself to detect a position. In the method according to the modification, even though ideal characteristics
5 constituted by a sine component value and a cosine component value include distortion with respect to an off-track position, an accurate position can be detected, and servo performance can be improved.

(Second Modification)

10 This modification is obtained by applying the off-track position detecting scheme according to the embodiment to a fine position detecting scheme in an incremental encoder using a pseudo sine wave output scheme.

15 For example, in a carriage operation of an optical disk drive, speed detection using a DC motor in which a hall element is arranged is applied. In this case, in a low-speed operation called trace, speed feedback control is not performed, so that lens
20 offset (DC offset of a lens fine focus system) is caused disadvantageously.

As a scheme which improves this drawback, a scheme which detects a position of a hall element in a resolution section at a low speed to control the
25 position of a lens to a target track position. However, an intermediate position must be detected by detecting a phase difference between an A-phase signal

and a B-phase signal. For this reason, realization of the arctangent processing and a distortion caused by sine waves of the A- and B-phase signals are posed as problems. In the scheme according to the

5 modification, once a calibration process is performed, an arctangent-equivalent value can be calculated by a cubic function to make it possible to cope with distortion from the sine waves of the A- and B-phase signals.

10 According to the embodiment, there can be provided a disk drive having a servo control function which applies a phase difference detecting scheme using a servo burst pattern to make it possible to detect a genuine off-track position at a high
15 accuracy.

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

WHAT IS CLAIMED IS:

1. A disk drive comprising:

a head which reads data recorded on a disk medium;

5 an actuator which moves the head in a radial direction on the disk medium; and

a servo processor which uses servo information recorded on the disk medium to drive and control the actuator and performs positioning control of the head to a target track position on the disk medium,

wherein the servo processor

acquires a burst value from a servo burst pattern included in the servo information on the basis of a reproduced signal output from the head, and includes:

15 a tangent calculating unit which calculates a tangent from the burst value;

a phase calculating unit which uses an inverse function approximate expression structured on the basis of the characteristics of an off-track position of the head to calculate a phase-equivalent value from a tangent-equivalent value calculated by the tangent calculating unit; and

20 a position calculating unit which uses the phase-equivalent value calculated by the phase calculating unit to calculate the off-track position with respect to the target track position.

2. The disk drive according to claim 1, further

comprising:

a signal processing unit which extracts a burst value from the servo burst pattern included in the servo information on the basis of the reproduced
5 signal output from the head, wherein

the servo processor acquires the burst value from the signal processing unit.

3. The disk drive according to claim 1, further comprising;

10 a memory which stores information representing the inverse function approximate expression structured on the basis of characteristics of the tangent-equivalent value converted on the basis of the burst value and the off-track position, wherein

15 the phase calculating unit uses the inverse function approximate expression stored in the memory to calculate the phase-equivalent value.

4. The disk drive according to claim 1, wherein
the phase calculating unit calculates a phase
20 angle on the basis of the tangent-equivalent value, and

the position calculating unit includes a phase correcting unit which corrects the phase angle depending on phase event values obtained by dividing
25 the same address section at a track address to identify the target track position.

5. The disk drive according to claim 1, further

comprising;

a memory which stores the inverse function
approximate expression structured on the basis of
characteristics of a tangent-equivalent value
5 converted on the basis of the burst value and the off-
track position and information representing a
coefficient set on the basis of off-track position
characteristics measured for respective phase event
values obtained by dividing the same address section
10 at a track address to identify the target track
position, wherein

the phase calculating unit uses the inverse
function approximate expression and the coefficient
stored in the memory to calculate the phase-equivalent
15 value.

6. The disk drive according to claim 1, wherein
as the inverse function approximate expression of
the tangent-equivalent value, positive and negative
approximate expressions of two types are included.

20 7. The disk drive according to claim 1, wherein
as the inverse function approximate expression, a
cubic function expression is included.

8. The disk drive according to claim 1, wherein
as the inverse function approximate expression,
25 an approximate expression having an approximate
coefficient of an arctangent function is included.

9. The disk drive according to claim 1, further

comprising;

a signal processing unit which processes a reproduced signal output from the head to output a burst value from a servo burst pattern included in the servo information and a track address to identify the target track position, wherein

the servo processor has

an off-track position calculating unit which includes the tangent calculating unit, the phase calculating unit, and the position calculating unit and calculates the off-track position, and

a servo calculating unit which controls the actuator to position the head at the target track position on the basis of the track address and the off-track position.

10. A method of servo control for,

in a disk drive having a head which reads data recorded on a disk medium and an actuator which moves the head in a radial direction on the disk medium, using servo information recorded on the disk medium to drive and control the actuator and performing positioning control of the head to a target track position on the disk medium, the method comprising:

acquiring a burst value from a servo burst pattern included in the servo information on the basis of a reproduced signal output from the head,

calculating a tangent-equivalent value from the

burst value,

using an inverse function approximate expression
structured on the basis of the characteristics of an
off-track position of the head to calculate a phase-
5 equivalent value from the tangent-equivalent value,
and

using the phase-equivalent value to calculate the
off-track position with respect to the target track
position.

10 11. The method according to claim 10, wherein
the phase-equivalent value is calculated by using
the inverse function approximate expression structured
on the basis of the characteristics of the tangent-
equivalent value converted on the basis of the burst
15 value and the off-track position and a coefficient set
on the basis of off-track position characteristics
measured for respective phase event values obtained by
dividing the same address section at a track address
to identify the target track position.