ACOUSTIC IMPROVEMENT FOR SEEK OPERATION IN HARD DISK DRIVE

Related Application

This application claims the benefit of U.S. Provisional Application Serial Number 60/151,200 filed August 27, 1999 under 35 U.S.C. 119(e).

Field of the Invention

The present invention relates to the field of mass storage devices. More particularly, this invention relates to a method of reducing acoustic noise in a hard disc drive during a seek operation.

Background of the Invention

One key component of any computer system is a device to store data. Computer systems have many different places where data can be stored. One common place for storing massive amounts of data in a computer system is on a disc drive. The most basic parts of a disc drive are an information storage disc that is rotated, an actuator that moves a transducer head to various locations over the disc, and electrical circuitry that is used to write and read data to and from the disc. The disc drive also includes circuitry for encoding data so that it can be successfully retrieved and written to the disc surface. A microprocessor controls most of the operations of the disc drive as well as passing the data back to the requesting computer and taking data from a requesting computer for storing to the disc.

The transducer head is typically placed on a small ceramic block, also referred to as a slider, that is aerodynamically designed so that it flies over the disc. The slider is passed over the disc in a transducing relationship with the disc. Most sliders have an air-bearing surface ("ABS") which includes rails and a cavity between the rails. When the disc rotates, air is dragged between the rails and the disc surface causing pressure, which forces the head away from the disc. At the same time, the air rushing past the cavity or depression in the air bearing surface produces a negative pressure area. The negative pressure or suction counteracts the pressure produced at the rails. The slider is also attached to a load spring which produces a force on the slider directed toward the disc surface. The various forces equilibrate so the slider flies over the surface of the disc at a particular desired fly height. The fly height is the distance between the disc surface and the transducing head, which is typically the thickness of the air lubrication film. This film

eliminates the friction and resulting wear that would occur if the transducing head and disc were in mechanical contact during disc rotation. In some disc drives, the slider passes through a layer of lubricant rather than flying over the surface of the disc.

Information representative of data is stored on the surface of the storage disc. Disc drive systems read and write information stored on tracks on storage discs. Transducers, in the form of read/write heads attached to the sliders, located on both sides of the storage disc, read and write information on the storage discs when the transducers are accurately positioned over one of the designated tracks on the surface of the storage disc. The transducer is also said to be moved to a target track. As the storage disc spins and the read/write head is accurately positioned above a target track, the read/write head can store data onto a track by writing information representative of data onto the storage disc. Similarly, reading data on a storage disc is accomplished by positioning the read/write head above a target track and reading the stored material on the storage disc. To write on or read from different tracks, the read/write head is moved radially across the tracks to a selected target track. The data is divided or grouped together on the tracks. In some disc drives, the tracks are a multiplicity of concentric circular tracks. In other disc drives, a continuous spiral is one track on one side of disc drive. Servo feedback information is used to accurately locate the transducer head. The actuator assembly is moved to the required position and held very accurately during a read or write operation using the servo information.

The actuator is rotatably attached to a shaft via a bearing cartridge which generally includes one or more sets of ball bearings. The shaft is attached to the base and may be attached to the top cover of the disc drive. A yoke is attached to the actuator. The voice coil is attached to the yoke at one end of the rotary actuator. The voice coil is part of a voice coil motor which is used to rotate the actuator and the attached transducer or transducers. A permanent magnet is attached to the base and cover of the disc drive. The voice coil motor which drives the rotary actuator comprises the voice coil and the permanent magnet. The voice coil is attached to the rotary actuator and the permanent magnet is fixed on the base. A yoke is generally used to attach the permanent magnet to the base and to direct the flux of the permanent magnet. Since the voice coil sandwiched between the magnet and yoke assembly is subjected to magnetic fields, electricity can be applied to the voice coil to drive it so as to position the transducers at a target track.

Acoustic performance is becoming more and more a crucial factor in the design of hard disc drives. Generally, the acoustic noise is generated under two conditions, one being when the hard disc drive is in idle mode, and the other being when the disc drive is in seeking mode. In idle mode, the acoustic noise comes from spindle motor, which is like a baseline noise. In the seeking mode, the acoustic noise comes from a voice coil motor, in addition to the baseline spindle motor noise in idle mode. Generally the voice coil motor current profile during seeking consists of acceleration, coast state, and deceleration. It is generally seen that during acceleration the difference between the scheduled velocity (V_{sched}) to estimated velocity (V_{est}) is generally large, and this in turn results in a sudden ramping up of voice coil motor current, almost like an impulse, resulting in acoustic noise. Similarly the acoustic noise in the hard disc drive comes from a transition of acceleration to deceleration of voice coil motor during the seek, due to a sudden change in voice coil motor current.

What is needed is a controller that changes the voice coil motor current during seeking to reduce the acoustic noise.

Summary of the Invention

A disc drive controller includes a servo controller for changing a voice coil motor current profile to reduce an acoustic noise generated by the voice coil motor during a seek of a disc drive. The disc drive includes an actuator and a transducer head coupled to the voice coil motor to seek data from a disc of the disc drive during the seek. Upon receiving a command to seek, the servo controller retrieves a velocity profile for the seek from a memory in the disc drive controller. Then an analyzer coupled to the servo controller computes a voice coil motor current profile from the retrieved velocity profile. Then the analyzer changes the computed voice coil motor current profile to reduce the acoustic noise generated by the voice coil motor during the seek. Then the servo controller applies the changed voice coil motor current profile to the voice coil motor to complete the seek with a reduced noise.

Also discussed is a method of reducing an acoustic noise generated by a voice coil motor of a disc drive during a seek. The first step in the method includes retrieving a velocity profile for a seek upon receiving a command to seek. Then the method includes computing a voice coil motor current profile from the retrieved velocity profile for the seek. Then the next step in the method includes

changing the computed voice coil motor current profile to reduce the acoustic noise generated during the seek. Then the method includes applying the changed voice coil motor current profile to the voice coil motor to complete the seek.

Advantageously, the procedure set forth above and the apparatus for reducing an acoustic noise generated by a voice coil motor during a seek can reduce significantly the acoustic noise with considerably less CPU bandwidth. The above procedure can also be incorporated in a microcode and used to control the servo circuitry to implement the invention.

Brief Description of the Drawings

FIG. 1 is an exploded view of a disc drive with a multiple disc stack.

FIG. 2 is a schematic representation of a disc drive including portions of the disc drive controller used in the present invention.

FIG. 3 is a flow diagram of the procedure of the present invention.

FIG. 4 is a schematic view of a computer system.

Description of the Preferred Embodiment

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The invention described in this application is useful with all mechanical configurations of disc drives having either rotary or linear actuation. FIG. 1 is an exploded view of one type of a disc drive 100 having a rotary actuator. The disc drive 100 includes a housing or base 112, and a cover 114. The base 112 and cover 114 form a disc enclosure. An inertia ring 500 is attached to the cover 114. Rotatably attached to the base 112 on an actuator shaft 118 is an actuator arm assembly 120. The actuator arm assembly 120 includes a comb-like structure 122 having a plurality of actuator arms 123. Attached to the separate actuator arms 123 on the comb 122, are load beams or load springs 124. Load beams or load springs are also referred to as suspensions. Attached at the end of each load spring 124 is a

slider 126 which carries a magnetic transducer 150. The slider 126 with the transducer 150 form what is many times called the head. It should be noted that many sliders have one transducer 150 and that is what is shown in the figures. It should also be noted that this invention is equally applicable to sliders having more than one transducer, such as what is referred to as an MR or magneto resistive head in which one transducer 150 is generally used for reading and another is generally used for writing. On the end of the actuator arm assembly 120 opposite the load springs 124 and the sliders 126 is a voice coil 128.

Attached within the base 112 is a first magnet 131 and a second magnet 130. As shown in FIG. 1, the second magnet 130 is associated with the cover 114. The first and second magnets 130, 131, and the voice coil 128 are the key components of a voice coil motor which applies a force to the actuator assembly 120 to rotate it about the actuator shaft 118. Also mounted to the base 112 is a spindle motor. The spindle motor includes a rotating portion called the spindle hub 133. In this particular disc drive, the spindle motor is within the hub. In FIG. 1, a number of discs 134 are attached to the spindle hub 133. In other disc drives a single disc or a different number of discs may be attached to the hub. The invention described herein is equally applicable to disc drives which have a plurality of discs as well as disc drives that have a single disc. The invention described herein is also equally applicable to disc drives with spindle motors which are within the hub 133 or under the hub.

FIG. 2 is a schematic representation of one embodiment of a disc drive 100 including selected portions of a disc drive controller 200 used in reducing an acoustic noise generated by a voice coil motor of the disc drive 100 during a seek. In this embodiment the disc drive 100 includes at least one disc 134 rotatably attached to a base through a shaft 16. The disc drive 100 also includes an actuator 120 having a transducer head 126 and a transducer 150 for reading and writing to the at least one disc 134. The actuator 120 carrying the transducer 126 is in a transducing relation with respect to the disc 134. A voice coil 128 of a voice coil motor is attached to the actuator 120. A disc drive controller 200 including a servo controller 220 is coupled to the voice coil 128. The servo controller 220 retrieves a stored velocity profile for a seek upon receiving a command to seek from the disc drive controller 220. The disc drive controller 200 further includes an analyzer 210 coupled to the servo controller 220 to compute a voice coil motor current profile based on the retrieved velocity profile for the seek. The disc drive controller 200 also includes a comparator 230 to compare the received command to seek with a

predetermined seek length to categorize the seek as a long seek or a short seek. In one embodiment the analyzer computes the voice coil motor current profile based on

Voice coil motor current for the long seek = (K * (V_{sched} - V_{est}) + Feed Forward), where K = Velocity Gain, V_{sched} = Scheduled Velocity of the Voice Coil Motor, and V_{est} is Estimated Velocity of the Voice Coil Motor; and

Voice coil motor current for the short seek = (K * (V_{sched} - V_{est}) + Feed Forward), where V_{sched} = V_{sched} * Predetermined value, and Feed Forward = Feed Forward*(predetermined factor)^2, where the predetermined factor is greater than 0 and less than or equal to 1.

In one embodiment the servo controller 220 changes the computed voice coil motor current profile during an acceleration of the long seek by using a sine wave profile. In another embodiment the sine wave profiling is accomplished by using a half a sine wave such that the half the sine wave starts with a sine value of -1 and ends with a sine value of 1. In this embodiment the half the sine wave is rescaled to start with a sine value of 0 and end with a sine value of 1. Also in this embodiment the sine wave profiling consists of incrementing the voice coil motor current in approximately 12 to 20 incremental steps within the sine values of 0 and 1. In one embodiment the sine wave profiling consists of incrementing the voice coil motor current in approximately 12 to 20 incremental steps with in the half the sine wave. In one embodiment the servo controller changes the computed voice motor current profile during the short seek by limiting the voice coil motor current, and by further changing the limited voice coil motor current profile during the acceleration of the short seek by using the sine wave profile. Then the servo controller 220 applies the changed voice coil motor current profile to the voice coil motor to complete the seek. In one embodiment the servo controller 220 tunes a velocity estimator gain such that the V_{est} is not sensitive to any noise generated in the voice coil motor current during a deceleration of the seek. The disc drive controller 200 further includes a memory 250 to store the incremental steps of the sine wave values between 0 and 1.

FIG. 3 is a flow diagram illustrating one embodiment of the method of reducing an acoustic noise generated by the voice coil motor of a disc drive 100 during a seek using the present invention. Upon receiving a command to seek 310, the next step in the method consists of retrieving a stored velocity profile for the seek 320. Then the next step includes comparing the command to seek with a predetermined seek length to determine whether the command to seek is a short seek

or a long seek 330. Then the next step involves computing the voice coil motor current based on

Voice coil motor current for the long seek = (K * (V_{sched} - V_{est}) + Feed Forward) 340.1, where K = Velocity Gain, V_{sched} = Scheduled Velocity of the Voice Coil Motor, and V_{est} is Estimated Velocity of the Voice Coil Motor; and

Voice coil motor current = (K * (V_{sched} - V_{est}) + Feed Forward) for the short seek 340.2 and 340.3, where V_{sched} = V_{sched} * Predetermined value, and Feed Forward = Feed Forward*(predetermined factor)^2, where the predetermined factor is greater than 0 and less than or equal to 1.

Then the next step in the method includes limiting the voice coil motor current for the short seek 340.4. Then the next step in the method includes changing the computed voice motor current during acceleration to a sine wave profile when the command to seek is for the long seek 350.1, and changing the limited voice motor current during acceleration to a sine wave profile when the command to seek is a short seek 350.2. In one embodiment the sine wave profiling includes using a half a sine wave. In this embodiment the half the sine wave starts with a sine value of 0 and ends with a sine value of 1. Also in this embodiment the half the sine wave is rescaled to start with a sine value of 0 and end with a sine of 1. In another embodiment the sine wave profiling is accomplished by incrementing the voice coil motor current in about 12 to 20 incremental steps within the half the sine wave. In one embodiment the next step includes tuning a velocity estimator gain such that V_{est} is less sensitive to any noise generated during a deceleration of the seek 360. Then the next step includes applying the changed voice coil motor current to the voice coil motor to complete the seek 370.

Advantageously the acoustic noise reduction method set forth above allow for reducing the acoustic noise generated by the voice coil motor during a seek with significantly less CPU bandwidth.

FIG. 4 is a schematic view of a computer system. Advantageously, the invention is well-suited for use in a computer system 2000. The computer system 2000 may also be called an electronic system or an information handling system and includes a central processing unit, a memory and a system bus. The information handling system includes a central processing unit 2004, a random access memory 2032, and a system bus 2030 for communicatively coupling the central processing unit 2004 and the random access memory 2032. The information handling system 2000 includes a disc drive device which includes the ramp described above. The information handling system 2002 may also include an

input/output bus 2010 and several devices peripheral devices, such as 2012, 2014, 2016, 2018, 2020, and 2022 may be attached to the input output bus 2010. Peripheral devices may include hard disc drives, magneto optical drives, floppy disc drives, monitors, keyboards and other such peripherals. Any type of disc drive may use the method for loading or unloading the slider onto the disc surface as described above.

Conclusion

In conclusion, a disc drive controller 200 reduces the acoustic noise generated by the voice coil motor during a seek. The method comprises retrieving a stored velocity profile for the seek 320 upon receiving a command to seek 310, and comparing the command to seek with a predetermined seek length to determine whether the received command to seek is a short seek or a long seek 330. Then the next step involves computing the voice coil motor current 340.1, 340.2, 340.3, and 340.4, and changing the computed voice motor current during acceleration to a sine wave profile when the command to seek is for the long seek 350.1, and changing the limited voice motor current during acceleration to a sine wave profile when the command to seek is a short seek 350.2, and tuning a velocity estimator gain such that V_{est} is less sensitive to any noise generated during a deceleration of the seek 360. Then the next step includes applying the changed voice coil motor current to the voice coil motor to complete the seek 370.

Also discussed is a disc drive 100 including at least one disc 134 rotatably attached to a base through a shaft 16. The disc drive 100 also includes an actuator 120 having a transducer head 126 and a transducer 150 for reading and writing to the at least one disc 134. The actuator 120 carrying the transducer 126 is in a transducing relation with respect to the disc 134. A voice coil 128 of a voice coil motor is attached to the actuator 120. A disc drive controller 200 is coupled to the voice coil 128, includes a servo controller 220 to retrieve a stored velocity profile for a seek upon receiving a command to seek. The disc drive controller 200 further includes an analyzer 210 coupled to the servo controller 220 to compute a voice coil motor current profile based on the retrieved velocity profile for the seek. The disc drive controller 200 further includes a comparator 230 to compare the received command to seek with a predetermined seek length to categorize the seek as a long seek or a short seek. Then the servo controller 220 changes the computed voice coil motor current profile during an acceleration of the long seek by using a

sine wave profile to reduce the acoustic noise. The servo controller changes the computed voice motor current profile for the short seek by limiting the voice coil motor current, and by further changing the limited voice coil motor current profile during the acceleration of the short seek using the sine wave profile. The sine wave profiling is accomplished by using a half a sine wave such that the half the sine wave starts with a sine value of -1 and ends with a sine value of 1. In this embodiment the half the sine wave is rescaled to start with a sine value of 0 and end with a sine value of 1. Also the sine wave profiling consists of incrementing the voice coil motor current in approximately 12 to 20 incremental steps within the sine values of 0 and 1. Then the servo controller 220 applies the changed voice coil motor current profile to the voice coil motor to complete the seek. The disc drive controller 200 further includes a memory 250 to store the incremental steps of the sine wave values between 0 and 1.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.



What is claimed is:

1. A method of reducing an acoustic noise generated by a voice coil motor of a disc drive during a seek, comprising: (a) changing a voice coil motor current profile to reduce the acoustic noise generated by the voice coil motor during the seek.

2. The method of claim 1, further comprising steps of:

(a)(i) receiving a command to seek;

(a)(ii) retrieving a stored velocity profile corresponding to the seek;

(a)(iii) computing a voice coil motor current profile from the retrieved velocity profile for the seek; and

(a)(iv) changing the computed voice coil motor current profile to reduce the acoustic noise generated during the seek.

3. The method of claim 2, further comprising a step of (a)(v) applying the changed voice coil motor current profile to the voice coil motor to complete the seek.

4. The method of claim 2, further comprising a step of (a)(vi) categorizing the seek as a short seek and a long seek based on comparing the command to seek with a predetermined seek length.

5. The method of claim 4, wherein the computing step (a)(iii) further comprises steps of:

(a)(iii)(i) computing a voice coil motor current profile for the long seek using, $K * (V_{sched} - V_{est}) + \text{Feed Forward}$, where K = Velocity Gain, V_{sched} = Scheduled Velocity of the Voice Coil Motor, and V_{est} is Estimated Velocity of the Voice Coil Motor; and

(a)(iii)(ii) computing a voice coil motor current profile for the short seek using $(K * (V_{sched} - V_{est}) + \text{Feed Forward})$, where $V_{sched} = V_{sched} * \text{Predetermined value}$, and Feed Forward = Feed Forward*(predetermined factor)^2, where the predetermined factor is greater than 0 and less than or equal to 1.

6. The method of claim 5, wherein the changing step (a)(iv) further comprises steps of:

(a)(iv)(i) changing the voice coil motor current profile during an acceleration of the voice coil motor for the long seek to a sine wave profile;

(a)(iv)(ii) limiting the voice coil motor current, and further changing the limited voice coil motor current profile during the acceleration of the voice coil motor for the short seek to a sine wave profile; and

(a)(iv)(iii) tuning a velocity estimator gain such that the V_{est} is not sensitive to any noise in the voice coil motor current during a deceleration of the seek.

7. The method of claim 6, wherein the sine wave profiling comprises sine wave profiling using a half a sine wave, wherein the half the sine wave starts with a sine value of -1, and ends with a sine value of 1.

8. The method of claim 7, wherein the half the sine wave starting with the sine value of -1, and ending with the sine value of 1, is rescaled such that the half the sine wave starts with a sine value of 0 and ends with a sine value of 1.

9. The method of claim 8, wherein the sine wave profiling of the voice coil motor current is accomplished by incrementing the voice coil motor current in about 12 to 20 incremental steps within the half the sine wave.

10. A disc drive, comprising:

a disc;

an actuator for carrying a transducer head in a transducing relationship with respect to the disc;

a voice coil motor coupled to the actuator to position the transducer head during a seek;

a disc drive controller, communicatively coupled to the voice coil motor, further includes:

a servo controller, coupled to the voice coil motor, wherein the servo controller retrieves a stored velocity profile for the seek upon receiving a command to seek; and

an analyzer, coupled to the servo controller, wherein the analyzer computes a voice coil motor current profile based on the retrieved velocity profile for the seek, wherein the analyzer further changes the computed voice coil motor current to reduce an acoustic noise generated during the seek, and

wherein the servo controller applies the changed voice coil motor current profile to the voice coil motor to complete the seek.

11. The disc drive of claim 10, wherein the disc drive controller further includes a comparator, wherein the comparator compares the received command to seek with a predetermined seek length to categorize the seek as a long seek or a short seek.

12. The disc drive of claim 11, wherein the analyzer computes the voice coil motor current profile based on

Voice coil motor current for long seek = $(K * (V_{sched} - V_{est}) + \text{Feed Forward})$, where K = Velocity Gain, V_{sched} = Scheduled Velocity of the Voice Coil Motor, and V_{est} is Estimated Velocity of the Voice Coil Motor; and

Voice coil motor current for short seek = $(K * (V_{sched} - V_{est}) + \text{Feed Forward})$, where $V_{sched} = V_{sched} *$ Predetermined value, and Feed Forward = Feed Forward*(predetermined factor)^2, where the predetermined factor is greater than 0 and less than or equal to 1.

13. The disc drive of claim 12, wherein the servo controller changes the computed voice coil motor current profile during an acceleration of the long seek by using a sine wave profile.

14. The disc drive of claim 13, wherein the servo controller changes the computed voice coil motor current profile during the short seek by limiting the voice coil motor current, and further changes the limited voice coil motor current profile during an acceleration of the short seek using the sine wave profile.

15. The disc drive of claim 14, wherein the servo controller tunes a velocity estimator gain such that the V_{est} is not sensitive to any noise generated in the voice coil motor current during a deceleration of the seek.

16. The disc drive of claim 14, wherein the sine wave profiling comprises profiling using a half a sine wave, wherein the half the sine wave starts with a sine value of -1, and ends with a sine value of 1.

17. The disc drive of claim 16, wherein the half the sine wave is rescaled to start with a sine value of 0 and end with a sine value of 1.

18. The disc drive of claim 17, wherein the sine wave profiling further consists of incrementing the voice coil motor current in approximately 12 to 20 incremental steps between the sine values of 0 and 1.

19. The disc drive of claim 18, further includes a memory coupled to the analyzer for storing the incremental steps of the sine wave values between 0 and 1.

20. A disc drive, comprising:

a disc;

an actuator for carrying a transducer head in a transducing relationship with respect to the disc;

a voice coil motor, coupled to the actuator, for positioning the transducer head during a seek; and

means coupled to the voice coil motor to change a voice coil motor current profile to reduce an acoustic noise generated during the seek.