

APPARATUS AND METHOD OF COMPENSATING FOR DISTURBANCE USING LEARNING CONTROL IN OPTICAL RECORDING/REPRODUCING APPARATUS AND OPTICAL RECORDING MEDIUM DRIVE SERVO SYSTEM USING THE APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the compensation of disturbance in an optical recording/reproducing apparatus, and more particularly, to an apparatus and method of compensating for disturbance using learning control in an optical recording/reproducing apparatus by which periodic disturbances such as eccentricity existing in a disk drive system is compensated for by performing feed-forward control using an iterative learning method, memorizing the result of the feed-forward control, and applying the result of the feed-forward control to the compensation for disturbance generated later, and an optical recording medium drive servo system using the apparatus and method.

2. Description of the Related Art

FIG. 1 shows an example of a tracking error signal generated due to the eccentricity of an optical recording medium. Eccentricity occurring in an optical recording medium is due to the inconsistency of the rotation shaft of spindle for rotating a disk with the center of the track of a disk. In an optical recording medium drive system, the eccentricity of an optical recording medium has served as an important periodic disturbance factor, and its influence increases with an increase in the speed multiple. An accurate track following cannot be accomplished without compensation of the eccentricity. Accordingly, a conventional system has utilized various eccentricity compensation methods.

FIG. 2 is a block diagram of a pickup head (PUH) position control system in a typical optical recording/reproducing apparatus. The PUH position control system receives a position command for directing a pickup head (not shown) to be positioned at a desired location. A signal representing the actual position of an actuator 220 of an optical recording medium drive for moving a pickup head is fed

back in a negative direction and added to a position command signal in an adder 200. An error signal e output from the adder 200 is applied to a controller 210. The controller 210 performs a predetermined algorithm for compensating for the error signal e , and outputs a compensated signal to the actuator 220. The actuator 220 moves the pickup head (not shown) in response to the compensated signal received from the controller 210. These operations are repeated, and thus the position of the pickup head is adjusted. However, this control system cannot deal with a disturbance such as a large eccentricity.

FIG. 3 is a block diagram of an embodiment of a conventional PUH position control system in which a routine for performing disturbance compensation is added to the control system of FIG. 2. In this system, a compensation routine 300 is performed on the assumption that a perfect sine wave $A\sin(\omega t + \psi)$ having an eccentricity of A , a disk rotation frequency ω , and an eccentricity phase ψ is an eccentricity signal. This compensation method is disclosed in U.S. Patent No. 5,892,742. In the operation of the system of FIG. 3, a feed-forward control input is calculated from an error waveform, as shown in FIG. 1, before control of tracking starts. That is, the size of the eccentricity is determined by the number of track errors generated during one rotation of a spindle over a track (i.e., during a cycle) shown in FIG. 1, and the phase of eccentricity is determined by a spindle index reference signal representing one rotation and a delay time at which the period of a track error is greatest. The thus-calculated feed-forward control input is added to the output of the controller 210 of FIG. 3 to accomplish track error compensation including the compensation of eccentricity. This disturbance compensation method is very simply performed and so it can be easily applied. However, this disturbance compensation method is an open-loop control method which does not consider the response characteristics of an existing servo (actuator) control system. There is a limit in the performance of the disturbance compensation method since periodic disturbances including eccentricity are not perfect sine waves.

FIG. 4 is a block diagram of another embodiment of a conventional PUH position control system in which a routine for performing disturbance compensation is added to the control system of FIG. 2. The system of FIG. 4 is disclosed in U.S. Patent No. 5,550,685, and is applied to hard disk drive systems. In this control

system, first, a fixed feed-forward control input is obtained using a track error signal and stored in a table 400 prior to starting control. Then, upon control, errors generated due to disturbances is compensated using the stored control input. This control system also includes a separate adaptive feed-forward control unit 410 in preparation for changes in characteristics of repeatable runout (RRO) caused by external factors during operation of a drive system. A discrete Fourier transform (DFT) and an inverse discrete Fourier transform (IDFT) are sequentially performed to extract a specific frequency component from a position error signal PES, thereby obtaining a signal with a specific frequency component. The obtained specific frequency component signal is added to the error input of an existing servo control loop. In this way, error compensation control can be accomplished. The system of FIG. 4 is complicated since it accomplishes error compensation control in consideration of the entire closed-loop response characteristics, but can be considered a more effective disturbance compensation system than FIG. 3. However, the system of FIG. 4 considers only disturbances of a specific frequency component rather than disturbances of all frequency components actually present in the control region of a disk drive system, and it is difficult to cope with changes in cycle such as variations in the speed multiple.

Therefore, in a periodic system such as a disk drive system, calculations of a control input in consideration of all frequency components within a control region is necessary for a high-performance disturbance compensation operation. Also, new disturbance compensation methods and apparatuses are required to effectively cope with changes in system cycle caused by a variation of the speed multiple and a variation of a control mode.

SUMMARY OF THE INVENTION

To solve the above problem, an objective of the present invention is to provide an apparatus and method of compensating for disk disturbances in consideration of periodic disturbances of all frequency components within the control region of an optical recording medium drive servo system and variations in the rotation speed multiple of the optical recording medium in an optical recording/reproducing apparatus.

To achieve the above objective, the present invention provides an optical recording medium drive servo system of an optical recording/reproducing apparatus, the system including an actuator for moving the position of a head for recording data on a recording medium or reproducing the recorded data from the recording medium, an error detector for detecting the difference between the reference position on the recording medium and the actual position of the head, that is, a position error, a compensator for receiving a value from the error detector and producing a value for driving the actuator, a first memory for storing a control input for compensating for the position error of the actuator due to a periodic disturbance such as eccentricity, a second memory for converting the content of the first memory according to phase and storing the converted content, a timing controller for generating addresses for the first memory and addresses for the second memory according to phase, and an adder for applying the content of the first or second memory together with the output of the compensator to the actuator.

The first memory preferably stores a control input for compensating for the position error generated during a determined rotation period of time through repeated operations of updating the value previously stored in the first memory unit with the sum of the position error filtered value and the values of previously stored in the first memory unit, the operations being repeated until the position error is at or below a predetermined value.

A filtering coefficient is preferably determined so that the sum is converged as the number of repetitions increases.

Preferably, the timing controller generates addresses corresponding to the number of sampling of position errors generated during one rotation cycle using the speed (FG) of a spindle motor for rotating the recording medium for the first memory and also generates an address corresponding to the number of rising edges and falling edges of the FG generated during one rotation cycle for the second memory.

The optical recording medium drive servo system may further include an interpolator for performing interpolation to restore for a value between the compensation control inputs stored in addresses of the second memory.

The optical recording medium drive servo system may further include a multiplexer for outputting the control input value of the first memory to the adder

during a process in which control input values are stored in the first memory until the values are converged to a predetermined value, and outputting the control input value of the interpolator after the process.

To achieve the above objective, the present invention also provides a
5 disturbance compensation module using learning control, for generating a control input for compensating for track position errors due to a periodic disturbance such as eccentricity occurring on an optical recording medium, in an optical recording medium drive servo system of an optical recording/reproducing apparatus, the module including a first filter for filtering the track position errors, a memory which
10 has addresses, the number of which corresponds to the number of sampling of the track position errors, and stores a control input value for compensating for a cycle of track position errors in a corresponding address of the addresses, a second filter for filtering the control input values stored in the memory, and an adder for adding the output of the first filter to the output of the second filter and applying the result of the
15 addition to the memory, wherein the track position errors are compensated using the control input values stored in the memory, and, if the compensated result does not satisfy a predetermined reference, the above-described members operate again, and the control input values of the memory are updated whenever the members operate again.

20 The disturbance compensation may further include a second memory for storing final control input values for compensating for a cycle of track errors generated during a cycle at a pulse edge timing generated during the track cycle after the final control input values are stored in the first memory, and an interpolator for interpolating the control input values stored in the second memory after the
25 learning control process is completed.

To achieve the above objective, the present invention also provides a disturbance compensation module using learning control, for generating a control input for compensating for track position errors due to a periodic disturbance such as eccentricity occurring on an optical recording medium, the module attached to an
30 optical recording medium drive servo system of an optical recording/reproducing apparatus, the module including a first filter for filtering the track position errors, a first memory which has addresses, the number of which corresponds to the number

of sampling of the track position errors, and stores control input values for compensating for a cycle of track position errors in the addresses, a second filter for filtering the control input values stored in the first memory, an adder for adding the output of the first filter to the output of the second filter and applying the result of the addition to the first memory, a second memory for storing final control input values for compensating for track errors generated during a cycle at a pulse edge timing generated during the track cycle when the final control input values are stored in the first memory, and an interpolator for interpolating the control input values stored in the second memory, wherein the track position errors are compensated using the control input values stored in the first memory, and, if the compensated result does not satisfy a predetermined reference, the first and second filters, the adder and the first memory operate again, and the control input values of the first memory are updated whenever the members operate again, and wherein a track position control is made using the output from the interpolator after the learning control is completed.

The disturbance compensation module may further include a multiplexer for outputting a control input value stored in the first memory to obtain an error-compensation control input value for a track position control during a cycle due to a disturbance and selecting the output of the interpolator after all control input values for disturbance compensation during the cycle are obtained and stored in the second memory.

To achieve the above objective, the present invention also provides a disturbance compensation method using learning control, of generating a control input for compensating for track position errors due to a periodic disturbance such as eccentricity occurring on an optical recording medium, this method including (a) determining whether a control input for disturbance compensation is required, (b) obtaining a feed-forward control input for compensating for a cycle of track position errors in an optical recording medium drive servo system, if it is determined in step (a) that a control input is required, (c) converting the feed-forward control input obtained in step (b) into a control input value depending on a spindle and storing the converted control input value, and (d) compensating for the track position errors generated due to the disturbance using the control input values obtained in step (c).

In the step (a), a track position error depending on the amount of a periodic disturbance such as the eccentricity of a disk is measured prior to starting control of tracking in an optical recording medium drive servo system, and, if the magnitude of the disturbance is measured equal to or greater than a predetermined value, it is determined that a disturbance compensation control input is required.

In the step (b), assuming that one rotation of a track is referred to as a control process, when a k-th attempted control input result is $u_k(t)$ and a track position error measured in this case is $e_k(t)$, a (k+1)th attempted control input result $u_{k+1}(t)$ is calculated as shown in Equation 1:

$$U_{k+1}(s) = P(s)U_k(s) + Q(s)E_k(s)$$

wherein $U_{k+1}(s)$, $U_k(s)$ and $E_k(s)$ denote the Laplace transforms of $u_{k+1}(t)$, $u_k(t)$ and $e_k(t)$, respectively, and $P(s)$ and $Q(s)$ denote functions representative of a predetermined filter characteristic determined so that $U_{k+1}(s)$ is converged, and a final periodic feed-forward control input is obtained by repetitive operations of Equation 1.

Preferably, the feed-forward control input obtained in step (b) is adapted to compensate for track position errors, until the final feed-forward control input values are obtained, and the control input converted according to phase in step (c) is adapted for track position error compensation after the final feed-forward control input for track position errors generated during a cycle is obtained.

After the step (c), there may be further provided the step of interpolating the stored values and taking the interpolated values to a disturbance compensation control input.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objective and advantage of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 illustrates an example of a tracking error signal generated due to the eccentricity of an optical recording medium drive servo system;

FIG. 2 is a block diagram of a pickup head position control system of a typical optical recording/reproducing apparatus;

FIG. 3 is a block diagram of an embodiment of a conventional pickup head position control system obtained by adding a disturbance compensating routine to the control system of FIG. 2;

FIG. 4 is a block diagram of another embodiment of a conventional pickup head position control system obtained by adding a disturbance compensating routine to the control system of FIG. 2;

FIG. 5 is a block diagram of an optical recording medium drive servo system of an optical recording/reproducing apparatus according to the present invention;

FIG. 6 is a block diagram of a disturbance compensation module using learning control according to the present invention;

FIG. 7A illustrates sampling points with respect to a periodic control input waveform during a track rotation cycle in FIG. 6 and points corresponding to pulse edges representative of the phases of a spindle which rotates over a track in FIG. 6;

FIG. 7B shows an example of a control input table which is stored in the first and second memory units of FIGS. 5 and 6, respectively, corresponding to the points of FIG. 7A;

FIG. 8 is a flowchart illustrating a disturbance compensation method using learning control, according to the present invention; and

FIG. 9 shows an example of a change in the speed multiple of an optical recording medium and a change in the waveform of an error compensation control input corresponding to the change in the speed multiple of an optical recording medium.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 5, an optical recording medium drive servo system of an optical recording/reproducing apparatus according to the present invention includes an actuator 500, an error detector 510, a compensator 520, a first memory 530, a second memory 540, and an adder 560.

The actuator 500 moves the position of a head (for example, a pickup head) for recording data on an optical recording medium or reproducing data therefrom. The error detector 510 detects the difference (position error) between the reference

position on the recording medium and the actual position of the head. The compensator 520 receives the output value of the error detector 510 and produces an actuator driving value by applying a predetermined algorithm for reducing the position error. The first memory 530 stores a control input for compensating for the position error for one period made by the actuator 500 due to a periodic disturbance such as an eccentricity on an optical recording medium. The first memory 530 stores a control input(s) for compensating for the position error generated for a determined rotation period of time through repeated operations of updating the value previously stored in the first memory unit 530 with the sum of the position error filtered value and the values of previously stored in the first memory unit 530, the operations being repeated until the position error is at or below a predetermined value. Determination of the most appropriate control input through the above-described repetitive summing of a previously-generated control input and a resultant error compensation result (which is indicated as a position error) can be referred to as a learning control. As the number of repetitions increases, a filtering coefficient must be determined so that the sums are converged. The second memory 540 converts the content stored in the first memory 530 according to phase and stores the converted content after the learning control is completely performed, in order to uniformly use the control input value in the first memory 530 regardless of the number of rotations of a spindle depending on a variation in the reproduction speed multiple of a recording medium. A timing controller 550 generates the addresses of the first and second memories 530 and 540 according to phase. That is, the timing controller 550 generates an address corresponding to the number of sampling of position errors generated during one rotation cycle, using the frequency generator pulse (FG) of a spindle motor for rotating a recording medium, and outputs the generated address to the first memory 530. The timing controller 550 also generates an address corresponding to the number of rising edges and falling edges of the FG generated during one rotation cycle and outputs the generated address to the second memory 540. The adder 560 adds the output of the first or second memory 530 or 540 to the output of the compensator 520 and provides the resulting sum to the actuator 500. The optical recording medium drive servo system can further include an interpolator 570 for interpolating the compensation control

inputs stored in neighboring addresses of the second memory 540 before the control input value of the second memory 540 is applied to the adder 560. The optical recording medium drive servo system can further include a multiplexer 580 for outputting the control input value of the first memory 530 to the adder 560 during a learning control process in which control input values are stored in the first memory 530 and for outputting the control input value of the interpolator 570 after the learning control process is completed.

FIG. 6 is a block diagram of a disturbance compensation module using learning control according to the present invention. In this disturbance compensation module using learning control, a control input for compensating for a cycle of track position errors due to periodic disturbance such as eccentricity occurring on an optical recording medium, is added to the output of the existing position error compensation controller 210 (see FIG. 2) of an optical recording medium drive servo system of an optical recording/reproducing apparatus.

This disturbance compensation module using learning control, includes a first filter 600, a memory 610, a second filter 620 and an adder 630. The first filter 600 receives and filters a track position error. The memory 610 has addresses, the number of which corresponds to the number of sampling of track position errors, and stores a control input value for compensating for a cycle of track position errors in a corresponding address of the addresses. Until the track position error input to the first filter 600 is at or below a predetermined value, the memory 610 repeats operations of updating a value previously stored in the memory 610 with the sum of a value obtained by filtering a track position error by the first filter 600 and a value obtained by filtering the value stored in the memory 610 by the second filter 620. Here, the summation is made by the adder 630. Thus, the memory 610 stores a control input for compensating for position errors generated during a determined rotation period of time. The most appropriate control input is determined by taking the values of the above-described repetitive summing of a previously-generated control input and a resultant error compensation result (which is indicated as a position error), which can be referred to as a learning control. As the number of repetitions increases, the filtering coefficients of the first and second filters 600 and 620 are determined so that the sums are converged.

The disturbance compensation module of FIG. 6 can further include a second memory 640 and an interpolator 650 to output a control input value for disturbance compensation against a change in the speed multiple of an optical recording medium. When final control input values for compensating for track errors generated during a cycle are stored in the memory 610, a second memory 640 stores the final control input values in response to a pulse edge timing generated during a track rotation cycle. The interpolator 650 interpolates the stored control inputs to restore the control input values between the pulse edges not stored in the second memory 640.

The disturbance compensation module of FIG. 6 can further include a multiplexer 660 for outputting a control input value of the memory 610 in the middle of a learning control process in which control input values are stored in the memory 610 and outputting the resulting value of the interpolator 650 after the learning control process is completed.

FIG. 7A illustrates sampling points (s_0 through s_{12m}) on the waveform of a periodic control input during a track rotation cycle in FIG. 6 and points (P_0 through P_{12}) corresponding to FG pulse edges representative of the phases of a spindle which rotates over a track. There are 0 to m sampling points within a pulse edge.

FIG. 7B shows an example of control input tables which are in the first and second memory units 530 and 540 of FIG. 5 in synchronization with the points of FIG. 7A.

FIG. 8 is a flowchart illustrating a disturbance compensation method using learning control, according to the present invention. In the disturbance compensation method using learning control in which a learning-use optical recording/reproducing apparatus generates a control input for compensating for a cycle of track position errors due to a periodic disturbance such as eccentricity occurring on an optical recording medium, first, it is determined whether a disturbance compensation control input is required, in step 800. The magnitude of a periodic disturbance such as the eccentricity of a disk is measured prior to starting control of tracking in an optical recording medium drive servo system. If the magnitude of the track position error is equal to or greater than a predetermined value, it is determined that a disturbance compensation control input is required. If

the optical recording medium is an optical disk, a disk drive system performs focusing, and the amount of eccentricity of the disk is measured prior to tracking. If the amount of eccentricity is smaller than the predetermined reference, the magnitude of disturbance actually occurring in a control system is small enough to be sufficiently compensated for with an existing controller alone, so that a learning control is not required. On the other hand, if the amount of eccentricity is equal to or greater than the predetermined reference, disturbance compensation just by an existing controller alone is not possible, so that a feed-forward control input must be previously calculated using a learning control algorithm. If it is determined that a control input is required for disturbance compensation, a feed-forward control input for compensating for track position errors during one cycle is calculated, in step 810. Assuming that a control for one rotation of a track is referred to as a control process, when a k-th attempted control input result is $u_k(t)$ and a track position error measured in this case is $e_k(t)$, a (k+1)th attempted control input result $u_{k+1}(t)$ is calculated as shown in Equation 1. A final periodic feed-forward control input is obtained by repeating Equation 1 and stored in the first memory 530 of FIG. 5 and the memory 610 of FIG. 6. In the calculation of a feed-forward control input, a compensation control input value is obtained by a repetitive learning of a position error. After the learning control step 820 is completed, the calculated feed-forward control input is converted into a control input value depending on the phase of a spindle and stored, in step 830. This conversion is a conversion of control input values depending on a cycle of track rotation time into spacial control input values depending on the phase of rotation of a track. In an actual disk drive system, the rotation speed of a spindle which determines the rotation of a disk may vary according to a constant linear velocity (CLV) control or a variation in the speed multiple of reproduction of a disk. This disk drive system cannot directly use the control input values calculated in step 820, so the control inputs must be obtained depending on a variation in the speed multiple through a new learning process. Thus, in step 830, the calculated feed-forward control input is converted into a control input value depending on the phase of a spindle in order to effectively compensate for the eccentricity due to a variation in the reproduction the speed multiple of a disk, that is, a periodic disturbance, without performing a new learning

process, and the converted control input value is used in the case of a variation in the speed multiple of reproduction of a disk. FIG. 9 shows an example of error compensation control input values depending on a variation in the speed multiple of an optical recording medium using the result obtained in step 830. When there is a variation in the speed multiple of a disk, the rotation phase is constant, but the rotation frequency varies, so that the result obtained in step 830 can be applied without change in accordance with a variation in frequency. Since the control input value is produced at a time when an edge of a frequency generator (FG) pulse occurs, the control input value between edges is restored by linear interpolation, in step 840. Therefore, continuous control input values can be output.

According to the present invention, a periodic disturbance component including the eccentricity can be rapidly and effectively compensated for using a previously-learned control result regardless of the variation in cycle such as a variation in the speed of a spindle due to a variation in the reproduction speed of a recording medium.

What is claimed is:

1 1. An optical recording medium drive servo system of an optical
2 recording/reproducing apparatus, the system comprising:
3 an actuator for moving the position of a head for recording data on a
4 recording medium or reproducing the recorded data from the recording medium;
5 an error detector for detecting the difference between the reference position
6 on the recording medium and the actual position of the head, that is, a position
7 error;
8 a compensator for receiving a value from the error detector and producing a
9 value for driving the actuator;
10 a first memory for storing a control input for compensating for the position
11 error of the actuator due to a periodic disturbance such as eccentricity;
12 a second memory for converting the content of the first memory according to
13 phase and storing the converted content;
14 a timing controller for generating addresses for the first memory and
15 addresses for the second memory according to phase; and
16 an adder for applying the content of the first or second memory together with
17 the output of the compensator to the actuator.

1 2. The optical recording medium drive servo system of claim 1, wherein
2 the first memory stores a control input for compensating for the position error
3 generated during a determined rotation period of time through repeated operations
4 of updating the value previously stored in the first memory unit with the sum of the
5 position error filtered value and the values of previously stored in the first memory
6 unit, the operations being repeated until the position error is at or below a
7 predetermined value.

1 3. The optical recording medium drive servo system of claim 2, wherein a
2 filtering coefficient is determined so that the sum is converged as the number of
3 repetitions increases.

4. The optical recording medium drive servo system of claim 1, wherein the timing controller generates addresses corresponding to the number of sampling of position errors generated during one rotation cycle using the speed (FG) of a spindle motor for rotating the recording medium for the first memory and also generates an address corresponding to the number of rising edges and falling edges of the FG generated during one rotation cycle for the second memory.

5. The optical recording medium drive servo system of claim 1, further comprising an interpolator for performing interpolation to restore for a value between the compensation control inputs stored in addresses of the second memory.

6. The optical recording medium drive servo system of claim 5, further comprising a multiplexer for outputting the control input value of the first memory to the adder during a process in which control input values are stored in the first memory until the track position errors are converged to a predetermined value, and outputting the control input value of the interpolator after the process.

7. A disturbance compensation module using learning control, for generating a control input for compensating for track position errors due to a periodic disturbance such as eccentricity occurring on an optical recording medium, in an optical recording medium drive servo system of an optical recording/reproducing apparatus, the module comprising:

a first filter for filtering the track position errors;

a memory which has addresses, the number of which corresponds to the number of sampling of the track position errors, and stores a control input value for compensating for a cycle of track position errors in a corresponding address of the addresses;

a second filter for filtering the control input values stored in the memory; and

an adder for adding the output of the first filter to the output of the second filter and applying the result of the addition to the memory,

wherein the track position errors are compensated using the control input values stored in the memory, and, if the compensated result does not satisfy a

16 predetermined reference, the above-described members operate again, and the
17 control input values of the memory are updated whenever the members operate
18 again.

1 8. The disturbance compensation module of claim 7, further comprising:
2 a second memory for storing final control input values for compensating for a
3 cycle of track errors generated during a cycle at a pulse edge timing generated
4 during the track cycle after the final control input values are stored in the memory;
5 and
6 an interpolator for interpolating the control input values stored in the second
7 memory,
8 wherein a track position control is made using the control inputs output from
9 the interpolator when the tracks on an optical recording medium is controlled.

1 9. The disturbance compensation module of claim 7, wherein the filter
2 coefficients of the first and second filters are determined so that track position error
3 values and control input values are converged as the frequency of learning
4 increases.

1 10. A disturbance compensation module using learning control, for
2 generating a control input for compensating for track position errors due to a
3 periodic disturbance such as eccentricity occurring on an optical recording medium,
4 the module attached to an optical recording medium drive servo system of an optical
5 recording/reproducing apparatus, the module comprising:
6 a first filter for filtering the track position errors;
7 a first memory which has addresses, the number of which corresponds to the
8 number of sampling of the track position errors, and stores control input values for
9 compensating for a cycle of track position errors in the addresses;
10 a second filter for filtering the control input values stored in the first memory;
11 an adder for adding the output of the first filter to the output of the second
12 filter and applying the result of the addition to the first memory;

13 a second memory for storing final control input values for compensating for
14 track errors generated during a cycle at a pulse edge timing generated during the
15 track cycle when the final control input values are stored in the memory; and
16 an interpolator for interpolating the control input values stored in the second
17 memory,

18 wherein the track position errors are compensated using the control input
19 values stored in the first memory, and, if the compensated result does not satisfy a
20 predetermined reference, the first and second filters, the adder and the first memory
21 operate again, and the control input values of the first memory are updated
22 whenever the members operate again, and wherein a track position control is made
23 using the control inputs output from the interpolator when the tracks on an optical
24 recording medium is controlled.

1 11. The disturbance compensation module of claim 10, wherein the filter
2 coefficients of the first and second filters are determined so that track position error
3 values and control input values are converged as the frequency of learning
4 increases.

1 12. The disturbance compensation module of claim 10, further comprising
2 a multiplexer for outputting a control input value stored in the first memory to obtain
3 an error-compensation control input value for a track position control during a cycle
4 due to a disturbance and selecting the output of the interpolator after all control
5 input values for disturbance compensation during the cycle are obtained and stored
6 in the first memory.

13. A disturbance compensation method using learning control, of
generating a control input for compensating for track position errors due to a
periodic disturbance such as eccentricity occurring on an optical recording medium,
this method comprising:

(a) determining whether a control input for disturbance compensation is
required;

(b) obtaining a feed-forward control input for compensating for a cycle of track position errors on an optical recording medium, if it is determined in step (a) that a control input is required;

(c) converting the feed-forward control input obtained in step (b) into a control input value depending on the phase of a track driving spindle and storing the converted control input value; and

(d) compensating for the track position errors generated due to the disturbance using the control input values obtained in step (c).

1 14. The disturbance compensation method of claim 13, wherein, in the
2 step (a), a track position error depending on the amount of a periodic disturbance
3 such as the eccentricity of a disk is measured prior to controlling tracking in an
4 optical recording medium, and, if the magnitude of the track position error is
5 measured equal to or greater than a predetermined value, it is determined that a
6 disturbance compensation control input is required.

1 15. The disturbance compensation method of claim 13, wherein, in the
2 step (b), assuming that one rotation of a track is referred to as a control process,
3 when a k-th attempted control input result is $u_k(t)$ and a track position error
4 measured in this case is $e_k(t)$, a (k+1)th attempted control input result $u_{k+1}(t)$ is
5 calculated as shown in Equation 1:

$$U_{k+1}(s) = P(s)U_k(s) + Q(s)E_k(s)$$

7 wherein $U_{k+1}(s)$, $U_k(s)$ and $E_k(s)$ denote the Laplace transforms of $u_{k+1}(t)$, $u_k(t)$ and
8 $e_k(t)$, respectively, and $P(s)$ and $Q(s)$ denote functions representative of a
9 predetermined filter characteristic determined so that $U_{k+1}(s)$ is converged, and a
10 final periodic feed-forward control input is obtained by repetitive operations of
11 Equation 1.

1 16. The disturbance compensation method of claim 15, wherein the feed-
2 forward control input obtained in step (b) is adapted to compensate for track position
3 errors, until the final feed-forward control input values are obtained, and the control
4 input converted according to phase in step (c) is adapted for a track position error

5 compensation after the final feed-forward control input for track position errors
6 generated during a cycle is obtained.

1 17. The disturbance compensation method of claim 13, after the step (c),
2 further comprises the step of interpolating the stored values and taking the
3 interpolated values to a disturbance compensation control input.

Abstract

APPARATUS AND METHOD OF COMPENSATING FOR DISTURBANCE USING
LEARNING CONTROL IN OPTICAL RECORDING/REPRODUCING APPARATUS
5 AND OPTICAL RECORDING MEDIUM DRIVE SERVO SYSTEM USING THE
APPARATUS AND METHOD

10 An apparatus and method of compensating for disturbances using learning
control is provided. An optical recording medium drive servo system of an optical
recording/reproducing apparatus, the system including an actuator for moving the
position of a head for recording data on a recording medium or reproducing the
recorded data from the recording medium, an error detector for detecting the
15 difference between the reference position on the recording medium and the actual
position of the head, that is, a position error, a compensator for receiving a value
from the error detector and producing a value for driving the actuator, a first memory
for storing a control input for compensating for the position error of the actuator due
to a periodic disturbance such as eccentricity, a second memory for converting the
20 content of the first memory according to phase and storing the converted content, a
timing controller for generating addresses for the first memory and addresses for the
second memory according to phase, and an adder for applying the content of the
first or second memory together with the output of the compensator to the actuator.
Accordingly, a periodic disturbance component including the eccentricity can be
25 rapidly and effectively compensated for using a previously-learned control result
regardless of a variation in cycle such as a variation in the speed of a spindle due to
a variation in the reproduction speed of a recording medium.

Figure 5