Description

This invention relates generally to a method for controlling the position of a read/write head with respect to a rotating information storage disc, and more particularly to a method of reducing the ring-out time of a stepping motor used to control the position of a read/write head with respect to a rotating storage disc.

It is generally desirable to increase as much as practical the amount of data which can be stored on an information storage disc. Data is generally stored on a disc on concentric circular tracks. Obviously, it is desirable to fit as many tracks as possible on a disc surface, which means that the tracks should be as narrow as practical and as close together as practical. However, it is also necessary to position a read/write head over the middle of any desired track and to keep it there during rotation of the disc while the data is written into the track or read from the track. As the tracks become ever smaller in width and are spaced closer and closer together, it becomes increasingly difficult to correctly position the read/write head. It is this ability to reliably position a read/write head over the center of a desired track while the disc is rotating, which limits the practical density of the recording discs.

With magnetic storage discs, typically an open loop positioning system with no feedback control is used to coarse position either one or an array of read/write transducers over a desired track. With flexible magnetic storage discs, this is typically the only positioning system for the read/write head. With hard magnetic storage discs, coarse positioning is generally followed by fine positioning using a positioning system with feedback control to precisely position the read/write head over the center of the desired track. The fine positioning system generally locks onto and tracks a magnetic pattern of some kind. Most of these magnetic servo schemes use a significant portion of the recording surface for a magnetic servo pattern. This obviously reduces the amount of recording surface available for recording data.

In the past, it has been identified as being highly desirable in fine positioning a read/write head to reduce the settling time; that is, the time necessary to slow down and then finally stop a read/write head in its movement from one track to another. In order to achieve a reduction from about 65 milliseconds access time to below 40 milliseconds, open loop control methods were initially used wherein a minimum ring-out time was achieved by correctly timing the step input command pulses to a stepper motor. This open loop approach, however, has limited effectiveness because motor parameters will vary due to manufacturing tolerances. Therefore, with an invariant algorithm, the step response will no longer have minimum ring-out for every motor. The principles of closed loop methods to minimize the single step response ring-out time, that is, the time necessary to finally settle the read/write head over the target track, have been described in the literature, but they require an external sensor or an extensive amount of electronics to decode winding voltages and produce a feedback signal.

US-A-4396959 discloses a Data Transducer Position Control System For Rotating Disk Data Storage Equipment in accordance with the prior art portion of Claim 1. In the position control system of US-A-4396959, there is generally a motor for moving the transducer, a drive for rotating the disc, a drive control for the motor, a detector for detecting that the transducer is passing over the target track, and means for applying a predetermined fixed short deceleration to stop the transducer carriage assembly. As compared therewith, the present invention, as defined in Claim 1, senses not only the passing of the target track but also the speed and direction of the transducer as it passes the target track. This enables the present invention to apply a torque damping pulse at an appropriate delay time after the sensed target track crossing, in the appropriate direction, and of the appropriate duration, based on the speed and direction of the crossing, to settle the transducer heads in a minimum time.

Therefore, it is an objective of this invention to use and incorporate a simple voltage feedback method that uses the fact that the motor step size is small compared to one electrical cycle of the back emf of the motor.

This invention provides a system for positioning a read/write transducer relative to a magnetic storage disc carrying a plurality of concentric tracks to read and write data stored on the disc, said system including: motor means having a plurality of phases selectively energizable for moving the read/write transducer relative to said concentric tracks from a start track to a preselected recording position over a target track selected from said plurality of said tracks on said disc; drive means for rotating said disc to provide relative movement between said disc and the read/write transducer thereby enabling the transfer of data between said disc and the read/write transducer; and drive computer control means for sending a sequence of step pulses to said motor means thereby energizing selected plases to drive said transducer from track to track and finally holding selected phases energized corresponding to the position of said transducer over said target track; wherein ring detector means is provided for sensing the speed of said transducer relative to said target track each time said transducer is passing over said target track in the swing-in over said target track and for generating an output signal indicative of said sensed speed of each said passage; and in that said drive computer control means is responsive to each said ring detector output signal for

controlling the duration of a damping pulse applied to a phase of said motor means selected according to a detected direction of said passage.

Thus positioning apparatus in accordance with this invention, uses the output of the ring detector in controlling the settling of a read/write head over a desired track to significantly reduce the settling time. Prior art systems allow the read/write head positioning system to ring out naturally and then send the SEEK COMPLETE signal to the controlling microprocessor when this process is complete. The output of the ring detector in the present invention is used to change or control the timing of specially generated torque damping pulses which are fed to the stepper motor at the end of a SEEK step sequence. These torque damping pulses are step pulses, the timing and/or duration of which applies either a positive or negative torque to the stepper motor relative to the target track based on the "energy" that has to be dissipated to settle the read/write head over the desired track. The energy is measured indirectly by monitoring the back emf voltage of an open winding or unenergized phase of the motor, and developing an indication of how fast the read/write head is going through the desired track zero or target track point.

In a preferred embodiment, this speed is represented by the ring pulse time output (a measure of how rapidly the step motor crosses the zero velocity axis between predefined positive and negative thresholds relative to the zero velocity point) from the ring detector measured as the step motor crosses the zero velocity axis. By bringing an additional signal out of the ring detector, the direction in which the read/write head has crossed the track can also be defined. Based on how fast the read/write head is going and in which direction, the microprocessor accesses a look-up table for selecting the timing of the damping pulse.

More specifically, the lookup table includes the timing of damping pulses which can be applied to a selected phase of the motor to minimize the ring-out for various ring pulse time initial conditions. Given various initial velocities, the step time T1, which is the time from the zero velocity crossing to the beginning of the torque damping pulse (as commanded by a first damp step pulse command), can be plotted vs. the ring pulse time, i.e., energy. A similar plot can be made for the step time T2 which is the time from the zero velocity crossing to the end of the torque damping pulse (as commanded by a second damp step pulse command). From this data, a polynomial using least square's method is fitted through the data points, and an energy function is developed comprising ring pulse time vs. the torque damping pulse command times T1 and T2; that is, the time to the application of and duration of the torque damping pulse. This pulse deenergizes a selected phase of the motor to minimize the ring-out time given the initial energy function calculation and the knowledge of which motor phases are energized to settle on a particular track. Based on this information, the microprocessor can control the deenergization of a selected phase of the motor in order to rapidly settle the read/write head over the desired track and significantly reduce the settling time of the device.

It should be noted that while this application discloses the method and apparatus in conjunction with a 10-phase motor driven in a star drive configuration, the results can be applied to a motor with any number of phases and other drive configurations.

In the preferred embodiment, one of the phases normally deenergized in positioning the motor at a target track is briefly energized to damp the motor; alternatively, a normally energized phase could be deenergized for the duration of the torque damping pulse to achieve the same goal.

It should further be noted that this invention is especially useful to control the timing of the last step pulse commands of a long seek to reduce the settling time. These step pulse commands are added to the end of a normally generated sequence of step pulse signals to rapidly settle the motor over the track.

References to energy should be understood to mean the width of the ring detector pulse as the read/write head passes through zero velocity, i.e., at the point of maximum displacement from the target track, as this pulse width is directly related to the energy of the transducer relative to the target track.

In describing this invention, the following conventions will be used: "motor detent position" shall mean a position of stable equilibrium for the motor; "positive torque damping pulse" shall mean a pulse which creates additional motor torque in the original track seek direction; "negative torque damping pulse" shall mean a pulse which reduces motor torque in the original track seek direction; "ringing" is a measure of the energy the transducer has as it crosses the target track at the end of a seek. The features and advantages of this invention will be better understood with reference to the following drawings and the accompanying detailed description of a preferred embodiment of the invention.

FIG 1 is a block diagram of the essential elements of the system;

FIG 2 schematically illustrates 20 motor detent positions that can be reached in a given electrical cycle by energizing selected phases of the motor;

FIG 3A illustrates a preferred implementation of this invention showing the connections between the ring detector and the motor phases, and also illustrating the necessary connections to develop signals illustrating both pulse width and the direction in which the read/write head crosses the track;

FIG 3B illustrates an alternate implementation of the invention illustrated in FIG 3A;

FIG 4 illustrates the signals which are developed by the ring detector and the controlling microprocessor by tapping into the unenergized phase of the motor;

FIGs 5A, 5B and 5C illustrate in greater detail the positioning of a read/write head over a desired target track and the signals which can be measured to develop the necessary positioning information;

FIGs 6A, B, C illustrate the application of the last two torque damping pulses which are applied in response to the ring detector output to finally position the read/write head at the target track or track zero;

FIGs 7 through 12 illustrate various positioning sequences used to develop the final two positioning pulses and position the read/write head over the target track;

FIG 13 illustrates a curve fitted to data generated from FIGs 6-12 to develop step pulse command time period T1;

FIG 14 illustrates a curve fitted to data generated from these same figures to generate step pulse command time period T2; and

FIGs 15-19 indicate potential system responses using the control sequence developed for this invention.

Referring to FIG 1, one or more read/write heads 10 positionable relative to a storage medium such as a disc 12 are illustrated. The disc 12 includes a plurality of concentric tracks 14; the disc is a magnetizable medium such that data may be recorded and retrieved along the lines of the tracks 14 by means of the read/write head 10 in a conventional manner. Positioning means comprising the motor 16 is energized to move the read/write head 10 to preselected recording positions or tracks 14 over the disc 12. The positioning means comprises a stepper motor 16 (multiple phases of which appear in FIG 2) that may be selectively energized to position the read/write head 10 over any one of the tracks 14. The head is supported on an arm 18 adjacent the surface of the disc where the read/write head 10 flies on a thin film of air when the disc 12 is rotated. Drive means 20 located concentric with central axis 22 of the disc 12 are provided to create relative movement between the disc 12 and the read/write head 10, thereby enabling the transfer of data between the magnetic storage medium and the heads in a conventional manner. The drive means 20 in this case comprises a direct drive motor that spins the disc 12 about the central axis 22.

To briefly review the other major elements in FIG 1, when a read/write head 10 is being moved in a seek mode from one track to a desired target track, the number of step pulses that have been fed to the motor is monitored so that the processor 28 may continuously calculate the position of the moving read/write head 10 relative to the target track. This target track is defined by the position command 29 from memory 30. When the target track is passed by the read/write head 10, the output of the ring detector 30 is monitored to determine how much ringing exists. When the target track is reached, a predetermined algorithm is used to finally position the read/write head 10 relative to the target track. The present invention uses the ring detector output in a novel manner to reduce the settling time and thereby reduce the access time, that is, the time needed to move the read/write head from an initial track to the target track on the surface of the disc.

The specific positioning of read/write head 10 relative to a selected track is accomplished by selective energization of the differing phases of the exemplary 10-phase stepper motor. This may be better understood by referring to FIG 2. In this explanation, the motor has ten poles, each of which is wound with a coil. The coils of opposing poles (180° apart) are wound together in series, as illustrated in FIGs 3A and 3B by the coils 30A-30E. Five external motor coils are brought out separately as ten leads, A+, A-; B+, B-; C+, C-; D+, D-; and E+, E-. Alternatively, all leads of the same polarity may be tied together internally and brought out as a single center tap lead along with the five remaining motor leads. The preferred adaptive damping scheme is compatible with either method of accessing the motor leads.

Referring again to the vector diagram of FIG 2, there are 20 motor detent positions per electrical cycle. The positions with two or four phases on are even read/write track centers, while the five or three phase positions are odd read/write track centers. It should be noted for purposes of understanding the operability of this invention that odd numbered on-track centers may be held with either five phases on or with three phases on. For example, track 5, represented by the number "5" appearing at the arrow end of one vector, can be held with the sequence $\overline{A}$ B $\overline{C}$ $\overline{D}$ E or with the sequence $\overline{A}$, B, E. Track 4 can be held with sequence $\overline{A}$ B $\overline{D}$ E or $\overline{A}$E.

When the motor phases are active, the torque generated by the motor varies sinusoidally with rotor position. The point of stable motor detent is where the torque is zero and the torque position curve is on a negative tangent. The detent position is then a point of zero torque, and minimum back emf for the combined active windings. For example refer to the vector diagram for track 4, wherein the active windings are $\overline{A}$, B, $\overline{D}$, E while the C winding is off. Note that the combined active windings are at 90° to the inactive winding C. Thus, the back emf generated by winding C is at its peak at track 4 (as well as at track 14). Likewise, for track 5 if this track is being held with three phases on, the active phases are $\overline{A}$, B, E, and the off phases $\overline{C}$ and $\overline{D}$ are 72° from the combined active phases. Hence, the back emf generated by winding $\overline{C}$ or $\overline{D}$ is near its peak at track 5 (as well as at track 15).

By following this pattern, it can be seen that every even track detent location has an off winding which generates maximum back emf, and every odd track location, in three-phase-on mode, has an off winding which generates near maximum back emf. This back emf can be read by a ring detector to develop a signal indicating system energy and thereby transducer velocity as a target track position is crossed.

In known stepper motor positioning systems not using any feedback, the settling time must be fixed as the maximum worst case expected time, resulting in an inordinately long time to settle at the end of any seek. The objective of this invention is to modify this system to minimize seek settling time by using the output of a modified ring detector, the ring detector indicating both the velocity at which a target track is crossed by the seeking read/write head and the direction. The timing diagram of FIG 4 shows the signals -RING 39 and DIRECTION 41 that comprise the outputs of this ring detector 32.

Referring to the schematic diagram of FIG 3, a ring detector 32 is shown selectively connected to the output of any of the coils in response to commands through a selector 34 from the microprocessor 28. The ring detector 32 takes the back emf signal from a selected, i.e., non-energized, coil of the stepper motor and applies it to an input of each of a pair of operational amplifiers 33A, B. The other input receives a threshold level bias voltage +V,- V, set to represent a specified level of off-track, e.g., ±5%. The ring detector, which has a binary output, will switch output levels when the back emf signal is between the voltage levels +V, -V and passes sufficiently rapidly from one threshold to the other. The assumption being made is that the speed with which the stepper motor switches from a positive to negative velocity (relative to the target track) directly represents the speed at which the transducer passed over the target track and therefore the amount of mistracking. To achieve this goal, a separate amplifier 36 is provided for each winding 30A-E, connected across the two outputs of the series connected coils of the motor. The output of each amplifier 36A-E is multiplexed to the ring detector 32 (which functions as a window comparator) by microprocessor 28 via selector 34. The microprocessor 28 keeps account of which track the stepper is arriving at as illustrated in FIG 2, and selects the amplifier 36A-E connected to a non-energized winding as discussed above. The back emf signal is a lightly damped sinusoid the amplitude of which is proportional to head velocity. Since the velocity is known to be sinusoidal, the distance from detent at the target track is also inferred from the back emf signal. The window comparator threshold of the ring detector is set to correspond to ± 5% off-track, thereby defining the available width of the ring detector output, -RING 39 (FIG 4).

The ring detector digitizes the output of the selected amplifier 36 during the window period, i.e., when the back emf signal is within the thresholds defined by the window comparator. By separating the outputs of the two amplifiers which are incorporated in the window comparator or ring detector 32, and looking only at the output of one amplifier, the DIRECTION signal 41 is developed which indicates which direction the read/write head is moving as it crosses the target track.

The microprocessor monitors the comparator output, which is shown as -RING 39 during arrival at the target track, and sets the SEEK COMPLETE signal 40, (FIG 4), true when the back emf signal stays within the window for more than one-half cycle of oscillation. This allows the SEEK COMPLETE 40 signal to be set true as soon as the heads have settled.

The above method monitors the back emf to determine when the seek settle time is ended and SEEK COMPLETE can be sent to the microprocessor. The discussion below will demonstrate use of the back emf information to reduce the stepper settling time.

The back emf of a non-energized coil is always being monitored. If a four-phase-on track is designated as the target track, the back emf monitored 37 is that induced in the non-energized coil which is at a 90° angle to the vector direction of the target track.

In the case where a track is held with five phases energized, a non-energized phase would ordinarily not be readily available for reading the back emf signal. However, it is apparent from inspection of FIG 2 that a target track reached with five phases energized can also be reached with three phases energized. In the three energized coil cases, one of the two coils at a 72° angle to the vector direction of the target track is monitored to provide the back emf signal. For example, if the system is seeking to track 5, that position is held by deenergizing coils $\overline{D}$ and $\overline{C}$, and sampling the back emf from one of these coils, the same vector position being achieved with $\overline{A}BE$ energized. These two coils can later be re-energized to hold the target track.

FIGs 2 and 4 can be used to illustrate how a torque damping pulse derived from the ring detector output is used to reduce the seek settle time in accordance with this invention. A lookup table accessed on the basis of the duration of the RING pulse 39 determines delay time to and duration of each torque damping pulse T_D1, 2, 3 applied to selected coils of the stepper motor which is positioning the transducer.

For example, if the read/write head is targeted to track 4, motor phases $\overline{A}B\overline{D}E$ are energized. If the head has crossed the track as shown at the top line of FIG 4, a RING pulse 39, T_D1 is generated in the ring detector 32. Based on the duration of this pulse and the indicated direction of travel, a torque damping pulse T_D1, 42 is generated and applied to a selected phase of the motor. This pulse is termed a forward pulse because it corrects the motor torque to lie in the

direction of the original seek. This pulse T_D1 is delayed a fixed period 52 with respect to the trailing edge of ring pulse T_P1. The pulse also has a calculated duration to modify motor torque by energizing a selected non-energized phase, e.g., $\overline{C}$, or preferably shutting off an otherwise energized phase, e.g., $\overline{D}$. This provides a position correcting torque on the read/write head toward track 4, thereby properly positioning the read/write head on the target track. If the head moves back across track 4, as shown at the top of FIG 4, a second ring pulse T_P2 is generated resulting in generation of a torque pulse T_D2, 44. This is referred to as a reverse pulse because the change in motor torque is opposite to the effects of the first pulse T_D1.

The forward and reverse pulses 42, 44 constitute torque damping pulses, as each pulse T_D 1, 2, 3 indicates that a phase of the motor normally energized to reach a target track has been shut off at the leading edge of the pulse and turned back on at the trailing edge of the pulse to modify, for that brief period, the existing motor torque.

This produces the motor torque necessary to settle the motor on the target track. The width of each pulse T_D1, 2 or 3 represents the time that one of the coils normally energized according to the positioning algorithm and phase diagram (FIG 2) to drive the motor to a particular predefined position at a target track is deenergized. This provides a proper position correcting torque to the motor. Alternatively, a phase of the motor normally deenergized when a particular target track is defined may be energized for the period T_D1, T_D2 or T_D3.

Considering a specific example of seeking from track zero to track 4 (and referring to the phase diagram of FIG 2 and the timing diagram of FIG 4, the coils $\overline{A}B\overline{D}E$ are energized to reach this position, and the back emf 37 is read from coil C, a non-energized coil. In this example, signals RING 39 and DIRECTION 41 indicate that the read/write head has moved too far toward cylinder 5 and a damping torque must be created. For a period of positive torque damping pulse 42, T_D1, coil C is turned on. As the motor moves back toward the target track, the coil will be de-energized at the end of that time defined by torque damping pulse T_D1. The next pulse on line RING 39, Tp2, indicates that the read/write head which previously overshot cylinder 4 towards cylinder 5 is now moving in the opposite direction and is crossing the target track 4 toward cylinder 3. Since the read/write head has now moved too far toward cylinder 3, coil $\overline{C}$ is energized at about the time of maximum displacement from track 4, creating a damping torque for the period of pulse T_D2. This reduces the torque which would drive the motor back past cylinder 4 toward cylinder 5. In this example, a third target track crossing occurs as represented by pulse Tp3. Thus, a third torque damping pulse T_D3 is applied, again briefly energizing a normally de-energized coil for a period of the pulse, and settles the read/write head on the track.

As will be apparent from a study of FIG 4, the damping pulses TD 1, 2, 3 are usually applied at or slightly before a point 50 where the velocity is at a maximum. Thus the points 50 are aligned with the leading edge of the first and second damping pulses T_D1, T_D2 41 42.

In a situation such as where the track indicated by the number 5 is the target track, in order to sample the back emf, targeting of this track is done with only three phases ($\overline{A}BE$) of the five phases ($\overline{A}B\overline{C}\overline{D}E$) energized. The read/write head reaches this track with only phases $\overline{A}BE$ energized; the back emf is read from a nonenergized phase ($\overline{C}$ or $\overline{D}$). To settle the transducer on the track and damp the ring-out, the forward and/or reverse pulses, phases $\overline{C}$ or $\overline{D}$ must be turned on for the period of pulse T_D1, T_D2 respectively. The force normally applied to reach the track is modified by turning on one coil of the two coils that are not energized to reach the target track.

As the rate of movement of the read/write head across the target track slows down, the width of the window pulse indicated at RING 39 becomes greater. The delay time from the trailing edge of that window to the leading edge of the next succeeding torque damping pulse is correspondingly reduced.

In calculating the lookup table value for the damping pulses the width of the RING pulse must be taken into account in calculating both the duration of torque damping pulse T_D1, 2, 42, 44, and the time delay 52 from the trailing edge of the window at ring 39 to the lead edge of the torque damping pulse. Reviewing the example in FIG 4, the signal RING 39, Tp1 created at the point of maximum displacement of write head past the target track is very narrow, and the delay 52 between the trailing edge of pulse Tp1 and the leading edge of the first torque damping pulse T_D1 is fairly significant. In contrast, a transition indicated by the width of pulse Tp3 is much slower, with the read/write head having a reduced velocity such that in passing over the target track barely passes outside the 5% mistrack window, and therefore the delay 54 from the trailing edge of window pulse T_P3 to the leading edge of torque damping pulse T_D3 is quite short. As noted above, these delays are defined in the lookup table which is accessed by the microprocessor after it reads the width of the RING pulse T_P1, T_P2 or T_P3.

It is also a known characteristic of the motor to have a certain amount of built-in damping. Once the window pulse RING 39 reaches a certain predetermined width, it is assumed that at the next zero crossing the read/write head will settle on the track because of the inherent damping of the motor.

If the first torque damping pulse does not achieve settling, forward torque damping pulse 42, T_D1, is followed by a reverse torque damping pulse 44, T_D2, to achieve proper settling. In some cases only a limited

number of torque damping pulses 42, 44 are applied. The reason for this and other operating assumptions will be more apparent from the specific example given below.

The following sequence of figures beginning with FIG 5 represents the development of a set of torque damping pulse times which can be stored in a lookup table to be accessed on the basis of measurements of the width of the window pulse RING 39 from the ring detector as the read/write head crosses the target track. The embodiment above was primarily concerned with generation of a torque damping pulse for a period of time T_Dn by energizing an otherwise non-energized phase of the motor. The discussion below relates to a computer generated simulation of a situation wherein, for the period T_Dn, an otherwise non-energized phase is energized. FIG 5A is a computer simulation plot of a 10-phase motor showing the velocity vs. position error, with eight phases on; the motor starts from the initial track with an initial velocity of 1500 half steps per second and an initial positional error of zero. FIG 5B is a plot of motor velocity and position versus time for the same motor. FIG 5C is a plot of the open circuited phase pair back emf voltage versus time and ring detector output versus time. This is the back emf signal which is monitored at the ring detector to establish position and positioning error as explained above. The back emf voltage shown in the lower plot in FIG 5C is gradually damped down to zero as the transducer settles on the target track. The upper plot in FIG 5C which is the ring detector output demonstrates how the pulse width is very narrow at the ring detector output when the target track crossings are rapid, the width widening as the read/write head settles onto the target track.

FIG 6A is a phase plane for a sample disc drive showing speed vs. position error. This study assumed that the initial target track crossing is going from positive velocity to negative velocity; the opposite could also be true as under the preferred embodiment discussed above the direction output of the ring detector conveys a signal indicating the direction of track crossing.

FIG 6C illustrates at point A the first zero velocity crossing which is used to infer the velocity at the time of the first crossing of the target track by the transducer; it is located by monitoring the back emf of a non-energized phase. Since the target track crossing is rapid, a corresponding narrow ring detector output ensues. By measuring the width of the ring detector output, delays T1 and T2 to the beginning and end of the torque damping pulse to be applied to the selected phase of the motor can be established. It should be noted from FIG 6C that the pulse width shown in the upper figure is directly dependent on the slope of the zero velocity crossing defined by the back emf signal.

FIGs 13 and 14 illustrate the calculation of the times T1 and T2. It is known that, as discussed above, the ring pulse time or width of the detector window pulse output (RING 39, FIG 4) is directly relatable to the amount of energy in the system at the zero velocity crossing which relates directly to position error. To define this relationship in a manner which can be consistently implemented, the initial velocity of the system was varied as shown in FIGs 7-12, providing a series of points that could be plotted in FIGs 13 and 14 as time T1 or T2 in microseconds vs. the ring pulse time. For any initial velocity, as represented by the ring detector output, two time periods, one the period T_1 to the application of the damping pulse and the second T_2-T_1 representing the duration of the damping pulse, were found to minimize the ring out. These two step times were found for various initial velocities as in FIGs 7-12 and plotted vs. ring pulse time for each solution. Thus, the forward step time T1 (time from the zero velocity crossing to the positive step command) can be plotted vs. ring pulse time as shown in FIG 13. A similar plot can be made for the time T2 which is the time from the zero velocity crossing to the end of the torque pulse command as shown in FIG 14. From this data a polynomial using least square's methods can be fitted through the data points. Given this energy function, the ring pulse time can be measured as the step motor crosses the zero velocity axis, and the time periods T1 and T2 can be either calculated by an algorithm or selected from the above lookup table and applied to a desired phase of the motor to create the necessary damping torque and minimize the ring out time.

By storing sets of points selected for each ring pulse time width, delay times and durations for appropriate forward and reverse step damping commands can be selected. The appropriate pulse of the motor to be affected by the command can be easily derived on the basis of the polar diagram of FIG 2. By a combination of these commands applied to the appropriate phase of the motor, a landing with zero position error with very rapid settling times can be consistently achieved. As noted above, the curves of FIGs 13 and 14 were generated from the conditions mapped in FIGs 7-12. FIG 7, for example, shows an initial condition of a velocity of 600 steps a second; the two times T1 and T2 that result are 770 microseconds and 1285 microseconds. After the curves shown in FIGs 13 and 14 have been developed the initial velocity and initial position of the system were varied to observe the system response, resulting in the curve shown in FIGs 15-19. Each of FIGs 15-19 shows a different initial speed and initial off-track error ranging from 500 to 2500 steps per second and an off-track error ranging from -1 step to +1 step.

While in this example a single pair of time periods are shown, each generated in response to a separate ring pulse Tp1 is used, in many cases two pulses T_D1 and T_D2 are used. The use of a pair of pulses 42, 44 is the most common and efficient case for settling the

motor at the target track. Beyond the use of two pairs, limited efficiency is achieved in the reduction of ring-out time.

Other alternatives to this invention may become apparent of person of skill in the art who studies this disclosure. Therefore, the scope of this invention is to be limited only by the following claims.

Where technical features mentioned in any claim herein are followed by reference symbols, those reference symbols are included solely for the purpose of increasing the intelligibility of the claims.

Claims

1. A system for positioning a read/write transducer (10) relative to a magnetic storage disc (12) carrying a plurality of concentric tracks (14) to read and write data stored on the disc (12), said system including: motor means (16) having a plurality of phases selectively energizable for moving the read/write transducer (10) relative to said concentric tracks (14) from a start track to a preselected recording position over a target track selected from said plurality of said tracks (14) on said disc (12); drive means (20) for rotating said disc to provide relative movement between said disc (12) and the read/write transducer (10) thereby enabling the transfer of data between said disc (12) and the read/write transducer (10); and drive computer control means (28) for sending a sequence of step pulses to said motor means (16) thereby energizing selected plases to drive said transducer (10) from track to track and finally holding selected phases energized corresponding to the position of said transducer over said target track; characterised in that ring detector means (30) is provided for sensing the speed of said transducer (10) relative to said target track each time said transducer (10) is passing over said target track (14) in the swing-in over said target track and for generating an output signal indicative of said sensed speed of each said passage; and in that said drive computer control means (28) is responsive to each said ring detector (30) output signal for controlling the duration of a damping pulse applied to a phase of said motor means (16) selected according to a detected direction of said passage.

2. A positioning system as in Claim 1, characterised in that said target track is reached by energizing selected ones of said phases, said ring detector (30) momentarily reading the back emf signal of one of the phases which is not energized to reach said target track.

3. A positioning system as in Claim 2, characterised in that an odd number of said phases of said motor (16) are energized to reach the target track, said positioning system including means for momentarily deenergizing two of said odd number of phases (28), as said transducer (10) passes over said target track, said ring detector (30) being selection connected to one of said two momentarily deenergized phases to detect a maximum back emf signal.

4. A positioning system as in Claim 2 or Claim 3, characterised in that said ring detector (30) includes means for setting voltage thresholds corresponding to a specified off track margin, the width of said ring detector output signal being a function of the time said transducer traverses between said voltage thresholds to thereby represent the velocity of the transducer at the target track.

5. A positioning system as in Claim 4, characterised in that said ring detector (30) includes means for indicating the direction said transducer is travelling (26) as it traverses the target track.

6. A positioning system as in Claim 4 or Claim 5, characterised in that said drive computer control (28) is responsive to said ring detector (30) output to modify the timing of the application of said damping pulse relative to the time of said target track crossing to minimize the ring-out time for said motor (16).

7. A positioning system as in Claim 6, characterised in that said motor (16) is a 10-phase motor driven in a star drive configuration.

8. A positioning system as in Claim 6 or Claim 7, characterised in that said back emf signal is a sinusoid, the system setting a SEEK COMPLETE signal (40) when the back emf stays within said voltage thresholds for more than one-half cycle.

9. A positioning system as in Claim 8, characterised in that said ring detector (30) is selectively connected to one of the phases which is not energized to reach said target track in which maximum back emf is induced.

10. A positioning system as in Claim 9, characterised in that the energized phases comprise an even number of said phases, the phase selectively connected to the ring detector (30) being at an angle of 90 degrees to a vector direction representation of the target track location.

11. A positioning system as in Claim 9, characterised in that the energized phases comprise an odd

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motor at the target track. Beyond the use of two pairs, limited efficiency is achieved in the reduction of ring-out time.

Other alternatives to this invention may become apparent of person of skill in the art who studies this disclosure. Therefore, the scope of this invention is to be limited only by the following claims.

Where technical features mentioned in any claim herein are followed by reference symbols, those reference symbols are included solely for the purpose of increasing the intelligibility of the claims.

Claims

1. A system for positioning a read/write transducer (10) relative to a magnetic storage disc (12) carrying a plurality of concentric tracks (14) to read and write data stored on the disc (12), said system including: motor means (16) having a plurality of phases selectively energizable for moving the read/write transducer (10) relative to said concentric tracks (14) from a start track to a preselected recording position over a target track selected from said plurality of said tracks (14) on said disc (12); drive means (20) for rotating said disc to provide relative movement between said disc (12) and the read/write transducer (10) thereby enabling the transfer of data between said disc (12) and the read/write transducer (10); and drive computer control means (28) for sending a sequence of step pulses to said motor means (16) thereby energizing selected plases to drive said transducer (10) from track to track and finally holding selected phases energized corresponding to the position of said transducer over said target track; characterised in that ring detector means (30) is provided for sensing the speed of said transducer (10) relative to said target track each time said transducer (10) is passing over said target track (14) in the swing-in over said target track and for generating an output signal indicative of said sensed speed of each said passage; and in that said drive computer control means (28) is responsive to each said ring detector (30) output signal for controlling the duration of a damping pulse applied to a phase of said motor means (16) selected according to a detected direction of said passage.

2. A positioning system as in Claim 1, characterised in that said target track is reached by energizing selected ones of said phases, said ring detector (30) momentarily reading the back emf signal of one of the phases which is not energized to reach said target track.

3. A positioning system as in Claim 2, characterised in that an odd number of said phases of said motor (16) are energized to reach the target track, said positioning system including means for momentarily deenergizing two of said odd number of phases (28), as said transducer (10) passes over said target track, said ring detector (30) being selection connected to one of said two momentarily deenergized phases to detect a maximum back emf signal.

4. A positioning system as in Claim 2 or Claim 3, characterised in that said ring detector (30) includes means for setting voltage thresholds corresponding to a specified off track margin, the width of said ring detector output signal being a function of the time said transducer traverses between said voltage thresholds to thereby represent the velocity of the transducer at the target track.

5. A positioning system as in Claim 4, characterised in that said ring detector (30) includes means for indicating the direction said transducer is travelling (26) as it traverses the target track.

6. A positioning system as in Claim 4 or Claim 5, characterised in that said drive computer control (28) is responsive to said ring detector (30) output to modify the timing of the application of said damping pulse relative to the time of said target track crossing to minimize the ring-out time for said motor (16).

7. A positioning system as in Claim 6, characterised in that said motor (16) is a 10-phase motor driven in a star drive configuration.

8. A positioning system as in Claim 6 or Claim 7, characterised in that said back emf signal is a sinusoid, the system setting a SEEK COMPLETE signal (40) when the back emf stays within said voltage thresholds for more than one-half cycle.

9. A positioning system as in Claim 8, characterised in that said ring detector (30) is selectively connected to one of the phases which is not energized to reach said target track in which maximum back emf is induced.

10. A positioning system as in Claim 9, characterised in that the energized phases comprise an even number of said phases, the phase selectively connected to the ring detector (30) being at an angle of 90 degrees to a vector direction representation of the target track location.

11. A positioning system as in Claim 9, characterised in that the energized phases comprise an odd

number of said phases, the phase selectively connected to the ring detector (30) being at an angle of 72 degrees to a vector direction representation of the target track location.

12. A positioning system as in any of Claims 6 to 11, characterised in that said drive computer control means (28) includes a lookup table means for storing the delay times from said ring detector (30) output signal to said damping pulse, said lookup table being accessed on the basis of the width of said ring detector (30) output signal.

13. A positioning system as in Claim 12, characterised in that said drive computer control means (28) is responsive to the information in said lookup table to turn off a selected phase of said motor (16) for the duration of the damping pulse, whereby the motor torque is modified to settle the motor (16) on target track.

14. A positioning system as in Claim 13, characterised in that said lookup table further includes, in addition to the delay times to said damping pulse, information defining the width of said damping pulse to define the time period that said selected windings are deenergized.

15. A positioning system as in Claim 14, characterised in that said drive computer control means (28) includes means for carrying out said sequence for selectively controlling a final damping pulse before setting a SEEK COMPLETE signal is carried out twice.

16. A positioning system as in Claim 14 or Claim 15, characterised in that the leading edge of said damping pulse is aligned with the point of maximum displacement of said transducer (10) from said target track as defined by said back emf signal.

Patentansprüche

1. System zur Positionierung eines Schreib-Lese-Wandlers (10) in bezug auf eine magnetische Speicherplatte (12), mit einer Vielzahl konzentrischer Spuren (14) zum Lesen und Schreiben der auf der Platte (12) gespeicherten Daten, wobei dieses System folgendes enthält:
   - eine Motoreinrichtung (16) mit einer Anzahl selektiv betreibbarer Phasen zur Bewegung des Schreib-Lese-Wandlers (10) relativ zu den konzentrischen Spuren (14) von einer Startspur zu einer vorbestimmten Aufnahmeposition bis über eine aus der Vielzahl der Spuren (14) auf der Platte (12) ausgewählte Zielspur,
   - eine Treibereinrichtung (20) zur Drehung der Platte zur Erzeugung einer Relativbewegung zwischen der Platte (12) und dem Schreib-Lese-Wandler (10), wobei der Datentransfer zwischen der Platte (12) und dem Schreib-Lese-Wandler (10) ermöglicht wird,
   - eine Treiber-Computersteuerungseinrichtung (28) zum Aussenden einer Folge von Schrittimpulsen an die Motoreinrichtung (16), wobei die ausgewählten Phasen in Betrieb gesetzt werden, um den Wandler (10) von Spur zu Spur zu bewegen und schließlich die ausgewählte Phase eingeschaltet bleibt, die der Position des Wandlers über der Zielspur entspricht,

   dadurch **gekennzeichnet**, daß

   eine Abkling-Detektoreinrichtung (30) vorgesehen ist, die jedes Mal, wenn der Wandler (10) während des Einschwingens über die Zielspur (14) streicht, die Geschwindigkeit des Wandlers (10) relativ zu der Zielspur mißt und ein Ausgangssignal erzeugt, welches die gemessene Geschwindigkeit für jede Passage angibt,

   und dadurch, daß die Treiber-Computersteuereinrichtung (28) auf jedes Ausgangssignal des Abkling-Detektors (30) reagiert, um die Dauer des Dämpfungsimpulses zu steuern, der an die Phase der Motoreinrichtung (16) angelegt wird, die entsprechend der festgestellten Richtung der Passage ausgewählt wird.

2. Positionierungssystem nach Anspruch 1, dadurch gekennzeichnet, daß die Zielspur durch das Betreiben der ausgewählten der Phasen erreicht wird, wobei der Abkling-Detektor (30) augenblicklich das Signal der Gegen-EMK einer der Phasen liest, die nicht betrieben werden, um die Zielspur zu erreichen.

3. Positionierungssystem nach Anspruch 2, dadurch gekennzeichnet, daß eine ungerade Anzahl von Phasen des Motors (16) betrieben wird, um die Zielspur zu erreichen, wobei das Positionierungssystem eine Einrichtung (28) zum augenblicklichen Abschalten zweier dieser Phasen beim Überstreichen der Zielspur durch den Wandler (10) enthält und der Abkling-Detektor (30) wahlweise verbunden ist mit einer der augenblicklich abgeschalteten Phasen, um ein maximales Signal der Gegen-EMK zu erfassen.

4. Positionierungssystem nach Anspruch 2 oder 3, dadurch gekennzeichnet, daß der Abkling-Detektor (30) eine Einrichtung zum Einstellen von einer

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bestimmten Spurengrenze entsprechenden Spannungsschwellen aufweist und die Breite des Abkling-Detektor-Ausgangssignals eine Funktion der Zeit ist, während der der Wandler zwischen den Spannungsschwellen kreuzt und dabei die Geschwindigkeit des Wandlers auf der Zielspur repräsentiert.

5. Positionierungssystem nach Anspruch 4, dadurch gekennzeichnet, daß der Abkling-Detektor (30) eine Einrichtung (26) aufweist, welche die Bewegungsrichtung des Wandlers anzeigt, wenn dieser die Zielspur kreuzt.

6. Positionierungssystem nach Anspruch 4 oder 5, dadurch gekennzeichnet, daß die Treiber-Computersteuerung (28) auf das Ausgangssignal des Abkling-Detektors (30) anspricht, um die zeitliche Abfolge des Anlegens der Dämpfungsimpulse bezogen auf das Kreuzen der Zielspur zur Minimierung der Ausklingzeit des Motors (16) zu modifizieren.

7. Positionierungssystem nach Anspruch 6, dadurch gekennzeichnet, daß der Motor (16) ein in Sternschaltung betriebener 10-Phasen-Motor ist.

8. Positionierungssystem nach Anspruch 6 oder 7, dadurch gekennzeichnet, daß das Signal der Gegen-EMK die Form einer Sinusoide hat und das System ein SUCH-ENDE-Signal (40) setzt, wenn die Gegen-EMK für mehr als eine halbe Periode innerhalb der Spannungsschwellen verbleibt.

9. Positionierungssystem nach Anspruch 8, dadurch gekennzeichnet, daß der Abkling-Detektor (30) selektiv verbunden ist mit einer der zum Erreichen der Zielspur nicht eingeschalteten Phasen, in der der die maximale Gegen-EMK induziert wird.

10. Positionierungssystem nach Anspruch 9, dadurch gekennzeichnet, daß die eingeschalteten Phasen eine gerade Anzahl solcher Phasen umfassen und die mit dem Abkling-Detektor (30) selektiv verbundene Phase einen Winkel von 90° in bezug auf die Vektorrichtungsdarstellung der Zielspurlage aufweist.

11. Positionierungssystem nach Anspruch 9, dadurch gekennzeichnet, daß die eingeschalteten Phasen eine ungerade Anzahl solcher Phasen umfassen und die mit dem Abkling-Detektor (30) selektiv verbundene Phase einen Winkel von 72° in bezug auf die Vektorrichtungsdarstellung der Zielspurlage aufweist.

12. Positionierungssystem nach einem der Ansprüche 6 bis 11, dadurch gekennzeichnet, daß die Treiber-Computersteuerungseinrichtung (28) eine Suchtabelleneinrichtung zur Speicherung der Verzögerungszeiten vom Ausgangssignal des Abklingdetektors (30) bis zum Dämpfungsimpuls enthält und auf diese Suchtabelle auf der Grundlage der Breite des Ausgangssignals des Abkling-Detektors (30) zugegriffen wird.

13. Positionierungssystem nach Anspruch 12, dadurch gekennzeichnet, daß die Treiber-Computersteuerungseinrichtung (28) auf die Information in der Suchtabelle reagiert, um die ausgewählte Phase des Motors (16) für die Dauer des Dämpfungsimpulses auszuschalten, wobei das Drehmoment des Motors modifiziert wird, um den Motor (16) über der Zielspur festzusetzen.

14. Positionierungssystem nach Anspruch 13, dadurch gekennzeichnet, daß die Suchtabelle zusätzlich zu den Verzögerungszeiten zum Dämpfungsimpuls ferner Informationen enthält, die die Breite des Dämpfungsimpulses beschreiben, um die Zeitperiode festzulegen, während der die ausgewählten Phasen ausgeschaltet sind.

15. Positionierungssystem nach Anspruch 14, dadurch gekennzeichnet, daß die Treiber-Computersteuerungseinrichtung (28) eine Einrichtung zur Ausführung der Schrittfolge zur selektiven Steuerung eines letztendlichen Dämpfungimpulses aufweist, ehe das Setzen des SUCH-ENDE-Signals zweifach ausgeführt wird.

16. Positionierungssystem nach Anspruch 14 oder 15, dadurch gekennzeichnet, daß die Vorderflanke des Dämpfungsimpulses zusammenfällt mit dem durch das Signal der Gegen-EMK definierten Punkt der maximalen Versetzung des Wandlers (10) von der Zielspur.

Revendications

1. Un système pour positionner un transducteur de lecture/écriture (10) par rapport à un disque d'enregistrement magnétique (12) qui porte un ensemble de pistes concentriques (14), pour lire et écrire des données enregistrées sur le disque (12), ce système comprenant : des moyens à moteur (16) comportant un ensemble de phases pouvant être excitées sélectivement pour déplacer le transducteur de lecture/écriture (10) par rapport aux pistes concentriques (14), depuis une position de départ jusqu'à une position d'enregistrement présélectionnée sur une piste objectif, qui est sélectionnée parmi l'ensemble des

pistes (14) sur le disque (12); des moyens d'entraînement (20) pour faire tourner le disque, de façon à produire un mouvement relatif entre le disque (12) et le transducteur de lecture/écriture (10), pour permettre ainsi le transfert de données entre le disque (12) et le transducteur de lecture/écriture (10); et des moyens de commande d'entraînement à ordinateur (28), pour émettre une séquence d'impulsions vers les moyens à moteur (16) pour ainsi exciter des phases sélectionnées de façon à entraîner le transducteur (10) de piste en piste, et maintenir finalement à l'état excité des phases sélectionnées correspondant à la position du transducteur sur la piste objectif; caractérisé en ce que des moyens détecteurs de suroscillation (30) sont incorporés pour détecter la vitesse du transducteur (10) par rapport à la piste objectif, chaque fois que le transducteur (10) passe sur la piste objectif (14) dans le déplacement l'amenant sur la piste objectif, et pour produire un signal de sortie indiquant la vitesse détectée de chacun de ces passages; et en ce que les moyens de commande d'entraînement à ordinateur (28) réagissent à chaque signal de sortie du détecteur de suroscillation (30), en commandant la durée d'une impulsion d'amortissement qui est appliquée à une phase des moyens à moteur (16) qui est sélectionnée conformément à une direction détectée du passage.

2. Un système de positionnement selon la revendication 1, caractérisé en ce que la piste objectif est atteinte en excitant certaines phases sélectionnées, le détecteur de suroscillation (30) lisant momentanément le signal de fcém de l'une des phases qui n'est pas excitée pour atteindre la piste objectif.

3. Un système de positionnement selon la revendication 2, caractérisé en ce qu'un nombre impair des phases du moteur (16) sont excitées pour atteindre la piste objectif, le système de positionnement comprenant des moyens pour désexciter momentanément deux des phases du nombre impair de phases (28), lorsque le transducteur (10) passe sur la piste objectif, le détecteur de suroscillation (30) étant connecté sélectivement à l'une des deux phases qui sont momentanément désexcitées, pour détecter un signal de fcém maximal.

4. Un système de positionnement selon la revendication 2 ou la revendication 3, caractérisé en ce que le détecteur de suroscillation (30) comprend des moyens pour fixer des tensions de seuil correspondant à une marge spécifiée de décalage par rapport à la piste, la largeur du signal de sortie du détecteur de suroscillation étant fonction du temps que met le transducteur pour passer de l'un à l'autre des seuils de tension, pour représenter ainsi la vitesse du transducteur sur la piste objectif.

5. Un système de positionnement selon la revendication 4, caractérisé en ce que le détecteur de suroscillation (30) comprend des moyens pour indiquer la direction dans laquelle le transducteur se déplace (26) lorsqu'il traverse la piste objectif.

6. Un système de positionnement selon la revendication 4 ou la revendication 5, caractérisé en ce que les moyens de commande d'entraînement à ordinateur (28) réagissent au signal de sortie du détecteur de suroscillation (30) en modifiant l'instant d'application de l'impulsion d'amortissement par rapport à l'instant de la traversée de la piste objectif, pour minimiser le temps d'extinction de suroscillation pour le moteur (16).

7. Un système de positionnement selon la revendication 6, caractérisé en ce que le moteur (16) est un moteur à 10 phases qui est attaqué avec une configuration d'attaque en étoile.

8. Un système de positionnement selon la revendication 6 ou la revendication 7, caractérisé en ce que le signal de fcém est une sinusoïde, le système activant un signal RECHERCHE TERMINEE (40) lorsque la fcém reste comprise entre les seuils de tension pendant plus d'un demi-cycle.

9. Un système de positionnement selon la revendication 8, caractérisé en ce que le détecteur de suroscillation (30) est connecté sélectivement à l'une des phases qui n'est pas excitée pour atteindre la piste objectif, dans laquelle la fcém maximale est induite.

10. Un système de positionnement selon la revendication 9, caractérisé en ce que les phases excitées comprennent un nombre pair de phases, la phase qui est connectée sélectivement au détecteur de suroscillation (30) étant à un angle de 90 degrés par rapport à une représentation sous forme d'une direction vectorielle de la position de la piste objectif.

11. Un système de positionnement selon la revendication 9, caractérisé en ce que les phases excitées comprennent un nombre impair de phases, la phase qui est connectée sélectivement au détecteur de suroscillation (30) étant à un angle de 72 degrés par rapport à une représentation sous forme de direction vectorielle de la position de la piste objectif.

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12. Un système de positionnement selon l'une quelconque des revendications 6 à 11, caractérisé en ce que les moyens de commande d'entraînement à ordinateur (28) comprennent une structure de table pour enregistrer les retards depuis le signal de sortie du détecteur de suroscillation (30) jusqu'à l'impulsion d'amortissement, l'accès à cette table ayant lieu sur la base de la largeur du signal de sortie du détecteur de suroscillation (30).

13. Un système de positionnement selon la revendication 12, caractérisé en ce que les moyens de commande d'entraînement à ordinateur (28) réagissent à l'information contenue dans la table en désactivant une phase sélectionnée du moteur (16) pendant la durée de l'impulsion d'amortissement, grâce à quoi le couple du moteur est modifié pour stabiliser le moteur (16) sur la piste objectif.

14. Un système de positionnement selon la revendication 13, caractérisé en ce que la table contient en outre, en plus des retards jusqu'à l'impulsion d'amortissement, une information définissant la largeur de l'impulsion d'amortissement, pour définir la durée pendant laquelle les enroulements sélectionnés sont désexcités.

15. Un système de positionnement selon la revendication 14, caractérisé en ce que les moyens de commande d'entraînement à ordinateur (28) comprennent des moyens pour accomplir deux fois la séquence pour commander sélectivement une impulsion d'amortissement finale, avant d'activer un signal RECHERCHE TERMINEE.

16. Un système de positionnement selon la revendication 14 ou la revendication 15, caractérisé en ce que le front avant de l'impulsion d'amortissement est aligné avec le point de déplacement maximal du transducteur (10) par rapport à la piste objectif, tel qu'il est défini par le signal de fcém.