during acceleration and deceleration of the actuator arm. Since the velocity profile is designed assuming worst case conditions so that adequate deceleration is available, then all of the files not operating under worst case conditions operate at less than an optimal level.

SUMMARY OF THE INVENTION

According to one aspect of the invention there is disclosed a method for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said method comprising the steps of: selecting a desired target position, and desired target velocity associated with the desired target position; applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly; determining the position of the actuator arm assembly and the distance of the actuator arm assembly from the target position at a plurality of sample times; determining the velocity associated with each of the positions of the actuator arm assembly at each of said plurality of sample times; determining a minimum distance to decelerate the actuator arm assembly by applying deceleration current in saturation mode, from the velocity associated with each of said plurality of sample times to the target velocity; comparing the determined minimum distance, to the distance of the actuator arm assembly from the target position for each of said plurality of sample times; and applying deceleration current operating in saturation mode to the coil once the determined minimum distance is within a selected amount of the distance of the actuator arm from the target position for the particular sample time until reaching the desired target.

According to another aspect of the invention there is disclosed a method for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said method comprising the steps of: generating a conservative velocity against position profile for decelerating the actuator arm assembly

so the actuator arm assembly will stop and settle at a desired position; selecting a first position, X1(arrive max), from the desired position where the actuator will stop and settle; selecting a second position, X1(arrive min), a number of tracks away from the desired position where the actuator will stop and settle; applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly; continuing to accelerate the actuator arm after exceeding the conservative velocity profile; applying deceleration current in saturation mode to decelerate the coil; determining a third position, X1(arrive) by determining the position of the actuator arm when the velocity of actuator arm due to the deceleration current in the saturation mode is within a selected value of the conservative velocity against position profile; and adjusting the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode when X1(arrive) is not between X1(arrive min) and X1(arrive max).

According to another aspect of the invention there is disclosed a method for estimating deceleration of an actuator arm assembly by a deceleration current in saturation mode, said method comprising the steps of: measuring the resistance of the coil before the seek; measuring the change in coil current during the acceleration portion of the seek; determining the change in velocity during the acceleration portion of the seek; measuring the maximum current in the coil during the acceleration portion of the seek; and determining the maximum velocity associated with the maximum current in coil during the acceleration portion of the seek.

According to another aspect of the invention there is disclosed an apparatus for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said apparatus comprising: means for generating a conservative velocity against position profile for decelerating the actuator arm assembly so the actuator arm assembly will stop and settle at a desired position; means for selecting a first position, X1(arrive max), from the desired position where the actuator will stop and settle; means for selecting a second position, X1(arrive min), a number of

tracks away from the desired position where the actuator will stop and settle; means for applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly; means for continuing to accelerate the actuator arm after exceeding the conservative velocity profile; means for applying deceleration current in saturation mode to decelerate the coil; means for determining a third position, X1(arrive) by determining the position of the actuator arm when the velocity of actuator arm due to the deceleration current in the saturation mode is within a selected value of the conservative velocity against position profile; and means for adjusting the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode when X1(arrive) is not between X1(arrive min) and X1(arrive max).

According to yet another aspect of the invention there is disclosed an apparatus for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said apparatus comprising: means for selecting a desired target position, and desired target velocity associated with the desired target position; means for applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly; means for determining the position of the actuator arm assembly and the distance of the actuator arm assembly from the target position at a plurality of sample times; means for determining the velocity associated with each of the positions of the actuator arm assembly at each of said plurality of sample times; means for determining a minimum distance to decelerate the actuator arm assembly by applying deceleration current in saturation mode, from the velocity associated with each of said plurality of sample times to the target velocity; means for comparing the determined minimum distance, to the distance of the actuator arm assembly from the target position for each of said plurality of sample times; and means for applying deceleration current operating in saturation mode to the coil once the determined minimum distance is within a selected amount of the distance of the actuator arm from the target position for the particular sample time until reaching the desired target.

According to still another aspect of the invention there is disclosed a method for controlling the movement of an actuator arm in a disk drive, the actuator arm movement being controlled by energy supplied to a motor associated with the actuator arm, said method comprising the steps of: determining a conservative velocity to position profile for the actuator arm; accelerating the actuator arm to a first position and an actual velocity, the actual velocity associated with the first position being substantially greater than the velocity associated with the first position according to the conservative velocity to position profile; and decelerating the actuator arm in saturation mode to a second position which is within a predetermined distance from a desired track, the deceleration in saturation mode reducing the actual velocity associated with the second position to a value within a selected amount of the velocity according to the conservative velocity to position profile.

DESCRIPTION OF PREFERRED EMBODIMENTS

In order that the invention will be fully understood preferred embodiments thereof will now be described by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is an exploded view of a disk drive;

Fig. 2 is an exploded view of the actuator arm assembly of a disk drive;

Fig. 3 is a schematic diagram of the actuator arm and the voice coil motor and other portions of the positioning apparatus for the disk drive;

CLAIMS

1. A method for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said method comprising the steps of:

selecting a desired target position, and desired target velocity associated with the desired target position;

applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly;

determining the position of the actuator arm assembly and the distance of the actuator arm assembly from the target position at a plurality of sample times;

determining the velocity associated with each of the positions of the actuator arm assembly at each of said plurality of sample times;

determining a minimum distance to decelerate the actuator arm assembly by applying deceleration current in saturation mode, from the velocity associated with each of said plurality of sample times to the target velocity;

comparing the determined minimum distance, to the distance of the actuator arm assembly from the target position for each of said plurality of sample times; and

applying deceleration current operating in saturation mode to the coil once the determined minimum distance is within a selected amount of the distance of the actuator arm from the target position for the particular sample time until reaching the desired target.

2. The method of claim 1 wherein the step of selecting a target position comprises the steps of:

determining the desired position where the actuator will settle and stop; and

selecting a position a number of tracks away from the desired position.

3. The method of claim 2 wherein the step of determining the minimum distance to decelerate the actuator arm assembly in saturation mode is estimated from values of coil current and coil resistance.

4. The method of claim 2 further comprising the steps of:

generating a conservative velocity against position profile assuming worst case conditions for deceleration; and

following the conservative velocity against position profile between the target position and the desired position.

5. The method of claim 3 wherein the deceleration associated with the step of generating the velocity against position profile for decelerating the actuator arm assembly is determined from the following formulas:

$$X1(\text{min}) = X1(\text{target}) + \text{slew} + \frac{X2(\text{present})^2 - X2(\text{target})^2}{2 \times ACC} + ADJ$$

Where

X1(min) - minimum distance needed to slow the actuator to a given target velocity. units-track A value of position is read from the file once per sample time.

X1(target) - target position where target velocity is expected. units-tracks

X2(present) - present velocity. units-tracks/sample

X2(target) - velocity desired at target position. units-tracks/sample

slew - correction factor to account for current slew rate. units-tracks. Formula for calculating slew is:

$slew$ = X2(present)×S

Where

S - number of samples that it takes to reverse the current from acceleration to deceleration. units-samples

ACC - acceleration available during decelerate phase. units-tracks/sample^2

and, where ACC is determined from:

$$ACC = \frac{Kt \times Lhead \times TPM \times T^2 \times (Ipeak + Ibemf)}{J}$$

Where

Kt - Torque constant. units-Newton-meter/amp 1 Newton=1 Kilogram-meter/second^2

Lhead - Distance to servo head. units-meters

TPM - Number of tracks per meter. units- tracks/meter

T - Sample time. units-seconds/sample

J - Moment of inertia. units-kilogram x meter^2

Ipeak - Peak current capable of being delivered by the power supply. units- amps. Formula for calculating the peak current is:

$$Ipeak = \frac{Vsup}{Rcoil + Rdriver}$$

Where

Vsup - Power supply voltage. units-volts

Rcoil - Resistance of voice coil. units- ohms

Rdriver - Resistance of all other elements in the system (eg. voice coil driver FET's when fully on, current sense resistor, flex cable lead resistance, etc.). units- ohms

Ibemf - Current available during deceleration due to the back EMF of the moving voice coil. units- amps. Since the coil slows down during deceleration the current available from the back EMF goes down. Therefore the average Ibemf could be

assumed to equal one half the Ibemf available at each sample that we compute the X1(min) value. Formula for calculating the back EMF current is:

$$Ibemf = \frac{X2(\text{present}) \times Ke \times Kemf}{2 \times Rcoil}$$

Where

Ke - Same value as Kt but units are Volts/radian/second

Kemf - Calibration factor to convert units of numerator to volts. The formula for Kemf is:

$$Kemf = \frac{1}{TPM \times Lhead \times T}$$

6. The method of claim 5 further including the step of measuring the coil resistance prior the each seek.

7. The method of claim 6 further comprising the step of measuring the coil current during the acceleration phase of the seek at least twice to determine I(delta).

8. The method of claim 7 wherein the velocities associated with the position of the actuator arm at the beginning and at the end of I(delta) are used to determine the change in velocity, X2(delta), due to the change in current, the values of coil resistance, I(delta) and X2(delta) used in the following formula to estimate the torque constant:

$$Kt = \frac{Rcoil + I(\text{delta})}{X2(\text{delta}) \times Kemf}$$

said torque constant used to estimate ACC, which is used to generate a velocity to position profile for the deceleration under saturation mode.

9. The method of claim 8 further comprising the steps of:

measuring the maximum current, I(max) and the velocity corresponding to maximum current, X2(max) while applying the acceleration current to the coil; and

estimating I(peak) using I(max) and X2(max), I(peak) is used to estimate the ACC term in generating the velocity to position profile:

$$I(\text{peak}) = I(\text{max}) + \frac{X2(\text{max}) \times Ke \times Kemf}{Rcoil}$$

10. A method for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said method comprising the steps of:

generating a conservative velocity against position profile for decelerating the actuator arm assembly so the actuator arm assembly will stop and settle at a desired position;

selecting a first position, X1(arrive max), from the desired position where the actuator will stop and settle;

selecting a second position, X1(arrive min), a number of tracks away from the desired position where the actuator will stop and settle;

applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly;

continuing to accelerate the actuator arm after exceeding the conservative velocity profile;

applying deceleration current in saturation mode to decelerate the coil;

determining a third position, X1(arrive) by determining the position of the actuator arm when the velocity of actuator arm due to the deceleration current in the saturation mode is within a selected value of the conservative velocity against position profile; and

adjusting the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode when X1(arrive) is not between X1(arrive min) and X1(arrive max).

11. The method of claim 10 wherein the minimum deceleration associated with the worst case conditions is used in the step of generating a conservative velocity against position profile.

12. The method of claim 10 wherein the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode is delayed when X1(arrive) occurs before X1(arrive min).

13. The method of claim 12 wherein the time is delayed by one sample time.

14. The method of claim 10 wherein the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode begins sooner when X1(arrive) occurs after X1(arrive max).

15. The method of claim 14 wherein the time is incremented by one sample time.

16. A method for estimating deceleration of an actuator arm assembly by a deceleration current in saturation mode, said method comprising the steps of:

measuring the resistance of the coil before the seek;

measuring the change in coil current during the acceleration portion of the seek;

determining the change in velocity during the acceleration portion of the seek;

measuring the maximum current in the coil during the acceleration portion of the seek; and

determining the maximum velocity associated with the maximum current in coil during the acceleration portion of the seek.

17. The method of claim 16 wherein the estimate of deceleration under saturation mode is determined using the following formula:

$$ACC = \frac{Kt \times Lhead \times TPM \times T^2 \times (Ipeak + Ibemf)}{J}$$

where

Kt - Torque constant. units-Newton-meter/amp 1 Newton=1 Kilogram-meter/second^2

Lhead - Distance to servo head. units-meters

TPM - Number of tracks per meter. units- tracks/meter

T - Sample time. units-seconds/sample

J - Moment of inertia. units-kilogram x meter^2

Ipeak - Peak current capable of being delivered by the power supply. units- amps. Formula for calculating the peak current is:

$$Ipeak = \frac{Vsup}{Rcoil + Rdriver}$$

Where Vsup - Power supply voltage. units-volts Rcoil - Resistance of voice coil. units-ohms

Rdriver - Resistance of all other elements in the system (eg. voice coil driver FET's when fully on, current sense resistor, flex cable lead resistance, etc.). units- ohms

Ibemf - Current available during deceleration due to the back EMF of the moving voice coil. units- amps. Since the coil slows down during deceleration the current available from the back EMF goes down. Therefore the average Ibemf could be

assumed to equal one half the Ibemf available at each sample that we compute the X1(min) value. Formula for calculating the back EMF current is:

$$Ibemf = \frac{X2(\text{present}) \times Ke \times Kemf}{2 \times Rcoil}$$

where

Ke - Same value as Kt but units are Volts/radian/second

Kemf - Calibration factor to convert units of numerator to volts. The formula for Kemf is:

$$Kemf = \frac{1}{TPM \times Lhead \times T}$$

wherein, the torque constant, Kt, is estimated using the measured coil resistance, measured change in coil current during the acceleration phase and determined change in velocity according to the following formula:

$$Kt = \frac{Rcoil + I(\text{delta})}{X2(\text{delta}) \times Kemf}$$

and, wherein, the peak current, I(peak) is estimated using the measured maximum current and the determined maximum velocity for the acceleration phase of the seek, according to the following formula:

$$I(\text{peak}) = I(\text{max}) + \frac{X2(\text{max}) \times Ke \times Kemf}{Rcoil}$$

18. The method of claim 17 further comprising the step of measuring the coil current during the acceleration phase of the seek at least twice to determine I(delta).

19. The method of claim 18 wherein the velocities associated with the position of the actuator arm at the beginning and at the end of I(delta) are used to determine the change in velocity, X2(delta), due to the change in current, the values of coil resistance, I(delta) and X2(delta) used in the following formula to estimate the torque constant:

$$Kt = \frac{Rcoil + I(\text{delta})}{X2(\text{delta}) \times Kemf}$$

torque constant used to estimate ACC, which is used to generate a velocity to position profile for the deceleration under saturation mode.

20. The method of claim 17 further comprising the steps of:

measuring the maximum current, I(max) and the velocity corresponding to maximum current, X2(max) while applying the acceleration current to the coil; and

estimating I(peak) using I(max) and X2(max), I(peak) is used to estimate the ACC term in generating the velocity to position profile:

$$I(peak) = I(\max) + \frac{X2(\max) \times Ke \times Kemf}{Rcoil}$$

21. An apparatus for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said apparatus comprising:

means for generating a conservative velocity against position profile for decelerating the actuator arm assembly so the actuator arm assembly will stop and settle at a desired position;

means for selecting a first position, X1(arrive max), from the desired position where the actuator will stop and settle;

means for selecting a second position, X1(arrive min), a number of tracks away from the desired position where the actuator will stop and settle;

means for applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly;

means for continuing to accelerate the actuator arm after exceeding the conservative velocity profile;

means for applying deceleration current in saturation mode to decelerate the coil;

means for determining a third position, X1(arrive) by determining the position of the actuator arm when the velocity of actuator arm due to the deceleration current in the saturation mode is within a selected value of the conservative velocity against position profile; and

means for adjusting the time at which the current in the coil is switched from acceleration current to deceleration current in saturation mode when X1(arrive) is not between X1(arrive min) and X1(arrive max).

22. An apparatus for controlling the movement of an actuator arm assembly in a disk drive, the actuator arm assembly movement being controlled by controlling the current to a coil of an electrical motor associated with the actuator, said apparatus comprising:

means for selecting a desired target position, and desired target velocity associated with the desired target position;

means for applying an acceleration current to the coil of the electrical motor to accelerate the actuator arm assembly;

means for determining the position of the actuator arm assembly and the distance of the actuator arm assembly from the target position at a plurality of sample times;

means for determining the velocity associated with each of the positions of the actuator arm assembly at each of said plurality of sample times;

means for determining a minimum distance to decelerate the actuator arm assembly by applying deceleration current in saturation mode, from the velocity associated with each of said plurality of sample times to the target velocity;

means for comparing the determined minimum distance, to the distance of the actuator arm assembly from the target position for each of said plurality of sample times; and

means for applying deceleration current operating in saturation mode to the coil once the determined minimum distance is within a selected amount of the distance of the actuator arm from the target position for the particular sample time until reaching the desired target.

23. A method for controlling the movement of an actuator arm in a disk drive, the actuator arm movement being controlled by energy supplied to a motor associated with the actuator arm, said method comprising the steps of:

determining a conservative velocity to position profile for the actuator arm;

accelerating the actuator arm to a first position and an actual velocity, the actual velocity associated with the first position being substantially greater than the velocity associated with the first position according to the conservative velocity to position profile; and

decelerating the actuator arm in saturation mode to a second position which is within a predetermined distance from a desired track, the deceleration in saturation mode reducing the actual velocity associated with the second position to a value within a selected amount of the velocity according to the conservative velocity to position profile.

METHOD AND APPARATUS FOR PERFORMING A SEEK

ABSTRACT

A method for performing a seek operation in a disk drive (10) using current in the saturation mode to accelerate and decelerate the actuator arm (20) is disclosed. In the first embodiment, several measurements are made during the acceleration portion of the seek to estimate the deceleration available in saturation mode. In a second emodiment, the point at which the current is switched from acceleration current to deceleration current is adjusted based upon the position where the actuator arm (20) comes within a desired amount of the velocity of a velocity profile assuming worst case conditions.

Fig. 3