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☒ Claim(s) : paged ...¹⁶... to paged ...²⁰...
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METHOD AND APPARATUS FOR POSITIONING TRANSDUCERS

The present invention pertains to the field of disk drives which are also called direct access storage devices (DASD).

More particularly, this invention pertains to a method and apparatus for positioning a read element or a write element over a data track for a disk drive.

One of the key components of some electrical devices is a place to store and read data. For example, compact disk players read data, such as music, from a plastic disk. Another example is a VCR which reads data from a tape. Computer systems also store and read large amounts of data. Typically computer systems employ a number of storage means to store data. One of the places where a computer can store data is in a disk drive which is also called a direct access storage device.

Although this invention is not limited to a direct access storage device one will be described by way of example. A disk drive or direct access storage device includes several disks which look similar to records used on a record player or compact disks which are used in a CD player. The disks are stacked on a spindle, much like several records awaiting to be played. In a disk drive, however, the disks are mounted to the spindle and spaced apart so that the separate disks do not touch each other.

The surface of each disk is uniform in appearance. However, in actuality, each of the surfaces is divided into portions where data is stored. There are a number of

tracks situated in concentric circles like rings on a tree. Each track in a disk drive is further subdivided into a number of sectors which is essentially just one section of the circumferential track.

Storage of data on a magnetic disk entails magnetizing portions of the disk in a pattern which represents the data. To store data on a disk the disk is magnetized. In order to magnetize the magnetic layer, a small ceramic block which contains a magnetic transducer known as a write element is passed over the surface of the disk. More specifically, the write element is flown at a height of approximately six millionths of an inch from the surface of the disk and is flown over the track as the write element is energized to various states causing the track below to be magnetized to represent the data to be stored.

To retrieve data stored on a magnetic disk, a read element is flown over the disk. The magnetized portions of the disk provide a signal from the read element. By looking at output from the read element, the data can be reconstructed and then used by the computer system.

Like a record, both sides of a disk are generally used to store data or other information necessary for the operation of the disk drive. Since the disks are held in a stack and are spaced apart from one another, both the top and the bottom surface of each disk in the stack of disks has its own read element and write element. This would be comparable to having a stereo that could play both sides of a record at once. Each side would have a stylus which played the particular side of the record.

Disk drives also have something that compares to the tone arm of a stereo record player. There are two types of disk drives, rotary and linear. Rotary disk drives have a

tone arm that rotates much ³like a record player. The tone arm of a rotary disk drive, termed an actuator arm, holds all the transducers or read/write elements, one head for each surface of each disk supported in a structure that looks like a comb. Sometimes the structure is called an E block. Like a tone arm, the actuator arms rotate so that the read element and write element attached to the actuator arm can be moved to locations over various tracks on the disk. In this way, the write element can be used to magnetize the surface of the disk in a pattern representing the data at one of several track locations. The read element is used to detect the magnetized pattern on one of the tracks of a disk. For example, the needed data may be stored on two different tracks on one particular disk, so to read the magnetic representations of data, the actuator arm is rotated from one track to another track.

It should be noted that this invention is not limited to use in disk drives using magnetic media but is useful in any device having rotating media which uses a pair of transducers which pass over the rotating media. In this particular application, magnetic media is described as an example only. This invention would be useful in other storage devices which have different read elements and write elements.

The problem this invention addresses is most easily explained by showing the case of a rotary actuator as shown in Figs. 3 and 4 of the drawings. Fig. 3 provides the background necessary to understand Fig. 4. Figs. 3 shows a portion of the disk drive referred to as the slider 26 which holds a read element 40 and a write element 42. The slider 26 is attached to an actuator arm depicted by line 48 in Fig. 4. As can be seen from Figs. 3 and 4, the read element 40 and the write element 42 are aligned either parallel to or along the longitudinal axis 44 of the slid-

er. However, due to manufacturing misalignment tolerances the read element 40 and write element 42 may not be precisely aligned. Basically, the problem is that when either the read element or the write element is positioned over a particular track the other element is offtrack from track 50. The amount that one of the elements is offtrack varies as a function of the radius of the track in the case of a radial actuator being followed. This problem is known as track misregistration and can and will affect data integrity. Track misregistration must be corrected to allow track pitch or width to get smaller, and thus allow for increased track density without errors. Another problem is that repositioning between the write function and the read function on the track takes time and affects the data throughput rate of the disk drive.

In the case of a linear actuator which uses a slider as is shown in Fig. 3 which has the read element 40 aligned with the write element 42, the heads can still be misaligned due to manufacturing error. In addition, linear actuators may also have a carriage which may be difficult to mount perfectly so the read element 40 and the write element 42 remain on a tangent to the tracks of a disk 34. As a result, there is a possibility that the read element 40 can be tracking over a desired track in a disk drive while the write element 42 does not track over the same desired track. Again, this is track misregistration. It is important to minimize track misregistration to assure that the data is being read from or written to the desired track. It is also important since a well known goal in designing disk drive devices is to increase capacity. This translates into smaller track pitch or smaller track width. Thus, any problems with track misregistration must be overcome to allow increased capacity of disk drives. In addition, since the data throughput is affected there is a need for a method and apparatus that minimizes the

distance an actuator must move to reposition the read or write element when switching from a write or read operation to the other operation on the same track. Since the amount of repositioning distance will vary as a function of the radius of the tracks on a disk drive and as a function of manufacturing tolerances, there is a need for a solution that minimizes the repositioning distance for all of the tracks in the disk drive.

Disclosed is a method and apparatus which allows for correction of track misregistration and which minimizes the repositioning distance needed to switch from a read operation to a write operation in a disk drive or other information storage and retrieval device which uses a separate read element and write element.

The actual offset of the read element with respect to the write element is measured which includes the manufacturing tolerances. The position offtrack that either the read element or write element is when the read and write element are aligned along the longitudinal axis of the slider can be mathematically described as a function of the cylinder position of the track. This distance is calculated using values measured and stored at the time the disk drive is manufactured and then summed with the read/write centerline offset so that the actual repositioning distance is then determined and the slider can then be repositioned.

In addition, the read element is intentionally offset at an angle from the write element rather than being aligned along the longitudinal axis of the slider for a rotary actuated disk drive. Of course, the write element could also be offset from the read element. The angle of offset is selected to minimize the distance necessary to move the



actuator for any track on the disk drive. Since the repositioning distance is minimized the amount of time lost due to repositioning is minimized.

As a result, track misregistration can be minimized which allows for better data integrity and allows smaller track pitch. In addition, the slow down in throughput of data due to switching operations on a track can be minimized for a rotary actuator that uses a separate read element and write element.

For a better understanding of the present invention, reference can be made 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.

Fig. 3 is a bottom view of a slider showing a read element and a write element which are aligned along a radial from the actuator arm.

Fig. 4 is a schematic of the actuator arm with the read element and write element as shown in Fig. 2 attached.

Fig. 5 is a top view of a disk with an actuator arm having a slider attached thereto shown schematically.

Fig. 6 is a top cutaway view of a slider with the write element on the radial from the actuator pivot point through the center of the slider and the read element offset therefrom.

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Fig. 7 is a schematic diagram similar to Fig. 5 for a slider with the write element offset from the read element.

These drawings are not intended as a definition of the invention but are provided solely for the purpose of illustrating the preferred embodiments of the invention described below.

The invention described in this application is useful with all mechanical configurations of disk drives or direct access storage devices ("DASD"). Fig. 1 is an exploded view of a disk drive 10. It should be noted that although a rotary actuator is shown the invention described herein is applicable to linear actuators. The disk drive 10 includes a housing 12, and a housing cover 14 which, after assembly, is mounted within a frame 16. Rotatably attached within the housing 12 on an actuator shaft 18 is an actuator arm assembly 20. One end of the actuator arm assembly 20 includes an E block or comb like structure 22 having a plurality of arms 23. Attached to the separate arms 23 on the comb or E block 22, are load springs 24. Attached at the end of each load spring is a slider 26 which carries a pair of magnetic transducers (shown as a read element and a write element in Figs. 3-7). On the other end of the actuator arm assembly 20 opposite the load springs 24 and the sliders 26 is a voice coil 28.

Attached within the housing 12 is a pair of magnets 30. The pair of magnets 30 and the voice coil 28 are key parts of a voice coil motor which applies a force to the actuator assembly 20 to rotate it about the actuator shaft 18. Also mounted within the housing 12 is a spindle shaft 32. Rotatably attached to the spindle shaft 32 are a number of disks 34. In Fig. 1, eight disks are attached to the

spindle shaft 32. As shown in Fig. 1, the disks 34 are attached to the spindle shaft 32 in spaced apart relation. An internal motor (not shown) rotates the disks 34.

Fig. 2 details the actuator arm assembly 20 in an exploded view. Each of the arms 23 of the E block or comb assembly 22, except the arms 23 on the top and bottom of the E block 22, carry two load springs. In this particular disk drive 10, there is a slider for both the top and bottom surface of each of the disks 34. The top and bottom arms 23 of the E block 22 have only one load spring 24 since these are used for the top surface of the top disk and the bottom surface of the bottom disk in the stack of disks 34. Attached to the load springs 24 are sliders 26 which include magnetic transducers which magnetize the surface of the disk 34 to represent and store desired data. As is well known in the art of disk drives, each of the disks has a series of concentric tracks onto which the magnetic information is recorded. The sliders 26 and the magnetic transducers incorporated therein are moved over the surface of a particular disk 34 so that a magnetic representation of data can be stored in any of the tracks on the disk 34. In this particular disk drive 10, the transducer movement is rotational and about the actuator shaft 18. Rotating the actuator arm assembly 20 causes the slider 26 and the transducer therein to be repositioned over surface of the disk 34.

Fig. 3 shows a slider 26 which has a read element or head 40 and a write element or head 42. The slider has a longitudinal axis 44. The read element 40 and the write element 42 are aligned along the longitudinal axis 44 of the slider 26 within a given manufacturing tolerance.

Fig. 4 is a schematic of a disk drive that uses the slider shown in Fig. 3. Fig. 4 includes the axis of rotation 46

of an actuator arm assembly about an actuator shaft. The actuator arm is shown schematically as line 48. In this particular figure the schematic actuator arm 48 is shown in two positions so as to illustrate a point that will be made in the next paragraph. The schematic actuator arm 48 includes the write element 42 and the read element 40 which are shown along line 48 and are separated by a distance d . The read element 40 and the write element 42 are shown on the schematic actuator arm depicted by line 48 since the axis of the slider 44 is colinear in this example with the radial from the centerpoint of the axis of rotation 46 of the actuator arm assembly. In general the head is not required to be in line with the radial. Fig. 4 also shows a data track 50 which is on one of the disks 34 shown in Fig. 1. The data track 50 is at a radius RT from the center of the disk 34 (not shown in Fig. 4). The radius RT is shown to the write element 42 in one of the positions of the schematic arm depicted as line 48 and the radius of the track RT is also shown to the read element 40 in the second position of the schematic actuator arm 48.

As can be seen in Fig. 4, when the actuator arm is in a position where the write element 42 is positioned over the track 50 then the read element 40 is off of the track 50. Fig. 4 also shows that when the read element 40 is positioned over the track 50 the write element 42 is not positioned over the track 50. This presents problems when it is required to switch from a read operation to a write operation for data that is on the same track 50. To switch from reading with the read element 40 positioned over the track 50 to writing on the same track 50, the actuator arm 48 must be shifted to the position shown in Fig. 4 where the write element 42 is now positioned over the track 50. Rotating the actuator arm 48 between these two positions takes valuable time which affects the rate

of throughput of data. One aspect of this particular invention deals with minimizing the amount of distance a slider on a rotary actuator is offtrack. More importantly, this invention deals with minimizing track misregistration.

Fig. 5 deals with skew angles and shows that the skew angles vary as the actuator arm 48 crosses the disk 34. On a disk 34 there are a multiplicity of data tracks 50. Other tracks such as reference tracks are also typically written on a disk 34. In Fig. 5, the outermost data track 50' and the innermost data track 50" are shown. Fig. 5 also shows two positions of the schematic actuator arm 48. One of the positions of the actuator arm has the write element 42 at the back of the slider 26 tracking over track 50' and the other of these positions is with the write element 42 tracking over the track 50". The skew angle is the angle between a radial of the disk 34 through the midpoint of the back of the slider 26 and a line perpendicular to the longitudinal axis of the actuator arm 48. In Fig. 5, the skew angle A is associated with the slider 26 when it is positioned over track 50' and the skew angle B is associated with the slider 26 when it is positioned over track 50".

Simple geometry can also be used to find angles equalling the skew angle as defined above. For example, an angle equal to skew angle A occurs between the longitudinal axis of the load arm depicted as line 48 and a tangent to the track at the midpoint of the back of the slider 26 which contains the write element and which is positioned over the track. Knowing this it can be seen from Fig. 5 that for larger skew angles the offtrack distance between the read and write elements will be greater than for a smaller skew angle.

Fig. 6 shows a slider 26 having the read element 40 positioned away from the longitudinal axis 44 of the slider 26. The view of the slider 26 shown in Fig. 6 is a cutaway view from the top of the slider 26. An angle C is defined by the angle between the sliders longitudinal axis 44 and a line 52 between the read element 40 and the write element 42.

Now turning to Fig. 7, the type of slider 26 shown in Fig. 6 is depicted in Fig. 7 as a straight line from the centerpoint of the axis of rotation for the actuator arm assembly 20 and then the line 52 making the same angle C between the read element 40 and the write element 42. By offsetting the write element 42 at an angle C from the read element 40 the distance that the write element 42 goes off track while the read element is tracking over a track 50 closer to the inner diameter or tracking over a track near the outer diameter is lessened considerably. By lessening the distance that the actuator must be moved to switch from a position where the read element 40 is tracking over the track 50 to a position when the write element 42 is tracking over the track 50, the time necessary for this change is also lessened which aids in data throughput. It should be noted that the angling of the write element with respect to the read element also produces the same benefits when switching from a write operation on a particular track to a read operation on a particular track.

The angle C can be selected to minimize the off track distance that either the read element 40 or the write element 42 is off track when the other head is in operation. When the angle is properly selected, the distance and time necessary for repositioning between reading with the read element 40 and writing with the write element 42 or vice versa is minimized in the disk drive for each

position. Basically, the angle C in Figs. 6 and 7 that will minimize the distance that the write element 42 will be off track when the read element 40 is following any track 50 on the disk is determined by measuring the skew angle A at the inner radius (track 50" in Fig. 5) and skew angle B at the outer radius (track 50' in Fig. 5). The value for angle C is that which minimizes the distance that the actuator arm must move for repositioning from a read operation to a write operation. Difference in various performance characteristics between the inner and outer data tracks may make the optimum angle C slightly different than the calculated angle C.

When the angle C is selected to minimize the distance which the actuator arm must move to switch between a write operation and a read operation or vice versa, at approximately midway between the track 50' at the outer diameter and the track 50" at the inner diameter, the read element 40 and the write element 44 will both pass over a track at the same time. At this track, no movement will be necessary to switch between reading with the read element 40 and writing with the write element 42.

As mentioned previously, when switching between reading and writing or vice versa, the actuator arm generally must be moved so that the head about to be used is positioned over the track. Even though the angle C has been optimized and set, there can be differences in the actual offset between the read element 40 and the write element 42 in a particular slider 26. There are many possible reasons the offset between the write element 42 and the read element 40 will not be the same as the offset associated with the angle C. Manufacturing tolerances will cause the actual offset to be slightly different. In addition, the physical center of a read element 40 or a write element 42 may not correspond to its magnetic cen-

ter. These are just some of the factors that may cause the actual offset of the write element from the read element 40 to differ from the calculated case.

Trigonometry can be used to yield an essentially linear function which describes the distance off track a write element 42 is with respect to a read element 40 (as shown in Figs. 3 and 4) while the read element is on track as a function of the particular cylinder. The cylinder location is defined by the servo tracks on the servo surface in the disk drive. The same linear function will describe the amount offtrack a read element is when the write element is on track as a function of the cylinder location except for the sign of the offset. To quicken the time necessary to move the actuator from a position where the read element 40 is over a track to a position where the write element 42 is over the same track the linear function is used to determine the amount of offtrack for the case where the read element and write element are aligned. This is a fast calculation as a constant is multiplied by the cylinder location. The actual offset as measured and stored for each head is then summed with the calculated result to determine the amount of distance the actuator must be moved to reposition the other element over the same track. Advantageously, the distance needed to move the actuator can be quickly determined which facilitates data throughput.

Determination of the actual offset of the write element 42 from the read element 40 is accomplished by writing temporary servo reference information along the edge of the disk 34 beyond the outer radius of the data region. The servo reference information is temporarily written from outer edge of a disk toward the inner radius of the disk 34 over a few tracks in the reference area. The servo reference information is then read using the read element

and the amount of bias read by the read element 40 is retained. Writing from the outer edge toward the inner radius is considered moving in a positive direction.

The next step in determining the actual offset is to write permanent servo reference information toward the outer radius in the region of the disk beyond the data tracks. Again the read element 40 is then positioned to the center of the cylinder as defined by the servo tracks on the servo surface. The servo reference tracks are then read and the amount of bias is then observed and retained.

By writing the servo reference information initially in one direction and then in the other direction, the actual offset between the center of the read element and the center of the write element can be determined. In addition the total width of the write element can be determined.

The slider is then moved to a position near the inner diameter of the disk 34 and the above steps are repeated. Namely, a temporary servo reference track is initially written in one direction, then in the other. From this information the write width and the offset between the write element and the read element can be determined. The offset at the inner radius and the outer radius are significant due to the distance d between the read element and the write element and the angle the heads are rotated. Thus the difference in the offsets at the inner radius and the outer radius gives the effect due to the distance d . The offsets at the extremes are generally positive and negative in sign and are statistically comparable in magnitude.

It should be noted that this invention is applicable to any system having a separate read element and write ele-

ment to minimize track misregistration. In addition, offsetting the read or write element can be used in any environment where a rotary actuator is used to access a circular or spiral track, such as flexible disks, optical disks or disks with magnetic layers.

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CLAIMS

1. An information storage and retrieval device comprising:

a rotating media;

an actuator for reading and writing information which cooperates with the rotating media, said actuator rotating about an axis and further including:

a read element for reading information from the rotating media; and

a write element for writing information to the rotating media, one of said read element offset from said write element in a direction substantially perpendicular to a radial from the axis of rotation of the actuator.

2. The information storage and retrieval device of Claim 1 wherein the offset also occurs along a line parallel with a radial of the axis of rotation or the actuator.
3. The information storage and retrieval device of Claim 2 wherein the read element has a center and the write element has a center, wherein a line drawn between the center of the read element and the center of the write element forms an angle with respect to a line parallel a radial of the axis of rotation.
4. The information storage and retrieval device wherein the angle formed between the centers of the read and write elements and the line parallel to the axis of rotation is selected so that the distance needed to





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reposition the actuator arm when changing between a read operation and a write operation is minimized for every position over said rotating magnetic media.

5. The information storage and retrieval device of Claim 3 further comprising a slider attached to the actuator arm, said slider having the read element and the write element therein, said slider flying at a skew angle with respect to the the innermost portion of the rotating magnetic media and a skew angle with respect to the outermost portion of the rotating magnetic media, wherein the angle between the centers of the read and write elements and the line parallel to the axis of rotation is equal to half of the difference between the skew angle at the outermost portion and the the skew angle at the innermost portion.
6. The information storage and retrieval device of Claim 3 further comprising a slider attached to the actuator arm, said slider having the read element and the write element therein, said slider flying at a skew angle with respect to the the middle of the rotating magnetic media, the middle being halfway between the outermost portion of the rotating magnetic media and the innermost portion of the rotating magnetic media, wherein the angle between the centers of the read and write elements and the line parallel to the axis of rotation is approximately equal to the skew angle at the middle of the rotating magnetic media.
7. A method for determining an amount of distance to move an actuator arm to correct for track misregistration when a separate read element and a separate write element which are separated by a

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distance d , which is the distance along a tangent to a track on a disk, said read element and write element used in a data recording device with a rotating media, said method comprising the steps of:

measuring the amount of offset between a read element and a write element at a first position on a disk; and

measuring the amount of offset between a read element and a write element at a second position on a disk.

8. The method of Claim 7 further comprising the steps of:

determining a constant and a multiplier to apply to a particular cylinder number to find the distance necessary for repositioning the actuator arm to correct for track misregistration, the constant and the multiplier determined from the measured amount of offset from the first position and the second position; and

repositioning the actuator arm.

9. The method of Claim 7 further comprising the steps of:

determining a function from the measured offset at the first position and the measured offset at the second position which describes the change in offset; and

repositioning the actuator arm.



10. The method of Claim 7 wherein the step of determining the offset between a read element and a write element at a first position includes:

writing servo reference information in a first direction;

reading the servo reference information in a first direction;

writing servo reference information in a second direction; and

reading the servo reference information in a second direction.

11. The method of Claim 10 wherein the step of determining the offset between the read element and the write element includes comparing the position error signal from the read element from the step reading the servo reference information in the first direction with the the position error signal from the read element from the step reading the servo reference information in the second direction.

12. The method of Claim 7 further comprising the step of selecting an angle to minimize the distance an actuator arm having a slider carrying a separate read element and a separate write element must be repositioned to correct for track misregistration in a rotary actuator.

13. The method of Claim 12 wherein the step measuring the offset at a first position is done at the outer edge



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of the disk and the step of measuring the offset at the second position is done at the inner radius of the disk.

14. The method of Claim 13 wherein the step of selecting an angle includes the steps of:

determining the difference between the offset in the first position and the offset in the second position; and

selecting an angle that has produces an offset about midway between the offset associated with the first position and the second position.

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