

SLIDER ASSEMBLY FOR HARD DISK DRIVE

This invention relates to slider assemblies for hard disk drives and more particularly to a slider that improves read/write performance at large air bearing skew angles.

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BACKGROUND TO THE INVENTION

Recent developments in processing power of computers, especially personal computers, has put increased pressure on the performance of digital storage devices, such as hard disk drives. Developments in hard disk drives are focussed on minimising data access time and data transfer time. A key aspect of minimising data access times is to shorten the time required to seek a track.

A hard disk drive typically comprises a read/write head that accesses data on a rotating magnetic storage medium, typically a disk. The read/write head is mounted in a slider that 'flies' above the surface of the disk on a bearing of air formed between the slider and the rotating disk. The face of the slider toward the disk may be shaped to form an air bearing surface that enhances the formation of the air bearing so as to maintain a desired and constant spacing. The slider is attached to an arm that is connected to a voice coil motor or stepper motor. In order to seek tracks on a circular recording medium the slider must be able to move substantially along the line of the radius of the disk.

Two arrangements are known for moving the slider. One choice is to drive the slider directly along a radius direction. This is known as the in-line

mode. The in-line mode is not preferred in most of the current disk drives, due to the limitation of the available space inside the disk drive chamber.

The preferred approach is to drive the slider in an arc so that the slider covers a path that is approximately along a radial direction of the disk.

5 This is called the rotary mode. The rotary mode is preferred to the in-line mode because a smaller space is required for the mechanical components to move the slider. The angular deviation of the centre axis of the air bearing surface and the centre axis of the read/write head from the circular track of the disk surface under the slider and read/write element is referred to as the
10 skew angle of the air bearing surface and the skew angle of the read/write head respectively.

The rotary mode uses a rotary actuator comprising a voice coil motor that drives an arm above the disk. At the end of the arm is a flexure or suspension below which a gimbal is used to connect the flexure and a slider,
15 and the read/write head is mounted on the rear of the slider. The voice coil motor drives the arm in an arc thereby moving the slider across the surface of the disk approximately along a radius of the disk. One way of miniaturizing the seeking mechanics setup is to reduce the length of the arms, however this increases the span of both the skew angle of the read/write head and
20 the skew angle of the air bearing surface.

The effect of skew angle on the flying height and the read/write performance of the read/write head has a complex dependency on disk speed, disk radius, slider shape, magnetic properties of the recording media and other factors. Reference is made to a number of publications that

consider aspects of these dependencies including : "Skew Angle and its Effects on Gb/in² Density Magnetic Recording", B. Liu, S.B. Hu, T.S. Low, S.H. Soh and J. Yip, IEEE Transactions on Magnetics, Vol 23 No. 3 1996; and "Skew Angle and Head-Disk Integration for Gb/in² Areal Density Recording", Bo Liu, Sheng-Bin Hu, Sue-Teck Lim, Gang Sheng, Dan Wei, Kian-Thiam Soo, and Teck Seng Low, Technical Report of the Institute of Electronics, Information and Communication Engineers, MR96-39, 1996.

Attempts have been made to address the problems of skew angle by designing air bearing surfaces that reduce the flying performance dependency of the slider assembly on the slider's skew angle. In this regard reference is made to :

1. United States Patent number 4673996 for "Magnetic head air bearing slider assembly utilizing transverse pressurization contours" issued June 16, 1987;

2. United States Patent number 4870519 for "Uniform flying height slider assembly with improved dynamic air bearing characteristics" issued September 26, 1989;

3. United States Patent number 5218496 for "Magnetic disk drive with reduced disk-to-disk spacing and improved actuator design" issued June 8, 1993;

4. United States Patent number 5537273 for "Speed and skew independent air bearing slider" issued July 16, 1996; and

5. United States Patent number 5557488 for "Gimbaled micro-head/flexure/conductor assembly and system" issued September 17, 1996.

6. George Clifford and Dick Henze, "An air bearing minimizing the effects of the slider skew angle", IEEE Transactions on Magnetics, Vol. 25 No. 5 1989.

In most of the prior art, the actuator assemblies are arranged with the arm, flexure, slider and head coaxial so that both the air bearing skew angle and the read/write skew angle are determined by the geometric relationship between the position of the actuator arm and the disk. Although in some cases the centre axis of the flexure and the centre axis of the slider may be decomposed, as depicted in Clifford and Henze's paper, the centre axis of the slider and the centre axis of the read/write head are not decomposed. Therefore, both the read/write skew angle and air bearing skew angle are the same in the prior art and can be of large value (20-35 degrees) when the slider is flying at the outer diameter region of the disk. The larger the read/write skew angle, the more severe the read/write performance degradation will be. Thus the prior art assemblies face an actual limitation from the read/write performance requirement.

OBJECT OF THE INVENTION

It is an object of the present invention to provide a slider that reduces the read/write skew angle, even with a large air bearing skew angle, to improve the read/write performance of a hard disk drive.

It is a further object of the invention to offer the public a useful alternative to known slider assemblies for hard disk drives.

Further objects will be evident from the following description.

DISCLOSURE OF THE INVENTION

In one form, although it needs not be the only or indeed the broadest form, the invention resides in a slider for a hard disk drive employing a rotary actuator comprising:-

- 5 an air bearing surface formed on the slider; and
- a read/write head associated with the slider;
- said slider characterised by a centre axis of the read/write head being decomposed from a centre axis of the air bearing surface.

 The read/write head is suitably attached on the slider at an angle
10 such that the read/write head will have a centre axis at an angle to the centre axis of the air bearing surface. The angle between the centre axis of the read/write head and the centre axis of the air bearing surface will be selected to minimize the degradation of the read/write performance caused by the skew angle in the whole data recording zone, whilst the flying
15 performance of the slider may still be retained.

 In preference the absolute angle between the centre axis of the read/write head and the centre axis of the slider is in the range of five degrees to thirty degrees.

 Furthermore, the angle between the centre axis of the read/write head
20 and the centre axis of the air bearing is preferably around half of the maximum air bearing skew angle when the slider is at the outer diameter of the disk surface.

 The read/write head is suitably associated with a rear face of the slider and the rear face is formed at an angle with respect to a centre axis

of the slider.

Suitably a centre axis of the air bearing surface is decomposed from the centre axis of the slider. The angle between the centre axis of the air bearing surface and the centre axis of the slider is suitably in the range of five degrees to thirty degrees.

In a further form, the invention resides in a slider for a hard disk drive employing a rotary actuator comprising:-

an air bearing surface formed on the slider; and

a read/write head associated with the slider;

said slider assembly characterised by a centre axis of the read/write head being decomposed from a centre axis of the air bearing surface, and by the centre axis of the air bearing surface being decomposed from the centre axis of the slider.

An angle between a centre axis of the air bearing surface and a centre axis of the read/write head may be in the range of five degrees to thirty degrees.

An angle between a centre axis of the air bearing surface and a centre axis of the slider may be in the range five degrees to thirty degrees.

In yet a further form, the invention resides in a slider assembly for a hard disk drive employing a rotary actuator including:-

a flexure attachable at one end to an arm of the rotary actuator;

a slider mounted to another end of the flexure by a gimbal;

an air bearing surface formed on the slider; and

a read/write head associated with the slider;

said slider characterised by a centre axis of the read/write head being decomposed from a centre axis of the air bearing surface of the slider.

BRIEF DETAILS OF THE DRAWINGS

5 To assist in understanding the invention preferred embodiments will now be described with reference to the following figures in which :

FIG 1 is a plan view sketch of a hard disk drive incorporating a rotary actuator assembly;

10 FIG 2 is a side view sketch of the end of the actuator assembly showing a slider assembly incorporating a flexure, air bearing slider and gimbal;

FIG 3 shows the air bearing skew angle and the read/write skew angle;

FIG 4 shows a prior art embodiment of a slider assembly;

15 FIG 5 shows a prior art embodiment of a slider assembly in which the centre axis of the slider is decomposed from the centre axis of the flexure;

20 FIG 6 shows an underside view of a first embodiment of a slider assembly in which the centre axis of read/write head is decomposed from the centre axis of air bearing surface;

FIG 7 shows an underside view of a second embodiment of a slider assembly in which the centre axis of the read/write head is decomposed from the centre axis of the air bearing surface;

FIG 8 shows an underside view of a third embodiment of a slider

assembly in which the centre axis of the read/write head is decomposed from the centre axis of the air bearing surface;

FIG 9 shows a underside view of the fourth embodiment of a slider assembly which the centre axis of the read/write head is decomposed from the centre axis of the air bearing surface;

FIG 10 shows a fifth embodiment of a slider assembly which is similar to FIG 6 except the slider is positioned in the opposite direction;

DETAILED DESCRIPTION OF THE DRAWINGS

In the drawings, like reference numerals refer to like parts.

Referring to FIG 1 there is shown a sketch of a hard disk drive 1 utilising a rotary actuator 2 to read and write on a disk 3 coated with a recording medium.

The rotary actuator 2 comprises an arm 2a which is driven by a voice coil motor 4 at one end. A flexure 5 is attached at the other end of the arm and projects over the disk 3. A slider 6 is suspended from the flexure 5 on gimbal 7, as shown in FIG 2. The attachment between the slider 6 and the gimbal 7 is suitably made by mucilage 8, although other attachments are known.

FIG 3 shows the skew angle 16 of the read/write head 9 and the skew angle 17 of air bearing surface 10, where the skew angle 16 of the read/write head 9 refers to the angle between the centre axis 14 of read/write head 9 and the direction of the data track 18 of disk surface under the read/write head, while the skew angle 17 of the air bearing surface 10 refers to the

angle between the centre axis 13 of the air bearing surface 10 and the direction of air flow 19 between the slider and the disk surface.

The magnetic read/write head 9 is associated with the slider 6 as shown in FIG 4. The head 9 may be formed in the slider 6 or formed separately and mounted on the slider 6. For prior art, the skew angle 16 of the read/write head 9 and the skew angle 17 of air bearing surface 10 are the same.

An air bearing is formed between the slider 6 and the disk 3 by high speed relative motion between air bearing surface 10 and disk surface 3. The air bearing is formed by the pressure of air forced between the slider 6 and the disk 3 by the rotating motion of the disk 3. The prior art referred to earlier discusses the formation of the bearing in greater detail. The air bearing typically produces a flying height for the slider of around 100nm or less.

As depicted in FIG 4, air bearing surface 10 is shaped to meet the requirement of slider's flying performance. In the prior art, the air bearing surface 10 is shaped to form two rails 10a, 10b that terminate in a wedge 10c. It will be appreciated that the shape of the air bearing surface 10 of the slider 6 is a matter of design choice and not essential to the operation of the present invention. Other shapes may be chosen to suit particular situations. Methods of forming the air bearing surface 10 are described in the prior art and include mechanical milling etching, chemical etching and several other known methods.

A prior art arrangement of the underside of a slider assembly 11 is

shown in FIG 4. The slider assembly 11 comprises the flexure 5, slider 6 with formed air bearing surface 10, the read/write head 9, and the gimbal 7 which connects the flexure and the slider, as shown in FIG 2. The figure shows the centre axis 12 of the flexure 5 is coaxial with the centre axis 13 of the air bearing surface 10 and the centre axis 14 of the read/write head 9. The skew angle of the slider and the skew angle of the read/write head are the same. This coaxial arrangement is common in the prior art and means that the skew angle of the air bearing surface and the skew angle of the read/write head are determined by the spatial relationship of the read/write track, the distance between read/write head and the pivot of the actuator and the distance between the pivot and the spindle centre. The rotary actuator may be set up for a skew angle of the air bearing surface of $-10 \sim +8$ degrees at inner diameter and $15 \sim 30$ degrees at the outer diameter of the disk. As a result, the skew angle of the read/write head will vary greatly from the inner diameter to the outer diameter and the read/write performance will decline when the skew angle of the read/write head is large.

In some of the prior art arrangements, the centre axis 12 of flexure 5 and the centre axis 6a of slider 6 are decomposed, as illustrated in FIG 5. Such an arrangement may improve the flying performance of the slider for the same air bearing surface designs. However, such an arrangement cannot improve the read/write performance as the read/write skew angle is still as large as the air bearing skew angle.

The inventors have found that the problem of skew can be ameliorated by decomposing the axes of the air bearing surface and the

read/write head to minimise the effect of a large air bearing skew angle on the read/write performance of the hard disk drive.

The read/write performance is not sensitive to the direction of the skew angle but just sensitive to the value of the skew angle. Therefore, the read/write performance degradation, caused by large skew angles, can be reduced significantly by decomposing the centre axes of the air bearing surface from the centre axis of the read/write head. In the first embodiment, as shown in FIG 6, the centre axis 13 of the air bearing surface 10 and the centre axis of 14 of the read/write head 9 are decomposed. The slider 6 is formed with an angled rear face 15 so that the centre axis 14 of the read/write head 9, is rotated from the axis 13 of the air bearing surface 10. When the slider 6 is set-up on the flexure 5 through gimbal 7 in the conventional manner, the centre axis 14 of the read/write head 9 will be rotated with respect to the centre axis 12 of the flexure 5 and the centre axis 13 of the air bearing surface 10. The rotated centre axis 14 of the read/write head 9 is optimised to get the maximum performance of the read/write performance over the entire disk surface.

The second embodiment for decomposing the centre axis 13 of the air bearing surface 10 and the centre axis 14 of the read/write head 9 is shown in FIG 7. In this case both the centre axis 13 of the air bearing surface 10 and the centre axis 14 of the read/write head 9 are decomposed by rotating the centre axis 13 of the air bearing surface 10 from the centre axis 6a of the slider 6 and the centre axis 14 of the read/write head 9. The centre axis of each component can be independently set to optimise the

head's read/write performance and the slider's flying performance over the entire disk surface.

The embodiments of FIG 6 and FIG 7 can be modified in the manner shown in the third embodiment of FIG 8 to decompose the centre axes of 13 and 14 by forming the centre axis 13 of the air bearing surface 10 and the
5 centre axis 14 of the read/write head 9 at suitable angles in respect to the centre axis 6a of the slider 6. The slider 6 is set-up on the flexure 5 through gimbal 7 in the conventional manner. The centre axis 13 of the air bearing surface 10 and the centre axis 14 of the read/write head 9 are optimised
10 independently for maximum flying performance of the slider and the maximum recording performance of the read/write head.

An alternate approach to that shown in FIG 7 is the fourth embodiment shown in FIG 9 in which the centre axis 14 of the read/write head 9 is decomposed from the centre axis 13 of the air bearing surface.

15 For some applications, the invention described in FIG 6 can be modified as shown in FIG 10. The embodiment of FIG 10 is similar to that shown in FIG 6 but with the slider 6 reversed. It will be appreciated that other embodiments described above can be modified correspondingly by reversing the slider in the manner shown in FIG 10.

20 By decomposing the axes 13 and 14 a slider assembly can be manufactured to maximise recording performance of the read/write head in a hard disk drive even when the air bearing skew angle is large. For the type of hard disk drive shown in FIG 1, a suitable absolute angle between the centre axis 13 of the air bearing surface and the centre axis 14 of the

read/write head is in the range of five degrees to thirty degrees.

Throughout the specification the aim has been to describe the preferred embodiments of the invention without limiting the invention to any one embodiment or specific collection of features.



CLAIMS

1. A slider (6) for a hard disk drive employing a rotary actuator including:
an air bearing surface (10) formed on the slider (6); and
a read/write head (9) associated with the slider (6);
5 said slider characterised by a centre axis (14) of the read/write head (9) being decomposed from a centre axis (13) of the air bearing surface (10) of the slider.
2. The slider of claim 1 wherein the centre axis of the air bearing surface is decomposed from a centre axis of the slider.
- 10 3. The slider of claim 1 wherein the read/write head is associated with a rear face of the slider and said rear face is formed at an angle with respect to a centre axis of the slider.
4. The slider of claim 1 having an absolute angle between the centre axis of the air bearing surface and the centre axis of the read/write head in
15 the range of five degrees to thirty degrees.
5. The slider of claim 1 having an angle between a centre axis of the air bearing surface and the centre axis of the slider in the range of five degrees to thirty degrees.
6. A slider for a hard disk drive employing a rotary actuator including:
20 an air bearing surface formed on the slider; and
a read/write head associated with the slider;
said slider assembly characterised by a centre axis of the read/write head being decomposed from a centre axis of the air bearing surface, and
by the centre axis of the air bearing surface being decomposed from the



centre axis of the slider.

7. The slider of claim 6 wherein an absolute angle between a centre axis of the read/write head and the centre axis of the air bearing surface is in the range of five degrees to thirty degrees.

5 8. The slider of claim 6 wherein an absolute angle between the centre axis of the air bearing surface and the centre axis of the slider is in the range of five degrees to thirty degrees.

9. A slider assembly for a hard disk drive employing a rotary actuator including:-

10 a flexure attachable at one end to an arm of the rotary actuator;
a slider mounted to another end of the flexure by a gimbal;
an air bearing surface formed on the slider; and
a read/write head associated with the slider;
said slider characterised by a centre axis of the read/write head being
15 decomposed from a centre axis of the air bearing surface of the slider.

Dated this day of 1998

Signed for and on behalf of

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By Their Patent Attorneys

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