Description

This invention relates to a servo control system for both track seeking and track following which is usable with a data recording disk file having servo information on either a dedicated servo disk surface or in sectors on a data disk surface.

Disk files are information storage devices which utilise a rotatable disk with concentric data tracks containing the information, a head for reading or writing data onto the various tracks, and an actuator connected by a support arm assembly to the head for moving the head to the desired track and maintaining it over the track centreline during read or write operations. The movement of the head to a desired track is referred to as track accessing or "seeking", while the maintaining of the head over the centreline of the desired track during a read or write operation is referred to as track "following".

The actuator is typically a "voice coil motor" (VCM) which comprises a coil movable through the magnetic field of a permanent magnetic stator. The application of current to the VCM causes the coil, and thus the attached head, to move radially. The acceleration of the coil is proportional to the applied current, so that ideally there is no current to the coil if the head is perfectly stationary over a desired track.

In disk files which have a relatively high density of data tracks on the disk, it is necessary to incorporate a servo control system to maintain the head precisely over the centreline of the desired track during read or write operations. This is accomplished by utilising prerecorded servo information either on a dedicated servo disk or on sectors angularly spaced and interspersed among the data on a data disk. The servo information sensed by the read/write head (or the dedicated servo head if a dedicated servo disk is used) is demodulated to generate a position error signal (PES) which is an indication of the position error of the head away from the nearest track centreline. One type of conventional servo pattern for use with either a sector servo disk or a dedicated servo disk is the quadrature pattern described by Mueller, et al. in IBM Technical Disclosure Bulletin, Vol. 21, No. 2 (February 1978) pp. 804-805. In the quadrature pattern there are four unique track types which repeat so as to form radially repetitive four-track bands of servo information.

During track seeking, when the head is moving across the tracks, the PES is used to generate track crossing pulses. This track crossing information, together with the PES and a signal representing the desired or target track, is used to generate a total error signal. The total error signal is equal to the sum of the PES plus the difference between the position of the target track and the position of the actual track over which the head is located. The total error signal is then used in the servo feedback loop to compute the desired velocity of the head, via a reference velocity trajectory generator, to assure that the head arrives at the target track according to the optimum velocity trajectory to effect a move to the target track in minimum time. The computed velocity is then compared with the estimated velocity from an electronic tachometer to generate a velocity error signal to a power amplifier which in turn applies a control current to the VCM. An electronic tachometer for generating a velocity estimate from inputs of VCM control current and quadrature PES is described in U.S. -A- 4,246,536. In some disk files the estimated velocity is provided by a mechanical tachometer, such as a linear variable differential transformer (LVDT).

During track following, when the head is located within the boundaries of the desired track, the PES alone is used in the servo feedback loop to generate a control signal to the VCM to move the head back to the track centreline.

A description of operation of a general disk file servo control system during track seeking and track following is given by R. K. Oswald in "Design of a Disk File Head-Positioning Servo", IBM Journal of Research and Development, November 1974, pp. 506-512.

In such conventional disk files, the use of track crossing pulses to determine the total error signal during a track seek requires additional costly and complex analog circuitry in the demodulator to generate the track crossing pulses from the PES. More importantly, in the case of disk files which use sector servo data, it is not possible to accurately count track crossing pulses directly from the PES since the head will typically have crossed numerous tracks between PES samples.

During operation of the disk file the VCM is subjected to certain generally constant or very low frequency forces which tend to bias the coil, and thus the attached head, away from the desired position, i.e. the position needed to follow the desired velocity trajectory during track seeking, or the position of the centreline of the desired track during track following. These bias forces are caused by such things as circulating air flow passing the coil and the arm assembly which connects the head to the coil, the movement of the flexible ribbon conductor connecting the coil and arm assembly to the read/write electronics of the disk file, friction between the bearings and guide rails of the actuator, and the gravitational effect on the coil and arm assembly if the radial access direction of the VCM is not perfectly aligned horizontally. In addition to bias forces, there is typically an input voltage offset in the power amplifier which

supplies the control current to the VCM, so that even in the absence of a velocity error signal to the power amplifier, the VCM may experience a non-zero input current.

The bias forces and voltage offset have little effect on the performance of the servo control system during track seeking when the primary contribution to the total force on the actuator is that due to the current in the actuator. However, at the completion of a track seek and during track following, when the head is within approximately one-half track width of the centreline of the target track and when the total error signal is simply the PES, the bias forces and voltage offset are primary contributions to the PES and must be rapidly and effectively compensated by the control signal to the power amplifier to produce current in the VCM to maintain the head over the track centreline.

One technique for rapidly forcing the total error signal to zero during track following is to incorporate an integrator for the PES into the servo feedback loop. This is accomplished by the use of a separate "stiffness" integrator which is switched into the servo feedback loop only during track following. However, use of the switchable stiffness integrator generates an electrical transient which occurs as a result of switching of the integrator when large system bias forces and voltage offset is present. In addition, the stiffness integrator must be switched in at precisely the proper moment. Both the transient caused by switching of the stiffness integrator and switching at the improper time can cause overshoot or undershoot of the head with respect to the centreline of the target track which thus delays the subsequent read or write operation.

An additional problem caused by bias forces in all disk files is that there is a gain in the feedback path around the power amplifier in the presence of a generally constant or very low frequency PES. In the case of disk files which use an electronic tachometer, this is because the electronic tachometer receives as input the VCM control current and the measured PES and, through a combination of control current integration and PES differentiation, estimates the velocity of the head. Thus even if the head is stationary, but the coil and arm assembly is subjected to generally constant or very low frequency bias forces, the electronic tachometer will output a non-zero velocity estimate. In the case of disk files which use a mechanical tachometer, electrical offsets cause a non-zero output of estimated velocity even when the head is stationary.

EPA 0003070 discloses a sampled servo system which uses a physical model of the system to overcome bandwidth constraints. An analog electrical equivalent of the actuator provides predictive coarse positioning, which allows the servo system to operate with a higher effective bandwidth than the frequency of servo sampling would otherwise permit. The problem of bias forces is not discussed.

The invention seeks to provide an improved serve control system.

Accordingly, the invention provides a method for controlling data track seeking and following in a disk file having a disk with serve information thereon defining data track centrelines, a head for reading samples of the servo information during rotation of the disk, an actuator connected to the head and responsive to an input signal for positioning the head to the centreline of a target track during track seeking and maintaining the head over the centreline of the target track during track following, the method comprising the steps of:

generating from the servo information a sampled head position error signal (PES) representative of the position of the head relative to the centreline of the nearest track;

for each PES sample:

computing a measured absolute head position, relative to a fixed reference, from the sampled head position error signal (PES) and a prior predicted absolute head position; and computing an error signal based on the difference between said measured absolute head position and said prior predicted absolute head position;

measuring the input signal to the actuator;

estimating the absolute head position, relative to the fixed reference, and the head velocity, using said error signal, said prior predicted absolute head position, and a prior predicted velocity; estimating the equivalent actuator input signal required to compensate for bias forces acting on the actuator, using a prior predicted bias force equivalent actuator input signal; and estimating the head acceleration as a function of the measured actuator input signal and estimated bias force equivalent actuator input signal;

computing a commanded head velocity as a function of the distance from the estimated absolute head position to the target track; and computing the head velocity error as a function of the difference between the commanded head velocity and the estimated head velocity;

predicting using a state estimator for the subsequent PES sample the absolute head position and the head velocity as functions of prior control signals, the prior estimated absolute head position, the prior estimated head velocity, the prior estimated bias force equivalent actuator input signal and constants representative of physical parameters of the actuator; and also predicting the bias force actuator input signal as a function of the prior estimated bias force actuator input signal;

generating a control signal as a function of the head velocity error, the estimated head acceleration, and the control signal generated for the prior PES sample;

and storing the digital values representative of the control signals, the measured actuator input signal, the estimated head position, the estimated head velocity, the estimated bias force equivalent actuator input signals, and constants representing predetermined physical parameters of the actuator;

and integrating the control signal to provide the input signal to the actuator.

The preferred servo control system receives as input, at discrete sample times, the PES and a digital value representative of the VCM current, and outputs, at discrete sample times, a digital control signal. The digital control signal is converted to an analog control signal and input to an integrating power amplifier which provides the control current input to the VCM.

The digital control signal is generated by a microprocessor attached by a data bus to associated memory devices. As part of the computation of the control signal for each PES sample, the microprocessor computes the measured absolute head position from the PES and an estimate of VCM current equivalent to the amount of current required to compensate for bias forces acting on the actuator. In addition, the microprocessor computes an estimate of the absolute head position relative to a fixed reference and an estimate of the head velocity. A digital velocity trajectory generator provides a value representative of the optimum velocity of the head as a function of the difference between the absolute position of the target track and the estimated absolute head position. A velocity error is then computed as the difference between the computed estimate of head velocity and the optimum velocity from the velocity trajectory generator. The microprocessor also computes an estimate of head acceleration from the measured VCM current and the estimated bias force equivalent VCM current. The estimated head acceleration, together with the velocity error and a value representative of the control signal for the prior PES sample, are used to form the digital control signal.

The estimated absolute head position, head velocity, and bias force equivalent VCM current are computed from respective predicted values of those terms. The predicted values are updated with each PES sample and are functions of, among other things, constants representing the digital sampling time and physical parameters of the VCM, such as frictional effects and force constants. The estimated values of these terms are computed with the use of an error term which is the difference between the computed measurement of absolute head position and the predicted absolute head position.

The estimation of head acceleration is made such that, during track following when the head is generally within one-half track of the centreline of the target track, the average value of the estimated head acceleration is zero. Thus when the head is relatively stationary and the VCM is subjected to bias forces, there is no feedback path around the integrating power amplifier which has a gain in the presence of bias forces.

With the use of the digital servo control system according to the present invention, it is not necessary to measure or estimate track crossings so that the system is fully operable with either a dedicated servo disk or a data disk with sector servo information. The prediction of the absolute head position is made with sufficient accuracy such that the error between the measurement of the absolute head position and the predicted absolute head position is always less than a specific number of tracks. For example, when the servo control system is utilised with a quadrature pattern in which the servo information is radially repetitive in four-track bands, it is only necessary to measure the position of the head within a band without knowing in which particular band the head is located.

The digital servo control system also includes means for computing a value representative of a correction signal to the digital control signal in order to compensate for voltage offsets to the integrating power amplifier. The correction signal is applied to the control signal and updated during track following.

How the invention can be carried out will now be described by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagram of a conventional analog servo control system with a stiffness integrator switchable into the system during track following;

Fig. 2 is a block diagram of a digital servo control system embodying the invention;

Fig. 3 is an illustration of servo signals from a quadrature pattern and the manner in which the signals are compared to identify a specific track in one of the four-track bands in the quadrature pattern;

Fig. 4 is a graphical representation illustrating the function of the state estimator and control signal algorithm of the digital servo control system;

Fig. 5 is a flow chart of the state estimator and control signal algorithm;

Fig. 6 is an illustration of head arrival trajectories for the digital servo control system with and without a switchable stiffness integrator in the presence of a large frictional bias force; and

Fig. 7 is an illustration of a digital integrator in the digital servo control system to compensate for an

input voltage offset to the integrating power amplifier.

The block diagram of Fig. 1 is an illustration of a conventional analog disk file servo control system. A pair of disks 10, 12 are supported on a spindle 14 of the disk file drive motor 16. Each of the disks 10, 12 has two surfaces 20, 22 and 24, 26, respectively. For purposes of this description, surface 20 on disk 10 and surfaces 24, 26 on disk 12 are data recording surfaces. Surface 22 on disk 10 is a dedicated servo surface and contains only prerecorded servo information. The servo information is recorded in concentric tracks and is typically written in such a manner that the intersections of adjacent servo tracks on servo surface 22 are radially aligned with the centrelines of the data tracks on surfaces 20, 24, and 26. The servo information on surface 20 may be the quadrature pattern, as described in the previously cited IBM Technical Disclosure Bulletin.

The specific tracks on the data disks and the servo disk are accessed by heads 30, 32, 34, 36, each of which is associated with a respective disk surface and supported by an associated arm assembly. The heads 30, 32, 34, 36 are attached to a common accessing means or actuator, such as VCM 40. Thus the heads 30, 32, 34, 36 are all maintained in a fixed relationship with each other relative to the radial position on their respective disk surfaces.

The output of the dedicated servo head 32 is supplied to an amplifier 42 and then to a demodulator 44. Demodulator 44 processes the servo information signal from disk surface 22 and demodulates it to generate an analog PES. The PES from demodulator 44 is an indication of the position of servo head 32 away from the nearest servo track centreline, and thus the position of the data heads 30, 34, 36 away from the centrelines of the nearest data tracks on the respective disk surfaces 20, 24, 26. Demodulator 44 also provides a track crossing pulse which is input to a difference counter 46 and, if the servo pattern is a quadrature pattern, a signal (not shown) which identifies one of the four specific track types in the quadrature pattern.

The difference counter 46 also receives a command from the disk file control unit (not shown) indicating the target or desired track, denoted as t_d. With each track crossing by the servo head 32, the track crossing pulse causes the value of t_d stored in difference counter 46 to be decremented. The output from difference counter 46 is passed to a digital-to-analog converter (D/A) 48 which provides an analog value representative of the number of tracks to go to reach the desired track, $t_d - t_a$, where t_a is the nearest actual track position of servo head 32 at the time of the PES measurement.

The generation of track crossing pulses from the PES requires relatively costly and complex circuitry (not shown) in demodulator 44. The servo control system shown in Fig. 1 requires a dedicated servo disk and is not operable with sector servo information since during a track seek the head will typically cross numerous tracks between PES measurements. Thus, if the basic servo control system shown in Fig. 1 is to be operable with sector servo information, then an alternative to direct counting of track crossings must be used to determine the number of tracks to go, $t_d - t_a$.

The value $t_d - t_a$ from D/A converter 48 is then summed in junction 50 with the PES, the output of summing junction 50 being the total error signal representative of the distance-to-go, x_{tg}, to the centreline of the desired track.

The distance-to-go is fed to a velocity trajectory generator (VTG) 54 after addition in summing junction 55 with the output from switch 52. During a track seek, switch 52 is opened and the output of stiffness integrator 53 is reset to zero. The output of summing junction 55 is then only x_{tg}. Within some specified distance from the target track, for example less than one-quarter of a track width, the switch 52 is closed, the reset signal is removed from stiffness integrator 53 and stiffness integrator 53 is allowed to operate. When switch 52 is closed the input to VTG 54 consists of x_{tg} and the integral of x_{tg}. During track following the effect of stiffness integrator 53 on the servo control system is to force the average value of x_{tg} (which is equal to the PES) to zero.

VTG 54 computes a commanded velocity, v_c, based upon the value of x_{tg}. Conventional analog type velocity trajectory generators are typically either diode breakpoint or multiplier circuit implementations, both of which are described and shown as prior art in Figs. 1A and 1B of U. S. -A- 4,486,797.

Located between VTG 54 and VCM 40, as shown in Fig. 1, is a compensator 56 and an integrating power amplifier (IPA) 58. The compensator 56 contains circuitry having specific gain and phase shifting characteristics to assure stability and performance of the overall closed loop system. The output of compensator 56 is the control signal, u, which is directed to IPA 58 where the compensated control signal is integrated and amplified to generate a control current, i, to VCM 40. The control current to VCM 40 is a specific current level to move the coil so that the servo head 32, and thus the data heads 30, 34, 36, are moved with the desired velocity toward the centreline of the desired track.

An electronic tachometer (ETACH) 60 is located in a feedback path around the compensator 56 and IPA 58. ETACH 60 receives as inputs the VCM control current, i, from IPA 58 and the PES from demodulator

44. The output of ETACH 60 is an estimate of the velocity of the head. ETACH 60 provides a signal, v_e, based upon a combination of the differentiated PES and integrated control current i. A more thorough description of ETACH 60 is set forth in the previously cited US -A- 4,246,536. The result of the incorporation of ETACH 60 in the servo feedback loop is that the input to compensator 56 is a velocity error signal, v_{es}, which is the difference between the commanded velocity, v_c, output by VTG 54 and the estimated velocity, v_e, output by ETACH 60.

During track following, if the servo head 32 is stationary but the VCM 40 is subjected to bias forces, ETACH 60 continues to provide a feedback path around the IPA 58 and thus continues to generate a non-zero velocity estimate, v_e.

During a track seek, switch 52 is opened so that stiffness integrator 53 is bypassed. VTG 54 computes the velocity signal, v_c, as a non-linear function of x_{tg} by a reference curve, as explained in the prior art description of the previously cited patent US -A- 4,486,797. The total error signal, x_{tg}, is the sum of the PES and the computed number of tracks to go, $t_d - t_e$. However, near the completion of a seek, when the head has approached to within approximately one-quarter track of the centreline of the desired track, switch 52 is closed, thus switching stiffness integrator 53 into the servo feedback loop. At this time the total error signal, x_{tg}, is simply the PES since the head is now within the track boundaries of the desired track. Stiffness integrator 53 now rapidly drives the total error signal to zero. VTG 54 now provides a velocity command, v_c, which is a linear function of the output from summing junction 55.

The switching of stiffness integrator 53 into the servo loop near the termination of a track seek causes a transient in the velocity command, v_c, which causes overshoot or undershoot of the head with respect to the centreline of the desired track, thus delaying the subsequent read or write operation.

A simplified block diagram of a digital servo control system embodying the present invention is shown in Fig. 2. A microprocessor 80 is connected to a random access memory (RAM) 82 and a programmable read only memory (PROM) 83 via a data bus 84. The disk file control unit 86 is also connected to data bus 84. Control unit 86 provides numerous commands to microprocessor 80, including a signal, t_d, representing the target track, and a signal, RZ, representing a "re-zero" to initialise the servo control system. Not shown in Fig. 2 are address and control lines for microprocessor 80. The analog portion of the servo control system is shown essentially to the right of data bus 84 in Fig. 2.

The signal read by servo head 32 is input to amplifier 42 and then demodulator 44. While the invention can be applied to operation with numerous types of servo patterns and servo signal demodulation techniques, the preferred servo control system will be explained with reference to a quadrature servo pattern. The quadrature pattern on servo surface 22 is demodulated by demodulator 44 in the following manner. First, demodulator 44 receives the quadrature servo signal from amplifier 42 and generates two separate analog waveforms, which are designated primary (PESP) and quadrature (PESQ), as shown in Fig. 2. The analog PESP and PESQ signals from demodulator 44 are sent to analog-to-digital (A/D) converters 88, 89, respectively. The discrete values of PESP and PESQ at any sample time are designated PESP(n) and PESQ(n), where n represents a time index for each digital sample. PESP(n) and PESQ(n) are then used by microprocessor 80 to determine on which of the four tracks in one of the four-track bands of the quadrature pattern the servo head 32 is located. Once that has been determined, then the selection of the correct signal, i.e. either PESP(n) or PESQ(n), is made to determine PES(n). The determination of track type, denoted $t_q(n)$, and PES(n) is made according to the following truth table.

PESP to PESQ Relationship	Track Type, $t_q(n)$	PES(n)
[PESP(n) < PESQ(n)] and [PESP(n) > -PESQ(n)]	0	PESP(n)
[PESP(n) < PESQ(n)] and [PESP(n) < -PESQ(n)]	1	PESQ(n)
[PESP(n) > PESQ(n)] and [PESP(n) < -PESQ(n)]	2	-PESP(n)
[PESP(n) > PESQ(n)] and [PESP(n) > -PESQ(n)]	3	-PESQ(n)

Table 1

The truth table in Table 1 can also be understood by reference to Fig. 3. Fig. 3A represents the PESP and PESQ signals output by demodulator 44 as a function of radial position of servo head 32. Figs. 3B and 3C are the digital values of the two comparisons of PESP(n) to +/- PESQ(n). Fig. 3D is the digital track type signal, $t_q(n)$, computed from the logic of Table 1. In the preferred embodiment $t_q(n)$ and PES(n) are computed by microprocessor 80. Alternatively, Table 1 can be implemented in analog hardware and the resulting track type number, $t_q(n)$, input to data bus 84. Similarly, PESP and PESQ can be selected through analog switches to generate, according to the logic of Table 1, a PES which is then sent to a single A/D converter.

Referring again to Fig. 2, demodulator 44 also provides directly to data bus 84 a one-bit digital signal, GBOD, to indicate that servo head 32 is located over the "guard band outside diameter", i.e. the radially outermost head position in the disk file. This signal is generated from a special code recorded on the radially outermost track on servo surface 22.

IPA 58 provides the analog control current, i(t), to VCM 40 and as feedback to A/D converter 90. A/D converter 90 provides to data bus 84 a digital current sample, i(n), corresponding to the sample of analog current, i(t).

Thus, as shown in Fig. 2, the data inputs to microprocessor 80 of the digital servo control system for purposes of this explanation are control unit commands for target track t_d and re-zero RZ, head position relative to nearest track centreline PES(n), which is determined from PESP(n) and PESQ(n) according to Table 1, VCM control current i(n), and GBOD.

A digital control signal, u(n), is output by microprocessor 80 to a digital-to-analog converter (DAC) 92. As shown in Fig. 2, A/D converters 88, 89, 90 are driven by the same clock input so that the digital sampling of PESP, PESQ and i, all occur simultaneously. The output of the control signal u(n) computed from the digital sample of PESP(n), PESQ(n) and i(n) occurs after a fixed calculation delay time and before the input of the next digital sample of PESP(n+1), PESQ(n+1) and i(n+1). DAC 92 provides the analog control signal, u(t), to IPA 58.

Microprocessor 80 also sends a special inhibit signal to IPA 58. IPA 58 is inhibited when the servo control system is first turned on to prevent any initial signal conditions from causing undesired movement of VCM 40.

The simplified block diagram of Fig. 2 is intended only to represent possible hardware implementation of the digital servo control system. An important feature of the digital servo control system which is not shown in Fig. 2, but which will be explained below, is the manner in which the microprocessor 80 computes the control signal u(n) so as to eliminate the necessity of a stiffness integrator and the adverse effects of a feedback path around the IPA 58 which has a gain in the presence of bias forces.

The microprocessor 80 uses an algorithm, referred to as a state estimator, to estimate absolute head position x_e, head velocity v_e, and head acceleration a_e. The estimated head position, velocity and acceleration for each digital sample n are functions of the predicted head position, velocity and acceleration, the measured head position and the measured VCM current. The predicted head position, velocity and acceleration are updated with each sample and are derived from functions based upon a physical model of the VCM and arm assembly.

The operation of the digital servo control system, and in particular the state estimator, will be explained with reference to the graphical representation of Fig. 4. It should be noted that the items in the non-analog portions of Fig. 4, such as the summing junctions, are not discrete hardware components but merely graphical aids to assist in understanding the computations performed by microprocessor 80.

As shown in Fig. 4, the state estimator 100 generates outputs of $x_e(n)$, $v_e(n)$ and $a_e(n)$. The difference between the target track t_d from control unit 86 (Fig. 2) and the estimated head position $x_e(n)$ is the "distance-to-go", $x_{tg}(n)$, which is represented as the output of summing junction 101 and is input to VTG 102. The input signal representing $x_{tg}(n)$ is operated on in digital VTG 102 to form an output address which is then input to a lookup table stored in PROM 83. The output from PROM 83 is a digitised value for the velocity curve which is used directly as a digital velocity command output, $V_c(n)$, from VTG 102. A more thorough description of digital VTG 102 is given in the previously cited US -A- 4,486,797. Alternatively, VTG 102 may utilise a digital curve implementation, as shown in Fig. 1C of US -A- 4,486,797. The output of VTG 102 is a velocity command, $v_c(n)$, which is a function of the distance-to-go, $x_{tg}(n)$. If the head is within approximately plus or minus one-half track of the centreline of the target track t_d, then $v_c(n)$ is essentially a linear function of the input, $x_{tg}(n)$, and can be represented as $k_1 x_{tg}(n)$, where k_1 is a constant.

The output $v_c(n)$ of VTG 102 is a signal representative of the optimum velocity of the head for the particular sample n and distance to the target $x_{tg}(n)$. This value is then compared, as shown by summing junction 104, with the estimated velocity $v_e(n)$ generated by state estimator 100. The difference between $v_c(n)$ and $v_e(n)$ is the velocity error signal, $v_{es}(n)$, from summing junction 104.

Located between VTG 102 and summing junction 104 is a switch 103 for switching VTG 102 out of the servo control system. When switch 103 is "switched on" microprocessor 80 provides a constant velocity, v_{coast}, to summing junction 104. Switch 103 is switched on and the constant velocity input v_{coast} is provided during initialisation of the servo control system in order to cause the servo head 32 to "coast" at constant velocity from the inside diameter to the guard band outside diameter. Thus, during the coast phase $v_{es}(n)$ from summing junction 104 is the difference between v_{coast} and the estimated head velocity $v_e(n)$.

The value of $v_{es}(n)$ from summing junction 104 is operated on by a lead-lag algorithm, which is represented graphically as a lead-lag network 106, and then input to summing junction 110.

As shown between state estimator 100 and summing junction 108, the estimated head acceleration, $a_e(n)$, from state estimator 100 is multiplied by a constant scale factor k_2, and the prior control signal u(n-1) is multiplied by a constant scale factor k_3. These two products are then summed, as shown by summing junction 108, and the sum subtracted from the output of lead-lag network 106, as shown by summing junction 110. The result is the digital control signal, u(n), which is input to DAC 92.

Located between summing junction 110 and DAC 92 is a switch 111 for switching the normal control signal out of the servo control system. When switch 111 is "switched on", microprocessor 80 provides a control signal to DAC 92 which is equal to $i(n) - i_{park}$, where i_{park} is a constant current level. The purpose of switch 111 is to "park" the actuator by moving VCM 40 up against the inside diameter crash stop of the disk file. When the actuator is parked, servo head 32 is located over the radially innermost track.

As described and illustrated by Fig. 4, the control signal u(n) is expressed as follows:

$$u(n) = -k_3 u(n-1) + k_2 a_e(n) + (k_{s3} + k_{s2} * k_{s4}) d_{s1}(n) + k_{s2} * v_{es}(n), \quad (1)$$

where $d_{s1}(n)$ is the state variable of the lead-lag network 106 and is determined by

$$d_{s1}(n) = v_{es}(n-1) + k_{s4} d_{s1}(n-1). \quad (2)$$

The last two terms in equation (1) are the output from lead-lag network 106 and are strictly a function of constant scale factors, k_{si}, and the present and prior velocity error signals, $v_{es}(n)$ and $v_{es}(n-1)$, respectively.

The algorithm for computing $x_e(n)$, $v_e(n)$ and $a_e(n)$, and ultimately the control signal u(n), will now be explained with reference to the flow chart of Fig. 5 and, where indicated, the block diagram of Fig. 4. This explanation will begin with the initial "power on" of the disk file, after which the servo control system is initialised, and then with operation during track seeking and following.

When the disk file is first turned on, the inhibit signal to IPA 58 is on, thus preventing any initial signal conditions to IPA 58 from causing movement of VCM 40. The servo control system then undergoes a "re-zero" routine and receives the re-zero command, RZ, from control unit 86.

If a re-zero command has been received by microprocessor 80, then the servo control system's initial function is to park the actuator. The park phase is commenced by turning on switch 111. This prevents the otherwise normal control signal from reaching DAC 92. The control signal to DAC 92 is now equal to the current to VCM 40 less a constant value, i_{park}. The current to VCM 40 will increase until it reaches the value i_{park}. VCM 40 will accelerate until it reaches the crash stop and will be maintained at the crash stop as long as switch 111 is on. The park phase continues for a predetermined time delay which is sufficient to assure that VCM 40 has been parked.

After the time delay, the state estimator 100 initialises the estimated values by setting x_e equal to x_{max}, the largest possible absolute head position, and v_e and a_e to zero. Switch 111 is then turned off, so that the normal control signal u(n) is provided to DAC 92.

Following the park phase, the servo control system commences the coast phase, the purpose of which is to move VCM 40 from the inside diameter crash stop to the radially outermost track, i.e. the guard band outside diameter. This is commenced by turning switch 103 on to switch VTG 102 out of the servo control system.

Since the servo head 32 is now moving across the tracks, n is set equal to zero and the sampling of PESP(n) and PESQ(n) begins. GBOD is also input to microprocessor 80 and has an initial value of zero. The coast phase continues so long as both switch 103 is on and GBOD equals zero, indicating that servo head 32 has not yet reached the guard band outside diameter.

During the first digital sample of PESP(n) and PESQ(n), microprocessor 80 computes the absolute head position, x_a, relative to some fixed reference, such as track zero, which is typically the guard band outside diameter. The term $x_a(n)$ is computed according to the following equations (3) and (4).

$$x_m(n) = TW * t_q(n) + PES(n) \quad (3)$$

$$x_a(n) = J(4TW) + x_m(n) \quad (4)$$

As previously described, PES(n) is the distance of the head from the nearest track centreline and is computed from the logic of Table 1. The term "TW · $t_q(n)$" is the "track width" times the digital value corresponding to the track type. Thus in equation (3) the term $x_m(n)$ is the measured position of the head within some four-track band of the quadrature pattern. In equation (4) the term $x_a(n)$, i.e. the measured absolute position of the head relative to a fixed reference, is equal to $x_m(n)$ plus some integral multiple, denoted "J", times the width of a four-track band (4TW). In the operation of the servo control system, only $x_m(n)$ is actually measured. The expression "J(4TW)" is determined based upon the predicted absolute position of the head from an expression for $x_p(n)$ to be described later. This is possible because the state estimator is designed such that the error between the measured absolute head position, x_a, and the predicted absolute head position, x_p, is always less than two track widths. Thus x_a is computed by determining J, which is the number of integral multiples of four-track bands, in the predicted absolute head position x_p. (The predicted position x_p can be considered as a distance equal to some integral multiple J of four-track bands plus a remainder or fraction of a four-track band). In this manner the term J is used to compute x_a in equation (4).

Referring again to the flow chart of Fig. 5, after the computation of x_a, the term e(n) is computed according to the following equation (5):

$$e(n) = x_a(n) - x_p(n) \quad (5)$$

The term e(n) is the error between the measured absolute head position, $x_a(n)$, and the predicted absolute head position, $x_p(n)$, for that sample.

The estimated head position and velocity and a term $w_e(n)$ are then computed according to the following equations (6)-(8):

$$x_e(n) = x_p(n) - L_1 \cdot e(n) \quad (6)$$
$$v_e(n) = v_p(n) - L_2 \cdot e(n) \quad (7)$$
$$w_e(n) = w_p(n) - L_3 \cdot e(n) \quad (8)$$

The term $x_p(n)$ in equation (6), $v_p(n)$ in equation (7), and $w_p(n)$ in equation (8) are the predicted position, velocity and bias force equivalent VCM current, respectively. These terms have been computed during the prediction update phase from the prior sample, and will be explained with reference to that portion of the flow chart of Fig. 5. The term $w_e(n)$ in equation (8) is the estimated bias force component of the total VCM current required to give the estimated acceleration of servo head 32. The L_l terms in equations (6)-(8) are constants.

Referring again to the flow chart of Fig. 5, the measured VCM current sample, i, is input to microprocessor 80. After the current has been input to microprocessor 80, then a decision is made as to whether the servo control system is still in coast, i.e. whether the head is still moving from the inside diameter crash stop towards the guard band outside diameter. If switch 103 is still on, then the coast phase is still in progress, the commanded velocity, v_c, is set equal to v_{coast}, and VTG 102 is bypassed.

The following equations (9) and (10) are then computed:

$$v_{es}(n) = v_c(n) - v_e(n) \quad (9)$$
$$a_e(n) = (K_t/M)[i(n) + w_e(n)] \quad (10)$$

The velocity error signal from equation (9) is the difference between the commanded velocity, in this case v_{coast}, and the estimated velocity, $v_e(n)$. The estimated acceleration $a_e(n)$ in equation (10) is proportional to the sum of the measured VCM current i(n) and the term $w_e(n)$, the estimated bias force equivalent current. The term $w_e(n)$ is an estimate of the VCM current required to compensate for bias forces. The proportional constant K_t/M in equation (10) is the actuator force constant divided by the actuator mass.

After $v_{es}(n)$ and $a_e(n)$ have been computed in equations (9) and (10) the control signal u(n) is computed according to equation (1) and output to DAC 92.

The microprocessor 80 next computes the term $d_{s1}(n)$ from equation (2) and the predicted head position $x_p(n)$, velocity $v_p(n)$ and bias force equivalent current $w_p(n)$ from the following equations (11)-(13).

$$x_p(n) = x_e(n-1) + g_{11} \cdot u(n-2) + g_{21} \cdot u(n-1) + g_{31} \cdot i(n-1) + p_{12} \cdot v_e(n-1) + p_{13} \cdot w_e(n-1) \quad (11)$$
$$v_p(n) = v_e(n-1) + g_{12} \cdot u(n-2) + g_{22} \cdot u(n-1) + g_{32} \cdot i(n-1) + p_{23} \cdot w_e(n-1) \quad (12)$$

$$W_p(n) = w_e(n-1) \quad (13)$$

As is apparent, the predicted terms $x_p(n)$, $v_p(n)$ and $w_p(n)$ are functions of prior control signals, the prior measured VCM current and the prior estimated head position, velocity and bias force equivalent current.

As shown in the flow chart of Fig. 5, the counter is then incremented by one, to $n+1$. If there is no change in the target track, then control is returned for receipt of the next PESP(n) and PESQ(n) input.

The above-described routine for the computation of the control signal u during the coast phase continues so long as GBOD equals zero. When the servo head 32 reaches the guard band outside diameter, then GBOD equals 1 and control transfers to connector 3 (Fig. 5). At this point the coast phase has been completed and the estimated values are re-initialised. The estimated head position x_e is set equal to x_{GBOD} (the absolute position of the guard band outside diameter), the estimated velocity v_e is set equal to v_{coast}, and the estimated acceleration a_e is set equal to zero. The target track t_d is then set equal to x_{GBOD}.

The coast phase is terminated by "switching off" switch 103. Control is transferred back to connector 4 (Fig. 5) for receipt of a target track command. If control unit 86 sends a command different from $t_d = x_{GBOD}$, then a track seek will begin. The counter is reset to $n=0$, and control is transferred back to connector 1 (Fig. 5). The same computations as previously described occur with the exception that when the second decision point for switch 103 is reached, the distance-to-go, x_{tg}, and new commanded velocity, v_c, are computed according to the following equations (14) and (15).

$$x_{tg}(n) = t_d - x_e(n) \quad (14)$$

$$v_c(n) = F[x_{tg}(n)] \quad (15)$$

The total error signal, x_{tg}, computed according to equation (14) is merely the difference between the absolute position of the target track centreline and the estimated absolute head position. The function term in equation (15) represents the output from VTG 102 and is a nonlinear function of $x_{tg}(n)$ during track seeking and a linear function, $k_1 x_{tg}(n)$, during track following. During the seek the control signal u continues to be calculated according to equation (1) for each sample and output to DAC 92. The seek continues and the counter is incremented to $n+1$ until a new target track command, t_d, is received. Even at the completion of a seek, the above-described sampling of PESP(n), PESQ(n) and i(n), and the computation of u(n), continue. This is now the track following mode, which, from the perspective of the state estimator and control signal algorithm, is indistinguishable from track seeking.

The g_{ij} and p_{ij} in equations (11)-(13) are constants determined from a physical model of the actuator, including such parameters as the mass of the coil and arm assembly, the frictional effects, the force constants, and the digital sampling time. A description of the manner in which the g_{ij} and p_{ij} constants are generated for a physical system is given by Franklin and Powell in Digital Control of Dynamic Systems, Addison-Wesley Publishing Co. (1983), Chapter 6, pp. 131-139.

The k_{si}, L_i, and k_i constants, as shown in Fig. 2 and used in control signal equation (1) and equations (6)-(8), are selected constants which yield the desired overall servo control system requirements for servo bandwidth, closed-loop pole locations and transient response. The specific values of these constants are a direct function of system design objectives and the specific hardware to be controlled.

With the use of this state estimator and control signal algorithm in the digital servo control system there is but one servo control system, which is identical in function during both track seeking and track following. There is no switching of a stiffness integrator into the servo control system during track following. The only difference between track seeking and track following is that during track following, when the head has approached to within approximately one-half track of the centreline of the target track, the function of distance-to-go output from VTG 102 is now a linear function represented as $k_1 x_{tg}$.

The control signal represented by equation (1) is a function of the prior control signal; the velocity error signal, which in turn is a function of the estimated head velocity and the total error signal; and the estimated head acceleration, which in turn is a function of the measured VCM current and the estimated bias force equivalent VCM current. Thus, the control signal can be represented in functional terms as follows:

$$u(n) = F_n\{u(n-1), v_e(n), x_{tg}(n), i(n), w_e(n)\}, \quad (16)$$

where F_n merely represents the function expressed by equation (1). During track following the mean or expected value of absolute head position x_e is a constant and the mean or expected value of the head velocity v_e is zero. Similarly, during track following the prior control signal u(n-1) has a mean or expected value of zero. The state estimator estimates the bias force equivalent VCM current, w_e, so that the total acceleration estimate, which is $(K_t/M) \cdot [i(n) + w_e(n)]$, has a mean or expected value of zero. In this manner

the only term remaining in equation (16) which has a non-zero mean or expected value is the total error signal, x_{tg}, which during track following is simply the PES. The PES is driven to zero by IPA 58 without the need for a separate switchable stiffness integrator. With the use of the state estimator in the digital servo control system as described herein to estimate w_e, there is thus no feedback path around IPA 58 that provides a gain in the presence of generally constant or very low frequency bias forces.

In addition, the use of the state estimator eliminates the necessity for counting or otherwise estimating track crossings, and thus permits the servo control system to be fully operable with sector servo information. The state estimator is designed, through the selection of constants L_1, L_2 and L_3 in equations (6)-(8), so that the measured absolute head position, $x_a(n)$, is always within less than two track widths of the predicted head position, $x_p(n)$. Thus, since it is only necessary to actually measure the position of the head within a four-track band, through the use of PES(n) and $t_q(n)$, it does not matter how many tracks have been crossed by servo head 32 between PES samples.

Referring now to Fig. 6, the improved arrival of servo head 32 to the centreline of the target track is shown with the use of the above-described digital servo control system. Curve A of Fig. 6 illustrates an arrival trajectory of head 32 to the centreline of a target track for a typical multiple track seek. The discontinuity at approximately 6.0 ms. is caused by the switching of a stiffness integrator into the servo feedback loop. The arrival trajectory of Curve A was simulated by the use of a digital servo control system identical to that shown in Fig. 4 but in which a digital stiffness integrator (not shown) was located between summing junction 101 and VTG 102. This stiffness integrator was switched into the loop to drive x_{tg} to zero when the servo head 32 was within approximately one-half track of the centreline of the target track. In comparison with the arrival trajectory of Curve A, the trajectory of Curve B in Fig. 6 shows a smooth, continuous arrival of servo head 32 to the centreline of the target track. This arrival was reached with a digital servo control system embodying the present invention, i.e. without a switchable stiffness integrator.

Referring now to Fig. 7, there is illustrated a modification to the above-described digital servo control system which compensates for an offset input voltage to IPA 58. Even in the presence of no input to DAC 92, there can be an output voltage offset on DAC 92 and an input voltage offset to IPA 58. The value of this offset can vary with time and temperature. In order to compensate for this offset during track following, the control current u(n) is digitally integrated by digital integrator 120. This results in a correction factor b(n) summed with the control signal u(n) to compensate for an input signal offset to IPA 58. The equation computed by microprocessor 80 is expressed as follows:

$$b(n) = b(n-1) + c_0(n) * u(n-1), \quad (17)$$

where c_0 is a non-zero positive constant. During track seeking the microprocessor sets $c_0(n)$ equal to zero. Thus the digital integration and updating of b(n) for voltage offset only occurs during track following. The use of integrator 120, by setting $c_0(n)$ equal to a non-zero value, causes no adverse effects because the variation in the value of b is extremely slow relative to any bias force variations which can occur over the time it takes to do any track seek.

Claims

1. A method for controlling data track seeking and following in a disk file having a disk (12) with servo information thereon defining data track centrelines, a head (32) for reading samples of the servo information during rotation of the disk, an actuator (40) connected to the head and responsive to an input signal for positioning the head to the centreline of a target track during track seeking and maintaining the head over the centreline of the target track during track following, the method comprising the steps of:

   generating from the servo information a sampled head position error signal (PES) representative of the position of the head relative to the centreline of the nearest track;

   for each PES sample:

   computing a measured absolute head position ($x_a(n)$), relative to a fixed reference, from the sampled head position error signal (PES) and a prior predicted absolute head position ($x_p(n)$); and computing an error signal (e(n)) based on the difference between said measured absolute head position ($x_a(n)$) and said prior predicted absolute head position ($x_p(n)$);

   measuring the input signal (i(t)) to the actuator;

   estimating the absolute head position ($x_e(n)$), relative to the fixed reference, and the head velocity ($v_e(n)$), using said error signal (e(n)), said prior predicted absolute head position ($x_p(n)$, and a prior predicted velocity ($v_p(n)$); estimating the equivalent actuator input signal ($w_e(n)$) required to compensate

the only term remaining in equation (16) which has a non-zero mean or expected value is the total error signal, x_{tg}, which during track following is simply the PES. The PES is driven to zero by IPA 58 without the need for a separate switchable stiffness integrator. With the use of the state estimator in the digital servo control system as described herein to estimate w_e, there is thus no feedback path around IPA 58 that provides a gain in the presence of generally constant or very low frequency bias forces.

In addition, the use of the state estimator eliminates the necessity for counting or otherwise estimating track crossings, and thus permits the servo control system to be fully operable with sector servo information. The state estimator is designed, through the selection of constants L_1, L_2 and L_3 in equations (6)-(8), so that the measured absolute head position, $x_a(n)$, is always within less than two track widths of the predicted head position, $x_p(n)$. Thus, since it is only necessary to actually measure the position of the head within a four-track band, through the use of PES(n) and $t_q(n)$, it does not matter how many tracks have been crossed by servo head 32 between PES samples.

Referring now to Fig. 6, the improved arrival of servo head 32 to the centreline of the target track is shown with the use of the above-described digital servo control system. Curve A of Fig. 6 illustrates an arrival trajectory of head 32 to the centreline of a target track for a typical multiple track seek. The discontinuity at approximately 6.0 ms. is caused by the switching of a stiffness integrator into the servo feedback loop. The arrival trajectory of Curve A was simulated by the use of a digital servo control system identical to that shown in Fig. 4 but in which a digital stiffness integrator (not shown) was located between summing junction 101 and VTG 102. This stiffness integrator was switched into the loop to drive x_{tg} to zero when the servo head 32 was within approximately one-half track of the centreline of the target track. In comparison with the arrival trajectory of Curve A, the trajectory of Curve B in Fig. 6 shows a smooth, continuous arrival of servo head 32 to the centreline of the target track. This arrival was reached with a digital servo control system embodying the present invention, i.e. without a switchable stiffness integrator.

Referring now to Fig. 7, there is illustrated a modification to the above-described digital servo control system which compensates for an offset input voltage to IPA 58. Even in the presence of no input to DAC 92, there can be an output voltage offset on DAC 92 and an input voltage offset to IPA 58. The value of this offset can vary with time and temperature. In order to compensate for this offset during track following, the control current u(n) is digitally integrated by digital integrator 120. This results in a correction factor b(n) summed with the control signal u(n) to compensate for an input signal offset to IPA 58. The equation computed by microprocessor 80 is expressed as follows:

$$b(n) = b(n-1) + c_0(n) \cdot u(n-1), \qquad (17)$$

where c_0 is a non-zero positive constant. During track seeking the microprocessor sets $c_0(n)$ equal to zero. Thus the digital integration and updating of b(n) for voltage offset only occurs during track following. The use of integrator 120, by setting $c_0(n)$ equal to a non-zero value, causes no adverse effects because the variation in the value of b is extremely slow relative to any bias force variations which can occur over the time it takes to do any track seek.

Claims

1. A method for controlling data track seeking and following in a disk file having a disk (12) with servo information thereon defining data track centrelines, a head (32) for reading samples of the servo information during rotation of the disk, an actuator (40) connected to the head and responsive to an input signal for positioning the head to the centreline of a target track during track seeking and maintaining the head over the centreline of the target track during track following, the method comprising the steps of:

   generating from the servo information a sampled head position error signal (PES) representative of the position of the head relative to the centreline of the nearest track;

   for each PES sample:

   computing a measured absolute head position ($x_a(n)$), relative to a fixed reference, from the sampled head position error signal (PES) and a prior predicted absolute head position ($x_p(n)$); and computing an error signal ($e(n)$) based on the difference between said measured absolute head position ($x_a(n)$) and said prior predicted absolute head position ($x_p(n)$);

   measuring the input signal ($i(t)$) to the actuator;

   estimating the absolute head position ($x_e(n)$), relative to the fixed reference, and the head velocity ($v_e(n)$), using said error signal ($e(n)$), said prior predicted absolute head position ($x_p(n)$, and a prior predicted velocity ($v_p(n)$); estimating the equivalent actuator input signal ($w_e(n)$) required to compensate

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for bias forces acting on the actuator, using a prior predicted bias force equivalent actuator input signal ($w_p(n)$); and estimating the head acceleration ($a_e(n)$) as a function of the measured actuator input signal ($i(n)$) and estimated bias force equivalent actuator input signal ($w_e(n)$);

computing a commanded head velocity ($v_c(n)$) as a function of the distance ($x_{tg}(n)$) from the estimated absolute head position ($x_e(n)$) to the target track (t_d); and computing the head velocity error ($v_{es}(n)$) as a function of the difference between the commanded head velocity ($v_c(n)$) and the estimated head velocity ($v_e(n)$);

predicting using a state estimator, for the subsequent PES sample, the absolute head position ($x_p(n+1)$) and the head velocity ($v_p(n+1)$) as functions of prior control signals ($u(n)$, $u(n-1)$), the prior estimated absolute head position ($x_e(n)$), the prior estimated head velocity ($v_e(n)$), the prior estimated bias force equivalent actuator input signal ($w_e(n)$), and constants (g_{ij}, p_{ij}) representative of physical parameters of the actuator; and also predicting the bias force equivalent actuator input signal ($w_p(n+1)$) as a function of the prior estimated bias force equivalent actuator input signal ($w_e(n)$);

generating a control signal ($u(n)$) as a function of the head velocity error ($v_{es}(n)$), the estimated head acceleration ($a_e(n)$), and the control signal ($u(n-1)$) generated for the prior PES sample;

and storing digital values representative of the control signals ($u(n)$, $u(n-1)$), the measured actuator input signal ($i(n)$), the estimated head position ($x_e(n)$), the estimated head velocity ($v_e(n)$), the estimated bias force equivalent actuator input signal ($w_e(n)$), and constants (g_{ij}, P_{ij}) representing predetermined physical parameters of the actuator;

and integrating the control signal ($u(n)$) to provide the input signal ($i(t)$) to the actuator.

2. A method as claimed in claim 1, wherein the servo information is of the type providing a primary signal and a quadrature signal from a quadrature pattern recorded in radially repetitive four-track bands, each track in the band being a unique track type, and wherein the step of generating the PES includes the step of determining, from the primary and quadrature signals, which of the four track types the head is on.

3. A method as claimed in claim 2, wherein the disk file includes a demodulator which provides an analog primary PES and an analog quadrature PES from the quadrature pattern servo information, and wherein the step of generating a PES sample includes the steps of generating a primary digital PES sample (PESP) and a quadrature digital PES sample (PESQ) and selecting either PESP or PESQ as the PES sample.

4. A method according to claim 2 or 3, wherein the step of measuring the position of the head within a band includes the steps of identifying the specific track number over which the head is located within the band, multiplying the identified track number by the track width (TW), and summing the resultant product with the PES ($x_m(n)$).

5. A method as claimed in any preceding claim, wherein the servo information is recorded in radially repetitive bands, each band containing a fixed number of uniquely identifiable tracks, and wherein the step of estimating the absolute head position includes the step of measuring the position of the head within a band without detecting or estimating track crossings by the head.

6. A method as claimed in claim 5, wherein the step of estimating the absolute head position further comprises the step of determining a distance equivalent to the integral number (J) of bands comprised by the predicted absolute head position and summing that distance with the measured head position within a band, thereby computing a measured absolute head position ($x_e(n)$).

7. A method as claimed in any preceding claim, wherein the actuator is a voice coil motor (VCM) (40), wherein the step of measuring the actuator input signal further comprises the step of measuring the input current ($i(n)$) to the VCM, and wherein the step of estimating the bias force equivalent actuator input signal further comprises the step of estimating the equivalent VCM current to compensate for bias forces.

8. A method as claimed in any preceding claim, wherein the step of estimating the head acceleration further comprises the step of estimating the head acceleration to have a mean value of zero when the expected value of the head position is a constant.

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9. A method as claimed in any preceding claim, wherein the disk file is of the type also having integration means (58) coupled to the actuator, and further comprising the steps of, prior to integrating the control signal, adding to the control signal a correction signal to compensate for an input voltage offset in the integrating means, and updating the correction signal during track following.

10. A disk file having a disk (12) with servo information thereon defining data track centrelines, comprising a head (32) for reading the servo information during rotation of the disk and for providing an analog servo signal; an actuator (40) connected to the head and responsive to an input signal for positioning the head to the centreline of a target track in response to a seek command from a control unit (86) and for maintaining the head over the centreline of the target track during track following, the actuator having predetermined physical parameters (g_{ij}, p_{ij}) and being subjected to generally constant or low frequency bias forces during operation of the disk file; and a demodulator (44) for processing the analog servo signal to provide a head position error signal (PES) representative of the distance of the head from the nearest track centreline, and analog-to digital conversion means (88, 89) for converting the analog PES from the demodulator;

and further comprising:

means (80) for computing, for each PES sample, a measured absolute head position ($x_a(n)$), relative to a fixed reference, from the digital PES and a prior predicted absolute head position ($x_p(n)$); and for computing an error signal (e(n)) based on the difference between said measured absolute head position ($x_a(n)$) and said prior predicted absolute head position ($x_p(n)$);

means for measuring the analog actuator input signal (i(t)), and analog-to-digital conversion means (90) for providing a measured actuator input signal (i(n));

means for estimating the absolute held position ($x_e(n)$) relative to the fixed reference, and the head velocity ($v_e(n)$), using said error signal (e(n)), said prior predicted absolute head position ($x_p(n)$), and a prior predicted velocity ($v_p(n)$); means for estimating the equivalent actuator input signal ($w_e(n)$) required to compensate for said bias forces acting on the actuator, using a prior predicted bias force equivalent actuator input signal (wp(n)): and means (80, 108) for estimating the head acceleration ($a_e(n)$) as a function of the measured actuator input signal (i(n)) and estimated bias force equivalent actuator input signal ($w_e(n)$);

a velocity trajectory generator (102) for computing an optimum commanded head velocity ($v_c(n)$) as a function of the distance ($x_{tg}(n)$) from the estimated absolute head position ($x_e(n)$) to the target track (t_d); and means (104) for computing the head velocity error ($v_{es}(n)$) as a function of the difference between the commanded head velocity ($v_c(n)$) and the estimated head velocity ($v_e(n)$);

a state estimator (80) for predicting for the subsequent PES sample, the absolute head position ($x_p(n+1)$) and the head velocity ($v_p(n+1)$) as functions of prior control signals (u(n), u(n-1)), the prior estimated absolute head position ($x_e(n)$), the prior estimated head velocity ($v_e(n)$), the prior estimated bias force equivalent actuator input signal ($w_e(n)$), and said constants (g_{ij}, p_{ij}) representative of the physical parameters of the actuator; and for predicting the bias force equivalent actuator input signal ($w_p(n+1)$) as a function of the prior estimated bias force equivalent actuator input signal ($w_e(n)$);

means (106) for computing a control signal (u(n)) as a function of the head velocity error ($v_{es}(n)$), the estimated head acceleration ($a_e(n)$), and the control signal (u(n-1)) generated for the prior PES sample;

means for storing the digital values representative of the control signals (u(n), u(n-1)), the measured actuator input signal (i(n)), the estimated head position ($x_e(n)$), the estimated head velocity ($v_e(n)$), the estimated bias force equivalent actuator input signal ($w_e(n)$), and said constants (g_{ij}, p_{ij}) representing predetermined physical parameters of the actuator;

and means (92) for converting the digital control signal (u(n)) to an analog input signal to the actuator (i(t)).

11. A disk file as claimed in claim 10 wherein the servo information is recorded in radially repetitive bands of a fixed number of tracks per band, and wherein the demodulator provides a primary analog servo signal and a quadrature analog servo signal, wherein the analog-to-digital conversion means for the PES received from the demodulator includes means for generating a digital primary PES (PESP) and a digital quadrature PES (PESQ), and further comprising means for identifying from the digital PESP and PESQ the specific track within a band over which the head is located.

12. A disk file as claimed in claim 10 or claim 11, wherein the means for computing an estimate of head acceleration includes means for estimating the average head acceleration during track following to be

zero.

13. A disk file as claimed in any of claims 10 to 12, wherein the means for converting the digital control signal to an analog actuator input signal includes an integrating power amplifier (58).

14. A disk file as claimed in claim 13 further comprising means for computing a value representative of a correction signal as compensation for a voltage offset to the integrating power amplifier, means for adding the correction signal value to the digital control signal prior to conversion of the digital control signal to analog, and means for updating the correction signal value during track following.

Patentansprüche

1. Verfahren zum Steuern des Suchens und Folgens einer Datenspur in einem Plattenspeicher, mit einer Platte (12), auf der sich eine Datenspurmittellinien definierende Servoinformation befindet, mit einem Kopf (32) zum Lesen von Abtastungen der Servoinformation während eines Drehens der Platte, und mit einem mit dem Kopf verbundenen Antrieb (40), der auf ein Eingangssignal anspricht, um den Kopf während der Spurensuche zu der Mittellinie einer Zielspur in Lage zu bringen und um den Kopf während des Spurfolgens über der Mittellinie der Zielspur zu halten, wobei das Verfahren die folgenden Schritte enthält:
Erzeugen eines abgetasteten Kopfposition-Fehlersignals (PES), das für die Lage des Kopfes bezüglich der Mittellinie der nächstgelegenen Spur repräsentiert ist;
für jede PES Abtastung:
Berechnen einer gemessenen absoluten Kopfposition ($x_a(n)$) bezüglich einer festen Referenz aus dem abgetasteten Kopfposition-Fehlersignal (PES) und einer zuvor vorausgesagten absoluten Kopfposition ($x_p(n)$); und Berechnen eines Fehlersignals (e(n)) auf der Grundlage der Differenz zwischen der gemessenen absoluten Kopfposition ($x_a(n)$) und der zuvor vorausgesagten absoluten Kopfposition ($x_p(n)$);
Messen des Eingangssignals (i(n)) an den Antrieb;
Schätzen der absoluten Kopfposition ($x_e(n)$) bezüglich der festen Referenz, sowie der Kopfgeschwindigkeit ($v_e(n)$) unter Verwendung des Fehlersignals (e(n)), der zuvor vorausgesagten absoluten Kopfposition ($x_p(n)$) und einer zuvor vorausgesagten Geschwindigkeit ($v_p(n)$); Schätzen des äquivalenten Antriebseingangssignals (we(n)), das erforderlich ist, um auf den Antrieb wirkende Vorbelastungskräfte zu kompensieren, unter Verwendung eines zuvor vorausgesagten den Vorbelastungskräften äquivalenten Antriebseingangssignals ($w_P(n)$); und Schützen der Kopfbeschleunigung ($a_e(n)$) als eine Funktion des gemessenen Antriebseingangssignals (i(n)) und des geschätzten den Vorbelastungskräften äquivalenten Antriebseingangssignals. (w_e (n));
Berechnen einer befohlenen Kopfgeschwindigkeit ($v_c(n)$) als eine Funktion des Abstandes ($x_{tg}(n)$) zwischen der geschätzten absoluten Kopfposition ($x_e(n)$) und der Zielspur (t_d); und Berechnen des Kopfgeschwindigkeitsfehlers ($v_{es}(n)$) als eine Funktion der Differenz zwischen der befohlenen Kopfgeschwindigkeit ($v_c(n)$) und der geschätzten Kopfgeschwindigkeit ($v_e(n)$);
für die nachfolgende PES-Abtastung Vorhersagen der absoluten Kopfposition ($x_p(n+1)$) und der Kopfgeschwindigkeit ($v_p(n+1)$) unter Verwendung einer Zustandsschätzfunktion als Funktionen früherer Steuersignale (u(n), u(n-1)), der zuvor geschätzten absoluten Kopfposition ($x_e(n)$), der zuvor geschätzten Kopfgeschwindigkeit ($v_e(n)$), des zuvor geschätzten, den Vorbelastungskräften äquivalenten Antriebseingangssignals ($w_e(n)$) und von für physikalische Parameter des Antriebs repräsentativen Konstanten (g_{ij}, p_{ij}); und auch das Vorhersagen des Vorbelastungskräfte-Antriebseingangssignals ($w_p(n+1)$) als eine Funktion des zuvor geschätzten Vorbelastungskräfte-Antriebseingangssignals ($w_p(n)$);
Erzeugen eines Steuersignals (u(n)) als eine Funktion des Kopfgeschwindigkeitsfehlers ($v_{es}(n)$), der geschätzten Kopfbeschleunigung ($a_e(n)$) und des für die vorgehende PES-Abtastung erzeugten Steuersignals (u(n-1));
und Speichern digitaler Werte, die repräsentativ sind für die Steuersignale (u(n), u(n-1)), das gemessene Antriebseingangssignal (i(n)), die geschätzte Kopfposition ($x_e(n)$), die geschätzte Kopfgeschwindigkeit ($v_e(n)$) das geschätzte, den Vorbelastungskräften äquivalente Antriebseingangssignal ($w_e(n)$) und Konstanten (g_{ij}, p_{ij}), welche vorbestimmte physikalische Parameter des Antriebes repräsentieren.;
und Integrieren des Steuersignals (u(n)), um das Eingangssignal (i(t)) für den Antrieb bereitzustellen.

2. Verfahren nach Anspruch 1, bei welchem die Servoinformation von jener Art ist, die ein Primärsignal und ein Quadratursignal aus einem Quadraturmuster liefert, das in sich radial wiederholenden Vierspur-



bändern aufgezeichnet ist, wobei jede Spur in dem Band eine eigene Spurart ist, und wobei der Schritt des Erzeugens des PES den Schritt beinhaltet, daß aus den Primär- und Quadratursignalen bestimmt wird, auf welcher der vier Spurarten sich der Kopf befindet.

3. Verfahren nach Anspruch 2, bei welchem der Plattenspeicher einen Demodulator besitzt, der aus der Servoinformation des Quadraturmusters ein analoges Primär-PES und ein analoges Quadratur-PES liefert, und bei welchem der Schritt des Erzeugens einer PES-Abtastung den Schritt beinhaltet, daß eine primäre digitale PES-Abtastung (PESP) und eine digitale Quadratur-PES-Abtastung erzeugt und als PES-Abtastung entweder PESP oder PESQ gewählt wird.

4. Verfahren nach Anspruch 2 oder 3, bei welchem der Schritt des Messens der Position des Kopfes innerhalb eines Bandes die Schritte beinhaltet, daß die spezifische Spurnummer, oberhalb der der Kopf innerhalb des Bandes gelegen ist, identifiziert wird, die identifizierte Spurnummer mit der Spurbreite (Tw) multipliziert und das resultierende Produkt mit dem PES ($x_m(n)$) summiert wird.

5. Verfahren nach irgendeinem der vorgehenden Ansprüche, bei welchem die Servoinformation in radial sich wiederholenden Bändern aufgezeichnet ist, jedes Band eine feste Anzahl eindeutig identifizierbarer Spuren enthält, und wobei der Schritt des Schätzens der absoluten Kopfposition den Schritt enthält, daß die Position des Kopfes innerhalb eines Bandes gemessen wird, ohne daß Spurüberquerungen durch den Kopf festgestellt oder geschätzt werden.

6. Verfahren nach Anspruch 5, bei welchem der Schritt des Schätzens der absoluten Kopfposition weiters den Schritt enthält, daß eine Distanz bestimmt wird, die der ganzzahligen Anzahl (J) von Bändern äquivalent ist, die in der vorausgesagten absoluten Kopfposition enthalten ist, und diese Distanz mit der gemessenen Kopfposition innerhalb eines Bandes summiert wird und auf diese Weise eine gemessene absolute Kopfposition ($x_a(n)$) berechnet wird.

7. Verfahren nach irgend einem der vorgehenden Ansprüche, bei welchem der Antrieb ein Tauchspulenantrieb (VCM)(40) ist, bei welchem der Schritt des Messens des Antriebseingangssignales weiters den Schritt enthält, daß der Eingangsstrom (i(n)) an den VCM gemessen wird, und bei welchem der Schritt des Schätzens des den Vorbelastungskräften äquivalenten Antriebseingangssignals weiters den Schritt enthält, daß der äquivalente VCM-Strom zum Kompensieren der Vorbelastungskräfte geschätzt wird.

8. Verfahren nach irgend einem der vorgehenden Ansprüche, bei welchem der Schritt des Schätzens der Kopfbeschleunigung weiters den Schritt enthält, daß die Kopfbeschleunigung geschätzt wird, sodaß man einen Mittelwert von Null erhält, wenn der erwartete Wert der Kopfposition, eine Konstante ist.

9. Verfahren nach irgend einem der vorgehenden Ansprüche, bei welchem der Plattenspeicher von jener Art ist, die auch eine an den Antrieb angeschlossene Integrationseinrichtung (58) besitzt, und welches weiters die Schritte aufweist, daß vor dem Integrieren des Steuersignals zu dem Steuersignal ein Korrektursignal addiert wird, um einen Offset der Eingangsspannung an der Integrationseinrichtung zu kompensieren und dass das Korrektursignal während des Spurfolgens aktualisiert wird.

10. Plattenspeicher mit einer Platte (12) mit Servoinformation zum Festlegen der Mittellinien von Datenspuren, die aufweist: einen Kopf (32) zum Lesen der Servoinformation während der Drehung der Platte und zum Bereitstellen eines analogen Servosignals, ein Stellglied (40), das mit dem Kopf verbunden ist und auf ein Eingangssignal reagiert, um den Kopf als Reaktion auf einen Such-Befehl von der Steuereinheit (86) an der Mittellinie einer Zielspur zu positionieren und den Kopf während der Spurverfolgung über der Mittellinie der Zielspur zu halten, wobei das Stellglied vorbestimmte physikalische Parameter (g_{ij}, P_{ij}) besitzt und während des Betriebes der Plattendatei im allgeimeinen Konstanten oder niederfrequenten Vorbelastungskräften unterliegt, und einen Demodulator (44) zum Verarbeiten des analogen Servosignals, um ein Kopffehlersignal (PES) zu liefern, das ein Maß für den Abstand des Kopfes von der nächsten Mittellinie einer Spur darstellt, und Analog/Digitalwandlermittel (88, 89) zum Umwandeln des analogen PES von dem Demodulator
und die weiters aufweist:
Mittel (80) zum Berechnen einer gemessenen absoluten Kopfposition ($x_a(n)$) für jede PES-Probe bezüglich einer festen Referenz, aus dem digitalen PES und einer zuvor vorhergesagten absoluten Kopfposition ($x_p(n)$) und zum Berechnen eines Fehlersignals (e(n)) auf der Basis des Unterschiedes

zwischen der gemessenen absoluten Kopfposition ($x_e(n)$) und der zuvor vorhergesagten absoluten Kopfposition ($x_p(n)$);
Mittel zum Messen des analogen Eingangssignals (i(t)) des Stellgliedes und Analog/Digitalwandlermittel (90) zum Bereitstellen eines gemessenen Eingangssignals (i(n)) des Stellgliedes,
Mittel zum Schätzen der absoluten Kopfposition ($x_e(n)$) bezüglich der festen Referenz und der Kopfgeschwindigkeit ($v_e(n)$) unter Verwendung des Fehlersignals (e(n)), der zuvor vorhergesagten absoluten Kopfposition ($x_p(n)$) und einer zuvor vorhergesagten Geschwindigkeit ($v_p(n)$), Mittel zum Schätzen des äquivalenten Eingangssignals ($w_e(n)$) des Stellgliedes, das erforderlich ist, um die an dem Stellglied wirkenden Vorbelastungskräfte unter Verwendung eines zuvor vorhergesagten äquivalten Eingangssignals ($w_p(n)$) des Stellgliedes für die Vorbelastungskraft zu kompensieren, und Mittel (80, 108) zum Schätzen der Kopfbeschleunigung ($n_e(n)$) in Abhängigkeit von dem Eingangssignal (i(n)) des Stellgliedes für die Vorbelastungskraft;
einen Geschwindigkeitstrajektoriengenerator (102) zum Berechnen einer optimalen angeordneten Kopfgeschwindigkeit ($v_c(n)$) in Abhängigkeit von dem Abstand ($x_{tg}(n)$) der geschätzten absoluten Kopfposition ($x_e(n)$) von der Zielspur (t_d) und Mittel (10) zum Berechnen des Fehlers ($v_{es}(n)$) der Kopfgeschwindigkeit in Abhängigkeit von der Differenz zwischen der angeordneten Kopfgeschwindigkeit ($v_c(n)$) und der geschätzten Kopfgeschwindigkeit ($v_e(n)$);
eine Zustandsabschätzung (80) zum Vorhersagen der absouten Kopfposition ($x_p(n+1)$) und der Kopfgeschwindigkeit ($v_p(n+1)$) für die nachfolgende PES-Probe in Abhängigkeit von vorhergehenden Steuersignalen (u(n), u(n-1)), der zuvor geschätzten absoluten Kopfgeschwindigkeit ($v_e(n)$), des zuvor geschätzen äquivalenten Eingangssignals ($w_e(n)$) des Stellgliedes für die Vorbelastungskraft und der Konstanten (g_{ij}, P_{ij}), die ein Maß für die physikalischen Parameter des Stellgliedes sind, und zum Vorhersagen des äquivalenten Eingangssignals ($w_p(n+1)$) des Stellgliedes für die Vorbelastungskraft in Abhängigkeit des zuvor geschätzten äquivalenten Eingangssignals ($w_e(n)$) des Stellgliedes für die Vorbelastungskraft;
Mittel (106) zum Berechnen eines Steuersignals (u(n)) in Abhängigkeit von dem Fehler ($v_{es}(n)$) der Kopfgeschwindigkeit, der geschätzten Kopfbeschleunigung ($a_e(n)$) und des Steuersignals (u(n-1)), das für eine vorhergehende PES-Probe erzeugt wurde;
Mittel zum Speichern der digitalen Werte, die ein Maß für die Steuersignale (u(n), u(n-1) darstellen, des gemessenen Eingangssignals (i(n)) des Stellgliedes, der geschätzten Kopfposition ($x_e(n)$), der geschätzten Kopfgeschwindigkeit ($v_e(n)$), des geschätzten äquivalenten Eingangssignals ($w_e(n)$) des Stellgliedes für die Vorbelastungskraft und der Konstanten (g_{ij}, P_{ij}), die vorbestimmte physikalische Parameter des Stellgliedes darstellen,
und Mittel (92) zum Umwandeln des digitalen Steuersignals (u(n)) in ein analoges Eingangssignal (i(t)) für das Stellglied.

11. Plattenspeicher nach Anspruch 10, bei welchem die Servoinformation in radial sich widerholenden Bändern aufgezeichnet ist, wobei eine feste Anzahl von Spuren je Band vorgesehen ist, und der Demodulator ein analoges Primär-Servosignal und ein analoges Quadratur-Servosignal zur Verfügung stellt, wobei die Analog-Digital-Wandlermittel für das von dem Demodulator empfangene PES Mittel aufweisen, um ein digitales Primär-PES (PESP) und ein digitales Quadratur-PES (PESQ) zu erzeugen, und ferner Mittel, um aus den digitalen PESP und PESQ die spezifische Spur innerhalb eines Bandes zu identifizieren, oberhalb der der Kopf gelegen ist.

12. Plattenspeicher nach Anspruch 10 oder 11, bei welchem die Mittel zum Berechnen einer Schätzung der Kopfbeschleunigung Mittel beinhalten, um die mittlere Kopfbeschleunigung während des Spurfolgens auf Null zu schätzen.

13. Plattenspeicher nach irgend einem der Ansprüche 10 bis 12, bei welchem die Mittel zum Umwandeln des digitalen Steuersignals in ein analoges Antriebseingangssignal einen integrierenden Kraftverstärker (58) beinhalten.

14. Plattenspeicher nach Anspruch 13, der weiters Mittel aufweist, um einen für ein Korrektursignal repräsentativen Wert zur Kompensation eines Spannungsoffsets an dem integrierenden Kraftverstärker zu berechnen, Mittel, um den Korrektursignalwert vor der Umwandlung des digitalen Steuersignals ins analoge zu dem digitalen Steuersignal zu addieren, sowie Mittel, um den Wert des Korrektursignals während des Spurfolgens zu aktualisieren.

Revendications

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1. Procédé pour commander la recherche et le suivi de pistes de données dans une unité de disque comportant un disque (12) avec des informations d'asservissement sur celui-ci définissant des centres de pistes de données, une tête (32) pour lire des échantillons des informations d'asservissement pendant la rotation du disque, un mécanisme de positionnement (40) connecté à la tête et sensible à un signal d'entrée pour positionner la tête au centre d'une piste cible pendant la recherche de piste et maintenir la tête sur le centre de la piste cible pendant le suivi de piste, le procédé comprenant les étapes consistant à :

produire à partir des informations d'asservissement un signal d'erreur de position de tête échantillonné (PES) représentatif de la position de la tête par rapport au centre de la piste la plus proche ;

pour chaque échantillon du signal d'erreur de position :

calculer une position absolue mesurée de la tête (xa(n)), par rapport à une référence fixe, à partir du signal d'erreur de position de tête échantillonné (PES) et d'une position de tête absolue prédite précédente (xp(n)) et calculer un signal d'erreur (e(n)) basé sur la différence entre ladite position absolue mesurée de la tête (xa(n)) et ladite position absolue prédite précédente de la tête (xp(n)) ;

mesurer le signal d'entrée (i(n)) vers le mécanisme de positionnement ;

estimer la position absolue de la tête (xe(n)), par rapport à la référence fixe et la vitesse de la tête (ve(n)), en utilisant ledit signal d'erreur (e(n)), ladite position absolue prédite précédente de la tête (xp(n)) et une vitesse prédite précédente (vp(n)) ; estimer le signal d'entrée du mécanisme de positionnement équivalent (we(n)) requis pour compenser les forces de sollicitation agissant sur le mécanisme de positionnement, en utilisant un signal d'entrée de mécanisme de positionnement équivalent aux forces de sollicitation prédite précédentes (wp(n)) et estimer l'accélération de la tâte (ae(n)) comme une fonction du signal d'entrée de mécanisme de positionnement mesure (i(n)) et du signal d'entrée de mécanisme de positionnement équivalent à des forces de sollicitation estimées (we(n)) ;

calculer une vitesse de tête ordonnée (vc(n)) comme une fonction de la distance (xtg(n)) à partir de la position absolue estimée de la tête (xe(n)) à la piste cible (td) et calculer l'erreur de vitesse de la tête (ves(n)) comme une fonction de la différence entre la vitesse de la tête ordonnée (vc(n)) et la vitesse de la tête estimée (ve(n)) ;

prédire en utilisant un estimateur d'état, pour l'échantillon ultérieur du signal d'erreur de position, la position absolue de la tête (xp(n+1)) et la vitesse de la tête (vp(n+1)) comme des fonctions des signaux de commande précédents (u(n), u(n-1)), de la position de la tête absolue estimée précédente (xe(n)), de la vitesse de la tête estimée précédente (ve(n)), du signal d'entrée du mécanisme de positionnement estimé précédent équivalent aux forces de sollicitation (we(n)) et des constantes (gij, pij) représentatives des paramètres physiques du mécanisme de positionnement et également prédire le signal d'entrée du mécanisme de positionnement de forces de sollicitation (wp(n+1)) comme une fonction du signal d'entrée estimé précédent du mécanisme de positionnement de forces de sollicitation (wp(n)) ;

produire un signal de commande (u(n)) comme une fonction de l'erreur de vitesse de la tête (ves(n)), de l'accélération de la tête estimée (ae(n)) et du signal de commande (u(n-1)) produit pour l'échantillon précédent du signal d'erreur de position ;

et mémoriser les valeurs numériques représentatives des signaux de commande (u(n), u(n-1)), du signal d'entrée du mécanisme de positionnement mesuré (i(n)), de la position de la tête estimée (xe(n)), de la vitesse de la tête estimée (ve(n)), du signal d'entrée du mécanisme de positionnement estimé équivalent aux forces de sollicitation (we(n)) et des constantes (gij, pij) représentant des paramètres physiques prédéterminés du mécanisme de positionnement ;

et intégrer le signal de commande (u(n)) pour délivrer le signal d'entrée (i(t)) vers mécanisme de positionnement.

2. Procédé selon a revendication 1, dans lequel les informations d'asservissement sont du type délivrant un signal principal et un signal en quadrature à partir d'une confiruration en quadrature enregistrée dans des bandes radialement répétitives à quatre pistes, chaque piste dans la bande étant un type de piste particulier et dans lequel l'étape pour produire le signal d'erreur de position comporte l'étape pour déterminer à partir des signaux principal et en quadrature sur lequel des quatre types de piste la tête se trouve.

3. Procédé selon la revendication 2, dans lequel l'unité de disque comporte un démodulateur qui délivre un signal d'erreur de position principal et un signal d'erreur de position en quadrature analogique à partir des informations d'asservissement de configuration en quadrature et dans lequel l'étape pour

produire un échantillon du signal d'erreur de position comporte les étapes consistant à produire un échantillon du signal d'erreur de position numérique principal (PESP) et un échantillon du signal d'erreur de position numérique en quadrature (PESQ) et sélectionné soit PESP soit PESQ comme échantillon du signal d'erreur de position.

4. Procédé selon la revendication 2 ou 3, dans lequel l'étape consistant à mesurer la position de la tête à l'intérieur d'une bande comporte les étapes consistant à identifier le numéro de la piste spécifique sur laquelle la tête se trouve à l'intérieur de la bande, multiplier le numéro de la piste identifiée par la largeur de la piste (TW) et sommer le produit obtenu avec le signal d'erreur de position (xm(n)).

5. Procédé selon l'une quelconque des revendications précédentes, dans lequel les informations d'asservissement sont enregistrées dans des bandes radialement répétitives, chaque bande contenant un nombre fixe de pistes particulièrement identifiables et dans lequel l'état consistant à estimer la position de la tête absolue comporte l'étape consistant à mesurer la position de la tête à l'intérieur d'une bande sans détecter ou estimer les croisements de pistes par la tête.

6. Procédé selon la revendication 5, dans lequel l'étape d'estimation de la position absolue de la tête comprend de plus l'étape de la détermination d'une distance équivalente au nombre intégral J de bandes constituée par la position absolue prédite de la tête et la sommation de cette distance avec la position de la tête mesurée à l'intérieur d'une bande, le calcul de ce fait d'une position de tête absolue mesurée (xa(n)).

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel le mécanisme de positionnement est un moteur à bobine mobile (mbm(40)), dans lequel l'étape consistant à mesurer le signal d'entrée du mécanisme de positionnement comprend par suite l'étape consistant à mesurer le courant d'entrée (i(n)) vers le moteur de la bobine mobile, et dans lequel l'étape consistant à estimer la force de sollicitation équivalente au signal d'entrée du mécanisme de positionnement comprend de plus l'étape consistant à estimer le courant équivalent du moteur de la bobine mobile pour compenser les forces de sollicitation.

8. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape consistant à estimer l'accélération de la tête comprend de plus l'étape consistant à estimer l'accélération de la tête pour avoir une valeur moyenne nulle lorsque la valeur attendue de la position de la tête est une constante.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'unité de disque est du type comportant également un moyen d'intégration (58) couplé au mécanisme de positionnement et comprend de plus les opérations consistant à, avant d'intégrer le signal de commande, ajouter au signal de commande un signal de correction pour corriger un courant résiduel d'entrée du moyen d'intégration et actualiser le signal de correction pendant le suivi de piste.

10. Unité de disque comportant un disque (12) avec des informations d'asservissement sur celui-ci définissant des lignes centrales de pistes de données, comprenant une tête (32) pour lire les informations d'asservissement pendant la rotation du disque et pour délivrer un signal d'asservissement analogique ; un mécanisme de positionnement (40) connecté à la tête et sensible à un signal d'entrée pour positionner la tête sur la ligne centrale d'une piste cible en réponse à un ordre de recherche provenant de l'unité de commande (86) et pour maintenir la tête sur la ligne centrale de la piste cible pendant le suivi de piste, le mécanisme de positionnement ayant des paramètres prédéterminés (g_{ij}, p_{ij}) et étant soumis à des forces de sollicitation généralement constantes ou à basse fréquence pendant le fonctionnement de l'unité de disque et un démodulateur (44) pour traiter le signal d'asservissement analogique pour délivrer un signal d'erreur de positionnement de tête (PES) représentatif de la distance de la tête au centre de ligne de la piste la plus proche et un moyen de conversion analogique/numérique (88, 89) pour convertir le signal d'erreur de positionnement analogique provenant du démodulateur et comprend de plus :

un moyen (80) pour calculer pour chaque échantillon de signal d'erreur de positionnement une position de tête absolue mesurée ($x_a(n)$) par rapport à une référence fixe, à partir du signal d'erreur de positionnement numérique et une position de tête absolue prédite précédemment ($x_p(n)$) et pour calculer un signal d'erreur (a(n)) basé sur la différence entre ladite position de tête absolue mesurée

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($x_a(n)$) et ladite position de tête absolue prédite précédente ($x_p(n)$) ;

un moyen pour mesurer le signal d'entrée analogique du mécanisme de positionnement (i(t)) et un moyen de conversion analogique/numérique (90) pour délivrer un signal d'entrée mesuré du mécanisme de positionnement (i(n)) ;

un moyen pour estimer la position absolue de la tête ($x_e(n)$) par rapport à la référence fixe et à la vitesse de la tête ($v_e(n)$), en utilisant ledit signal d'erreur (e(n)), ladite position de tête absolue prédite précédente ($x_p(n)$) et une vitesse prédite précédente ($v_p(n)$) ; un moyen pour estimer le signal d'entrée équivalent du mécanisme de positionnement ($w_e(n)$) requis pour compenser lesdites forces de sollicitation agissant sur le mécanisme de positionnement, en utilisant une force de sollicitation prédite précédente équivalente au signal d'entrée du mécanisme de positionnement ($w_p(n)$) et un moyen (80, 108) pour estimer l'accélération de la tête ($a_e(n)$) comme une fonction du signal d'entrée mesuré du mécanisme de positionnement (i(n)) et un signal d'entrée équivalent des forces de sollicitation estimées du mécanisme de positionnement ($w_e(n)$) ;

un générateur de trajectoire de vitesse (102) pour calculer une vitesse de tête ordonnée optimale ($v_c(n)$) comme une fonction de la distance ($x_{tg}(n)$) à partir de la position de la tête absolue estimée ($x_e(n)$) à la piste cible (t_d) et un moyen (104) pour calculer l'erreur de vitesse de la tête ($v_{es}(n)$) comme une fonction de la différence entre la vitesse ordonnée de la tête ($v_c(n)$) et de la vitesse estimée de la tête ($v_e(n)$) ;

un estimateur d'état (80) pour prédire pour l'échantillon de signal d'erreur de positionnement suivant, la position absolue de la tête ($x_p(n+1)$) et la vitesse de la tête ($v_p(n+1)$ comme des fonctions des signaux de commande précédents (u(n), u(n-1)), de la position de tête absolue estimée précédente ($x_e(n)$), de la vitesse de la tête estimée précédente ($v_e(n)$), du signal d'entrée équivalent des forces de sollicitation estimées précédentes du mécanisme de positionnement ($w_e(n)$) et desdites constantes (g_{ij}, p_{ij}) représentatives des paramètres physiques du mécanisme de positionnement et pour prédire le signal d'entrée équivalent des forces de sollicitation du mécanisme de positionnement ($x_p(n+1)$) comme une fonction du signal d'entrée équivalent des forces de sollicitation estimées précédentes du mécanisme de positionnement ($w_v(n)$) ;

un moyen (106) pour calculer un signal de commande (u(n)) comme une fonction de l'erreur de vitesse de la tête ($v_{es}(n)$), de l'accélération estimée de la tête ($a_e(n)$) et du signal de commande (u(n-1)) produit par l'échantillon précédent du signal d'erreur de positionnement ;

un moyen pour mémoriser les valeurs numériques représentatives des signaux de commande (u(n), u(n-1)), du signal d'entrée mesuré du mécanisme de positionnement (i(n)), de la position de tête estimée ($x_e(n)$), de la vitesse de la tête estimée ($v_e(n)$), du signal d'entrée équivalent des forces de sollicitation estimées du mécanisme de positionnement ($w_e(n)$) et desdites constantes (k_{ij}, p_{ij}) représentant les paramètres physiques prédéterminés du mécanisme de positionnement, et

un moyen (92) pour convertir le signal de commande numérique (u(n)) en un signal d'entrée analogique destiné au mécanisme de positionnement (i(t)).

11. Unité de disque selon la revendication 10, dans laquelle les informations d'asservissement sont enregistrées en bandes répétitives radialement d'un nombre fixe de pistes par bande et dans laquelle le démodulateur délivre un signal d'asservissement analogique en quadrature, dans lequel le moyen de conversion analogique/numérique pour le signal d'erreur de position reçu depuis le démodulateur comporte un moyen pour produire un signal d'erreur de position principalement numérique (PESP) et un signal d'erreur de position en quadrature numérique (PESQ) et comprend de plus un moyen pour identifier à partir des signaux d'erreur de position principalement numériques et en quadrature la piste spécifique à l'intérieur d'une bande sur laquelle la tête est placée.

12. Unité de disque selon la revendication 10 ou la revendication 11, dans laquelle le moyen pour calculer une estimation de l'accélération de la tête comporte un moyen pour estimer l'accélération moyenne de la tête pendant le suivi de piste pour qu'elle soit égale à zéro.

13. Unité de disque selon l'une quelconque des revendications 10 à 12, dans laquelle le moyen pour convertir le signal de commande numérique en un signal analogique de mécanisme de positionnement comporte un amplificateur de puissance intégrateur (58).

14. Unité de disque selon la revendication 13, comprenant de plus un moyen pour calculer une valeur représentative d'un signal de correction comme compensation pour un courant résiduel d'entrée vers un amplificateur de puissance intégrateur, un moyen pour ajouter la valeur du signal de correction au

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signal de commande numérique avant conversion du signal numérique en analogique et un moyen pour mettre à jour la valeur du signal de correction pendant le suivi de piste.