TITLE OF THE INVENTION

Data Processing Method and Apparatus

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a data processing method and apparatus for simulating the operation of a recording/reproducing apparatus for an optical disc.

Description of the Related Art

An optical disc drive for driving an optical disc, such as a compact disc (CD), a CD-ROM or a DVD, includes an optical pickup, referred to below as OP, and an electrical controller for controlling the movement of an objective lens provided in the OP, and is configured for correctly illuminating the laser light emitted from the OP on a track on the optical disc. With such OP, it is necessary to set mechanical and electro-optical parameters required for stable tracking and track jump under many different conditions, so that a lot of time and labor are required in newly studying and testing an OP.

This OP is made up of two operating portions, that is a sled and a bi-axial actuator. The sled is adapted to cause movement of a main body portion of the OP along a feed shaft of the OP. The bi-axial actuator causes movement of an object lens in the horizontal direction and in the vertical direction.

The OP has the function of causing movement of the laser light and accurately illuminating this laser light on the optical disc to read reflected signals. Since the

9902083-6

07 MAY 1999

distance between neighboring tracks on the optical disc is usually not larger than 1.6 μm, the OP has to be operated to a higher precision. Since the optical disc is not perfectly horizontal, its track is moved in the vertical direction (along the laser light illuminating direction) when the optical disc is run in rotation. Since the optical disc is slightly offset in the horizontal direction under actual operating conditions, its track is moved in the horizontal direction (in the direction perpendicular to the laser light illuminating direction). Therefore, there needs to be provided an electrical circuit which, if the laser light illuminating point (laser spot) is off the track, is able to detect an error signal corresponding to the offset to supply to the sled and to the bi-axial actuator a voltage necessary to cause movement of the OP to a desired site.

The OP movement in both the horizontal and vertical directions is controlled by a digital or an analog filter circuit. Since the OP has inertia, the filter circuit is able to predict the OP movement from the detected error signal to furnish the required voltage. An optical disc drive, detecting error signals by the filter circuit and furnishing the voltage for causing the OP movement, constitutes a feedback loop to control the OP. The mechanical operational control fort the OP employing a filter circuit is termed servo, with the feedback loop and the servo being collectively termed a servo mechanism.

In the optical disc drive, the control mechanism in the optical disc drive for adjusting the laser light spot so as to cause the spot to follow the track movement along the horizontal direction is termed tracking servo. Also, the control mechanism

in the optical disc drive for adjusting the laser light spot so as to cause the laser light spot to follow the track movement along the vertical direction is termed focussing servo. The bi-axial actuator performs tracking servo to cause movement of an object lens in order to adjust the laser spot position to a track movement on a rotating optical disc. At this time, the main body portion of the CPU is at a standstill until the deviation in the horizontal direction of the optical disc becomes significant. However, since the track of the optical disc is formed spirally, the position deviation in the horizontal direction between the main body portion of the OP and the spot position of the laser light becomes significant if the main body portion of the OP continues to remain at a standstill. This position deviation in the horizontal direction between the main body portion of the OP and the spot position of the laser light is detected by a circuit separate from the filter circuit used for tracking servo. The main body portion of the OP is moved slightly in its entirety, based on the detected amount of deviation, to compensate for this deviation. The mechanism for causing the movement of the main body portion of the OP is termed a sled, while the control mechanism for compensating for this position deviation of the main body portion of the CP is termed sled servo.

The OP not only has to be moved along the track, but also has to be movable from a given portion on the disc to a distinct portion spaced therefrom at a pre-set distance across plural tracks. This OP operation is termed track jump. This track jump is performed in order to access from a pre-set address to a new address. For effecting

track jump, complex voltage control is required because the positions of the sled and the bi-axial actuator need to be controlled accurately to minimize the lens deviation following the track jump. If the lens deviation is that large, there is produced a spring effect, as a result of which the bi-axial actuator is oscillated uncontrollably. This is termed f0 resonance. In this case, prolonged time has to elapse until the oscillations subside. The shorter accessing time at the time of track jump is desirable. Thus, it is not desirable that prolonged time is needed until subsidence of the oscillations.

In addition, the phenomenon that occurs between the sled and the bi-axial actuator differs depending on the difference in the track jump distance for the OP. If, in case of a long-distance jump, for example, a voltage is applied across the sled to cause the movement of the sled, the actuator is left behind, such that a spacing is produced therebetween to cause oscillations. In order to eliminate this, a suitable voltage is applied across the bi-axial actuator at the time of track jump to set the actuator at the sled center to reduce the oscillations. This is termed center servo. For example, in case of a short-distance jump, a kick voltage needs to be applied across the bi-axial actuator so that the bi-axial actuator will be moved first. Failing this kick voltage, the bi-axial actuator is left behind the main body portion of the OP even if the center servo is used.

In addition, in the track jump, it is difficult to cause the OP movement so that the OP will be moved at a time correctly to a desired track. Usually, an error is produced at the first jump, such that the jumps need to be repeated several times until

the desired track is reached. For eliminating this drawback, an optimum voltage for the OP to perform the most stable operation needs to be found out.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a data processing method and apparatus whereby OP movement can be accurately simulated under the effect of all sorts of interferences or control voltages.

In view of the above object, the present invention provides a computation processing unit for effecting data processing, a storage unit for storing the data processed by the computation processing unit, an input unit for inputting data to the computation processing unit and a display unit for displaying data processed by the computation processing unit. The present invention also provides a data processing method which carries out the data processing using a computation processing unit for effecting data processing, a storage unit for storing the data processed by the computation processing unit, an input unit for inputting data to the computation processing unit and a display unit for displaying data processed by the computation processing unit.

According to the present invention, parameters for servo control of the optical disc recording/reproducing apparatus, parameters for a sled, and parameters for an optical disc are set. The operation of the optical disc recording/reproducing apparatus is computed based on these parameters to simulate the OP operation.

Among the parameters set for servo control, there are filter frequencies for

tracking servo, focussing servo, sled servo, surf jump servo and center servo, an open-loop cut-off frequency, driver saturation, bit quantization and the sampling rate in digital processing as parameters for servo control.

Among the parameters set for an optical pickup, there are dc sensitivity, resonance frequency, Q-factor, coil inductance, coil resistance and the maximum possible movement distance.

Among the parameters set for a sled, there are the masses, Coulomb friction, viscous friction and the backlash of the sled and a gear, a sled motor constant, sled motor inductance and/or the sled motor resistance.

Among the parameters set for an optical disc, there are the disc rpm, frequency and harmonics of eccentricity, linear velocity, track pitch, S-curve characteristics, EF balance, RF level, frequency of vibrations from outside in both the horizontal and vertical directions and vibrations from outside in both the horizontal and vertical directions.

The above respective parameters are set by inputting by the user, using the results of simulation or by changing the input data.

The present invention also performs servo control simulation, simulation of the operation of the optical pickup subjected to free vibrations, the operation of the optical pickup at the time of focussing servo control or that at the time of tracking servo control, and the tolerance for tracking.

More specifically, the tracking servo control simulation is effected in

connection with the optical pickup operation at the time of one track jump, that is jump to the neighboring track, optical pickup operation at the time of 2N track jump, that is jump over plural tracks, optical pickup operation at the time of fine search (jump at a constant velocity) and on the optical pickup operation at the time of M track jump, that is jump with the center servo on.

The tracking tolerance simulation, more specifically, is performed in connection with the optical pickup operation at the time of one track jump, that at the time of 2N track jump and that at the time of fine search.

With the data processing method and apparatus according to the present invention, as described above, it is possible to conduct all sorts of tests for an optical pickup for an optical disc using a computer and to conduct these tests automatically under a variety of different conditions, thereby significantly reducing the time required for investigations or tests.

Also, according to the present invention, the operation of the servo system of the optical disc drive can be predicted accurately, thereby significantly reducing the time required for investigations or tests to realize more elaborate analyses.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1A is a block diagram showing a simulation device embodying the present invention.

Fig.1B is a block diagram for illustrating a calculation algorithm of the simulation device shown in Fig.1A.

Fig.2 is a block diagram showing main modules of the simulation device shown in Fig.1A.

Fig.3 is a block diagram showing a sub-module in a filter design module shown in Fig.2.

Fig.4 shows the GUI of a bi-axial actuator data module shown in Fig.3.

Fig.5 shows the GUI of a filter design module shown in Fig.3.

Fig.6 shows the GUI of a an optimization module shown in Fig.3.

Fig.7 shows the GUI of a bi-axial actuator modelling module shown in Fig.3.

Fig.8 shows the GUI of a filter design module (1) shown in Fig.3.

Fig.9 shows the GUI of a an optimization module (1) shown in Fig.3.

Fig.10 shows the GUI of a low/high boost filter module shown in Fig.3.

Fig.11 shows the GUI for inputting data concerning optical components of an OP to a system module shown in Fig.2.

Fig.12 shows the GUI for inputting data concerning electrical components of an OP to the system module shown in Fig.2.

Fig.13 shows the GUI for inputting data concerning mechanical components of an OP to the system module shown in Fig.2.

Fig.14 shows the GUI for inputting data concerning one track jump to a track jump simulation module shown in Fig.2.

Fig.15 shows the GUI for inputting data concerning 2N track jump to the track jump simulation module shown in Fig.2.

Fig.16 shows the GUI for inputting data concerning fine search to the track jump simulation module shown in Fig.2.

Fig.17 shows the GUI for inputting data concerning M track jump to the track jump simulation module shown in Fig.2.

Fig.18 shows the GUI for inputting data concerning one track jump to a tolerance simulation module shown in Fig.2.

Fig.19 shows the GUI for inputting data concerning 2N track jump to the tolerance simulation module shown in Fig.2.

Fig.20 shows the GUI for inputting data concerning fine search to the tolerance simulation module shown in Fig.2.

Fig.21 is a flowchart showing a processing sequence of a sled module (for least square method) of Fig.2.

Fig.22 is a flowchart showing the processing sequence of a free oscillation module of Fig.2.

Fig.23 is a flowchart showing the processing sequence of a focussin ON module of Fig.2.

Fig.24 is a flowchart showing the processing sequence of the track jump simulation module of Fig.2.

Fig.25 is a flowchart showing the processing sequence of the tolerance simulation module of Fig.2.

Fig.26 is a flowchart showing the processing sequence of the 1-track jump

module of Fig.2.

Fig.27 is a flowchart showing the processing sequence of the 2N track jump module of Fig.2.

Fig.28 is a flowchart showing the processing sequence of the fine search module of Fig.2.

Fig.29 is a flowchart showing the processing sequence of the M track jump module of Fig.2.

Fig.30 is a flowchart showing the processing sequence of a tracking servo module recalled from the tolerance simulation module of Fig.25.

Fig.31 is a flowchart showing the processing sequence of a kick D module recalled from the 2N track jump module etc of Fig.27.

Fig.32 is a flowchart showing the processing sequence of a constant voltage kick module recalled from the 2N track jump module etc of Fig.27.

Fig.33 is a flowchart showing the processing sequence of a tracking error frequency control module recalled from the fine search module of Fig.28.

Fig.34 is a flowchart showing the processing sequence of a braking circuit module recalled from the track jump simulation module etc of Fig.24.

Fig.35 is a flowchart showing the processing sequence of a plant model recalled from a sled model (least square method) shown in Fig.21.

Fig.36 is a flowchart showing the processing sequence of an optical module recalled from the one-track module shown in Fig.26.

Fig.37 is a flowchart showing the processing sequence of a filter module recalled from the one-track jump module shown in Fig.26.

Fig.38 is a graph showing focussing error signals on effecting simulation of the focussing search by the focussing ON module.

Fig.39 is a graph showing movement of a bi-axial actuator on effecting simulation of the focussing pull-in by the focussing ON module.

Fig.40A is a graph showing the relative position between the sled and the bi-axial actuator on effecting simulation of the focussing pull-in by the focussing ON module.

Fig.40B is a graph independently showing respective positions of the sled and the bi-axial actuator on effecting simulation of the focussing pull-in by the focussing ON module.

Fig.41A is a graph showing focussing error signals on effecting simulation of the focussing pull-in by the focussing ON module.

Fig.41B is a graph showing focussing drive signals on effecting simulation of the focussing pull-in by the focussing ON module.

Fig.42A is a graph showing the tracking drive voltage on effecting simulation of one track jump by the track jump module.

Fig.42B is a graph showing the tracking error signals on effecting simulation of one track jump by the track jump module.

Fig.43 shows results of an experiment on one track jump by an actual OP.

Fig.44 shows the relation of distribution between the tracking driving voltage and the supplying time, shown in terms of a grade, formulated on the basis of the results of simulation of one track jump by the track jump module.

Fig.45 shows the relation of distribution, shown in terms of a grade, for illustrating the relation betweenthe tracing drive voltage and the supplying time, based on the results of experiments on one track jump by an actual OP.

Fig.46A shows the movement trajectory of the OP in each grade of Fig.44.

Fig.46B shows tracking error signals for the grade 3.

Fig.46C shows tracking error signals for the grade 2.

Fig.46D shows tracking error signals for the grade 1.

Fig.46E shows tracking error signals for the grade 0.

Fig.47A is a graph showing a tracking driving voltage on effecting simulation of a 2N track jump by the track jump module.

Fig.47B is a graph showing a tracking driving voltage on effecting simulation of 2N track jump by the track jump module.

Fig.48 shows the results of an experiment on a 2N track jump by an actual OP.

Fig.49 is a graph showing the tracking driving voltage on effecting simulation of fine search by the track jump module.

Fig.50 shows the results of experiments on fine search by an actual OP.

Fig.51A is a graph showing the tracking driving voltage on effecting simulation of fine search plural times by a track jump module.

Fig.51B is a graph showing the tracking error signals on effecting simulation of fine search plural times by a track jump module.

Fig.52A is an enlarged view of Fig.51A.

Fig.52B is an enlarged view of Fig.51B.

Fig.53 shows the distribution of the braking time in case of effecting braking following track jump by the track jump module.

Fig.54 shows the distribution of the frequency variation ratio in case of effecting fine search by the track jump module.

Fig.55 shows the accessing time in case of doing fine search by the track jump module (long distance movement).

Fig.56 shows the accessing time in case of doing fine search by the track jump module (short distance movement).

Fig.57 shows a GUI for inputting data concerning the results of simulation to a sled model (averaging method) module of Fig.2 based on the results of the simulation.

Fig.58 shows another GUI for inputting data concerning the results of simulation to a sled model (averaging method) module of Fig.2 based on the results of the simulation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings, a simulation device according to a preferred embodiment of the present invention will be explained in detail.

Hardware Structure of Simulation Device

Fig.1A shows the hardware structure of a simulation device embodying the present invention.

The simulation device 1 includes a computer 2 storing plural modules formulated in accordance with the linear programming form or in an object-oriented programming form for executing these modules, a monitor 3 for displaying the results of executiuon of the respective modules by the computer 2, and a pointing device 4, such as a mouse, for a user to input data responsive to display on the monitor 3. The simulation device 1 also includes a keyboard 4 for a user to inputy data by keys, and a storage device 6 for data storage. This simulation device 1 simulates the OP operations under all possible conditions. The monitor 3 is responsive to the control by the computer 2 to display data processed by the computer 2 for the user. The pointing device 4 and the keyboard 5 routes data inputted by the user to the computer 2. The storage device 6 stores data processed by the computer 12. The stored data is read out by the computer 2.

Contents of Computational Processing Performed by the Simulation Device

The contents of processing performed by the simulation device 1 in effecting OP simulation are hereinafter explained.

The simulation device; 1 models respective elements of the OP based on the Newton's second law to perform the processing.

First, for obtaining models of the respective OP elements, it is necessary to take

all forces applied to the OP into account.

The bi-axial actuator is modelled by combining the degree-two spring system and a degree-one system of an electric coil supplying the mechanical force.

The sled is modelled using two frictional forces, namely the Coulomb friction Fc and the viscous friction $2\gamma v$.

An example of sled modelling is not known in general. The present inventors have made analyses of a large quantity of data of sled speed response on supplying an pulse voltage of a reactrnagulae wave to arrive at a model in which the sled is made up of two portions, namely the Coulomb friction Fc and the viscous friction $2\gamma v$, proportionate to the sled voltage.

By this, the sled model employing the Newton's second law is reduced to an equation

$$ma - K_m R_m I_m - 2\gamma v - F_c$$

where m is the mass of the sled, a is the acceleration, K_m is the motor constant of the sled motor, R_m is the sled motor resistance and I_m is the current.

The equations used for simulating the OP operation are hereinafter shown.

As for the bi-axial actuator, processing is executed in accordance with the following equation (1) to effect its simulation.

$$\frac{d^2x}{dt^2} + 2\varsigma\omega_n \frac{dx_a}{dt} + \omega_n{}^2 x_a = K_p \omega_n{}^2 x_s + \omega_n{}^2 x_s$$

···(1).

As for the order-two resonance, processing is executed in accordance with the following equation (2) to effect its simulation.

$$\frac{d^2x_2}{dt^2} + 2\varsigma_2\omega_2\frac{dx_2}{dt} + \omega_2{}^2x_2 = 2\varsigma\omega_n\frac{dx_a}{dt} + \omega_2{}^2x_a$$

···(2).

As for error signals, processing is executed in accordance with the following equation (3) to effect its simulation:

$$e(t) - A_e\text{sink}_e(x - x_a)$$

···(3).

As for a lead filter, processing is executed in accordance with the following equation (4) to effect its simulation:

$$T_b\frac{dV_{Ld}}{dt} + V_{Ld} = T_a\frac{de}{dt} + e$$

···(4).

As for a lag filter, processing is executed in accordance with the following equation (5) to effect its simulation:

$$\frac{dV_{Td}}{dt} + S_bV_{TD} = \frac{dV_{Ld}}{dt} + S_aV_{Ld}$$

···(5).

As for a tracking coil, processing is executed in accordance with the following equation (6) to effect its simulation:

$$L\frac{dI}{dt} + RI = V_{TD}$$

···(6).

As for the sled lag filter, processing is executed in accordance with the following equation (7) to effect its simulation:

$$\frac{dV_{SD}}{dt} + s_2 V_{SD} = \frac{dV_{TD}}{dt} + s_1 V_{TD}$$

···(7).

As for the sled motor, processing is executed in accordance with the following equation (8) to effect its simulation:

$$L_m \frac{dI_m}{dt} + R_m I_m = V_{SD} - K_b \frac{dx_s}{dt}$$

···(8).

As for a sled not contacted with the gear, processing is executed in accordance with the following equation (9) to effect its simulation:

$$m_1 \frac{d^2 x_1}{dt^2} = 2\gamma_1 \frac{dx_1}{dt} - F_1$$

...(9).

As for the gear not contacted with the sled, processing is executed in accordance with the following equation (10) to effect its simulation:

$$m_2 \frac{d^2 x_s}{dt^2} = K_m R_m I_m + 2\gamma_2 \frac{dx_s}{dt} - F_2$$

...(10).

As for the sled which contacted with the gear, processing is executed in accordance with the following equation (11) to effect its simulation:

$$m \frac{d^2 x_s}{dt^2} = K_m R_m I_m + 2\gamma \frac{dx_s}{dt} - F_1$$

...(11).

The simulation device 1 finds the solution, based on the above eqautions (1) to (11), by the algorithm shown in Fig.1B, in order to simulate the OP operation.

The algorithm shown in Fig.1B, is made up of three modules, namely a PD module 7, a DSP module 8 and an OP module 9.

The PD module 7 calculates predicted error signals on the basis of a function inicating how much a laser spot is removed from a track on the optical disc. The PD module 7 also computes the amount of blurring of the focal point of the laser spot.

The DSP module 8 computes an output voltage when error signals from the PD

module have been processed with phase compensation and filtering. The DSP module 8 discretely outputs a computed output voltage every pre-set unit time (one sampling period).

The OP module 9 computes the OP position every pre-set unit time (one sampling period), voltage and the coil current. The OP module 9 also computes the effect due to vibrations from outside and computes e.g., the positions of the sled or the bi-axial actuator. If the OP module 9 has computed the positions of the sled or the bi-axial actuator, it feeds back the results to the PD module 7.

The status variables (status vectors) of the OP computed by this simulation device 1 may be enumerated by the sled motor current and voltage, position and velocity of the sled and the gear, first and second resonance positions and velocity values of the bi-axial actuator, filter states (focussing, tracking, sled, surf, TZC (tracking zero-crossing), focussing error signals and pull-in signals, focussing driving voltage and current, and laser spot shifting on a photodetector.

In the present simulation device 1, a program for simulating e.g., M track jump, fine search and one track jump is written based on the above three modules. The fine search, for example, is the operation of applying a sequence of forward and backward voltages to control the velocity of the bi-axial actuator so that the velocity will be constant relative to a track. The respective parameters of the OP can be set as the result of computing the state of change of the status change (status vector). For example, the fine search accessing time can be acquired as the result of computing the

eight status variables (status vectors).

Specifically, the following setting can be made as the result of computing these status variables (status vectors).

a. Otimum track jump parameters are set in order to reduce the time since track jump until OP is at a standstill.

b. The track jump parameters are fixed at an optimum value determined at *a.* above and the OP specifications, such as dc sensitivity or resonance frequency, are varied to minimize the production tolerance in OP manufacture.

Meanwhile, this simulation device is fed with the following parameters of the optical disc drive:

rotational velocity of the disc;

frequency and harminics of the eccentricity;

linear velocity;

track pitch;

S-curve characteristics;

FF balance;

RF level;

open-loop cut-off frequency of the tracking servo filter, focussing servo filter, sled servo filter, surf jump servo filter and the center servo filter;

driver saturation, bit quantization and DSP sampling rate;

respective specifications of the OP, such as dc sensitivity, resonance frequency,

inclusive of the second resonance, Q-factor, and inductance and resistance of the maximum movable distance of the coil;

external vibrations (frequency and amplitude in the horizontal direction and in the vertical direction);

mass weight, Coulomb friction and viscous friction of the thread and gear and deviation between the gear and the sled; and

motor constant, inductance and the resistance of the sled motor. The present simulation device uses these parameters to effect the simulation.

Program of Simulation Device

The above-described simulation device 1 simulates the operation of the optical pickup (OP) in accordance with the program now explained.

Fig.2 shows principal modules in the above-described simulation device 1 and the direction of information transmission between respective modules.

Referring to Fig.2, the simulation device 1 includes a filter design module 11 for determining servo parameters, a system module 12 for determining system parameters, a sled model module (least square method) 13, a sled module (averaging method) 14, a free oscillation module 15 for simulating the operation of an OP in which servo is not engaged, a focussing ON module 16 for simulating the operation of an OP in which servo is engaged, and a track jump simulation module 17 for simulating the OP operation at the time of track jump. The simulation device1 also includes a tolerance simulation module 18 for simulating the OP operation for finding

the tolerance in track jump characteristics.

The simulation device 1 also includes a one track jump module 19, a 2N track jump module 20, a fine search module 21 and a 2N track jump module 22, as sub-modules recalled to the track jump simulation module 17. Meanwhile, the one track jump module 19, 2N track jump module 20 and the fine search module 21 are also recalled by the tolerance simulation module 18.

Each module is stated in the object oriented programming form and in the linear programming form. The modules stated in the form of the object oriented programming are displayed with a graphical user interface (GUI) by a pushbutton. If a pushbutton is clicked with a pointing device, such as a mouse, the program of the module associated with the pushbutton is started.

The filter design module 11 is a module for deteriming filter parameters for executing various servo control operations for the OP. The user uses this filter design module 11 to determine optimum filter parameters. The values obtained with this filter design module 11 are entered to the system module 12.

The system module 12 is a module for inputting parameters of all components making up an optical disc drive. Meanwhile, sicne part of sled parameters are not determined with this system module 12, the sled parameters are found by the sled model module (least square method) 13 or the sled module (averaging method) 14 so as to be entered to the system module 12.

The free oscillation module 15 simulates the state of the OP in the servo

disenaged state, using parameters as determined by the system module 12. The focussing ON module 16 simulates the operation in the vertical direction of the OP which is in the focussing search state and in the focussing servo engaged state. The results of simulation by the focussing ON module are inputted, if necessaary, to the track jump simulation module 17.

The track jump simulation module 17 simulates the operation in the horizontal direction of the OP to which tracking servo is applied. The user is able to select with the track jump simulation module 17 whether or not the results of simulation are to be reflected in the simulation of the operation in the vertical direction or only the simulation of the operation in the vertical direction is to be performed. If the results of simulation are to be reflected in the simulation of the operation in the vertical direction, the results of simulation by the focussing ON module are entered to the track jump simulation module 17.

The track jump simulation module 17 also effects simulation of a variety of track jumps, that is one track jump, 2N track jump, fine search and M track jump. For effecting simulation of one track jump, 2N track jump, fine search and M track jump, the one track jump module 19, 2N track jump module 20, fine search module 21 and M track jump module 22 are recalled, respectively.

The tolerance simulation module 18 simulates tracking characteristics of plural OPs for finding the porduction tolerance in OP manufacture. Th tolerance simulation module 18 effects simulation of a variety of track jumps, that is one track jump, 2N

track jump and fine search. For effecting simulation of one track jump, 2N track jump and fine search, the one track jump module 19, 2N track jump module 20 and the fine search module 21 are recalled, respectively.

GUI etc for Setting Parameters

The programs of the above-mentioned respective modules are further explained in detail.

First, the GUI for setting the parameters of the respective modules stated in the object oriented programming form is explained.

Filter Design Module

Fig.3 shows sub-modules in the filter design module 11 shown in Fig.2 and the direction of information transmission between the respective sub-modules.

A bi-axial actuator data module 25 selects the data file of the transfer function of the bi-axial actuator. With this bi-axial actuator data module 25, the transfer function can be selected as the user checks a graph. A filter design module 26 models the filter transfer function and adds data of the transfer function of the bi-axial actuator to check the stability of the optical disc drive. An optimization module 27 displays stability of the optical disc drive to effect automatic retrieval of the optimized filter transfer functions based on the value obtained from the filter design module 26. A bi-axial actuator modelling module 28 modesl the transfer function of the filter optimized by an optimization module 27. A simulator model module 31 stores the transfer function of a mnodelled filter.

A filter design module (1) module 29 models the filter transfer function and adds the transfer function of the bi-axial actuator modelled by the bi-axial actuator modelling module 28 to check the stability of the optical disc drive further. An optimization module (1) 30 displays stability of the optical disc drive on a graph to effect automatic retrieval of the optimized filter transfer function further.

A low/high boost filter module 32 models the transfer function of a low boost filter and a high boost filter. A low-pass filter module 33 modesl the transfer function of the low boost filter. The values obtained with the low-pass filter module 33 and the low-pass filter module 33 are used in the filter design module 26 and in the filter design module (1) module 29.

Referring to Figs.4 to 10, the contents of the respective sub-modules in the filter design module 11 are explained.

Fig.4 shows the GUI of the bi-axial actuator data module 25 which displays the GUI by a pushbutton, cursor, box and the graph. To a gain box 34 and to a frequency box 35, gain data of the bi-axial actuator and the frequency data of the bi-axial actuator are inputted, respectively. A cursor provided on the gain box 34 and a cursor provided on the frequency box 35 are moved vertically by the user for selecting data inputted from a file stated in the box accordingly. The files stated in the gain box 34 and the frequency box 35 are stated as row-wise text type files and are formulated on the basis of computed data. To data input boxes 37, 38 and 39 are inputted empirically obtained parameters, such as sensitivity or frequency response of the bi-axial actuator.

An open button 36, if clicked by the user, plots a graph showing the transfer function of the bi-axial actuator in a graph display area 40 surrounded by the ordinate and the abscissa based on the input data to the respective boxes. Thus, with the bi-axial actuator data module 25, it is possible to select the transfer function of the bi-axial actuator of the OP to be simulated as the user checks the transfer function on the graph.

Fig.5 shows the GUI of the filter design module 26 which displays a pushbutton, a box and the GUI in a graphic form. To a filter type box 42 are entgered filter types, such as a low boost filter, a high boost filter or a low-pass filter. To parameter boxes 43, 44 are entered parameters of the filters entered to the filter type box 42. In this filter design module 26, two parameters are inputted per filter. The filter types and the number of parameters entered to the filter type box 42 and to the parameter boxes 43, 44 can be varied optionally. A sampling rate box 45 is fed with the sampling rate of the digital filter. A cut-off frequency box 46 is fed with the cut-off frequency of an open loop of the filter. A plot button 47, if clicked, computes the filter transfer function, based on the value entered to each box, to plot on a graph display area 41, as a graph, a transfer function obtained on adding a transfer function of the bi-axial actuator selected by the bi-axial actuator data module 25 of Fig.4 to the computed transfer function. The graph plotted on the graph display area 41 represents an open-loop transfer function. On the other hand, the respective parameters indicated along with the graph plotted on the graph display area 41 represent the stability of the optical disc

drive. Thus, with the filter design module 26, it is possible not only to select the filter for use in servo but also to check the stability when the filter is used for the selected bi-axial actuator.

Fig.6 shows the GUI of the optimization module 27 which displays the pushbutton, cursor, box and the GUI in the graphic form. To a filter box 49 is entered an input parameter for a filter using a cursor. To a parameter selection box 50 is entered a parameter corresponding to the input filter using a cursor. On a parameter displaying box 51 are displayed specified value of the input parameter. On a graph displaying area 48 is plotted, with a solid line, an open loop transfer function when the input filter is used for the bi-axial actuator. This open loop transfer function is read from the filter design module 26. In the graph displaying area 48, the open-loop transfer function is plotted with a solid line, while a closed-loop transfer function when the filter is used for the selected bi-axial actuator is plotted with a broken line. In the optimization module 27, the filter parameter can be changed by moving the cursor in the left-and-right direction with the pointing device, such as a cursor. If, in the optimization module 27, the cursor 52 is moved, a new parameter is computed and a new graph is indicated on the graph displaying area 48. A parameter displaying box 53 displays this new parameter. To a minimum value displaying box 54 and to a maximum value displaying box 56, a maximum value and a minimum value of the filter parameter can be entered, respectively. An automatic button 55, when clicked, automatically shifts the parameter by, for example, ten stages to retrieve the most

stable parameter to display the retrieved parameter on the graph displaying area 48. The graph plotted on this graph displaying area 48 is displayed stage-wise like a moving picture. Therefore, the user is able to check the state of change of the transfer function. On the graph displaying area 48, there are shown three graphs indicating three stable parameters, from which the user selects an optimum value. A save button 57, if clicked, holds the parameter specified by the cursor 52. Thus, the optimization module 27 computes a new transfer function by changing the filter parameter to cause the transfer function to be incidentally displayed on the graph displaying area 48. Thus, the user is able to select and save an optimum parameter easily.

Fig.7 shows the GUI of the bi-axial actuator modelling module 28 which displays the push button, box and the GUI in the graphic form. To OP characteristics input boxes 59 to 63 are entered OP specifications (dc sensitivity, f0, Q-factors, inductance and resistance of the tracking coil). A plot button 64, if clicked, computes the transfer function of the bi-axial actuator to plot the results as a graph in a graph displaying area. An experimental value button 65, if clicked, displays a measured value of the bi-axial actuator on the graph displaying area 58. The user is able to compare the transfer function to the measured value of the bi-axial actuator.

Fig.8 shows the GUI of the filter design module (1) module 29 which displays a pushbutton, a box and the GUI in the graphic form. A filter type box 67 is fed with filter types, namely a low boost filter, a high boost filter or a low-pass filter. With the parameter boxes 68, 69, filter parameter entered to the filter type box 67are entered.

In this filter design module (1) module 29, two parameters are entered to one filter. The filter type or the number of parameters that can be entered to the filter type box 67 and to the parameter boxes 68, 69 can be changed optionally. A sampling rate box 70 is fed with the sampling rate of a digital filter. To a cut-off frequency box 71 is entered a cut-off frequency of the open loop of the filter. The plot button 72, if clicked, computes the transfer function of the filter based on the values entered to the respective boxes and plots on a graph displaying area 66, as a graph, a transfer function obtained on summing a transfer function of the bi-axial actuator modelled by the bi-axial actuator modelling module 28 of Fig.7 to the transfer function computed as described above. The graph thus plotted on the graph displaying area 66 represents the open-loop transfer function. The respective parameters, shown with the graph plotted on the graph displaying area 66, represent the stability of the optical disc drive. Thus, the filter design module (1) module 29 is able to select the filter user for servo, and to check the stability when the filter is used for the selected bi-axial actuator.

Fig.9 shows the GUI of the optimization module (1) 30, which displays a pushbutton, a cursor and the GUI in the graphic form. A filter box 74 is fed with a filter entered with the filter type box 67 of Fig.8 using a cursor. A parameter selection box 75 is entered a parameter corresponding to the entered filter using a cursor. On the parameter displaying box 76 is displayed a specified numerical figure of an input parameter. In the graph displaying area 73 is plotted, with a solid line, an open-loop

transfer function when the input filter is used for the selected bi-axial actuator. This open-loop transfer function is read from the filter design module (1) module 29. In the graph displaying area 73, the open-loop transfer function is plotted with a solid line, while a closed-loop transfer function when the filter is used for the selected bi-axial actuator is plotted with a broken line. With this optimization module (1) 30, the filter parameter can be changed by moving the cursor 77 in the transverse direction using a pointing device, such as a mouse. If, in the optimization module (1) 30, the cursor 77 is moved, a new parameter is entered. Based on this new parameter, a new transfer function is computed and a new graph is entered on the graph displaying area 73. A parameter displaying box 81 displays this new parameter. A maximum value and a minimum value of the filter parameter may be inputted to a minimum value input box 78 and a maximum value input box 80, respectively. An automatic button 79, when clicked, automatically sifts the cursor 77 by, for example, ten stages to retrieve the most stable parameter to display the parameter on the graph displaying area 73. The graph plotted on this graph displaying area 73 is displayed stage-wise like a moving picture. Therefore, the user is able to check the state of change of the transfer function. On the graph displaying area 73, there are shown three graphs indicating three stable parameters, from which the user selects an optimum value. A save button 82, if clicked, holds the parameter specified by the cursor 77. Thus, the optimization module (1) 30 computes a new transfer function by changing the filter parameter to cause the transfer function to be incidentally displayed on the graph displaying area 74. Thus,

the user is able to select and save an optimum parameter easily.

Fig.10 shows the GUI of the low/high boost filter module 32, which displays a pushbutton, a box and the GUI in a graphic form. To parameter input boxes 83 to 87 are entered boost filter parameters, such as cut-off frequency, dc gain, minimum frequency value or the maximum frequency value. A plot button 88, if clicked, computes the transfer function of the boost filter, based on the parameters inputted to the respective parameter boxes 83 to 87, and displays the results in a graphic form on a graph displaying area 89. The low-pass filter module 33 also executes similar processing using the GUI similar to that of the low/high boost filter module 32.

As explained with reference to Fig.4 to 10, each sub-module in the filter design module 11 operates as described above to design a filter optimized for the bi-axial actuator.

System Module

Figs.11 to 13 show the GUI of the system module 12 shown in Fig.2. In this system module 12, the GUI by the pushbutton and the box is displayed.

The system module 12 inputs data on optical, electrical and mechanical components of the optical disc drive to store the data.

Fig.11 shows the GUI for inputting data concerning the optical component of the system module 12. To the box 90 are entered data concerning the disc rpm, disc planarity or disc eccentricity. To the box 91 are entered data concerning focussing servo such as S-curve peak-to-peak time, maximum focussing pull-in voltage or

focussing leakage. To the box 92 are entered data concerning tracking servo such as FF balance or EF level. To the box 93 are entered lens shifting sensitivity, the information as to whether the velocity is CAV or CLV, track pitch and other data. An opening button 94, if clicked, causes previously saved data to be read from the file so as to enter each box. An overwrite save button 95, if clicked, overwrites and saves the newly entered data in the currently opened file. A different name save button 96, when clicked, specifies a new file name for newly entered data to save the data with the new name. An OK button 97, when clicked, transmits newly entered data to an input file of each module, such as a track jump simulation module 17. A cancellation button 98, if clicked, terminates the currently opened system module 12.

Fig.12 shows the GUI for inputting data on electrical components of the system module 12. To a box 99 is entered a signal indicating with which of the digital system or the analog system the simulation is to be made. To a box 100 are entered filter parameters of the totality of the servo systems, such as tracking, focussing or sled. The number of the filters can be changed optionally. A box 101 is fed with the dc gain of the sled filter. A box 102 is fed with the gain of the low-boost filter for surf jump. A box 103 is fed with a signal indicating whether the surf jump is to be included in the simulation, while a box 104 is fed with an actual limiting value for the digital filter. Buttons 105 to 109 have the same functions as those of the above-mentioned buttons 94 to 98.

Fig.13 shows the GUI for entering data concerning mechanical components of

the system module 12. To a box 110 are entered parameters of the tracking and focussing coils of the bi-axial actuator, such as dc sensitivity, resonance frequency, Q-factor or inductance. The resonance frequency and the corresponding number of the Q-factors can be optionally included in the second resonance. A box 111 is fed with parameters on sled friction. A box 112 is fed with the frequency and the amplitude of vibrations in the vertical direction and in the horizontal direction, while a box 113 is fed with sled motor parameters. Buttons 114 to 118 have the same functions as those of the above-mentioned bottons 94 to 98.

The system module 12, employing the GUI shown in Figs.11 to 13, is able to input parameters of all components making up the optical disc drive.

One Track Jump Module

Fig.14 shows the GUI for inputting data concerning the one track jump module 19 shown in Fig.2. A box 119 is fed with parameters, such as driving voltage or time necessary for one track jump. It is also possible for plural values to be fed to each sub-box of the box 119. A box 120 is fed with parameters of a braking circuit after one track jump, while a box 121 is fed with other parameters concerning one track jump. Buttons 122 to 126 have the same functions as those of the above-mentioned buttons 94 to 98.

2N Track Jump Module

Fig.15 shows the GUI for inputting data on the 2N track jump module 20 shown in Fig.2. A box 127 is fed with parameters, such as driving voltage and time, required

for 2N track jump. It is possible for plural data to be entered to respective sub-boxes of the box 127. A box 128 is fed with parameters of the braking circuit after 2N track jump, while a box 129 is fed with other parameters for 2N track jump. Buttons 130 t0 134 have the same functions as those of the above-mentioned buttons 94 to 98.

2N Track Jump Module

Fig.16 shows the GUI for inputting data on the fine search module 21 shown in Fig.2. A box 135 is fed with parameters, such as driving voltage and time, required for fine search. It is possible for plural data to be entered to respective sub-boxes of the box 135. A box 136 is fed with parameters of the braking circuit after fine search, while a box 129 is fed with other parameters for fine search. Buttons 138 to 142 have the same functions as those of the above-mentioned buttons 94 to 98.

M Track Jump Module

Fig.17 shows the GUI for inputting data on the M track jump module 22 shown in Fig.2. A box 143 is fed with parameters, such as driving voltage and time, required for M track jump. It is possible for plural data to be entered to respective sub-boxes of the box 135. A box 144 is fed with parameters of the braking circuit after M track jump, while a box 145 is fed with other parameters for M track jump. Buttons 146 to 150 have the same functions as those of the above-mentioned buttons 94 to 98.

The track jump modules 18 to 21 are fed with the necessary information, using the GUI shown in Figs.14 to 17, and calculate the OP operation at the time of track jump in accordance with the processing flow which will be explained subsequently in

detail.

Tolerance Simulation Module

Figs.18 to 20 show the GUI for entering data concerning the tolerance simulation module 18 shown in Fig.2.

Fig.18 shows the GUI for entering data on the OP tolerance at the time of measurement of one track jump. A box 151 is fed with jump parameters, and may be fed with one or more values. A box 152 is fed with the actuator sensitivity, resonance frequency and with the Q-factor. Buttons 153 to 157 have the same functions as those of the above-mentioned buttons 94 to 98.

Fig.19 shows the GUI for inputting data concerning the tolerance of the OP at the time of measuring the 2N track jump. The box 158 is fed with jump parameters. The box 158 may be fed with one or more values. A box 159 is fed with the actuator sensitivity, resonance frequency and with the Q-factor. Buttons 160 to 164 have the same functions as those of the above-mentioned buttons 94 to 98.

Fig.20 shows the GUI for inputting data concerning the tolerance of the OP at the time of measuring fine search. A box 166 is fed with jump parameters. The box 165 may be fed with one or more values. A box 166 is fed with the actuator sensitivity, resonance frequency and with the Q-factor. Buttons 167 to 171 have the same functions as those of the above-mentioned buttons 94 to 98.

The simulation device 1 of the present embodiment uses the GUI shown in Figs.3 to 20 to set parameters for servo control for simulation, parameters for sled and

parameters for an optical disc. The processing as later explained is executed to compute the OP operation to make simulation for the OP.

Simulation Processing Sequence

Based on the parameters, set by the respective GUIs as described above, the processing sequence for the respective modules, stated in the form of linear programming simulating the OP operation, is hereinafter explained.

(Sled Model Module (least square method))

Fig.21 shows the flowchart of the sled model module (least square method) 13 which is configured for finding parameters for the sled which has not been determined in the system module 12.

First, in the sled model module (least square method) 13, parameters of components making up the optical disc drive are read at step S201 from the system module 12. At step S202, empirically acquired data is read from another data file. At step S201, the values of the status vectors, such as the values of the position, velocity and voltages, are initialized. Usually, the initial value is 0. At step S204, the voltage value and the time (impulse time) of the sled voltage are set (here, a rectangular voltage is applied as the sled voltage). At step S205, a plant module, which will be explained subsequently in detail, is recalled, and calculates respective status vectors of the OP in a unit time (one sampling period). At step S206, it is checked whether or not calculations have been made until the impulse time is reached. If the result is negative, processing reverts to step S204 to compute the OP operation during the next

unit time to repeat the processing until the impulse time is reached. If the impulse time is reached, processing transfers to step S207 to set the sled voltage to 0. At step S208, the plant module is again recalled and calculates the respective status vectors of the OP in the unit time (sampling time). At step S210, it is checked whether or not the sled voltage is 0. If the result is negative, processing reverts to step S207 to calculate the respective status vectors of the OP during the next unit time. This processing is repeated until the sled voltage is again equal to 0. If the sled voltage is 0, processing transfers to step S210. If there is any non-simulated condition, processing reverts to step S203 to repeat the processing for the non-simulated condition. If the operation has been simulated for the totality of the conditions, processing transfers to step S211, where square errors of the simulated OP operations and the OP operations are calculated on the basis of the test conditions. At step S212, it is checked whether or not the square errors have been calculated for the totality of the parameters defined for the sled. If there is any parameter the square errors for which has not been calculated, processing reverts to step S203 to repeat the processing for the parameters. If the square error has been computed for the totality of the parameters, processing transfers to step S213 to check whether or not the least square error has been detected. If the result is negative, the processing reverts to step S203 to repeat the processing from step S203 to step S212 for new parameters. If the least square error has been detected, the corresponding sled parameters are saved at step S214 in the data file.

Free Vibration Module

Fig.22 shows the flowchart of the free oscillation module 15 configured for simulating the operation of an OP, the servo for which has been disengaged, using parameters determined in the system module 12.

First, the free oscillation module 15 reads parameters of components of an optical disc drive from the system module 12 at step S215. At step S216, the initial OP position and the simulation time etc are read. At step S217, the status vectors (positions, velocity, voltages etc) are initialized. At step S218, the disturbances in the unit time are calculated. At step S219, the values of the totality of voltages supplied to the OP are set to 0. At step S220, the plant module is recalled to compute the status vectors of the OP in unit time. At step S221, it is checked whether or not the simulation time has come to an end. If the simulation time has not come to an end, processing reverts to step S218 to repeat the processing as from this step S218. If the processing has come to an end, the status vectors of the OP are saved chronologically as the simulation result of the OP in the servo disengaged state.

Focussing ON Module

Fig.23 shows the flowchart of the focussing ON module 16 shown in Fig.2. The focussing ON module 16 is configured for simulating the OP in the focussing search state and the operation in the vertical direction of the OP in the focussing servo engaged state.

The focussing ON module 16 reads out at step S223 the parameters of components making up the optical disc drive. At step S224, the results of simulation

of the OP in the servo disengaged state, obtained by the free oscillation module 15, are read at step S222. At step S225, the focussing search voltage and the simulation time etc are read. At step S226, the vibration start time in the initial position of the OP is selected. At step S227, the sine wave focussing search voltage is applied to the actuator. At step S228, the amount of disturbance in the unit time is calculated. At step S229, the plant module is recalled to calculate the status vectors of the OP in the unit time (sampling period). At step S231, it is checked whether or not the bi-axial actuator has reached the just focus position. If the bi-axial actuator has not reached the just focus position, processing reverts to step S227 to repeat the processing as from this step S227. If the bi-axial actuator has reached the just focus position, processing transfers to step S231. At step S231, the focussing voltage is computed from the focussing error signals at the same time as the status vectors of the OP when the focussing servo is turned on are computed. At step S232, it is checked as to whether or not the focussing error signals have exceeded a threshold value. If the focussing error signals have exceeded the limiting value, processing reverts to step S227 to repeat the processing as from this step S227. If the focussing error signals have not exceeded the limiting value, that is if the focussing is satisfactory, processing transfers to step S233. At step S233, it is checked whether or not the simulation time has come to an end. If the simulation time has not come to an end, processing reverts to step S231 to repeat the processing as from this step S231. If the simulation time has come to an end, the status vector of the OP is stored chronologically as the OP results of

simulation, with the focussing servo turned on.

Track Jump Simulation Module

Fig.24 shows the flowchart of the track jump simulation module 17 of Fig.2. The track jump simulation module 17 is configured for simulating the operation of the OP in the horizontal direction at the time it effects various track jumps.

First, the track jump simulation module 17 reads parameters of the components making up the optical disc drive at step S235 from the system module 12. At step S236, it is checked whether or not the simulation is a new one. That is, it is checked whether or not the results of simulation of the focussing ON module 16 are to be taken into account. If the simulation is a new one, processing transfers to step S238, and effects the simulation on the assumption that there is no vertical movement. At step S237, the status vector obtained by the focussing ON module 16 is read at step S234. The focussing search voltage and the simulation time etc are read at step S238. At step S239, the vibration start time etc at the initial position is selected. At step S240, the initial status vector at the selected vibration start time is set. At step S241, the track jump type is determined and the OP operation at the timing of the track jump as determined is simulated. Specifically, the sub-module concerning the required track jump is recalled to calculate the status vector of the OP in the unit time (one sampling period).

The track jumps here are comprised of one track jump for effecting one track jump for effecting one track jump, a 2N track jump for effecting plural track jumps,

a fine search for effecting jump so that the frequency of the focussing error signals will be constant, that is so that the pickup will be moved at a constant velocity, and a M track jump for effecting jumps as the deviation between the sled and the bi-axial actuator will be eliminated, that is as the center servo is engaged. For effecting one track jump, the one track jump module as later explained is recalled. For effecting the 2N track jump, the 2N track jump module, as later explained, is recalled. For effecting fine search, the fine search module, as later explained, is recalled. Finally, for effecting M track jump, the M track jump module, as later explained, is recalled.

If, at this step 241, the track jump is simulated, and the OP is moved to a pre-set track, processing reverts to step S242.

At step S242, a braking circuit module, as later explained, is recalled, and the status vector of the OP when the sled and the bi-axial actuator are lowered in velocity to make a halt on the pre-set track at step S243 is calculated. At step 243, it is checked whether or not the jump has been completed up to the track of jump destination. If the jump has not been completed up to the track of jump destination, processing reverts to step S241 to repeat the processing as from this step S241. If at step S244 the jump has been completed up to the track of jump destination, the OP status vector, representing the results of the simulation of the OP which has effected track jump, is saved chronologically.

Tolerance Simulation Module

Fig.25 shows a flowchart of the tolerance simulation module 18 of Fig.2. The

tolerance simulation module 18 is configured for simulating tracking characteristics for plural OPs to find the production tolerance at the time of OP manufacture.

First, at step S245, the tolerance simulation module reads parameters of components that make up the optical disc drive from the system module 12. At step S246, the initial status vector at the selected vibration start time is set. At step S247, characteristics at the simulation start time of an OP are set. At step S248, the tolerance simulation module as later explained is recalled to compute the status vector of the OP in the tracking servo engaged state. At step S249, the type of the track jump is set and the operation of the OP effecting the so-set track jump is simulated. Specifically, the sub-module concerning the requried track jump is recalled to compute the OP status vector in a unittime (one sampling period).

The track jumps here are comprised of one track jump for effecting one track jump for effecting one track jump, a 2N track jump for effecting plural track jumps, and a fine search for effecting jump so that the frequency of the focussing error signals will be constant, that is so that the pickup will be moved at a constant velocity. For effecting one track jump, the one track jump module as later explained is recalled. For effecting the 2N track jump, the 2N track jump module, as later explained, is recalled. Finally, for effecting fine search, the fine search module, as later explained, is recalled.

If, at this step 249, the track jump is simulated, and the OP is moved to a pre-set track, processing reverts to step S250.

At step S250, a braking circuit module, as later explained, is recalled and the

status vector of the OP when the sled and the bi-axial actuator are lowered in velocity to make a halt on the pre-set track at step S243 is calculated. At step S251, it is checked whether or not the jump has been completed up to the track of jump destination. If the jump has not been completed up to the track of jump destination, processing reverts to step Socket for an IC 249 to repeat the processing as from this step Socket for an IC 249. If the jump has been completed up to the track of jump destination, processing transfers to step S252 to check whether or not simulation has been completed for all OPs. If the jump has not been completed up to the track of jump destination, processing transfers to step S247 to newly set the next characteristics of the OP to repeat the processing as from step S247. If the processing for the totality of the OP characteristics is completed, the totality of the OP status vectors are chronologically saved to indicatethe results of the simulation of the OP to show the results of the simulation of the OP which has effected track jump.

One Track Jump Module

Fig.26 shows the flowchart of the one track jump module. This one track jump module is a sub-module read out by the track jump simulation module 17 of Fig.24 and the tolerance simulation module 18 of Fig.25. This one track jump module is used for simulating track jump for one track and finds the respective status vectors of the OP at this time.

First, the one track jump module recalls an optical module used for simulating the track jump for one track, and finds the respective status vectors of the OP at this

time.

Firt, at step S254, the one track jump module recalls the optical module, which will be explained subsequently in detail, to compute the tracking error signals and the focussing error signals. At step S255, the filter module, which will be explained subsequently in detail, is recalled to perform by-pass filter calculations on the tracking error signals computed at step S254. At step S256, the filter module is recalled, the input signal is set to 0, a kick voltage to be supplied to the bi-axial actuator is superimposed on the input and the output to execute low boost filter calculations. At step S257, the plant module is recalled to compute the OP status vector in the unit time (one sampling period). At step S258, it is checked whether or not the blind time has elapsed. If the blind time has not elapsed, processing reverts to step S254 to repeat the processing as from this step S254. If the blind time has not elapsed, processing transfers to step S259. At this step S259, it is checked whether or not the results of high-pass filtering has crossed zero. If the results cross zero, processing transfers to step S260 and, if otherwise, processing reverts to step S254 to repeat the processing as from this step S254. At step S260, the optical module is recalled to compute the tracking error signals and the focussing error signals. At step S262, the filter module is recalled to execute high-pass filtering on the tracking error signals computed at step S260. On the other hand, at step S262, the filter module is recalled to perform by-pass filter calculations on the tracking error signals computed at step S260. At step S262, the filter module is recalled, the input signal is set to 0, a kick voltage to be supplied

to the bi-axial actuator is superimposed on the input and the output to execute low boost filter calculations. At step S263, the plant module is recalled to compute the OP status vector in the unit time (one sampling period). At step S264, it is checked whether or not the reverse time has elapsed. If the reverse time has not elapsed, processing reverts to step S260 to repeat the processing as from this step S260. If the reverse time has elapsed, the status vector as found and the high-pass filter computed tracking error signals are delivered to the main module which has recalled this one track jump module.

2N Track Jump Module

Fig.27 shows the flowchart of the 2N track jump module. This 2N track jump module is a sub-module read out by the track jump simulation module 17 of Fig.24 and the tolerance simulation module 18 of Fig.25. This 2n track jump module is used for simulating track jumps for plural tracks and finds the respective status vectors of the OP at this time. This 2N track jump module computes the OP movement prevailing when the kick voltage is applied to the sled, with the tracking servo remaining engaged.

First, at step S265, the 2N track jump module sets the kick voltage in the forward direction to be supplied to the sled. At step S266, a kick D module, which will be explained subsequently in detail, is recalled to compute the status vector of the OP prevailing when the kick voltage is applied to the sled, with the tracking servo remaining engaged. At step S267, the mode setting is so made that the sled will come to a standstill when the Nth track is detected (mode 1). At step S268, a constant

voltage kick module, which will be explained subsequently in detail, is recalled to compute the status vector of the OP when the constant voltage is supplied to the sled and to the bi-axial actuator. At this time, the constant voltage kick module is set to the mode 1 and halts the supply of the kick voltage on detection of the Nth track. At step S269, the mode setting is made so that the sled will be halted when the pre-set traverse time (overflow C) has elapsed (mode 2). At step S270, the constant voltage kick module is recalled to compute the OP status vector when the constant voltage is supplied to the sled and to the bi-axial actuator. At this time, the constant voltage kick module is set to the mode 2, such that, when the pre-set traverse time (overflow C) has elapsed, the supply of the kick voltage is terminated. At step S272, the kick D module is recalled to compute the status vector of the OP prevailing when the kick voltage is applied to the sled, with the tracking servo remaining engaged. The status vector as found and the high-pass filter computed tracking error signals are delivered to the main module which has recalled this one track jump module.

Fine Search Module

Fig.28 shows the flowchart of the fine search module which is a sub-module read out by the track jump simulation module 17 of Fig.24 and by the tolerance simulation module 18 of Fig.25. This fine search module is used when simulating the track jump for which tracking error signals will be produced at a constant frequency. The fine search module finds the status vectors of the OP at this time. This fine search module computes the OP movement when the kick voltage is applied to the sled, with

the tracking servo remaining engaged.

First, the tolerance simulation module sets at step S273 the kick voltage in the forward direction to be supplied to the sled. At step S274, the kick D module is recalled to compute the OP status vector prevailing when the kick voltage is applied to the sled, with the tracking servo remaining engaged. At step S275, the frequency of the tracking error signals detected by searching (first frequency) is set. At step S276, a tracking error frequency control module, which will be explained subsequently in detail, is recalled to compute the OP status vector when the tracking error signals are of a pre-set frequency (first frequency). At step S277, the frequency of the next tracking error signals (second frequency) is set. At step S278, the tracking error frequency control module is recalled to compute the OP status vector when the tracking error signals are of another pre-set frequency (second frequency). At step S279, the kick voltage in the reverse direction, to be supplied to the sled, is set. At step S280, the kick D module is recalled to compute the OP status vector prevailing when the kick voltage is applied to the sled, with the tracking servo remaining engaged. The status vector thus found is delivered to the main module which has recalled this one track jump module.

M Track Jump Module

Fig.29 shows the flowchart of the M track jump module which is a sub-module read pout by the track jump simulation module 17 of Fig.24. This M track jump module is used for simulating the track jump in which the bi-axial actuator is

positioned at the sled center, and finds the respective status vectors of the OP at this time. This M track jump module computes the OP movement prevailing when the track jump is effected, with the center servo in the engaged state.

At step S281, the M track jump module recalls the optical module to compute tracking error signals, focussing error signals and mirror signals. The mirror signals represent deviation of the bi-axial actuator. At step S282, it is checked whether or not center servo needs to be applied. If there is no such necessity, the M track jump module sets the voltage furnished to the bi-axial actuator to 0 to proceed to step S245. If there is such necessity, the M track jump module proceeds to step S283 to recall the filter module to compute low-range filtering and low-boost filtering computations for the actuator deviation in order to compute the voltage furnished to the bi-axial actuator. At step S284, the M track jump module recalls the plant module to compute the status vector of the OP in a unit time (one sampling period). At step S285, the jump mode is checked. If the jump mode is the mode 1, the M track jump module proceeds to step S286 and, if the jump mode is the mode 2, the M track jump module proceeds to step S287. At step S286, it is checked whether or not the Nth track has been reached. If the Nth track has not been reached, the M track jump module reverts to step S281 to repeat the processing as from this step S281. If the Nth track has been reached, the M track jump module delivers the status vector as found out to the main module which has recalled this M track jump module.

Tracking Servo Module

Fig.30 shows the flowchart of the tolerance simulation module which is read by the tolerance simulation module 18 of Fig.25. This tolerance simulation module finds the respective status vectors of the OP with the tracking servo and the sled servo turned on.

First, the tolerance simulation module recalls the optical module at step S288 to compute the tracking error signals and the sled error signals. At step S289, the tolerance simulation module recalls the filter module to compute the voltage supplied to the bi-axial actuator. At step S290, the tolerance simulation module is recalled to make sled filter computations for the sled error signals to compute the voltage supplied to the sled. At step S291, the tolerance simulation module recalls the plant module to compute the status vector of the OP in a unit time (one sampling period). At step S292, it is checked whether or not the simulation time has elapsed. If the simulation time has not elapsed, the tolerance simulation module reverts to step S288 to repeat the processing as from this step S288. If the simulation time has elapsed, the tolerance simulation module delivers the status vector as found out to the main module which has recalled the tolerance simulation module.

Kick D Module

Fig.31 shows the flowchart of the kick D module which is a sub-module read out by the.2N track jump module of Fig.27 and the fine search module of Fig.28. This kick D module finds respective status vectors of the OP when the kick voltage is applied to the sled.

First, the kick D module recalls the optical module at step S293 to compute the tracking error signals and the sled error signals. At step S294, the kick D module recalls the filter module to perform filtering computations of the tracking filter to compute the voltage to be furnished to the bi-axial actuator. At step S295, the kick D module computes the pre-set constant voltage to be supplied to the sled. At step S295, the kick D module recalls the plant module to compute the status vector of the OP in a unit time (one sampling period). At step S296, the kick D module checks whether or not the simulation time has elapsed. If the simulation time has not elapsed, the kick D module reverts to step S293 to repeat the processing as from this step S293. If the simulation time has elapsed, the kick D module delivers the status vector as found out to the main module which has recalled the kick D module.

Constant Voltage Kick Module

Fig.32 shows the flowchart of a constant voltage kick module which is a sub-module read out by the 2N track module of Fig.27. This constant voltage kick module finds the respective status vectors of the OP with the kick voltage being supplied to the bi-axial actuator and to the sled.

First, the constant voltage kick module recalls the optical module at step S298 to compute the tracking error signals and the sled error signals. At step S299, the constant voltage kick module computes the pre-set constant voltage to be supplied to the sled. At step S301, the constant voltage kick module recalls the plant module to compute the status vector of the OP in a unit time (one sampling period). At step S302,

the constant voltage kick module checks the jump mode. If the jump mode is the mode 1, the constant voltage kick module proceeds to step S303 and, if jump mode is the mode 2, the constant voltage kick module proceeds to step S304. At step S303, the constant voltage kick module checks whether or not the Nth track has been reached. If the Nth track has not been reached, the constant voltage kick module reverts to step S298 to repeat the processing as from this step S298. If the Nth track has been reached, the constant voltage kick module delivers the status vector as found out to the main module which has recalled the constant voltage kick module. On the other hand, the constant voltage kick module checks at step S304 whether or nor the overflow C has been reached. If the overflow C has not been reached, the constant voltage kick module reverts to step S298 to repeat the processing as from this step S298. If the overflow C has been reached, the constant voltage kick module delivers the status vector as found out to the main module which has recalled the constant voltage kick module.

Tracking Error Frequency Control Module

Fig.33 shows the flowchart of a tracking error frequency control module which is a sub-module read out by the fine search module of Fig.28. This tracking error frequency control module finds the respective status vectors of the OP in case of frequency controlling of the tracking error signals.

First, the tracking error frequency control module recalls the optical module at step S305 to compute the tracking error signals and the focussing error signals. At step

S306, the tracking error frequency control module checks whether or not the frequency of the tracking error signals is too low. If this frequency is too low, the tracking error frequency control module proceeds to step S307 and, if otherwise, to step S309. At step S307, the tracking error frequency control module sets the kick voltage in the forward direction to be supplied to the bi-axial actuator. At step S308, the tracking error frequency control module sets kick voltage in the forward direction to be suppliedto the sled. At step S309, the tracking error frequency control module sets the kick voltage in the reverse direction to be supplied to the bi-axial actuator. At step S310, the tracking error frequency control module sets the kick voltage in the reverse direction to be supplied to the bi-axial actuator. At step S311, the tracking error frequency control module recalls the plant module to compute the status vector of the OP in a unit time (one sampling period). At step S312, the tracking error frequency control module checks whether or not a pre-set number of tracks has been reached. If the pre-set number of tracks has not been reached, the tracking error frequency control module reverts to step S266 to repeart the processing as from this step S266. If the pre-set number of tracks has been reached, the tracking error frequency control module delivers the status vector as found out to the main module which has recalled the tracking error frequency control module.

Braking Circuit Module

Fig.34 shows the flowchart of a braking circuit module, which is a sub-module read out by the track jump simulation module 17 of Fig.24 and the tolerance simulation

module 18 of Fig.25. This plant module finds respective status vectors of the OP at the time of the end of track jump.

First, the braking circuit module recalls the optical module at step S313. This optical module computes mirror signals representing the deviation of the tracking error signals and the bi-axial actuator. At step S314, the braking circuit module recalls the filter module to perform high-pass filtering computations on the tracking error signals. At step S315, it is checked whether or not the results of high-pass filtering crosses 0 and moreover the mirror signal is high. The mirror signal is low and high if the laser spot is on the track ore between tracks, respectively. If the results of check of these two points are affirmative, the braking circuit module proceeds to step S316 and, if otherwise, it proceeds to step S317. At step S316, the filter module is recalled to perform surf filter computations, that is low boost filtering computations, on the results of high-pass filtering computations. The input signal subjected to filtering computations is 0, with the results of the computations as the output signal being the voltage supplied to the bi-axial actuator. At step S317, the filter module is recalled to effect tracking filtering computations on the results of the high-pass filtering computations. On the other hand, it is checked at step S318 whether or not the tracking servo is operating properly based on the results of step S314. That is, it is checked whether or not the tracking error signals are smaller than a pre-set value. If the tracking error signals are not smaller than a pre-set value, that is if the tracking servo is not operating properly, the braking circuit module proceeds to step S319,

whereas, if the tracking error signals are smaller than a pre-set value, that is if the tracking servo is operating properly, the braking circuit module proceeds to step S321. At step S319, it is checked whether or not the time during which sled servo is operating has cometo a close. If the time has not come to a close, the braking circuit module proceeds to step S321 and, if otherwise, to step S320. At step S320, the sled voltage is set to 0. At step S321, the filter module is recalled to perform sled servo filtering computationson the tracking error signals or on the bi-axial actuator voltage. The results of the computations, as an output signal, represents the sled voltage. At step S322, the plant module is recalled to compute the respective status vectors of the OP in a in a unit time (one sampling period) based on the bi-axial actuator voltage or the sled voltage found at steps S316, S317, S320 or S321. At step S323, it is checkes whether or not the simulation time has come to a close. If the simulation time has not come to a close, the braking circuit module reverts to step S313 to repeat the procesinhg as from this step S313. If the simulation time has come to a close, the braking circuit module delivers the status vector as found out to the main module which has revoled the braking circuit module.

Plant Module

Fig.35 shows the flowchartr of the plant module, which is a sub-module read out by the sled model module (least square method) 13 of Fig.21, free oscillation module 15 of Fig.22, focussing ON module 16 of Fig.23, one track jump module of Fig.26, M track jump module of Fig.29, tolerance simulation module of Fig.30, kick D module

of Fig.31, constant voltage kick module of Fig.32, tracking error frequency control module of Fig.33 and the braking circuit module of Fig.34. This plant module finds respective status vectors based on respective input parameters.

This plant module computes the operation in the horizontal direction of the OP by processing from step S324 to step S329, while computing the operation in the vertical direction of the OP by processing from step S330 to step S333.

At step S324, the position in the horizontal direction of the OP when the optical disc drive has been moved by vibrations from outside is computed. At step S325, it is checked whether or not the sled and the gear are contacted with each other. At step S326, degree-one integration is used to compute the sled operation in a unit time. For this computation, the above-mentioned equation (11) is used if the sled and the gear are contacted with each other and, if otherwise, the above-mentioned equations (9) and (10) are used. At step S326, it is also determined whether or not the sled and the gear have collided against each other in a unit time. For this decision, the law of conservation of the momentum taking into account the non-elastic collision is used. It is also determined whether or not the sled and the gear are separated away from each other in the next unit time. For this decision, the Newton's third law of motion is used to check if the directions of motion are reversed. At step S327, the operation in the horizontal direction of the bi-axial actuator due to vibrations and the voltage is computed using the above-mentioned equations (1) and (2). The correct solution is found using an eigenvalue. The degree-two resonance frequency is equivalent to the

digital sampling frequency (which also is deemed to be a numerical figure). At step S328, it is checked whether or not the new position of the bi-axial actuator has exceeded the position of the maximum possible distance of movement. If the position of the maximum possible distance of movement is exceeded, the new position of the bi-axial actuator is again set to the maximum possible distance of movement so that the bi-axial actuator voltage will be equal to the sled voltage. At step S329, new status vectors are found from the new OP movement and voltage values, obtained in the above process.

At step S330, the OP position in the vertical direction when the optical disc drive has been moved due to vibrations from outside is computed. At step S331, the operation of the bi-axial actuator in the vertical direction due to vibrations and the voltage is computed using the above-mentioned equations (1) and (2). The correct solution is found using an eigenvalue. The degree-two resonance frequency is equivalent to the digital sampling frequency (which also is deemed to be a numerical figure). At step S332, it is checked whether or not the new position of the bi-axial actuator has exceeded the position of the maximum possible distance of movement. If the position of the maximum possible distance of movement is exceeded, the new position of the bi-axial actuator is again set to the maximum possible distance. At step S333, new status vectors are found from the new OP movement and voltage values obtained by the above process.

The status vector as found out is delivered to the main module which has

recalled the plant module.

Optical Module

Fig.36 shows the flowchart of the optical module, which is the sub-module read out by the one track jump module of Fig.26, M track jump module of Fig.29, tolerance simulation module of Fig.30, kick D module of Fig.31, constant voltage kick module of Fig.32, tracking error frequency control module of Fig.33, and the braking circuit module of Fig.34. This optical module finds the tracking error signals, mirror signals, focussing error signals and the pull-in signals based on the OP positions in the horizontal direction and in the vertical direction. The mirror signals indicate the amount of offset between the bi-axial actuator and the sled, that is how much the bi-axial actuator is offset from the sled center.

This plant module computes at the steps S334 to S340 the error signals (that is tracking error signals and the mirror signals) in the horizontal direction of the OP, while computing at the steps S341 to S346 the error signals in the vertical direction of the OP (that is the focussing error signals and the pull-in signals).

At step S334, the OP position in the horizontal direction when the optical disc drive is moved due to vibrations from outside is computed. At step S335, it is checked whether or not the laser spot is on the disc. If the laser spot is on the disc, the plant module proceeds to step S336 and, if otherwise, to step S340. At step S336, the track movement due to eccentricity is computed. At step S337, the track movement at the time of reproduction is computed. At step S337, the plant module computes changes

in THE (EF balance) due to deviation of the bi-axial actuator from the sled center. At step S339, the tracking error signals and the focussing error signals are computed. At step S340, the tracking error signals and the focussing error signals are set to 0.

At step S341, the OP position in the vertical direction when the optical disc drive has been moved due to vibrations from outside is computed. At step S342, it is checked whether or not the laser spot is on the disc. If the laser spot is on the disc, the plant module proceeds to step S343 and, if otherwise, it proceeds to step S346. At step S343, the new OP position in the vertical direction, caused by blooming, is computed. At step S344, disc movement when the disc is not planar is computed. At step S345, the focussing error signals and the tracking error signals are computed. At step S346, the focussing error signals and the tracking error signals are set to 0.

The tracking error signals, mirror signals, focussing error signals and the pull-in signals, thus found out, are delivered to the main module which has recalled the optical module.

Filter Module

Fig.37 shows the flowchart of the filter module which is a sub-module read out by a module executing filtering computations. The filter module executes filtering computations for the low boost filter module, adapted for performing filtering computations of plural stages, a high boost filter, a low-pass filter and a high-pass filter.

First, the filter module at step S347 sets the filter types. At step S348, the filter

module executes digital filtering computations on the input signal in accordance with "$Y_{n+1} - bY_n = X_{n+1} - aX_n$". At step S349, it is further checked whether or not filtering computations are to be executed further. If the filtering computations are to be executed further, the filter module reverts to step S347 to repeat the processing as from this step S347. If the filtering computations are not to be executed further, the filter module at step S350 performs bit quantization of the filtering-processed output signal. The filtering-processed and bit-quantized values are delivered to the main module which has recalled the filter module.

The simulation device 1 of the preferred embodiment computes the OP operation, using the processing shown in the flowchart of Figs.21 to 37, to effect a variety of simulations.

Display of Results of Simulation

The results of simulation of the OP operations in each module are explained with reference to the output contents of the simulation device 1. The results of experiments are also shown in the drawings to verify the results of simulation by the simulation device 1.

Figs.38 to 41 show an example of a graph indicating the results of simulation of the OP operation by the focussing ON module 16.

In Fig.38, which is a graph showing the movement of the bi-axial actuator at the time of focussing search, the ordinate and the abscissa denote the movement in the vertical direction of the bi-axial actuator and time, respectively. If the movement of

the bi-axial actuator on effecting focussing search by the focussing ON module 16 is simulated, the curves for maximum and minimum values present planar regions when the bi-axial actuator is moved vertically to surpass the maximum possible movable distance, as shown in Fig.38.

In Fig.39, showing a graph showing focussing error signals on focussing pull-in, the ordinate and the abscissa denote focussing error signals and time, respectively. If the focussing error signals on effecting focussing pull-in by the focussing ON module 16 are simulated, the focussing error signals are oscillated significantly in the up-and-down direction ahead of the focussing pull-in point (time point of 0.053 in this figure), after which focussing servo is engaged, as shown in Fig.39.

Fig.40 shows a graph showing the relative position between the bi-axial actuator and the sled at the time of focussing pull-in. Fig.40A shows the relative position between the bi-axial actuator and the sled and time on the ordinate and on the abscissa, respectively. Fig.40B shows the respective positions of the bi-axial actuator and the sled and the time on the ordinate and on the abscissa, respectively. If the movement of the bi-axial actuator on focussing pull-in by the focussing ON module 16 is simulated, the amount of offset between the sled and the bi-axial actuator is initially large and becomes zero on engagement of the focussing servo.

Fig.41 shows a graph showing the focussing drive voltage on focussing pull-in. Fig.41A shows the focussing error signals and time on the ordinate and the abscissa, respectively, while Fig.41B shows the focussing error signals and time on the ordinate

and the abscissa, respectively. The driving voltage on focussing pull-in by the focussing ON module is constant at 0 V until the focussing pull-in point (a time point of 0.4) and thereafter the driving voltage is changed with the focussing error signals.

Fig.42 shows an example of a graph showing the results of simulation of the OP operation at the time of one track jump with the track jump simulation module 17. In Fig.42A, which is a graph showing the tracking driving voltage at the time of one track jump, the tracking driving voltage and the time are plotted on the ordinate and on the abscissa, respectively. Fig.42B is a graph showing tracking error signals at the time of one track jump. If the OP operation during this one track jump is simulated, the driving voltage corresponding to the tracking error signals is supplied to the OP after the driving voltage of one-period of a rectangular driving voltage is supplied to the OP to establish the just-track state.

Fig.43 is a graph showing measured results on actual measurement of the OP operation at the time of one track jump. The graph of Fig.43 shows fluctuations in the tracking error signals and in the driving voltage. It is seen on comparing Figs.42 and 43 that the test results coincide satisfactorily with the results of simulation.

Fig.44 shows an example of the results of simulation of the OP operation at the time of one track jump by the track jump simulation module 17. Fig.44 shows the relation between the voltage value of the tracking driving voltage supplied during this one track jump and the voltage supplying time as the grade-based distribution diagram. The grade is shown with an increasing grade number with increasing stability of the

jump. During one track jump, the jump stability is higher the lower the tracking driving voltage and the shorter the supplying time.

Fig.45 shows the results of measurement of the OP operation which gave the results of distribution of Fig.44. It is seen from comparison of Figs.44 and 45 that the test results coincide with the results of simulation.

Fig.46 shows the amount of OP movement for each grade shown in Fig.44. Specifically, Fig.46A schematically shows the locus of movement of the OP for each grade in case the OP is moved from a track TRK1 to a track TRK2. Fig.46B schematically shows tracking error signals for grade 3, Fig.46C schematically shows tracking error signals for grade 2, Fig.46D schematically shows tracking error signals for grade 1, and Fig.46E schematically shows tracking error signals for grade 0. As may be seen from Fig.46, the higher the grade, the smaller is the amount of OP movement, the smaller are the fluctuations in the tracking error signals, and hence the more stable are the tracking error signals. With grade 0, the OP cannot jump to the next track with one track jump, such that the OP jumps to the second next track.

Specifically, the grading for the overshoot during one track jump is as follows:

overshoot (deviation from the target track)	grade
<1/12	3
1/12 to 1/4	2
1/4 to 1/2	1

>1/2 0 -

Fig.47 shows a typical graph showing the results of simulation of the OP operation at the time of 2N track jump by the track jump simulation module 17. Specifically, Fig.47A is a graph showing the tracking driving voltage at the time of 2N track jump. In this figure, the ordinate and the abscissa denote the tracking driving voltage and the time, respectively. If the OP operation at the time of 2N track jump is simulated, the dc voltage is supplied for a pre-set time to the OP. During this time, traverse signals are detected. After the just-track is reached, the driving signal corresponding to the tracking error signals is supplied to the OP.

In Fig.48, which shows the results of measurement of the actual OP operation at the time of the 2N track jump, fluctuations in the driving voltage and in the tracking error signals are shown. Comparison of Figs.47 and 48 reveals that the test results coincide satisfactorily with the results of simulation.

Fig.49 shows a typical graph showing the results of simulation of the OP operation during fine search by the track jump simulation module 17. In Fig.49, showing the tracking driving voltage at the time of fine search, the ordinate and the abscissa denote the tracking driving voltage and the time, respectively. If the OP operation is simulated at the time of fine search, the driving voltage is perpetually fluctuated, because the OP movement is controlled to a constant velocity.

In Fig.50, which shows the results of measurement of the actual OP operation at the time of fine search, fluctuations in the driving voltage at the time of fine search

are shown. Comparison of Figs.49 and 50 reveals that the test results coincide satisfactorily with the results of simulation.

Fig.51 shows a typical graph showing the results of simulation of the OP operation during plural times of fine search operations by the track jump simulation module 17. Fig.51A shows the tracking driving voltage at the time of fine search. In this figure, the ordinate and the abscissa denote the tracking driving voltage and the time, respectively. Fig.51B shows the graph showing tracking error signals at the time of fine search. If the OP operation at the time of effecting plural times of the fine search operations is simulated, the dc voltage is supplied to the OP for a pre-set time. During this time duration, traverse signals are detected. After the just-track state is reached, the driving voltage corresponding to tracking error signals is supplied to the OP. This sequence of operations is repeated.

Fig.52 shows a certain time band of Fig.51 to an enlarged scale. Specifically, Fig.52A is a graph showing the tracking driving voltage at the time of fine search. In this figure, the ordinate and the abscissa denote the tracking driving voltage and the time, respectively. Fig.52B is a graph showing tracking error signals at the time of track search. In the graph shown in Fig.52, the time range to be enlarged can be set by setting the time from the display state of Fig.51, using a cursor etc.

Fig.53 shows the distribution of the braking time when braking is applied after effecting the track jump in the track jump simulation module 17. Specifically, Fig.53 shows the distribution of the braking time using the relation between the voltage value

of the tracking driving voltage and the voltage value of the sled voltage. The braking time means the time which elapses since the time of jump until standstill, and is a critical value for measuring the stability of jump. The jump with good stability has a short braking time. Using this Fig.53, optimum parameters for a jump can be set. In this type of the contour line distribution diagram, parameters other than those described above can be used as parameters for two jumps.

Fig.54 shows, in a distribution diagram, the rate of frequency fluctuations when fine search is effected by the track jump simulation module 17, that is the rate of offset from the target frequency in the fine search. Specifically, Fig.54 shows the distribution of the rate of frequency fluctuations with the aid of voltage values of the tracking driving voltage and those of the sled voltage. With a jump with high stability, the rate of frequency fluctuations is only small. If Fig.54 is referred to, optimum jump parameters can be set. For two jumps, parameters other than those mentioned above can be used.

Figs.55 and 56 are graphs showing the results of simulation of the accessing time when the fine search is effected by the track jump simulation module 17. In these figures, measured values of experiments for these two simulations, obtained by experiments employing a laser Doppler or an oscilloscope, are also shown. Comparison of the results of simulation to the experimental results indicate satisfactory coincidence between the two.

Figs.57 and 58 show the GUI for data inputting of the sled module (averaging

method) 14. This sled module (averaging method) 14 is a module which, based on the results of the experiment, finds parameters for the sled which were not determined in the system module 12.

To boxes 172, 173 shown in Fig.57 are inputted data obtained by the experiment. If an OK button 174 is clicked, processing for solving two equations and the processing for predicting the sled reaction are executed to compute parameters on the sled. If the first processing fails, a display bar 175a and an OK button 175b are displayed. If this OK button 175b is clicked, the display bar 175a and the OK button 175b are turned off. A setting picture is again displayed to enter data again. If the first processing is done successfully, a graph is displayed in a display region 176 to allow the program to proceed to the second processing. The ultimate results are displayed on a display region 177. This graph shows the predicted sled reaction, along with the desired sled parameters, in comparison with the measured results by the corresponding laser Doppler.

The simulation device 1, embodying the present invention, displays the above graphs, to output the results of simulation to the user.

The simulation device 1, embodying the present invention, as described above, can perform all sorts of tests for the optical pickup of the optical disc automatically under a variety of different conditions. This significantly shortens the time required for investigations or tests.

Also, simulation device 1, embodying the present invention, can predict the

operation of the servo system of the optical disc drive accurately, thereby shortening the time required for investigations and tests to realize more elaborate analyses.

WHAT IS CLAIMED IS:

1. A data processing apparatus comprising:

a computation processing unit for effecting data processing, a storage unit for storing the data processed by said computation processing unit, an input unit for inputting data to said computation processing unit and a display unit for displaying data processed by said computation processing unit, said computation processing unit including

servo control parameter setting means for setting parameters for servo control of an optical disc recording/reproducing apparatus, optical pickup parameter setting means for setting parameters for an optical pickup, sled parameter setting means for setting parameters for a sled, disc parameter setting means for setting parameters for an optical disc, and simulation means for computing the operation of the optical disc recording/reproducing apparatus for simulating said operation based on the parameters as set by respective ones of said setting means.

2. The data processing apparatus according to claim 1 wherein

said servo control parameter setting means sets filter frequencies for tracking servo, focussing servo, sled servo, surf jump servo and center servo, an open-loop cut-off frequency, driver saturation, bit quantization and/or the sampling rate in digital processing as parameters for servo control.

3. The data processing apparatus according to claim 2 wherein said servo control parameter setting means includes means for varying the parameters for servo control.



4. The data processing apparatus according to claim 1 wherein said optical pickup parameter setting means sets the dc sensitivity, resonance frequency, Q-factor, coil inductance, coil resistance and/or the maximum possible movement distance as parameters for the optical pickup.

5. The data processing apparatus according to claim 4 wherein said optical pickup parameter setting means includes means for changing the parameters for the optical pickup.

6. The data processing apparatus according to claim 1 wherein said sled parameter setting means sets the masses, Coulomb friction, viscous friction and the backlash of the sled and a gear, a sled motor constant, sled motor inductance and/or the sled motor resistance as parameters for the sled.

7. The data processing apparatus according to claim 6 wherein said sled parameter setting means includes means for changing parameters for the sled.

8. The data processing apparatus according to claim 1 wherein said disc parameter setting means sets the disc rpm, frequency and harmonics of eccentricity, linear velocity, track pitch, S-curve characteristics, EF balance, RF level, frequency of vibrations from outside in both the horizontal and vertical directions and/or vibrations from outside in both the horizontal and vertical directions, as the parameters for the optical disc.

9. The data processing apparatus according to claim 8 wherein said disc parameter setting means includes means for changing parameters for an optical disc.

* C L M S *

10. The data processing apparatus according to claim 1 wherein said simulation means includes

first means for effecting simulation for servo control;

second means for simulating the operation of the optical pickup subjected to free vibrations;

third means for simulating the operation of the optical pickup when the optical pickup is performing focussing servo control;

fourth means for simulating the operation of the optical pickup when the optical pickup is performing tracking servo control; and

fifth means for finding the tolerance for tracking.

11. The data processing apparatus according to claim 10 wherein said first means effects simulation for servo control based on parameters for servo control and on trial data for servo control.

12. The data processing apparatus according to claim 10 wherein said second means computes the movement of the optical pickup subjected to free vibrations based on the respective parameters to simulate the operation of the optical pickup.

13. The data processing apparatus according to claim 10 wherein said third means computes the movement of the optical pickup when the focussing servo control is going on, based on the respective parameters, to simulate the operation of the optical pickup.

14. The data processing apparatus according to claim 10 wherein said fourth means

* C L M S *

computes the movement of the optical pickup when the tracking servo control is going on, based on the respective parameters, to simulate the operation of the optical pickup.

15. The data processing apparatus according to claim 14 wherein said fourth means simulates the operation of the optical pickup when it is performing one track jump.

16. The data processing apparatus according to claim 14 wherein said fourth means simulates the operation of the optical pickup when it is performing 2N track jump.

17. The data processing apparatus according to claim 14 wherein said fourth means simulates the operation of the optical pickup when it is performing fine search.

18. The data processing apparatus according to claim 14 wherein said fourth means simulates the operation of the optical pickup when it is performing M track jump.

19. The data processing apparatus according to claim 10 wherein said fifth means computes movements of the optical pickup when it is performing tracking servo control to find the tolerance for tracking from data of movements of plural optical pickups.

20. The data processing apparatus according to claim 19 wherein said fourth means computes the movement of an optical pickup performing one track jump to find the tolerance for tracking.

21. The data processing apparatus according to claim 19 wherein said fourth means computes the movement of an optical pickup performing 2N track jump to find the tolerance for tracking.

22. The data processing apparatus according to claim 19 wherein said fourth means

* C L M S *

computes the movement of an optical pickup performing fine search to find the tolerance for tracking.

23. A data processing method comprising the steps of:

setting parameters for servo control of an optical disc recording/reproducing apparatus;

setting parameters for an optical pickup, sled parameter setting means for setting parameters for a sled;

setting parameters for an optical disc; and

computing the operation of the optical disc recording/reproducing apparatus for simulating said operation based on the parameters as set by respective ones of said setting step.

24. The data processing method according to claim 23 wherein

said servo control parameter setting step sets filter frequencies for tracking servo, focussing servo, sled servo, surf jump servo and center servo, an open-loop cut-off frequency, driver saturation, bit quantization and/or the sampling rate in digital processing as parameters for servo control.

25. The data processing method according to claim 24 wherein said servo control parameter setting step includes a step for varying the parameters for servo control.

26. The data processing method according to claim 23 wherein said optical pickup parameter setting step sets the dc sensitivity, resonance frequency, Q-factor, coil inductance, coil resistance and/or the maximum possible movement distance as

* C L M S *

parameters for the optical pickup.

27. The data processing method according to claim 26 wherein said optical pickup parameter setting step includes a step for changing the parameters for the optical pickup.

28. The data processing method according to claim 23 wherein said sled parameter setting step sets the masses, Coulomb friction, viscous friction and the backlash of the sled and a gear, a sled motor constant, sled motor inductance and/or the sled motor resistance as parameters for the sled.

29. The data processing method according to claim 28 wherein said sled parameter setting step includes a step for changing parameters for the sled.

30. The data processing method according to claim 23 wherein said disc parameter setting step sets the disc rpm, frequency and harmonics of eccentricity, linear velocity, track pitch, S-curve characteristics, EF balance, RF level, frequency of vibrations from outside in both the horizontal and vertical directions and/or vibrations from outside in both the horizontal and vertical directions, as the parameters for the optical disc.

31. The data processing method according to claim 30 wherein said disc parameter setting step includes a step for changing parameters for an optical disc.

32. The data processing method according to claim 23 wherein said simulation step includes

a first step for effecting simulation for servo control;

a second step for simulating the operation of the optical pickup subjected to free



vibrations;

a third step for simulating the operation of the optical pickup when the optical pickup is performing focussing servo control;

a fourth step for simulating the operation of the optical pickup when the optical pickup is performing tracking servo control; and

a fifth step for finding the tolerance for tracking.

33. The data processing method according to claim 32 wherein said first step effects simulation for servo control based on parameters for servo control and on trial data for servo control.

34. The data processing method according to claim 32 wherein said second step computes the movement of the optical pickup subjected to free vibrations based on the respective parameters to simulate the operation of the optical pickup.

35. The data processing method according to claim 32 wherein said third step computes the movement of the optical pickup when the focussing servo control is on, based on the respective parameters, to simulate the operation of the optical pickup.

36. The data processing method according to claim 32 wherein said fourth step computes the movement of the optical pickup when the tracking servo control is on, based on the respective parameters, to simulate the operation of the optical pickup.

37. The data processing method according to claim 36 wherein said fourth step simulates the operation of the optical pickup when it is performing one track jump.

38. The data processing method according to claim 36 wherein said fourth step



simulates the operation of the optical pickup when it is performing 2N track jump.

39. The data processing method according to claim 36 wherein said fourth step simulates the operation of the optical pickup when it is performing fine search.

40. The data processing method according to claim 36 wherein said fourth step simulates the operation of the optical pickup when it is performing M track jump.

41. The data processing method according to claim 32 wherein said fifth step computes movements of the optical pickup when it is performing tracking servo control to find the tolerance for tracking from data of movements of plural optical pickups.

42. The data processing method according to claim 41 wherein said fourth step computes the movement of an optical pickup performing one track jump to find the tolerance for tracking.

43. The data processing method according to claim 41 wherein said fourth step computes the movement of an optical pickup performing 2N track jump to find the tolerance for tracking.

44. The data processing method according to claim 41 wherein said fourth step computes the movement of an optical pickup performing fine search to find the tolerance for tracking.

