REPLACED SHEETS SG
☑ Description : paged ....1.. to paged ..17..
☑ Claim(s) : paged ..18.. to paged ..19..
☑ Drawing(s) : paged ....1.. to paged ..6..
☑ Abstract : paged ..21.. to paged —

RTMP's COPY

ORIGINAL

AIR BEARING DISK HEAD SLIDER

The present invention relates to an air bearing disk head slider for use with a rotary actuator in a transducer head assembly for a rotating disk drive.

Transducer head assemblies that could "fly" relative to a rotating disk are used extensively in rotating disk drives. The assemblies include an air bearing slider for carrying a magnetic transducer proximate the rotating disk.

Figure 1 illustrates a conventional slider 10 supported by a gimbal 11 over a disk 14. The gimbal 11 is secured to an arm 12. The arm 12 positions the slider 10 over individual data tracks (not shown) on the disk 14 along an arc 18. As the disk 14 rotates, it generates wind or air flow in the direction shown by arrows 16 (wind 16). The wind 16 is approximately parallel to the disk's tangential velocity, indicated by an arrow 22. The wind co-operates with the slider 10 to provide lift which allows the slider to fly above the disk 14.

The gimbal 11 is a resilient spring that allows the slider 10 to follow the topography of the disk 14. The gimbal 11 includes a dimple (not shown) that is in point contact with the slider 10. The dimple provides a pivot about which the slider 10 can pitch and roll while following the topography of the disk 14.

When the slider 10 is positioned near the outside edge of the disk 14, its longitudinal axis 20 is substantially parallel to the wind direction. Near the centre of the disk 14, the slider 10 is skewed with respect to the wind direction as illustrated by a skew angle $\emptyset$. The skew angle $\emptyset$ is measured between the longitudinal axis 20 and the wind 16.

The elements described to this point may be conventional in design and as shown in Figure 1 and

This Sheet Has Been Replaced



ORIGINAL

Figures 2a to 2e to facilitate an understanding of the present invention. Throughout the Figures, elements of the same design are designated by identical reference numerals.

Figure 2a as a perspective view of a head gimbal assembly having a conventional catamaran slider 30. The slider 30 is secured to the gimbal 11 in any known manner. The slider 30 and the gimbal 11 are supported by the arm 12. Rails 32 and 34, positioned along edges of the slider 30, form air bearing surfaces on which the slider flys, in a known manner.

Figure 2b is an end view of the slider 30 as seen from the line 2B-2B of Figure 2a. The arm 12 and the gimbal 11 support the slider 30 above the disk 14. The slider 30 includes the rails 32 and 34, which carry transducers 35 and 37. The rails 32 and 34 include air bearing surfaces 38 and 39, which provide lift to the slider 30, as described more fully below.

Flying height is viewed as one of the most critical parameters of non-contact recording. As the average flying height of the slider 30 decreases, the transducers 35 and 37 achieve greater resolution between individual data bit locations on the disk 14. Therefore, it is desirable to have the transducers 35 and 37 fly as close to the disk 14 as possible.

Figure 2c is a bottom plan view of the conventional catamaran slider 30 shown in Figures 2a and 2b. The rails 32 and 34 are positioned along edges of the slider 30 and are disposed about a recessed area 36 to form the air bearing surfaces 38 and 39. As the disk 14 rotates, the disk drags air (wind 16) under the slider 30 and along the air bearing surfaces 38 and 39. Under the air bearing surfaces 38 and 39, the air flow component due to the drag of the disk 14 is "couette flow". As couette flow passes beneath the rail 32 and 34, the skin friction on the air bearing surfaces 38 and

This Sheet Has Been Replaced



ORIGINAL

39 causes the air pressure between the disk 14 and the air bearing surfaces to increase and to thereby provide lift causing the slider 30 to fly above the disk surface. Hence, the greater the air bearing surface area, the greater the lift.

The flying height is preferably uniform regardless of variable flying conditions, such as tangential velocity variation from inside to outside tracks, lateral slider movement during a seek operation, and varying skew angles ϕ. Catamaran sliders provide just enough air bearing surface area to fly at a proper height above the disk surface. For example, without the rails 32 and 34, the air bearing surface area would be too large. Consequently, the slider 30 would fly too far from the disk surface at a height adversely affecting resolution.

Although conventional catamaran sliders are helpful in controlling flying height, they are very sensitive to the skew angle ϕ. Even with moderate skew angles in the range of 10 to 15 degrees, flying height from a conventional catamaran slider is adversely influenced. Increasing the skew angle ϕ at a fixed tangential velocity causes the air pressure distribution beneath the rails 32 and 34 to become distorted. This influences the net forces and torque acting upon the slider 30 and results in decreased flying height.

Figure 2d is a bottom view of the rail 32 with the wind 16 at a 0 skew angle. The air bearing surface 38 has an effective area 40 at the 0 skew angle, which is equal to the area of the air bearing surface 38. Figure 2e illustrates the wind 16 applied to the rail 32 at a skew angle ϕ greater than 0. The air bearing surface 38 now has a smaller effective area 41. As the skew angle ϕ increases, the effective surface area of the rails 32 and 34 decreases. The decrease of the effective surface area as the skew angle ϕ increases is caused by side

This Sheet Has Been Replaced



ORIGINAL

leakage. The air that leaks out of the sides of the rails 32 and 34 is not available to generate pressure under the rails. This causes a lot of pressure beneath the rails 32 and 34 resulting in a lower flying height at a greater skew angle. To prevent the slider 30 from ultimately contacting the disk surface at large skew angles, the slider's average flying height must be appropriately increased. Resolution is therefore sacrificed. Further, the pressurisation of one rail may differ from the pressurisation of the other rail at a skew angle ϕ. This difference causes the slider 30 roll. In other words, the rail 32 will fly at a different height from the rail 34 while the slider 30 flys at a skew angle ϕ.

As disk drives become more compact for applications in smaller and more portable equipment, rotary actuators are increasingly employed. Further, the designer is motivated to use a shorter actuator pivot arm to make the disk drive even more compact. However, these actuators create rather large skew angles ϕ and consequently make flying height control more difficult. Rotary actuators cause the geometric orientation between the longitudinal axis 20 (shown in Figure 1) and the disk rotation tangent, to change as the arm 12 moves the slider 10 along the arc 18.

One approach to reducing sensitivity of the flying characteristics to varying skew angles is to provide edge blends extending along the length of each rail. As early as 1982, designers applied these blends to reduce wear caused by contact between each rail and the disk surface. The edge blends also reduce sensitivity of the flying characteristics to varying skew angles created by rotary actuators. For example, the pressurisation distribution on each rail remained nearly constant relative to the slider's pivot point over varying skew angles. The benefits to flying characteristics became

This Sheet Has Been Replaced



SA1 95

known in 1982 when the edge blends were used in combination with rotary actuators in 5 1/4 inch disk drives, such as the WREN family manufactured by IMPRIMIS Technology, Inc.

U.S. Patent No. 4,693,996 discloses a similar approach. This patent shows transverse pressurisation contours (TPC) on each rail that extend from the leading edges to the trailing edges. The TPCs provide a pressurisation region across one side edge of each rail and a depressurisation region across the opposite side edge such that the pressure distributions across the air bearing surfaces are substantially unaltered over varying skew angles.

Patent Abstracts of Japan, vol. 9, no. 250 (p-394)(1973) 8th October 1993, (Fujitsu K.K.), discloses an air bearing head for supporting an electro-magnetic transducer. The slider comprises a slider body and first and second rails, each forming an air bearing surface. A portion of the inside and outside edges of each rail converge together towards a central region of the air bearing surface thereby forming intermediate surfaces recessed from the bearing.

It is an object of the present invention to provide an air bearing disk head slider, which reduces the effect of skew angle on flying height over a rotating disk.

The present invention provides a slider having side rails, in which an air bearing surface of each side rail decreases in width away from a leading end of the surface towards a narrowed surface portion and then increases in width after the narrowed surface portion towards a trailing end of the surface.

According to the present invention, there is provided an air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body having a leading edge, a trailing edge and first and second edges therebetween; and

This Sheet Has Been Replaced



first and second side rails disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces, characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

In one embodiment, the first and second side rails form an hour glass configuration in a catamaran slider, which includes a recessed area disposed between the side rails and extending from the leading edge to the trailing edge.

In another embodiment, the side rails form an hour glass configuration in a negative pressure air bearing (NPAB) slider, which includes a cross rail extending between the side rails. During operation, the cross rail creates a negative pressure area between the cross rail and the trailing edge of the slider.

In either embodiment, the side tails are preferably arranged to project by about 10 to 30 microns from the slider body.

Advantageously, the narrowed surface portion is spaced from the leading edge by about one third the length of the slider as measured from the leading edge to the trailing edge.

Preferably, the leading and trailing ends of each air bearing surface may have substantially the same width, and the narrowed surface portion may have a width which is substantially equal to one half the width of the leading and trailing ends.

The first and second side rails may include edge steps along their edges and/or chamfers and/or edge blends.

This Sheet Has Been Replaced



The invention is described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a top plan view of an air bearing slider supported above a rotating disk;

Figure 2a is a perspective view of a head gimbal assembly having a conventional catamaran slider;

Figure 2b is an end view of the head gimbal assembly taken along the line 2B - 2B of Figure 2a;

This Sheet Has Been Replaced



ORIGINAL

Figure 2c is bottom plan view of a conventional catamaran air bearing slider of Figures 2a and 2b;

Figure 2d is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 2e is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a skew angle Ø;

Figure 3 is a perspective view of an hour glass catamaran slider in accordance with the present invention as viewed from a trailing edge thereof;

Figure 4 is a bottom plan view of an hour glass rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 5 is a bottom plan view of the hour glass rail illustrating an effective air bearing surface area at a skew angle Ø;

Figure 6 is a perspective view of another embodiment of slider in accordance with the present invention having hour glass rails formed with shallow edge steps;

Figure 7 is an enlarged sectional view taken along the line 7 - 7 of Figure 6;

Figure 8 is an enlarged sectional view similar to Figure 7 but having a modified hour glass rail having chamfered edged steps;

Figure 9 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having chamfered edges;

Figure 10 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having shallow edge blends; and

Figure 11 is a perspective view of another embodiment of hour glass slider in accordance with the present invention.

Figure 3 is a perspective view of an hour glass catamaran slider 50 in accordance with the present

This Sheet Has Been Replaced



ORIGINAL

invention, as viewed from a trailing edge 52 thereof. The slider 50 includes a pair of projecting rails 42 and 44 having air bearing surfaces 46 and 48, respectively. The rails 42 and 44 extend from a leading edge 51 to the trailing edge 52. The slider 50 is a modified catamaran slider. The side rails 42 and 44 are not rectangular as are the rails 32 and 34 shown in Figure 2a. Instead, the rails 42 and 44 decrease in width from the leading edge 51 to breaks 56 and 60, and increase in width from the breaks 56 and 60 to the trailing edge 52. In other words, the rails 42 and 44 generally have "hour glass" configurations. Each air bearing surface 46 and 48 has a width measured at the leading edge 51 that is approximately equal to a width measured at the trailing edge 52. The rails 42 and 44 are formed such that the air bearing surfaces 46 and 48 have widths at the breaks 56 and 60 which are substantially equal to one half of the widths measured at the leading edge 51 and the trailing edge 52.

It should be understood that in any of the embodiments shown in the Figures, the present invention does not require that the inside and outside edges of the air bearing surfaces be straight: the edges may be curved from the leading edge of the slider to the trailing edge.

The slider 50 is secured to an actuator arm in any known manner. For example, the slider 50 may be secured to the actuator arm 12 shown in Figures 1, 2a and 2b. As the disk 14 rotates, air flow between the slider 50 and the disk 14 pressurises the air bearing surfaces 46 and 48 and lifts the slider 50 several micro-inches (some micro-centimetres) above the surface of the disk 14. In a preferred embodiment, the slider 50 flys about 8 micro-inches (20.32 micro-centimetres) above the disk surface when a disk 14 rotates at about 1000 inches per second (about 2540 cms per second). To provide faster

This Sheet Has Been Replaced



ORIGINAL

take off when the disk begins to rotate, the rails 42 and 44 include leading edge tapers 62 and 64. The tapers 62 and 64 provide faster take off by smoothing pressure transitions between ambient air and pressurised air beneath the rails 42 and 44. Faster take off decreases the length of time that the slider 50 slides on the disk surface before it begins to fly and thereby decreases wear on both the slider 50 and the disk 14.

The hour glass rails 42 and 44 are formed by etching with an ion beam. This forming process is known as ion milling. Figure 3 illustrates a "deep" etch in which the rails 42 and 44 project out from recessed areas 54 by about 25 microns. Virtually no air pressure builds up on the recessed areas 54. Alternatively, the rails 42 and 44 may be formed with a laser or a similar etching technique.

Figures 4 and 5 are bottom plan views of the hour glass rail 42 in Figure 3 and illustrate effective air bearing surface areas at a 0 skew angle and a skew angle ø. For simplicity of illustration and analysis, the effective areas of positive pressure are indicated generally by the numerals 61 and 63. In Figure 4, the rail 42 is shown at a 0 skew angle with respect the wind 16. In this instance, the effective area 61 develops positive pressure along the entire length of the rail 42, and triangular area 65, 66, 67 and 68 develop some additional positive pressure. Figure 5 illustrates the rail 42 at a skew angle ø with respect to the wind, and the resulting effective area 63 is substantially equal to the effective area 61. As a result, pressurisation and flying height of the rails 42 and 44 are more constant over varying skew angles than the conventional catamaran slider 30 (shown in Figures 2a to 2e). Triangular areas 69 and 71 formed at varying skew angles ø also develop some positive pressure but tend to balance with the areas 65, 66, 67 and 68. Since the slider 50

This Sheet Has Been Replaced



has less variation in flying height, the average flying height may be reduced in order to obtain greater resolution on the individual bit positions on the disk 14 without risk of the slider 50 contacting the disk surface at high skew angles.

Figure 6 is a perspective view of an alternative slider 70. The slider 70 has hour glass rails 72 and 74 with etches that form "shallow" edge steps or blends 76. The edge steps 76 form inside and outside surfaces that are recessed from air bearing surfaces 78 and 80 by about 0 microns to 2.0 microns. The edge steps 76 are positioned along each rail, between leading edges 86 and trailing edges 88, to form the hour glass shapes of the air bearing surfaces 78 and 80. When the slider 70 flys at a skew angle $\emptyset$ (shown in Figure 5), the recessed surfaces accumulate additional pressure that prevents the slider 70 from losing flying height. This results in a more even flying height for varying skew angles $\emptyset$.

In addition to flying height another critical flying characteristic is roll. At varying skew angles, sliders tend to roll about their longitudinal axes. Roll is caused by shifts in the pressure distributions across the air bearing surfaces 78 and 80 relative to the slider pivot point. To reduce roll and to obtain overall optimum flying characteristics, the dimensions of the air bearing surfaces 78 and 80 and the edge steps 76 must be adjusted to minimise shifts in pressure distribution. For example, the edge steps 76 on the inner and outer edges of each rail may be formed asymmetrically, with the inside surfaces wider, or having a larger indentation, than the outside surfaces. It should be known that the recessed inside and outside surfaces may be formed with different dimensions and may vary from one rail to the other.

In Figure 6, breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing

This Sheet Has Been Replaced



edges 88. The breaks 82 and 84 preferably are spaced from the leading edges 86 by approximately one third the length of the slider 70. Positioning of the breaks 82 and 84 may be varied in alternative embodiments (not shown) to vary flying characteristics, such as pitch. Pitch is measured by an angle between the disk surface and a plane generally defined by the air bearing surfaces 78 and 80.

When the slider has a positive pitch, the leading edges 86 typically fly at greater distances from the disk surface than the trailing edges 88. Increasing the pitch angle provides for faster take off when the disk begins to rotate. Positive pitch also reduces the risk of a "head crash". When the leading edges 86 fly at greater distances from the disk surface than the trailing edges 88, the air bearing surfaces 78 and 80 tend to resist a negative pitch in which the leading edges 86 will crash into the disk surface. However, too large a positive pitch adversely affects stiffness or stability of the trailing edges 88. A small positive pitch increases the stiffness of the trailing edges 88. Since transducers, such as the transducers 35 and 37 (shown in Figure 2b) are typically positioned on the trailing edges 88, increased stability will increase performance of read and write operations. If the slider 70 flys with too small a positive pitch, a bump may cause the slider to rotate into a negative pitch and crash into the disk surface.

Pitch much be accurately controlled to achieve optimum flying characteristics. The pitch angle is adjusted by varying the pressure gradients along the air bearing surfaces 78 and 80. The breaks 82 and 84 may be positioned closer to either the leading edges 86 or the trailing edges 88 to vary pressure distribution along the air bearing surfaces 78 and 80. Typical pitch angles range from about 100 micro-radians to about 300

This Sheet Has Been Replaced



micro-radians.

As the disk 14 drags air (wind 16) beneath the rail 72 and 74, skin friction along the air bearing surfaces 78 and 80 causes the air pressure to increase. The breaks 82 and 84 divide the air bearing surface 78 and 80 into forward surfaces and rearward surfaces. The forward surfaces are adjacent the leading edges 86 and rearward surfaces are adjacent the trailing edges 88. Positioned between the forward and rearward surfaces are central surfaces, which are adjacent the breaks 82 and 84. Since the central surfaces have narrower air bearing surfaces than the forward surfaces, a portion of the air pressure bleeds off at the breaks 82 and 84. This portion is not available to pressurise the rearward air bearing surfaces. This results in greater air pressure towards the leading edges 86 and less air pressure towards the trailing edges 88, which causes the slider 70 to increase pitch angle. To reduce the pitch angle, the breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing edges 88. The resulting pressure distribution reduces the pressure on the forward air bearing surface areas and thereby reduces the pitch angle.

Since the air pressure bleeds off near the breaks in the hour glass rails, the average flying height of an hour glass catamaran slider (with breaks) drops from that of a catamaran slider of the same width. Therefore, the air bearing surfaces 78 and 80 are formed to be wider near the leading and trailing edges 86 and 88 than the air bearing surfaces 38 and 39 of the conventional catamaran slider 30 shown in Figure 2c. The edge steps 76 do not fully extend from the breaks 82 and 84 to the leading and trailing edges 86 and 88 but terminate prior to the leading and trailing edges. Terminating the edge steps 76 prior to the leading and trailing edges 86 and 88 maximises the width of the air

This Sheet Has Been Replaced

ORIGINAL

bearing surfaces 78 and 80 near the leading and trailing edges. The wider surfaces build up more air pressure and prevent the slider 70 from flying too close to the disk surface. The wider air bearing surfaces 78 and 80 also create more room to secure transducers on the trailing edges 88, such as the transducers 35 and 37 shown in Figure 2b.

Typically, a gimbal spring connects the slider 70 to an actuator arm, such as the arm 12 shown in Figure 2a. The gimbal spring includes a dimple that provides a pivot about which the slider 70 can pitch and roll while following the topography of the disk surface. The hour glass shape of each rail improves pitch stiffness of the air bearing about the point at which the dimple contacts the slider. Because the air pressure bleeds off near the breaks 82 and 84, the "area elements" of the air bearing surfaces 78 and 80 having vertical stiffness (formed by positive pressure) are concentrated near the leading and trailing edges 86 and 88 of the slider 70, remote from the pivot point. Thus, the vertical stiffness of each area element is "multiplied" by a longer moment arm to give a higher pitch stiffness.

Creating the hour glass shapes by applying the edge steps 76 to each rail such that they terminate prior to the leading and trailing edges 86 and 88 also improves, or reduces, flying height sensitivity to crown height variations. The air bearing surfaces 78 and 80 are not perfectly flat from the leading edges 86 to the trailing edges 88, but are slightly convex. There are two causes for the convex shape. First, manufacturing errors in the process of securing the slider 70 to the gimbal cause deformation of the slider. Second, designers intentionally "round" the air bearing surfaces 78 and 80 to reduce wear on the surfaces. The crown height is a measure of the degree of roundness and can vary from one slider to the next. An increase in crown

This Sheet Has Been Replaced



ORIGINAL

height causes the pressure to increase near the mid-sections of the air bearing surfaces 78 and 80, which causes an increase in flying height. However, the edge steps 76 counter-act this effect. Since the edge steps 76 cause the air pressure to bleed off near the mid-sections, an increase in crown height has a negligible effect on the air pressure near the mid-sections. Therefore, the hour glass shapes reduce the flying height sensitivity to crown height variations. The hour glass shapes also reduce flying height sensitivity to low frequency disk waviness, since the disk waviness effect pressure on the air bearing surfaces 78 and 80 similar to crown height variations.

Figure 7 to 10 are greatly enlarged sectional views of a rail, such as the rail 74, taken along the lines 7 - 7 of Figure 6 and illustrate alternative edge step embodiments. Figure 7 illustrates an embodiment in which the edge step 76 are "true" steps. Figure 8 illustrates an alternative embodiment in which the edge steps 76 are chamfered. Figure 9 illustrates an alternative embodiment in which the edge steps 76 are wide, shallow chamfers between the air bearing surface 80 and the inside and outside edges of the rail 74. Figure 10 illustrates another alternative embodiment in which the edge steps 76 are shallow edge blends. It should be understood that any of these embodiments, or a combination of them, may be used within the scope of the present invention.

Figure 11 illustrates an hour glass slider similar to the slider 70 shown in Figure 6, but having a cross-rail. Sliders having cross-rails are typically called negative pressure air bearing (NPAB) sliders, as opposed to catamaran sliders which do not have cross-rails. An hour glass NPAB slider 110 includes rails 112 and 114 having air bearing surfaces 116 and 118 respectively. A cross-rail 120 extends between the rails 112 and 114.

This Sheet Has Been Replaced



In the preferred embodiment, the cross-rail 120 is positioned closer to the leading edge 121 than the trailing edge 123.

During operation, the cross rail 120 creates a negative pressure area 122, which counter-acts the positive pressure built along the air bearing surfaces 116 and 118 and increases slider stability and stiffness. The negative pressure area 122 is created between the rails 112 and 114 and between the cross-rail 120 and the trailing edge 123.

The slider 110 further includes edge steps 125. The cross-rail 120 and edge steps 125 may be etched to approximately 0 microns to 2.0 microns below the air bearing surfaces 116 and 118. The edge steps 125 are relatively shallow compared to the negative pressure area 122, which is etched to about 10 microns below the air bearing surfaces 116 and 118. The edge steps 125 are drawn out of scale and actually look similar to the edge steps 76 shown in Figure 8. To maximise the slider stiffness, the edge steps 125 are applied to each rail, such that they terminate prior to the leading and trailing edges 142 and 124. This maximises the air bearing surface area that develops positive pressure near the ends of the rails 112 and 114 while maximising the negative pressure area 122 near the centre of the slider 110. As a result, the counter-action between the positive and negative pressure is maximised to improve the slider stiffness.

The shallow edge steps 125 accumulate additional pressure. When the slider 110 flys at a skew angle $\emptyset$, the additional pressure that accumulates on the edge steps 125 reduces the effect of the skew angle on fly height by reducing shifts in the pressure distributions across the air bearing surface areas 116 and 118. The result is a more constant fly height for varying skew angles $\emptyset$. The slider 110 is also relatively insensitive

This Sheet Has Been Replaced



ORIGINAL

to crown height variation and disk waviness (see the discussion above with reference to Figure 6).

Figure 11 illustrates an alternative rail geometry that may be used with or without the cross-rail 120. Elongated breaks 126 and 128 divide the air bearing surfaces 116 and 118 into three portions. The air bearing surface 116 is divided into a forward surface 130, a central surface 132, and a rearward surface 134. Similarly, the air bearing surface 118 is divided into a forward surface 136, a central surface 138, and a rearward surface 140. The breaks 126 and 128 are spaced from the leading edges 142 by about approximately one third the length of the slider 110. As a result, the forward surfaces 130 and 136 are smaller than the rearward surfaces 134 and 140. The central surfaces 132 and 138 have generally rectangular shapes.

The negative pressure area 122 created by the cross-bar 120 reduces flying height senstivity to tangential disk velocity. As the disk rotates, the air velocity beneath the air bearing surfaces is greater at the outer radius of the disk than at the inner radius. Therefore, the positive pressure built along the air bearing surface is greater at the outer radius than at the inner radius. However, the negative pressure also increases at the outer radius. The increase in negative pressure counter-acts the increase in positive pressure to reduce changes to flying height caused by changes in air velocity.

The hour glass air bearing surfaces 116 and 118 further reduce changes in flying height caused by changes in air velocity. At higher air speeds, increases in positive pressure are greater than increases in negative pressure. Since the air bearing surfaces 116 and 118 are narrower at the central surfaces 132 and 138 the positive pressure bleeds off into the negative pressure cavity 122 to reduce increases in positive

This Sheet Has Been Replaced



pressure. The positive pressure is even further reduced since the area of greatest negative pressure, the central region of the negative pressure area 122 is adjacent the central surfaces 132 and 138. Therefore, the negative pressure area 122 draws more air off the central surfaces 132 and 138 to further reduce increases in positive pressure. As a result, changes in positive and negative pressure remain substantially equal over varying tangential disk velocities.

The slider having hour glass rails according to the present invention provides a near constant air bearing surface area and pressure distribution while flying at varying skew angles and disk velocities. As a result, the slider having hour glass rails has improved flying characteristics over the prior art.

This Sheet Has Been Replaced



This Sheet Has Been Replaced

CLAIMS

1. An air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body (50,70,110) having a leading edge (51,121), a trailing edge (52,123) and first and second edges therebetween; and

first and second side rails (42,44; 72,74; 112,114) disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface (46,48; 78, 80; 116,118) with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces (76,125), characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

2. A slider according to claim 1 characterised in that the air bearing surface of each of the first and second side rails has a forward surface portion (130,136) extending from the leading end thereof to the narrowed surface portion and a rearward surface portion (134,140) extending from the trailing end thereof to the narrowed surface portion, and in that the forward surface portion has a smaller area than the rearward surface portion.

3. A slider according to claim 1 or 2 characterised in that the narrowed surface portion of the air bearing surface of each of the first and second side rails is spaced from the leading end thereof by about one third of the length between the leading and the trailing ends thereof.

4. A slider according to any of claims 1 to 3 characterised in that the narrowed surface portion has a substantially rectangular shape.

* C L M S *

This Sheet Has Been Replaced

24/4/95

5. A slider according to any of claims 1 to 4 characterised in that the air bearing surface of each of the first and second side rails has substantially the same width adjacent the leading and trailing ends thereof, and in that the narrowed surface portion has a width which is substantially half said width adjacent the leading and trailing ends.

6. A slider according to any preceding claim characterised in that said converging inside and outside edge portions extend substantially the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

7. A slider according to any of claims 1 to 5 characterised in that said converging inside and outside edge portions extend less than the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

8. A slider according to any preceding claim characterised in that said converging inside and outside edge portions form edge steps.

9. A slider according to any preceding claim characterised in that said converging inside and outside edge portions comprise chamfers.

10. A slider according to any of claims 1 to 8 characterised in that said converging inside and outside edge portions comprise edge blends.

11. A slider according to any preceding claim characterised in that said converging inside and outside edge portions adjoin recessed inside and outside surfaces, which are set back from the air bearing surfaces by about 0 microns to 2.0 microns.

12. A slider according to claim 11 characterised in that the recessed inside surfaces have different dimensions from the recessed outside surfaces.

* C L M S *

ORIGINAL

ABSTRACT

AIR BEARING DISK HEAD SLIDER

The invention provides an air bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk. The slider comprises a slider body (50) having a leading edge (51), a trailing edge (52), and first and second side edges therebetween, and first and second side rails (42, 44) extending adjacent the first and second side edges, respectively. Each of the side rails forms an air bearing surface (46, 48) having a narrowed surface portion located between a leading end and a trailing end of the rail. Each air bearing surface has inside and outside edges, which converge towards the narrowed surface portion.

[Figure 3]

This Sheet Has Been Replaced



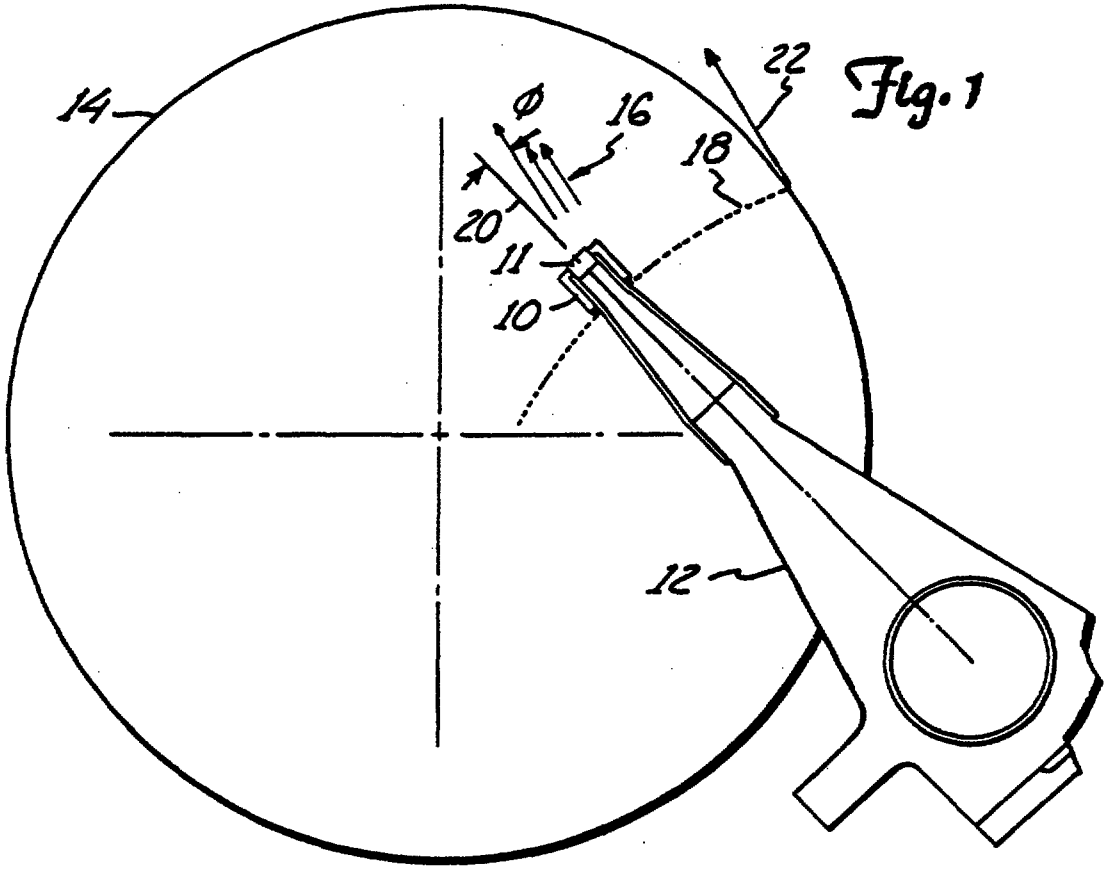


Fig. 1

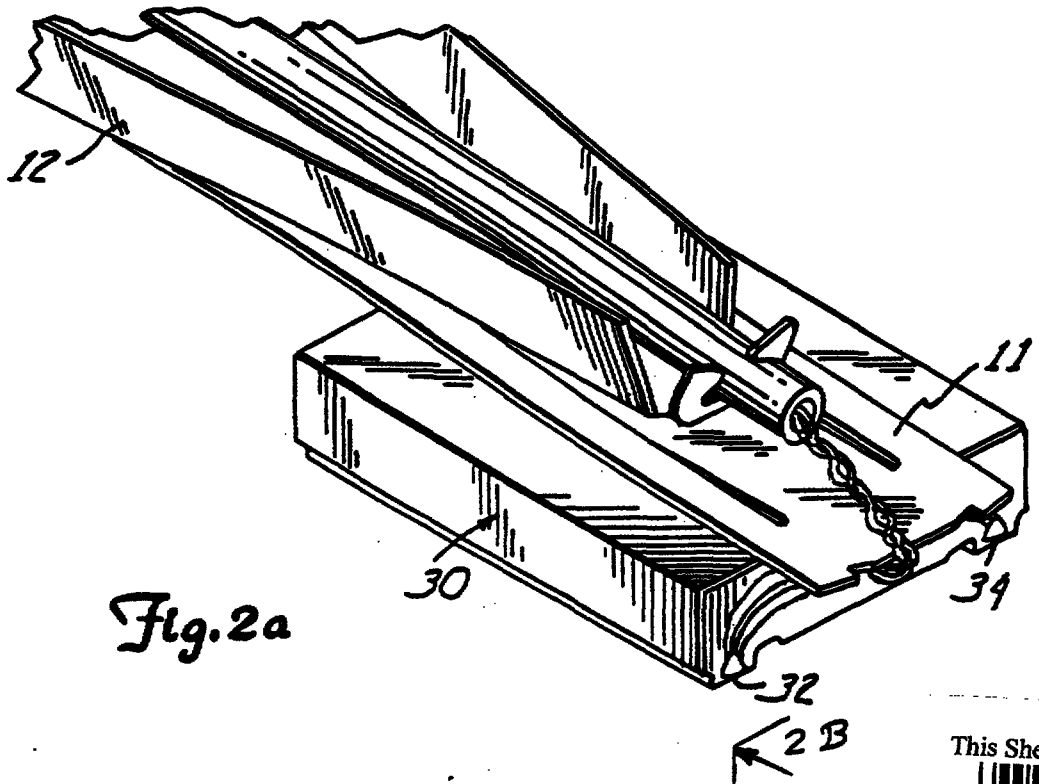


Fig. 2a

This Sheet Has Been Replaced

Fig. 2b

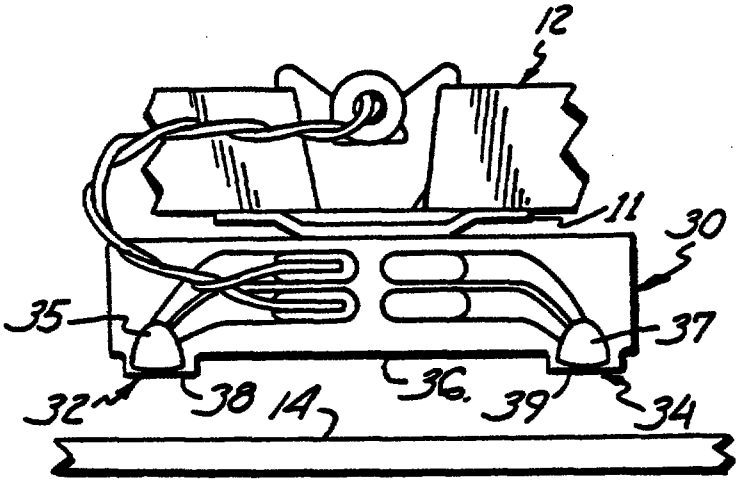
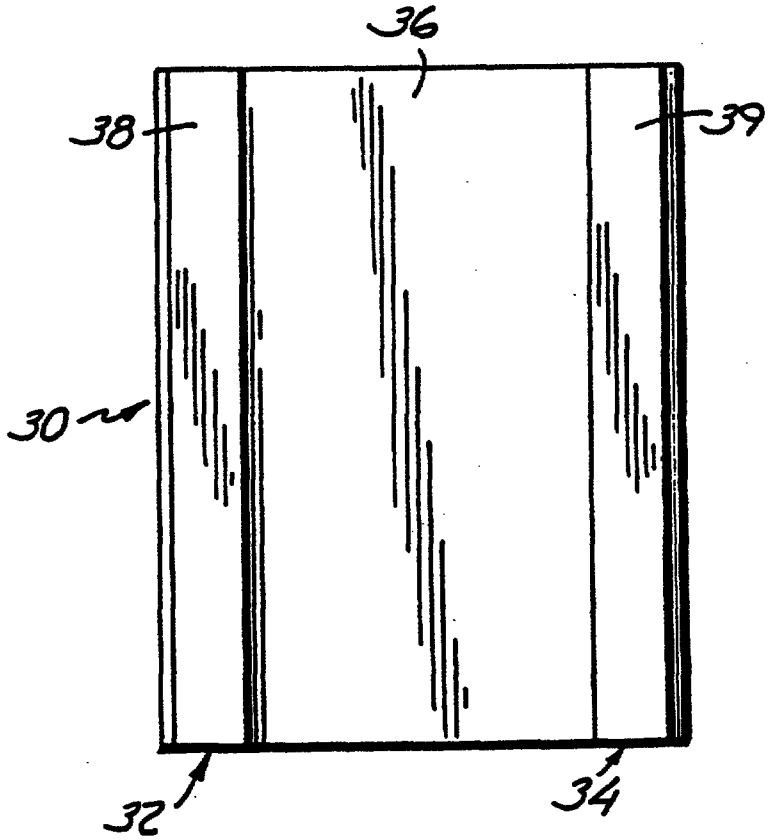


Fig. 2c



This Sheet Has Been Replaced

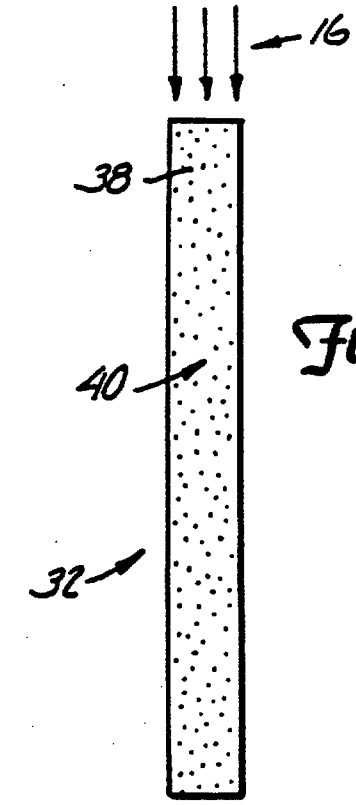


Fig.2d

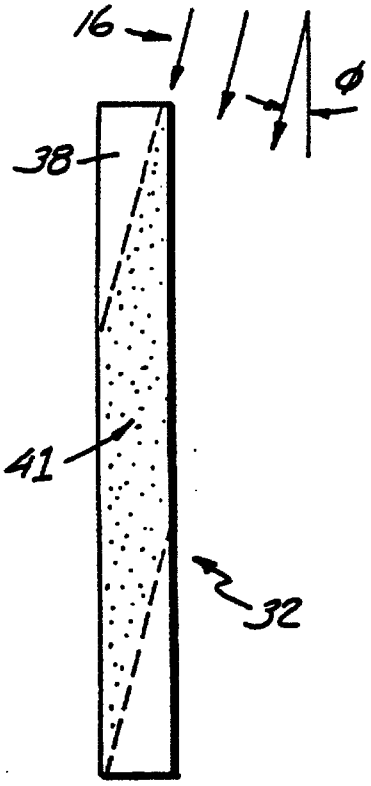


Fig.2e

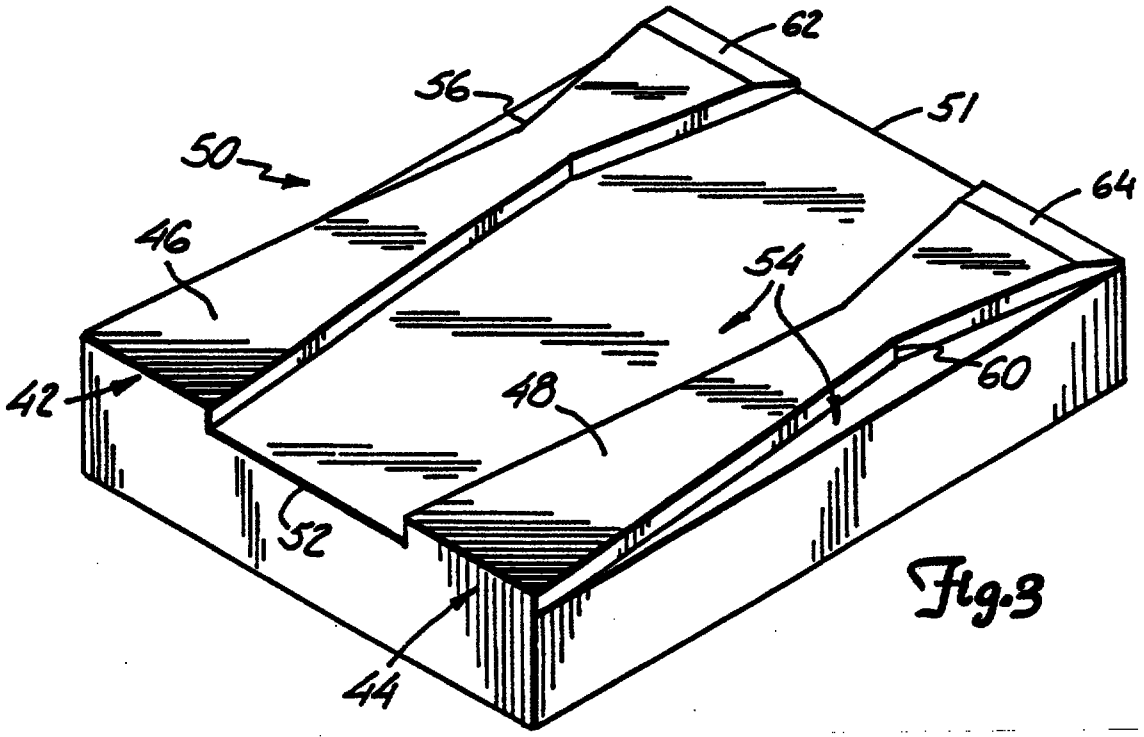


Fig.3

This Sheet Has Been Replaced

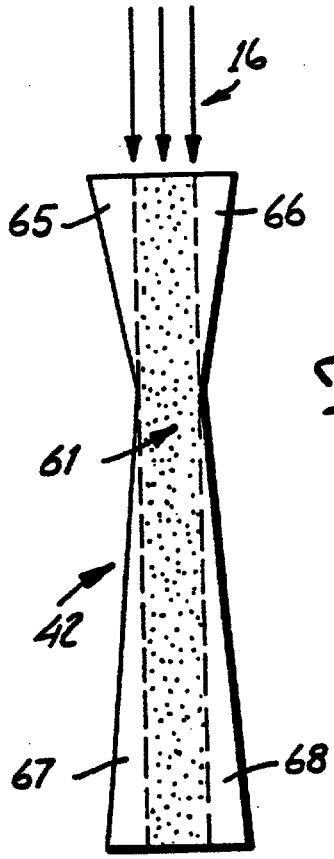


Fig. 4

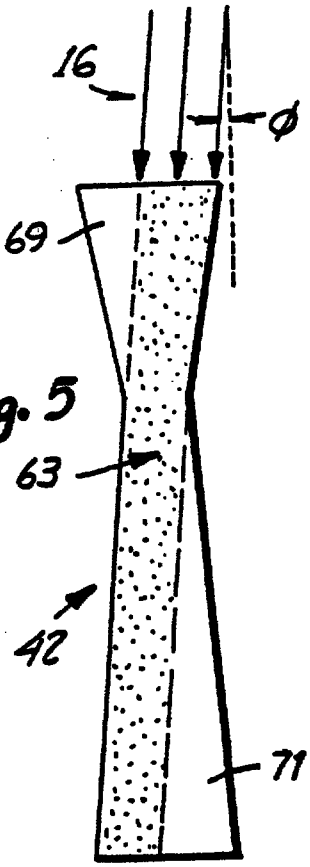


Fig. 5

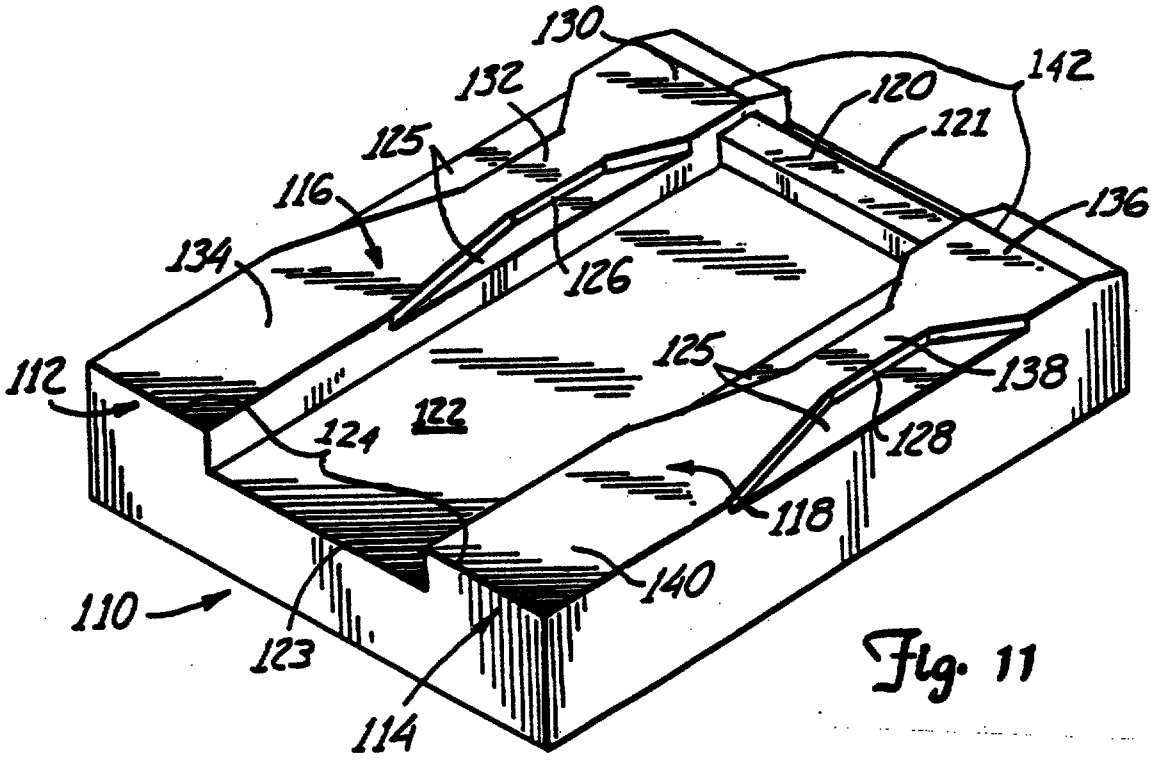


Fig. 11

This Sheet Has Been Replaced

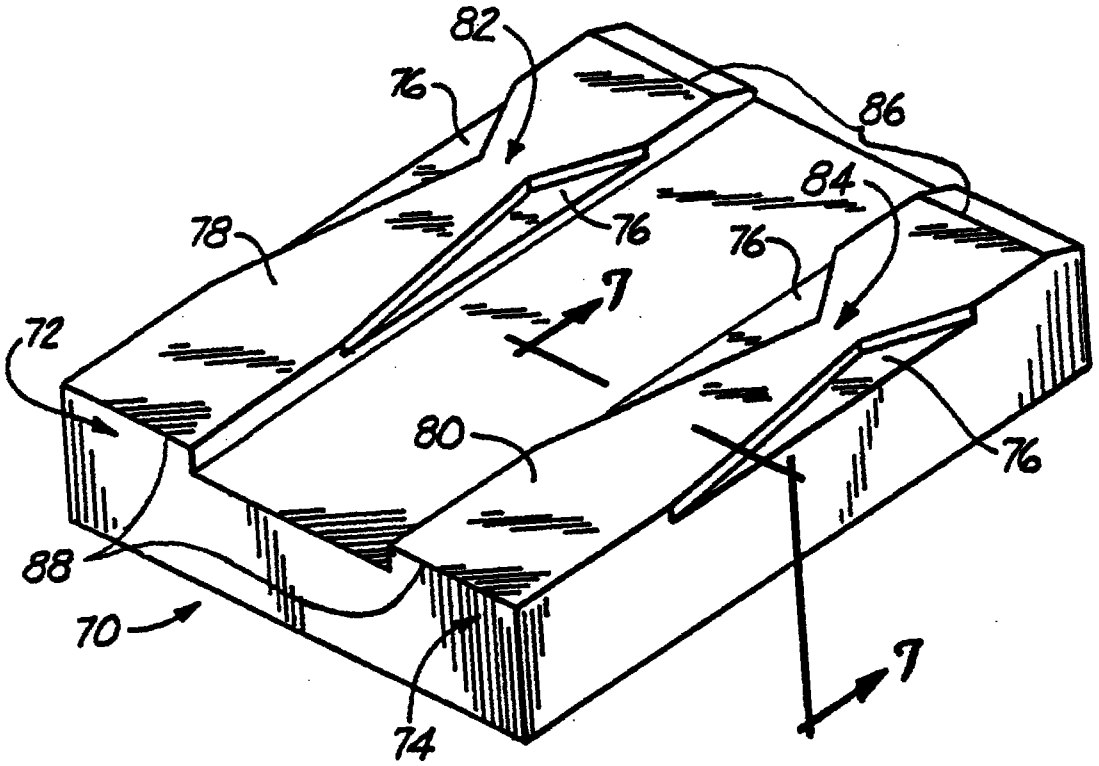


Fig. 6

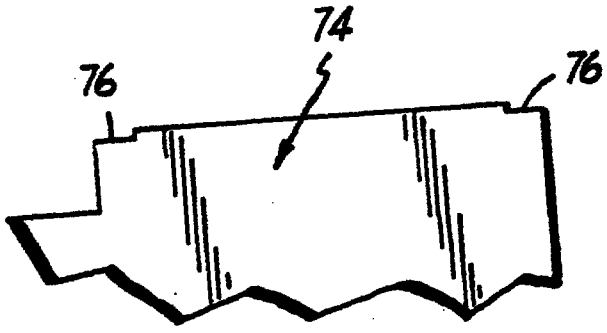


Fig. 7

This Sheet Has Been Replaced

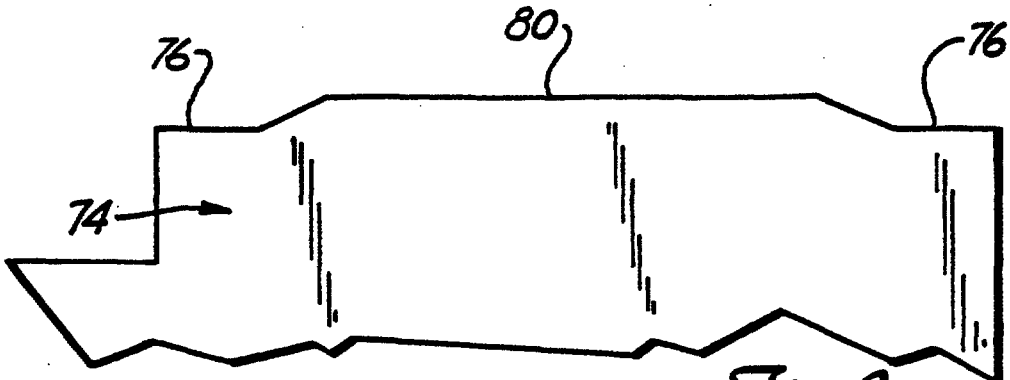


Fig. 8

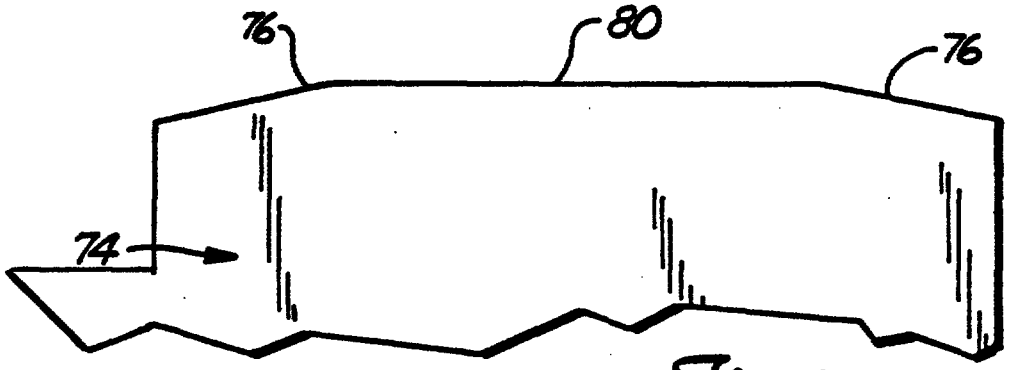


Fig. 9

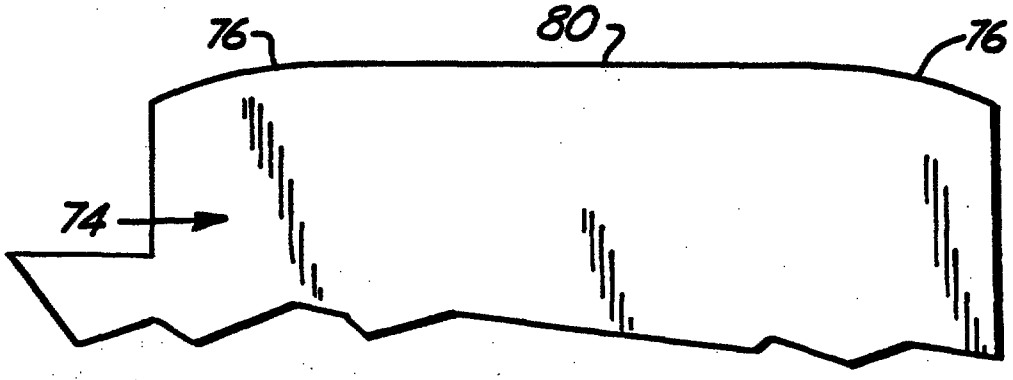


Fig. 10

This Sheet Has Been Replaced

REPLACED SHEETS SG
☑ Description : paged ..1.. to paged ..18..
☑ Claim(s) : paged ..19.. to paged ..20..
☑ Drawing(s) : paged ..1.. to paged ..6..
☑ Abstract : paged ..21.. to paged .....

REPLACEMENT SHEETS SG
☑ Description : paged ..1.. to paged ..18
☑ Claim(s) : paged ..19. to paged ..20
☑ Drawing(s) : paged ..1.. to paged ..6.
☑ Abstract : paged ..21. to paged .....
DATE OF RECEIPT 18-11-1996

AIR BEARING DISK HEAD SLIDER

The present invention relates to an air bearing disk head slider for use with a rotary actuator in a transducer head assembly for a rotating disk drive.

Transducer head assemblies that could "fly" relative to a rotating disk are used extensively in rotating disk drives. The assemblies include an air bearing slider for carrying a magnetic transducer proximate the rotating disk.

Figure 1 illustrates a conventional slider 10 supported by a gimbal 11 over a disk 14. The gimbal 11 is secured to an arm 12. The arm 12 positions the slider 10 over individual data tracks (not shown) on the disk 14 along an arc 18. As the disk 14 rotates, it generates wind or air flow in the direction shown by arrows 16 (wind 16). The wind 16 is approximately parallel to the disk's tangential velocity, indicated by an arrow 22. The wind co-operates with the slider 10 to provide lift which allows the slider to fly above the disk 14.

The gimbal 11 is a resilient spring that allows the slider 10 to follow the topography of the disk 14. The gimbal 11 includes a dimple (not shown) that is in point contact with the slider 10. The dimple provides a pivot about which the slider 10 can pitch and roll while following the topography of the disk 14.

When the slider 10 is positioned near the outside edge of the disk 14, its longitudinal axis 20 is substantially parallel to the wind direction. Near the centre of the disk 14, the slider 10 is skewed with respect to the wind direction as illustrated by a skew angle Ø. The skew angle Ø is measured between the longitudinal axis 20 and the wind 16.

The elements described to this point may be conventional in design and as shown in Figure 1 and

This Sheet Has Been Replaced



This is the replacement sheet
Date: 18 NOV 1996

Figures 2a to 2e to facilitate an understanding of the present invention. Throughout the Figures, elements of the same design are designated by identical reference numerals.

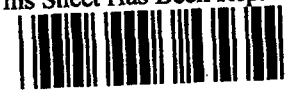
Figure 2a as a perspective view of a head gimbal assembly having a conventional catamaran slider 30. The slider 30 is secured to the gimbal 11 in any known manner. The slider 30 and the gimbal 11 are supported by the arm 12. Rails 32 and 34, positioned along edges of the slider 30, form air bearing surfaces on which the slider flys, in a known manner.

Figure 2b is an end view of the slider 30 as seen from the line 2B-2B of Figure 2a. The arm 12 and the gimbal 11 support the slider 30 above the disk 14. The slider 30 includes the rails 32 and 34, which carry transducers 35 and 37. The rails 32 and 34 include air bearing surfaces 38 and 39, which provide lift to the slider 30, as described more fully below.

Flying height is viewed as one of the most critical parameters of non-contact recording. As the average flying height of the slider 30 decreases, the transducers 35 and 37 achieve greater resolution between individual data bit locations on the disk 14. Therefore, it is desirable to have the transducers 35 and 37 fly as close to the disk 14 as possible.

Figure 2c is a bottom plan view of the conventional catamaran slider 30 shown in Figures 2a and 2b. The rails 32 and 34 are positioned along edges of the slider 30 and are disposed about a recessed area 36 to form the air bearing surfaces 38 and 39. As the disk 14 rotates, the disk drags air (wind 16) under the slider 30 and along the air bearing surfaces 38 and 39. Under the air bearing surfaces 38 and 39, the air flow component due to the drag of the disk 14 is "couette flow". As couette flow passes beneath the rail 32 and 34, the skin friction on the air bearing surfaces 38 and

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

39 causes the air pressure between the disk 14 and the air bearing surfaces to increase and to thereby provide lift causing the slider 30 to fly above the disk surface. Hence, the greater the air bearing surface area, the greater the lift.

The flying height is preferably uniform regardless of variable flying conditions, such as tangential velocity variation from inside to outside tracks, lateral slider movement during a seek operation, and varying skew angles ϕ. Catamaran sliders provide just enough air bearing surface area to fly at a proper height above the disk surface. For example, without the rails 32 and 34, the air bearing surface area would be too large. Consequently, the slider 30 would fly too far from the disk surface at a height adversely affecting resolution.

Although conventional catamaran sliders are helpful in controlling flying height, they are very sensitive to the skew angle ϕ. Even with moderate skew angles in the range of 10 to 15 degrees, flying height from a conventional catamaran slider is adversely influenced. Increasing the skew angle ϕ at a fixed tangential velocity causes the air pressure distribution beneath the rails 32 and 34 to become distorted. This influences the net forces and torque acting upon the slider 30 and results in decreased flying height.

Figure 2d is a bottom view of the rail 32 with the wind 16 at a 0 skew angle. The air bearing surface 38 has an effective area 40 at the 0 skew angle, which is equal to the area of the air bearing surface 38. Figure 2e illustrates the wind 16 applied to the rail 32 at a skew angle ϕ greater than 0. The air bearing surface 38 now has a smaller effective area 41. As the skew angle ϕ increases, the effective surface area of the rails 32 and 34 decreases. The decrease of the effective surface area as the skew angle ϕ increases is caused by side

This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

leakage. The air that leaks out of the sides of the rails 32 and 34 is not available to generate pressure under the rails. This causes a lot of pressure beneath the rails 32 and 34 resulting in a lower flying height at a greater skew angle. To prevent the slider 30 from ultimately contacting the disk surface at large skew angles, the slider's average flying height must be appropriately increased. Resolution is therefore sacrificed. Further, the pressurisation of one rail may differ from the pressurisation of the other rail at a skew angle ϕ. This difference causes the slider 30 roll. In other words, the rail 32 will fly at a different height from the rail 34 while the slider 30 flys at a skew angle ϕ.

As disk drives become more compact for applications in smaller and more portable equipment, rotary actuators are increasingly employed. Further, the designer is motivated to use a shorter actuator pivot arm to make the disk drive even more compact. However, these actuators create rather large skew angles ϕ and consequently make flying height control more difficult. Rotary actuators cause the geometric orientation between the longitudinal axis 20 (shown in Figure 1) and the disk rotation tangent, to change as the arm 12 moves the slider 10 along the arc 18.

One approach to reducing sensitivity of the flying characteristics to varying skew angles is to provide edge blends extending along the length of each rail. As early as 1982, designers applied these blends to reduce wear caused by contact between each rail and the disk surface. The edge blends also reduce sensitivity of the flying characteristics to varying skew angles created by rotary actuators. For example, the pressurisation distribution on each rail remained nearly constant relative to the slider's pivot point over varying skew angles. The benefits to flying characteristics became

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

known in 1982 when the edge blends were used in combination with rotary actuators in 5 1/4 inch disk drives, such as the WREN family manufactured by IMPRIMIS Technology, Inc.

U.S. Patent No. 4,693,996 discloses a similar approach. This patent shows transverse pressurisation contours (TPC) on each rail that extend from the leading edges to the trailing edges. The TPCs provide a pressurisation region across one side edge of each rail and a depressurisation region across the opposite side edge such that the pressure distributions across the air bearing surfaces are substantially unaltered over varying skew angles.

Patent Abstracts of Japan, vol. 9, no. 250 (p-394)(1973) 8th October 1993, (Fujitsu K.K.), discloses an air bearing head for supporting an electro-magnetic transducer. The slider comprises a slider body and first and second rails, each forming an air bearing surface. A portion of the inside and outside edges of each rail converge together towards a central region of the air bearing surface thereby forming intermediate surfaces recessed from the bearing.

It is an object of the present invention to provide an air bearing disk head slider, which reduces the effect of skew angle on flying height over a rotating disk.

The present invention provides a slider having side rails, in which an air bearing surface of each side rail decreases in width away from a leading end of the surface towards a narrowed surface portion and then increases in width after the narrowed surface portion towards a trailing end of the surface.

According to the present invention, there is provided an air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body having a leading edge, a trailing edge and first and second edges therebetween; and

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

first and second side rails disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces, characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

In one embodiment, the first and second side rails form an hour glass configuration in a catamaran slider, which includes a recessed area disposed between the side rails and extending from the leading edge to the trailing edge.

In another embodiment, the side rails form an hour glass configuration in a negative pressure air bearing (NPAB) slider, which includes a cross rail extending between the side rails. During operation, the cross rail creates a negative pressure area between the cross rail and the trailing edge of the slider.

In either embodiment, the side tails are preferably arranged to project by about 10 to 30 microns from the slider body.

Advantageously, the narrowed surface portion is spaced from the leading edge by about one third the length of the slider as measured from the leading edge to the trailing edge.

Preferably, the leading and trailing ends of each air bearing surface may have substantially the same width, and the narrowed surface portion may have a width which is substantially equal to one half the width of the leading and trailing ends.

The first and second side rails may include edge steps along their edges and/or chamfers and/or edge blends.

This Sheet Has Been Replaced



This is the replacement sheet

18 NOV 1996

Date:

The invention is described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a top plan view of an air bearing slider supported above a rotating disk;

Figure 2a is a perspective view of a head gimbal assembly having a conventional catamaran slider;

Figure 2b is an end view of the head gimbal assembly taken along the line 2B - 2B of Figure 2a;

This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

Figure 2c is bottom plan view of a conventional catamaran air bearing slider of Figures 2a and 2b;

Figure 2d is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 2e is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a skew angle Ø;

Figure 3 is a perspective view of an hour glass catamaran slider in accordance with the present invention as viewed from a trailing edge thereof;

Figure 4 is a bottom plan view of an hour glass rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 5 is a bottom plan view of the hour glass rail illustrating an effective air bearing surface area at a skew angle Ø;

Figure 6 is a perspective view of another embodiment of slider in accordance with the present invention having hour glass rails formed with shallow edge steps;

Figure 7 is an enlarged sectional view taken along the line 7 - 7 of Figure 6;

Figure 8 is an enlarged sectional view similar to Figure 7 but having a modified hour glass rail having chamfered edged steps;

Figure 9 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having chamfered edges;

Figure 10 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having shallow edge blends; and

Figure 11 is a perspective view of another embodiment of hour glass slider in accordance with the present invention.

Figure 3 is a perspective view of an hour glass catamaran slider 50 in accordance with the present

This Sheet Has Been Replaced

This is the replacement sheet
18 NOV 1996
Date:

invention, as viewed from a trailing edge 52 thereof. The slider 50 includes a pair of projecting rails 42 and 44 having air bearing surfaces 46 and 48, respectively. The rails 42 and 44 extend from a leading edge 51 to the trailing edge 52. The slider 50 is a modified catamaran slider. The side rails 42 and 44 are not rectangular as are the rails 32 and 34 shown in Figure 2a. Instead, the rails 42 and 44 decrease in width from the leading edge 51 to breaks 56 and 60, and increase in width from the breaks 56 and 60 to the trailing edge 52. In other words, the rails 42 and 44 generally have "hour glass" configurations. Each air bearing surface 46 and 48 has a width measured at the leading edge 51 that is approximately equal to a width measured at the trailing edge 52. The rails 42 and 44 are formed such that the air bearing surfaces 46 and 48 have widths at the breaks 56 and 60 which are substantially equal to one half of the widths measured at the leading edge 51 and the trailing edge 52.

It should be understood that in any of the embodiments shown in the Figures, the present invention does not require that the inside and outside edges of the air bearing surfaces be straight: the edges may be curved from the leading edge of the slider to the trailing edge.

The slider 50 is secured to an actuator arm in any known manner. For example, the slider 50 may be secured to the actuator arm 12 shown in Figures 1, 2a and 2b. As the disk 14 rotates, air flow between the slider 50 and the disk 14 pressurises the air bearing surfaces 46 and 48 and lifts the slider 50 several micro-inches (some micro-centimetres) above the surface of the disk 14. In a preferred embodiment, the slider 50 flys about 8 micro-inches (20.32 micro-centimetres) above the disk surface when a disk 14 rotates at about 1000 inches per second (about 2540 cms per second). To provide faster

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

take off when the disk begins to rotate, the rails 42 and 44 include leading edge tapers 62 and 64. The tapers 62 and 64 provide faster take off by smoothing pressure transitions between ambient air and pressurised air beneath the rails 42 and 44. Faster take off decreases the length of time that the slider 50 slides on the disk surface before it begins to fly and thereby decreases wear on both the slider 50 and the disk 14.

The hour glass rails 42 and 44 are formed by etching with an ion beam. This forming process is known as ion milling. Figure 3 illustrates a "deep" etch in which the rails 42 and 44 project out from recessed areas 54 by about 25 microns. Virtually no air pressure builds up on the recessed areas 54. Alternatively, the rails 42 and 44 may be formed with a laser or a similar etching technique.

Figures 4 and 5 are bottom plan views of the hour glass rail 42 in Figure 3 and illustrate effective air bearing surface areas at a 0 skew angle and a skew angle $\emptyset$. For simplicity of illustration and analysis, the effective areas of positive pressure are indicated generally by the numerals 61 and 63. In Figure 4, the rail 42 is shown at a 0 skew angle with respect the wind 16. In this instance, the effective area 61 develops positive pressure along the entire length of the rail 42, and triangular area 65, 66, 67 and 68 develop some additional positive pressure. Figure 5 illustrates the rail 42 at a skew angle $\emptyset$ with respect to the wind, and the resulting effective area 63 is substantially equal to the effective area 61. As a result, pressurisation and flying height of the rails 42 and 44 are more constant over varying skew angles than the conventional catamaran slider 30 (shown in Figures 2a to 2e). Triangular areas 69 and 71 formed at varying skew angles $\emptyset$ also develop some positive pressure but tend to balance with the areas 65, 66, 67 and 68. Since the slider 50

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

has less variation in flying height, the average flying height may be reduced in order to obtain greater resolution on the individual bit positions on the disk 14 without risk of the slider 50 contacting the disk surface at high skew angles.

Figure 6 is a perspective view of an alternative slider 70. The slider 70 has hour glass rails 72 and 74 with etches that form "shallow" edge steps or blends 76. The edge steps 76 form inside and outside surfaces that are recessed from air bearing surfaces 78 and 80 by about 0 microns to 2.0 microns. The edge steps 76 are positioned along each rail, between leading edges 86 and trailing edges 88, to form the hour glass shapes of the air bearing surfaces 78 and 80. When the slider 70 flys at a skew angle $\emptyset$ (shown in Figure 5), the recessed surfaces accumulate additional pressure that prevents the slider 70 from losing flying height. This results in a more even flying height for varying skew angles $\emptyset$.

In addition to flying height another critical flying characteristic is roll. At varying skew angles, sliders tend to roll about their longitudinal axes. Roll is caused by shifts in the pressure distributions across the air bearing surfaces 78 and 80 relative to the slider pivot point. To reduce roll and to obtain overall optimum flying characteristics, the dimensions of the air bearing surfaces 78 and 80 and the edge steps 76 must be adjusted to minimise shifts in pressure distribution. For example, the edge steps 76 on the inner and outer edges of each rail may be formed asymmetrically, with the inside surfaces wider, or having a larger indentation, than the outside surfaces. It should be known that the recessed inside and outside surfaces may be formed with different dimensions and may vary from one rail to the other.

In Figure 6, breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

edges 88. The breaks 82 and 84 preferably are spaced from the leading edges 86 by approximately one third the length of the slider 70. Positioning of the breaks 82 and 84 may be varied in alternative embodiments (not shown) to vary flying characteristics, such as pitch. Pitch is measured by an angle between the disk surface and a plane generally defined by the air bearing surfaces 78 and 80.

When the slider has a positive pitch, the leading edges 86 typically fly at greater distances from the disk surface than the trailing edges 88. Increasing the pitch angle provides for faster take off when the disk begins to rotate. Positive pitch also reduces the risk of a "head crash". When the leading edges 86 fly at greater distances from the disk surface than the trailing edges 88, the air bearing surfaces 78 and 80 tend to resist a negative pitch in which the leading edges 86 will crash into the disk surface. However, too large a positive pitch adversely affects stiffness or stability of the trailing edges 88. A small positive pitch increases the stiffness of the trailing edges 88. Since transducers, such as the transducers 35 and 37 (shown in Figure 2b) are typically positioned on the trailing edges 88, increased stability will increase performance of read and write operations. If the slider 70 flys with too small a positive pitch, a bump may cause the slider to rotate into a negative pitch and crash into the disk surface.

Pitch much be accurately controlled to achieve optimum flying characteristics. The pitch angle is adjusted by varying the pressure gradients along the air bearing surfaces 78 and 80. The breaks 82 and 84 may be positioned closer to either the leading edges 86 or the trailing edges 88 to vary pressure distribution along the air bearing surfaces 78 and 80. Typical pitch angles range from about 100 micro-radians to about 300

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

micro-radians.

As the disk 14 drags air (wind 16) beneath the rail 72 and 74, skin friction along the air bearing surfaces 78 and 80 causes the air pressure to increase. The breaks 82 and 84 divide the air bearing surface 78 and 80 into forward surfaces and rearward surfaces. The forward surfaces are adjacent the leading edges 86 and rearward surfaces are adjacent the trailing edges 88. Positioned between the forward and rearward surfaces are central surfaces, which are adjacent the breaks 82 and 84. Since the central surfaces have narrower air bearing surfaces than the forward surfaces, a portion of the air pressure bleeds off at the breaks 82 and 84. This portion is not available to pressurise the rearward air bearing surfaces. This results in greater air pressure towards the leading edges 86 and less air pressure towards the trailing edges 88, which causes the slider 70 to increase pitch angle. To reduce the pitch angle, the breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing edges 88. The resulting pressure distribution reduces the pressure on the forward air bearing surface areas and thereby reduces the pitch angle.

Since the air pressure bleeds off near the breaks in the hour glass rails, the average flying height of an hour glass catamaran slider (with breaks) drops from that of a catamaran slider of the same width. Therefore, the air bearing surfaces 78 and 80 are formed to be wider near the leading and trailing edges 86 and 88 than the air bearing surfaces 38 and 39 of the conventional catamaran slider 30 shown in Figure 2c. The edge steps 76 do not fully extend from the breaks 82 and 84 to the leading and trailing edges 86 and 88 but terminate prior to the leading and trailing edges. Terminating the edge steps 76 prior to the leading and trailing edges 86 and 88 maximises the width of the air

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

bearing surfaces 78 and 80 near the leading and trailing edges. The wider surfaces build up more air pressure and prevent the slider 70 from flying too close to the disk surface. The wider air bearing surfaces 78 and 80 also create more room to secure transducers on the trailing edges 88, such as the transducers 35 and 37 shown in Figure 2b.

Typically, a gimbal spring connects the slider 70 to an actuator arm, such as the arm 12 shown in Figure 2a. The gimbal spring includes a dimple that provides a pivot about which the slider 70 can pitch and roll while following the topography of the disk surface. The hour glass shape of each rail improves pitch stiffness of the air bearing about the point at which the dimple contacts the slider. Because the air pressure bleeds off near the breaks 82 and 84, the "area elements" of the air bearing surfaces 78 and 80 having vertical stiffness (formed by positive pressure) are concentrated near the leading and trailing edges 86 and 88 of the slider 70, remote from the pivot point. Thus, the vertical stiffness of each area element is "multiplied" by a longer moment arm to give a higher pitch stiffness.

Creating the hour glass shapes by applying the edge steps 76 to each rail such that they terminate prior to the leading and trailing edges 86 and 88 also improves, or reduces, flying height sensitivity to crown height variations. The air bearing surfaces 78 and 80 are not perfectly flat from the leading edges 86 to the trailing edges 88, but are slightly convex. There are two causes for the convex shape. First, manufacturing errors in the process of securing the slider 70 to the gimbal cause deformation of the slider. Second, designers intentionally "round" the air bearing surfaces 78 and 80 to reduce wear on the surfaces. The crown height is a measure of the degree of roundness and can vary from one slider to the next. An increase in crown

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

height causes the pressure to increase near the mid-sections of the air bearing surfaces 78 and 80, which causes an increase in flying height. However, the edge steps 76 counter-act this effect. Since the edge steps 76 cause the air pressure to bleed off near the mid-sections, an increase in crown height has a negligible effect on the air pressure near the mid-sections. Therefore, the hour glass shapes reduce the flying height sensitivity to crown height variations. The hour glass shapes also reduce flying height sensitivity to low frequency disk waviness, since the disk waviness effect pressure on the air bearing surfaces 78 and 80 similar to crown height variations.

Figure 7 to 10 are greatly enlarged sectional views of a rail, such as the rail 74, taken along the lines 7 - 7 of Figure 6 and illustrate alternative edge step embodiments. Figure 7 illustrates an embodiment in which the edge step 76 are "true" steps. Figure 8 illustrates an alternative embodiment in which the edge steps 76 are chamfered. Figure 9 illustrates an alternative embodiment in which the edge steps 76 are wide, shallow chamfers between the air bearing surface 80 and the inside and outside edges of the rail 74. Figure 10 illustrates another alternative embodiment in which the edge steps 76 are shallow edge blends. It should be understood that any of these embodiments, or a combination of them, may be used within the scope of the present invention.

Figure 11 illustrates an hour glass slider similar to the slider 70 shown in Figure 6, but having a cross-rail. Sliders having cross-rails are typically called negative pressure air bearing (NPAB) sliders, as opposed to catamaran sliders which do not have cross-rails. An hour glass NPAB slider 110 includes rails 112 and 114 having air bearing surfaces 116 and 118 respectively. A cross-rail 120 extends between the rails 112 and 114.

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

In the preferred embodiment, the cross-rail 120 is positioned closer to the leading edge 121 than the trailing edge 123.

During operation, the cross rail 120 creates a negative pressure area 122, which counter-acts the positive pressure built along the air bearing surfaces 116 and 118 and increases slider stability and stiffness. The negative pressure area 122 is created between the rails 112 and 114 and between the cross-rail 120 and the trailing edge 123.

The slider 110 further includes edge steps 125. The cross-rail 120 and edge steps 125 may be etched to approximately 0 microns to 2.0 microns below the air bearing surfaces 116 and 118. The edge steps 125 are relatively shallow compared to the negative pressure area 122, which is etched to about 10 microns below the air bearing surfaces 116 and 118. The edge steps 125 are drawn out of scale and actually look similar to the edge steps 76 shown in Figure 8. To maximise the slider stiffness, the edge steps 125 are applied to each rail, such that they terminate prior to the leading and trailing edges 142 and 124. This maximises the air bearing surface area that develops positive pressure near the ends of the rails 112 and 114 while maximising the negative pressure area 122 near the centre of the slider 110. As a result, the counter-action between the positive and negative pressure is maximised to improve the slider stiffness.

The shallow edge steps 125 accumulate additional pressure. When the slider 110 flys at a skew angle $\emptyset$, the additional pressure that accumulates on the edge steps 125 reduces the effect of the skew angle on fly height by reducing shifts in the pressure distributions across the air bearing surface areas 116 and 118. The result is a more constant fly height for varying skew angles $\emptyset$. The slider 110 is also relatively insensitive

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

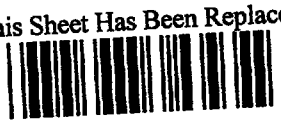
to crown height variation and disk waviness (see the discussion above with reference to Figure 6).

Figure 11 illustrates an alternative rail geometry that may be used with or without the cross-rail 120. Elongated breaks 126 and 128 divide the air bearing surfaces 116 and 118 into three portions. The air bearing surface 116 is divided into a forward surface 130, a central surface 132, and a rearward surface 134. Similarly, the air bearing surface 118 is divided into a forward surface 136, a central surface 138, and a rearward surface 140. The breaks 126 and 128 are spaced from the leading edges 142 by about approximately one third the length of the slider 110. As a result, the forward surfaces 130 and 136 are smaller than the rearward surfaces 134 and 140. The central surfaces 132 and 138 have generally rectangular shapes.

The negative pressure area 122 created by the cross-bar 120 reduces flying height senstivity to tangential disk velocity. As the disk rotates, the air velocity beneath the air bearing surfaces is greater at the outer radius of the disk than at the inner radius. Therefore, the positive pressure built along the air bearing surface is greater at the outer radius than at the inner radius. However, the negative pressure also increases at the outer radius. The increase in negative pressure counter-acts the increase in positive pressure to reduce changes to flying height caused by changes in air velocity.

The hour glass air bearing surfaces 116 and 118 further reduce changes in flying height caused by changes in air velocity. At higher air speeds, increases in positive pressure are greater than increases in negative pressure. Since the air bearing surfaces 116 and 118 are narrower at the central surfaces 132 and 138 the positive pressure bleeds off into the negative pressure cavity 122 to reduce increases in positive

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

pressure. The positive pressure is even further reduced since the area of greatest negative pressure, the central region of the negative pressure area 122 is adjacent the central surfaces 132 and 138. Therefore, the negative pressure area 122 draws more air off the central surfaces 132 and 138 to further reduce increases in positive pressure. As a result, changes in positive and negative pressure remain substantially equal over varying tangential disk velocities.

The slider having hour glass rails according to the present invention provides a near constant air bearing surface area and pressure distribution while flying at varying skew angles and disk velocities. As a result, the slider having hour glass rails has improved flying characteristics over the prior art.

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

This Sheet Has Been Replaced



CLAIMS

1. An air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body (50,70,110) having a leading edge (51,121), a trailing edge (52,123) and first and second edges therebetween; and

first and second side rails (42,44; 72,74; 112,114) disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface (46,48; 78, 80; 116,118) with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces (76,125), characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

2. A slider according to claim 1 characterised in that the air bearing surface of each of the first and second side rails has a forward surface portion (130,136) extending from the leading end thereof to the narrowed surface portion and a rearward surface portion (134,140) extending from the trailing end thereof to the narrowed surface portion, and in that the forward surface portion has a smaller area than the rearward surface portion.

3. A slider according to claim 1 or 2 characterised in that the narrowed surface portion of the air bearing surface of each of the first and second side rails is spaced from the leading end thereof by about one third of the length between the leading and the trailing ends thereof.

4. A slider according to any of claims 1 to 3 characterised in that the narrowed surface portion has a substantially rectangular shape.



* C L M S *

This is the replacement sheet

Date: 18 NOV 1996

This Sheet Has Been Replaced

5. A slider according to any of claims 1 to 4 characterised in that the air bearing surface of each of the first and second side rails has substantially the same width adjacent the leading and trailing ends thereof, and in that the narrowed surface portion has a width which is substantially half said width adjacent the leading and trailing ends.

6. A slider according to any preceding claim characterised in that said converging inside and outside edge portions extend substantially the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

7. A slider according to any of claims 1 to 5 characterised in that said converging inside and outside edge portions extend less than the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

8. A slider according to any preceding claim characterised in that said converging inside and outside edge portions form edge steps.

9. A slider according to any preceding claim characterised in that said converging inside and outside edge portions comprise chamfers.

10. A slider according to any of claims 1 to 8 characterised in that said converging inside and outside edge portions comprise edge blends.

11. A slider according to any preceding claim characterised in that said converging inside and outside edge portions adjoin recessed inside and outside surfaces, which are set back from the air bearing surfaces by about 0 microns to 2.0 microns.

12. A slider according to claim 11 characterised in that the recessed inside surfaces have different dimensions from the recessed outside surfaces.

* C L M S *

This is the replacement sheet

Date: 13 NOV 1996

ABSTRACT

AIR BEARING DISK HEAD SLIDER

The invention provides an air bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk. The slider comprises a slider body (50) having a leading edge (51), a trailing edge (52), and first and second side edges therebetween, and first and second side rails (42, 44) extending adjacent the first and second side edges, respectively. Each of the side rails forms an air bearing surface (46, 48) having a narrowed surface portion located between a leading end and a trailing end of the rail. Each air bearing surface has inside and outside edges, which converge towards the narrowed surface portion.

Figure 3

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

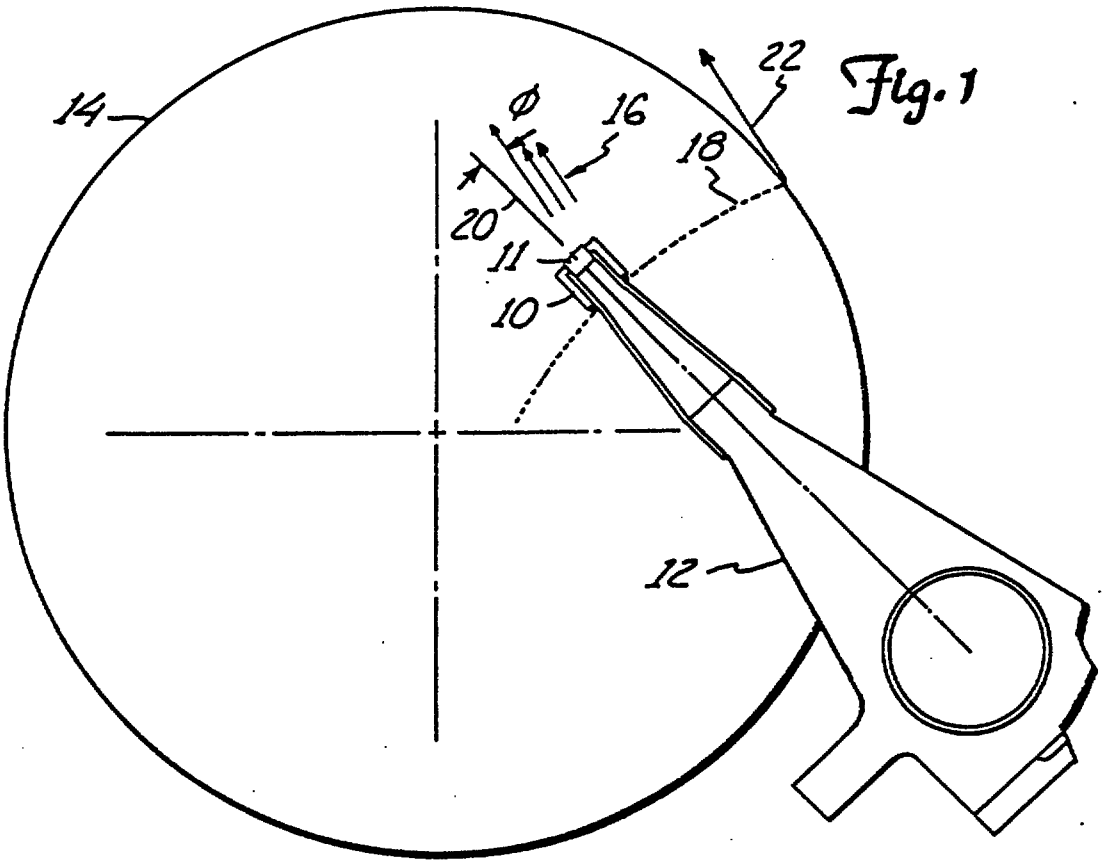


Fig. 1

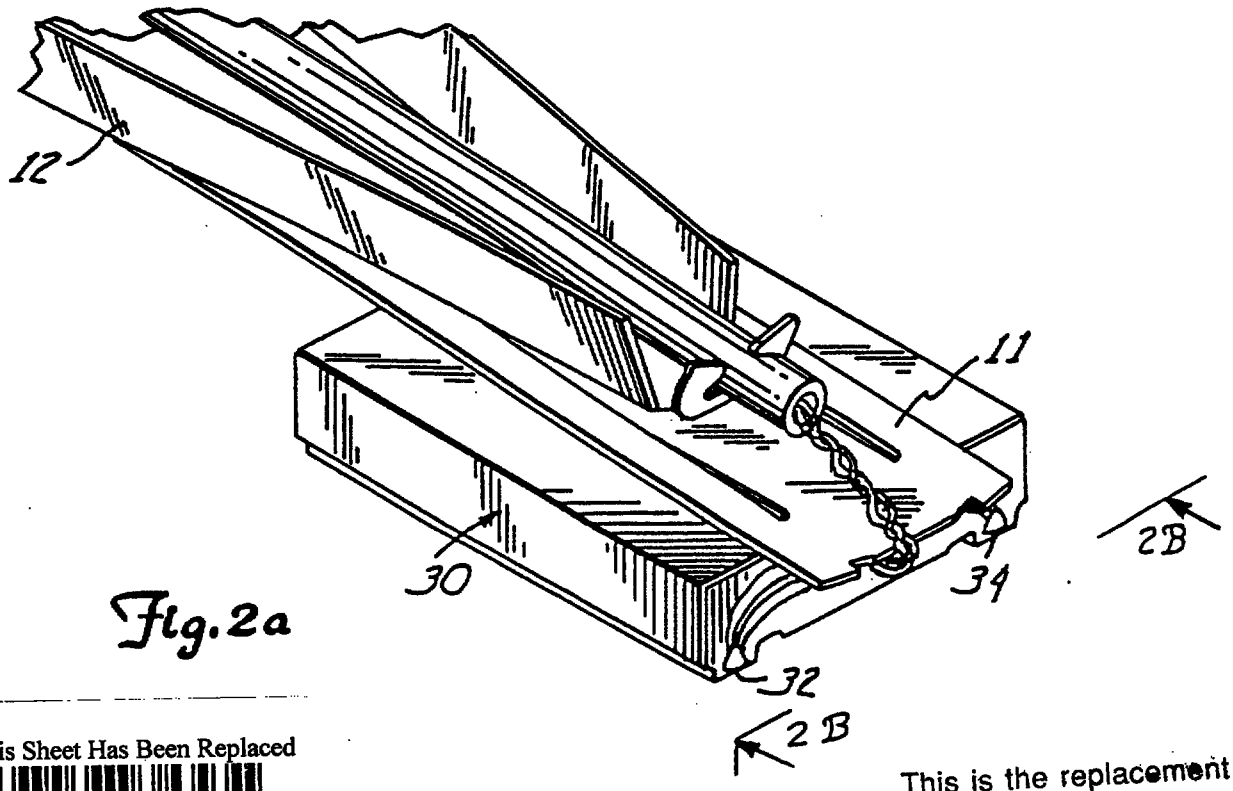


Fig. 2a

This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

Fig. 2b

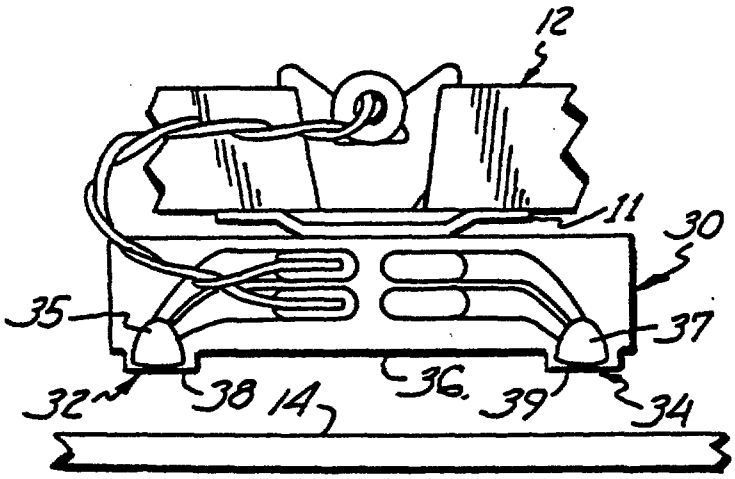
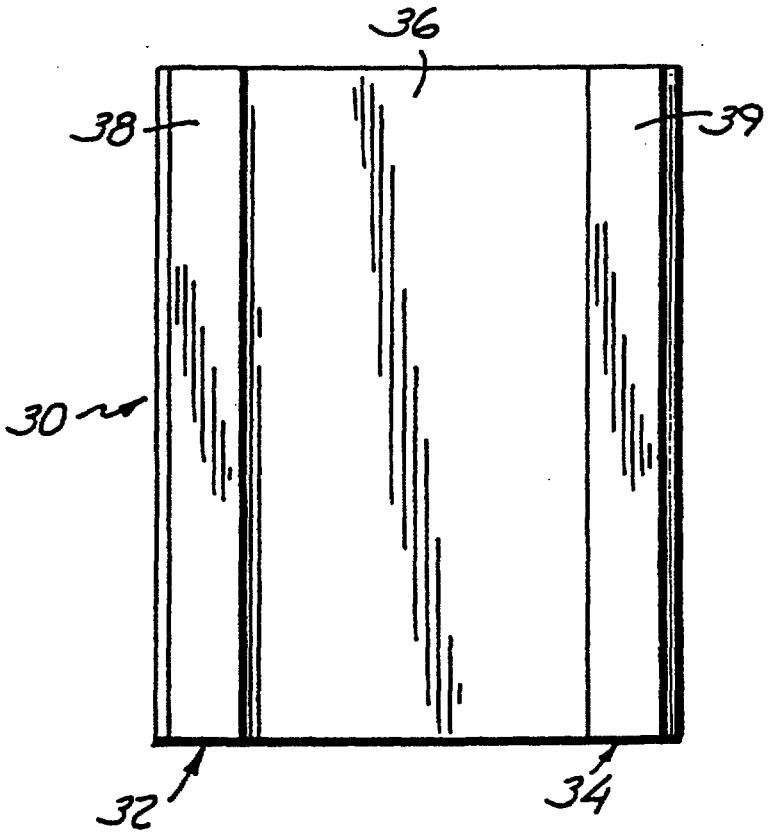


Fig. 2c



This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

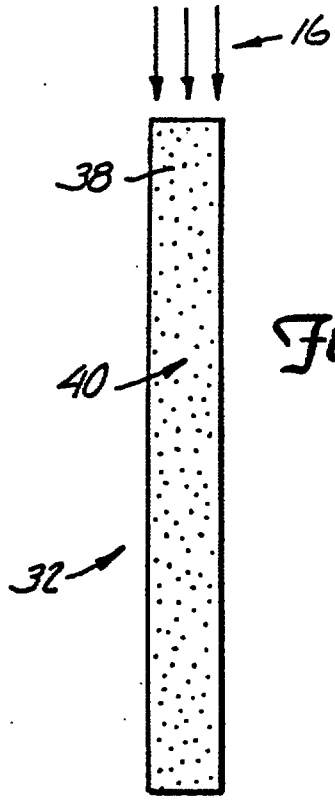


Fig.2d

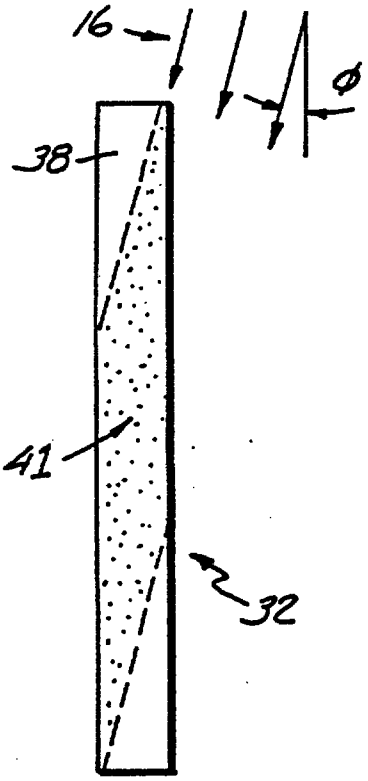


Fig.2e

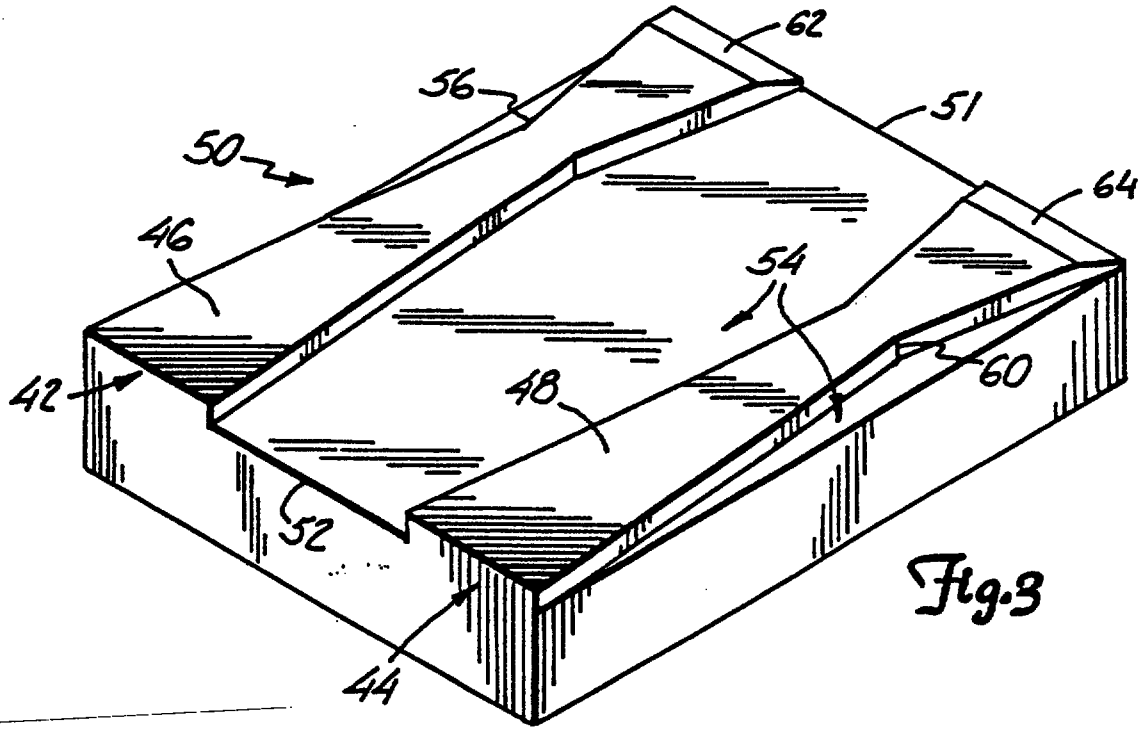


Fig.3

This Sheet Has Been Replaced

This is the replacement shee

Date: 18 NOV 1996

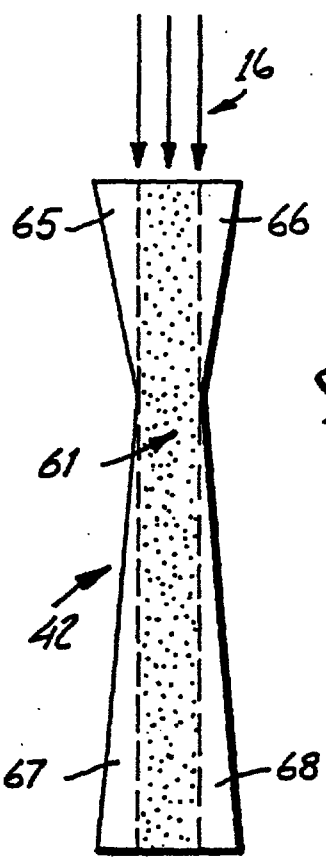


Fig. 4

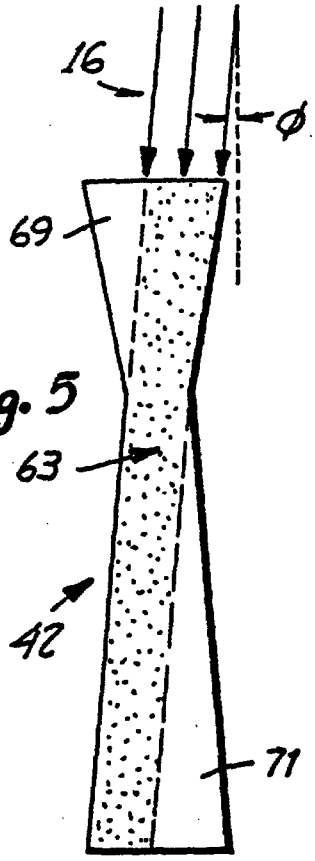


Fig. 5

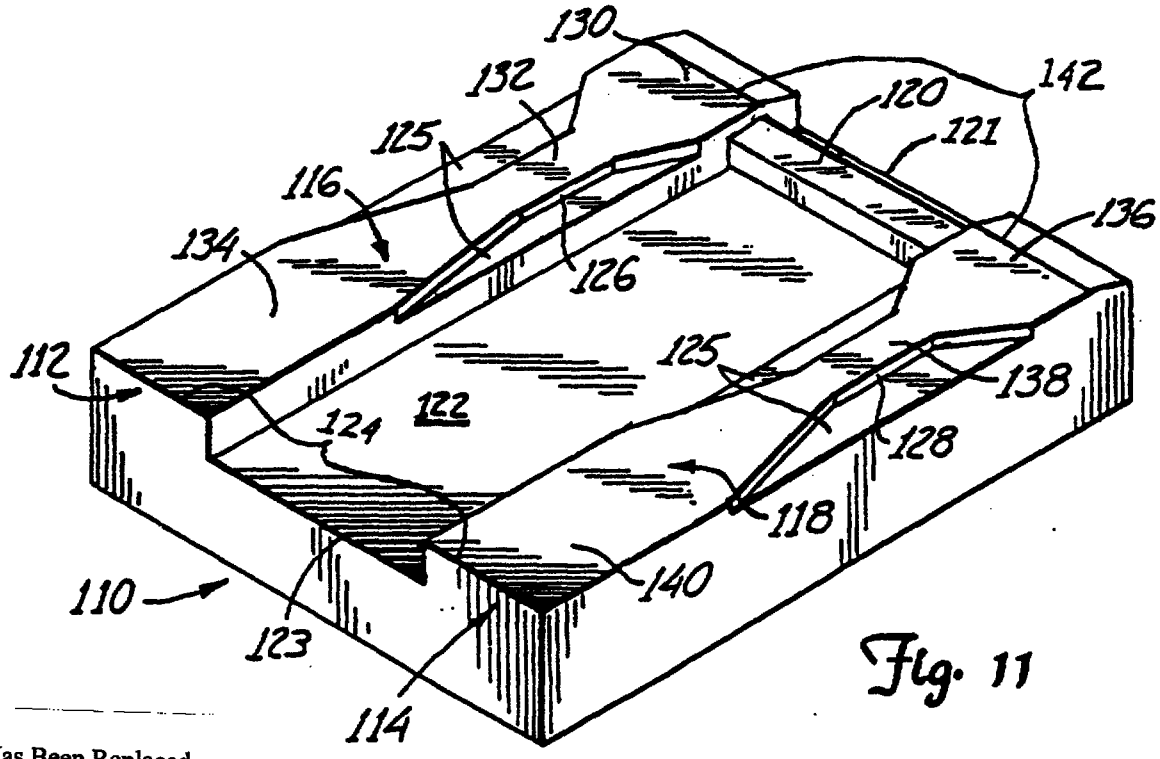


Fig. 11

This Sheet Has Been Replaced



This is the replacement sheet

Date: 18 NOV 1996

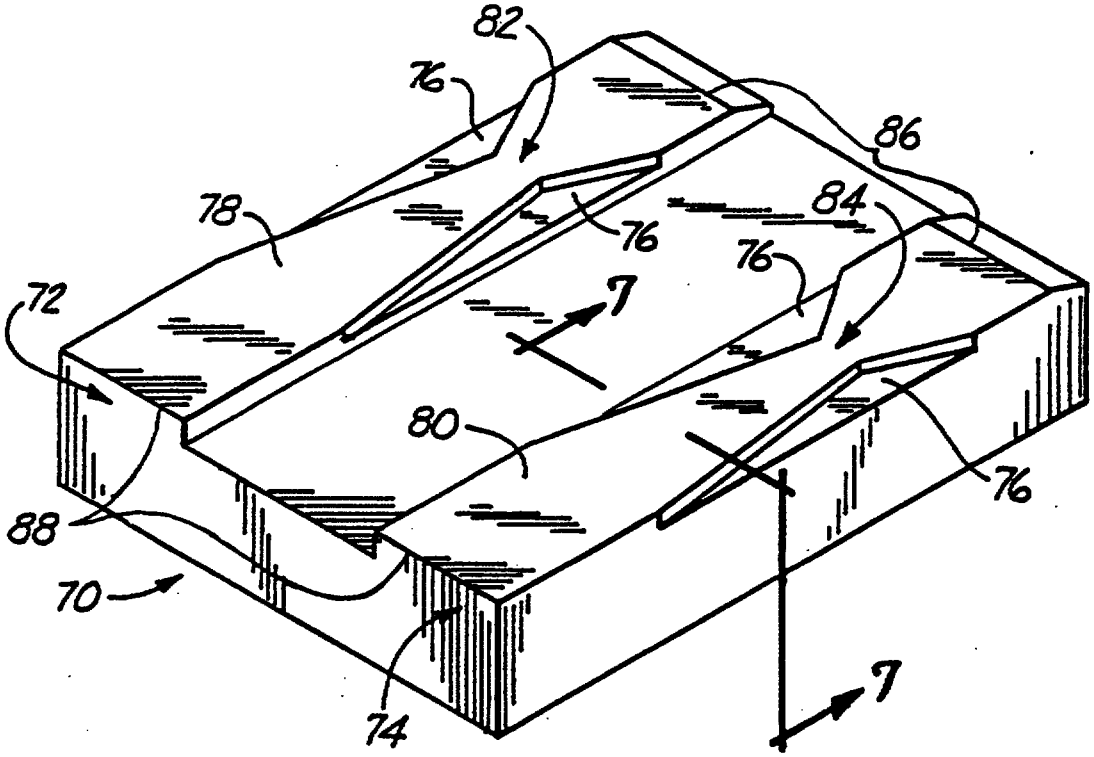


Fig. 6

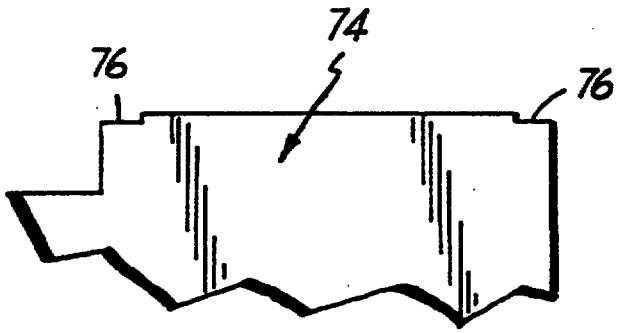


Fig. 7

This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

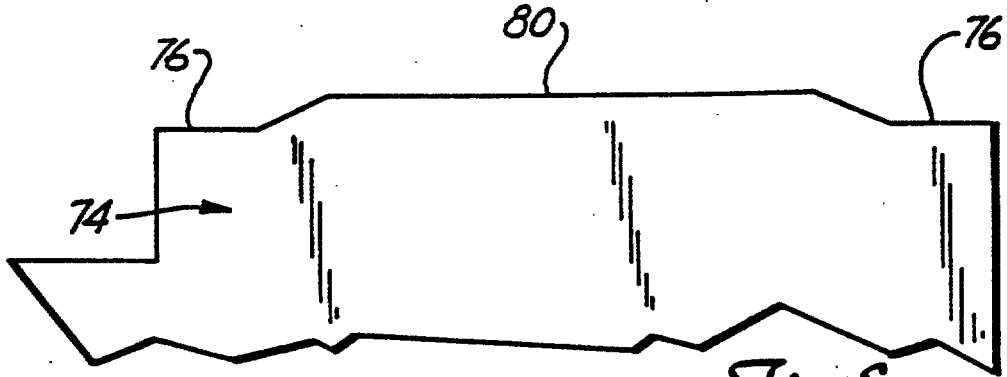


Fig. 8

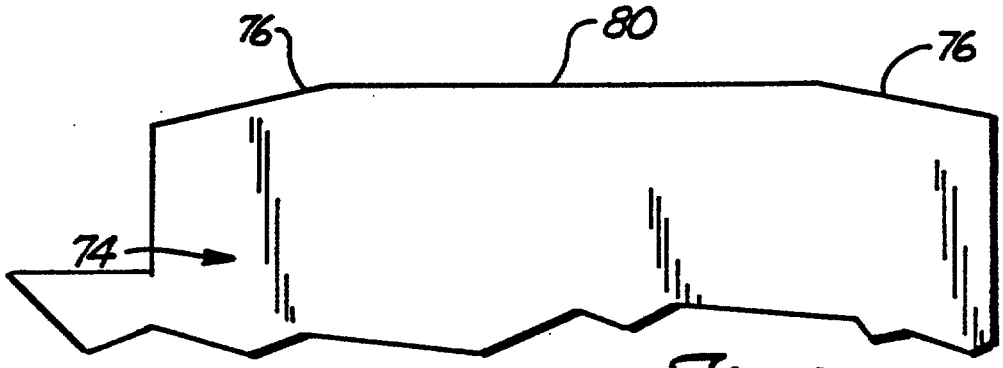


Fig. 9

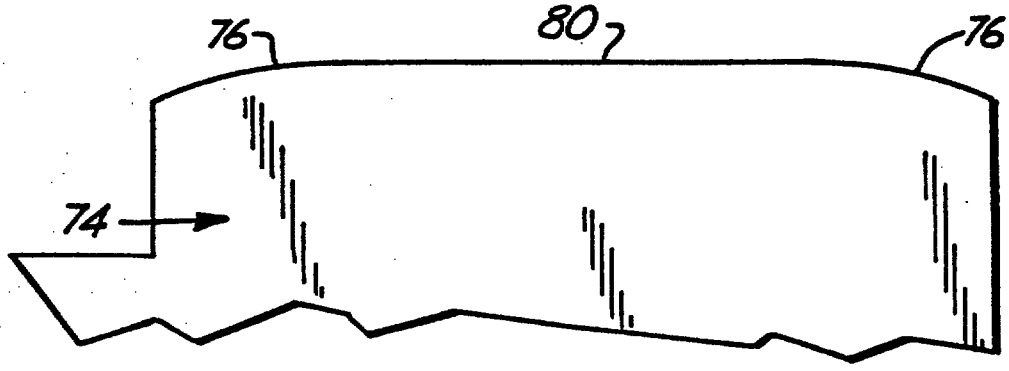


Fig. 10

This Sheet Has Been Replaced

This is the replacement sheet

Date: 18 NOV 1996

REPLACEMENT SHEETS SG
☑ Description : paged ..1.. to paged ..17..
☑ Claim(s) : paged ..18.. to paged ..19..
☑ Drawing(s) : paged ..1.. to paged ..6..
☐ Abstract : paged ..... to paged .....
DATE OF RECEIPT 22-9-1998

AIR BEARING DISK HEAD SLIDER

The present invention relates to an air bearing disk head slider for use with a rotary actuator in a transducer head assembly for a rotating disk drive.

Transducer head assemblies that could "fly" relative to a rotating disk are used extensively in rotating disk drives. The assemblies include an air bearing slider for carrying a magnetic transducer proximate the rotating disk.

Figure 1 illustrates a conventional slider 10 supported by a gimbal 11 over a disk 14. The gimbal 11 is secured to an arm 12. The arm 12 positions the slider 10 over individual data tracks (not shown) on the disk 14 along an arc 18. As the disk 14 rotates, it generates wind or air flow in the direction shown by arrows 16 (wind 16). The wind 16 is approximately parallel to the disk's tangential velocity, indicated by an arrow 22. The wind co-operates with the slider 10 to provide lift which allows the slider to fly above the disk 14.

The gimbal 11 is a resilient spring that allows the slider 10 to follow the topography of the disk 14. The gimbal 11 includes a dimple (not shown) that is in point contact with the slider 10. The dimple provides a pivot about which the slider 10 can pitch and roll while following the topography of the disk 14.

When the slider 10 is positioned near the outside edge of the disk 14, its longitudinal axis 20 is substantially parallel to the wind direction. Near the centre of the disk 14, the slider 10 is skewed with respect to the wind direction as illustrated by a skew angle $\emptyset$. The skew angle $\emptyset$ is measured between the longitudinal axis 20 and the wind 16.

The elements described to this point may be conventional in design and as shown in Figure 1 and

This is the replacement sheet
Date: 22 SEP 1998

Figures 2a to 2e to facilitate an understanding of the present invention. Throughout the Figures, elements of the same design are designated by identical reference numerals.

Figure 2a as a perspective view of a head gimbal assembly having a conventional catamaran slider 30. The slider 30 is secured to the gimbal 11 in any known manner. The slider 30 and the gimbal 11 are supported by the arm 12. Rails 32 and 34, positioned along edges of the slider 30, form air bearing surfaces on which the slider flys, in a known manner.

Figure 2b is an end view of the slider 30 as seen from the line 2B-2B of Figure 2a. The arm 12 and the gimbal 11 support the slider 30 above the disk 14. The slider 30 includes the rails 32 and 34, which carry transducers 35 and 37. The rails 32 and 34 include air bearing surfaces 38 and 39, which provide lift to the slider 30, as described more fully below.

Flying height is viewed as one of the most critical parameters of non-contact recording. As the average flying height of the slider 30 decreases, the transducers 35 and 37 achieve greater resolution between individual data bit locations on the disk 14. Therefore, it is desirable to have the transducers 35 and 37 fly as close to the disk 14 as possible.

Figure 2c is a bottom plan view of the conventional catamaran slider 30 shown in Figures 2a and 2b. The rails 32 and 34 are positioned along edges of the slider 30 and are disposed about a recessed area 36 to form the air bearing surfaces 38 and 39. As the disk 14 rotates, the disk drags air (wind 16) under the slider 30 and along the air bearing surfaces 38 and 39. Under the air bearing surfaces 38 and 39, the air flow component due to the drag of the disk 14 is "couette flow". As couette flow passes beneath the rail 32 and 34, the skin friction on the air bearing surfaces 38 and

This is the replacement sheet

Date: 22 SEP 1998

39 causes the air pressure between the disk 14 and the air bearing surfaces to increase and to thereby provide lift causing the slider 30 to fly above the disk surface. Hence, the greater the air bearing surface area, the greater the lift.

The flying height is preferably uniform regardless of variable flying conditions, such as tangential velocity variation from inside to outside tracks, lateral slider movement during a seek operation, and varying skew angles ϕ. Catamaran sliders provide just enough air bearing surface area to fly at a proper height above the disk surface. For example, without the rails 32 and 34, the air bearing surface area would be too large. Consequently, the slider 30 would fly too far from the disk surface at a height adversely affecting resolution.

Although conventional catamaran sliders are helpful in controlling flying height, they are very sensitive to the skew angle ϕ. Even with moderate skew angles in the range of 10 to 15 degrees, flying height from a conventional catamaran slider is adversely influenced. Increasing the skew angle ϕ at a fixed tangential velocity causes the air pressure distribution beneath the rails 32 and 34 to become distorted. This influences the net forces and torque acting upon the slider 30 and results in decreased flying height.

Figure 2d is a bottom view of the rail 32 with the wind 16 at a 0 skew angle. The air bearing surface 38 has an effective area 40 at the 0 skew angle, which is equal to the area of the air bearing surface 38. Figure 2e illustrates the wind 16 applied to the rail 32 at a skew angle ϕ greater than 0. The air bearing surface 38 now has a smaller effective area 41. As the skew angle ϕ increases, the effective surface area of the rails 32 and 34 decreases. The decrease of the effective surface area as the skew angle ϕ increases is caused by side

This is the replacement sheet
22 SEP 1998
Date

leakage. The air that leaks out of the sides of the rails 32 and 34 is not available to generate pressure under the rails. This causes a lot of pressure beneath the rails 32 and 34 resulting in a lower flying height at a greater skew angle. To prevent the slider 30 from ultimately contacting the disk surface at large skew angles, the slider's average flying height must be appropriately increased. Resolution is therefore sacrificed. Further, the pressurisation of one rail may differ from the pressurisation of the other rail at a skew angle ϕ. This difference causes the slider 30 roll. In other words, the rail 32 will fly at a different height from the rail 34 while the slider 30 flys at a skew angle ϕ.

As disk drives become more compact for applications in smaller and more portable equipment, rotary actuators are increasingly employed. Further, the designer is motivated to use a shorter actuator pivot arm to make the disk drive even more compact. However, these actuators create rather large skew angles ϕ and consequently make flying height control more difficult. Rotary actuators cause the geometric orientation between the longitudinal axis 20 (shown in Figure 1) and the disk rotation tangent, to change as the arm 12 moves the slider 10 along the arc 18.

One approach to reducing sensitivity of the flying characteristics to varying skew angles is to provide edge blends extending along the length of each rail. As early as 1982, designers applied these blends to reduce wear caused by contact between each rail and the disk surface. The edge blends also reduce sensitivity of the flying characteristics to varying skew angles created by rotary actuators. For example, the pressurisation distribution on each rail remained nearly constant relative to the slider's pivot point over varying skew angles. The benefits to flying characteristics became

This is the replacement sheet

Date: 22 SEP 1998

known in 1982 when the edge blends were used in combination with rotary actuators in 5 1/4 inch disk drives, such as the WREN family manufactured by IMPRIMIS Technology, Inc.

U.S. Patent No. 4,693,996 discloses a similar approach. This patent shows transverse pressurisation contours (TPC) on each rail that extend from the leading edges to the trailing edges. The TPCs provide a pressurisation region across one side edge of each rail and a depressurisation region across the opposite side edge such that the pressure distributions across the air bearing surfaces are substantially unaltered over varying skew angles.

Patent Abstracts of Japan, vol. 9, no. 250 (p-394)(1973) 8th October 1993, (Fujitsu K.K.), discloses an air bearing head for supporting an electro-magnetic transducer. The slider comprises a slider body and first and second rails, each forming an air bearing surface. A portion of the inside and outside edges of each rail converge together towards a central region of the air bearing surface thereby forming intermediate surfaces recessed from the bearing.

It is an object of the present invention to provide an air bearing disk head slider, which reduces the effect of skew angle on flying height over a rotating disk.

The present invention provides a slider having side rails, in which an air bearing surface of each side rail decreases in width away from a leading end of the surface towards a narrowed surface portion and then increases in width after the narrowed surface portion towards a trailing end of the surface.

According to the present invention, there is provided an air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body having a leading edge, a trailing edge and first and second edges therebetween; and

This is the replacement sheet

Date: 22 SEP 1998

first and second side rails disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces, characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

In one embodiment, the first and second side rails form an hour glass configuration in a catamaran slider, which includes a recessed area disposed between the side rails and extending from the leading edge to the trailing edge.

In another embodiment, the side rails form an hour glass configuration in a negative pressure air bearing (NPAB) slider, which includes a cross rail extending between the side rails. During operation, the cross rail creates a negative pressure area between the cross rail and the trailing edge of the slider.

In either embodiment, the side tails are preferably arranged to project by about 10 to 30 microns from the slider body.

Advantageously, the narrowed surface portion is spaced from the leading edge by about one third the length of the slider as measured from the leading edge to the trailing edge.

Preferably, the leading and trailing ends of each air bearing surface may have substantially the same width, and the narrowed surface portion may have a width which is substantially equal to one half the width of the leading and trailing ends.

The first and second side rails may include edge steps along their edges and/or chamfers and/or edge blends.

This is the replacement sheet

Date: 22 SEP 1998

The invention is described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a top plan view of an air bearing slider supported above a rotating disk;

Figure 2a is a perspective view of a head gimbal assembly having a conventional catamaran slider;

Figure 2b is an end view of the head gimbal assembly taken along the line 2B - 2B of Figure 2a;

This is the replacement sheet

Date: 22 SEP 1998

Figure 2c is bottom plan view of a conventional catamaran air bearing slider of Figures 2a and 2b;

Figure 2d is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 2e is a bottom plan view of a conventional catamaran rail illustrating an effective air bearing surface area at a skew angle ∅;

Figure 3 is a perspective view of an hour glass catamaran slider in accordance with the present invention as viewed from a trailing edge thereof;

Figure 4 is a bottom plan view of an hour glass rail illustrating an effective air bearing surface area at a 0 skew angle;

Figure 5 is a bottom plan view of the hour glass rail illustrating an effective air bearing surface area at a skew angle ∅;

Figure 6 is a perspective view of another embodiment of slider in accordance with the present invention having hour glass rails formed with shallow edge steps;

Figure 7 is an enlarged sectional view taken along the line 7 - 7 of Figure 6;

Figure 8 is an enlarged sectional view similar to Figure 7 but having a modified hour glass rail having chamfered edged steps;

Figure 9 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having chamfered edges;

Figure 10 is an enlarged sectional view similar to Figure 7 but showing modified hour glass rail having shallow edge blends; and

Figure 11 is a perspective view of another embodiment of hour glass slider in accordance with the present invention.

Figure 3 is a perspective view of an hour glass catamaran slider 50,

This is the replacement sheet

Date: 22 SEP 1998

as viewed from a trailing edge 52 thereof. The slider 50 includes a pair of projecting rails 42 and 44 having air bearing surfaces 46 and 48, respectively. The rails 42 and 44 extend from a leading edge 51 to the trailing edge 52. The slider 50 is a modified catamaran slider. The side rails 42 and 44 are not rectangular as are the rails 32 and 34 shown in Figure 2a. Instead, the rails 42 and 44 decrease in width from the leading edge 51 to breaks 56 and 60, and increase in width from the breaks 56 and 60 to the trailing edge 52. In other words, the rails 42 and 44 generally have "hour glass" configurations. Each air bearing surface 46 and 48 has a width measured at the leading edge 51 that is approximately equal to a width measured at the trailing edge 52. The rails 42 and 44 are formed such that the air bearing surfaces 46 and 48 have widths at the breaks 56 and 60 which are substantially equal to one half of the widths measured at the leading edge 51 and the trailing edge 52.

It should be understood that in any of the embodiments shown in the Figures, the present invention does not require that the inside and outside edges of the air bearing surfaces be straight: the edges may be curved from the leading edge of the slider to the trailing edge.

The slider 50 is secured to an actuator arm in any known manner. For example, the slider 50 may be secured to the actuator arm 12 shown in Figures 1, 2a and 2b. As the disk 14 rotates, air flow between the slider 50 and the disk 14 pressurises the air bearing surfaces 46 and 48 and lifts the slider 50 several micro-inches (some micro-centimetres) above the surface of the disk 14. In a preferred embodiment, the slider 50 flys about 8 micro-inches (20.32 micro-centimetres) above the disk surface when a disk 14 rotates at about 1000 inches per second (about 2540 cms per second). To provide faster

This is the replacement sheet

Date: 22 SEP 1998

take off when the disk begins to rotate, the rails 42 and 44 include leading edge tapers 62 and 64. The tapers 62 and 64 provide faster take off by smoothing pressure transitions between ambient air and pressurised air beneath the rails 42 and 44. Faster take off decreases the length of time that the slider 50 slides on the disk surface before it begins to fly and thereby decreases wear on both the slider 50 and the disk 14.

The hour glass rails 42 and 44 are formed by etching with an ion beam. This forming process is known as ion milling. Figure 3 illustrates a "deep" etch in which the rails 42 and 44 project out from recessed areas 54 by about 25 microns. Virtually no air pressure builds up on the recessed areas 54. Alternatively, the rails 42 and 44 may be formed with a laser or a similar etching technique.

Figures 4 and 5 are bottom plan views of the hour glass rail 42 in Figure 3 and illustrate effective air bearing surface areas at a 0 skew angle and a skew angle Ø. For simplicity of illustration and analysis, the effective areas of positive pressure are indicated generally by the numerals 61 and 63. In Figure 4, the rail 42 is shown at a 0 skew angle with respect the wind 16. In this instance, the effective area 61 develops positive pressure along the entire length of the rail 42, and triangular area 65, 66, 67 and 68 develop some additional positive pressure. Figure 5 illustrates the rail 42 at a skew angle Ø with respect to the wind, and the resulting effective area 63 is substantially equal to the effective area 61. As a result, pressurisation and flying height of the rails 42 and 44 are more constant over varying skew angles than the conventional catamaran slider 30 (shown in Figures 2a to 2e). Triangular areas 69 and 71 formed at varying skew angles Ø also develop some positive pressure but tend to balance with the areas 65, 66, 67 and 68. Since the slider 50

This is the replacement sheet

Date: 22 SEP 1998

has less variation in flying height, the average flying height may be reduced in order to obtain greater resolution on the individual bit positions on the disk 14 without risk of the slider 50 contacting the disk surface at high skew angles.

Figure 6 is a perspective view of an alternative slider 70. The slider 70 has hour glass rails 72 and 74 with etches that form "shallow" edge steps or blends 76. The edge steps 76 form inside and outside surfaces that are recessed from air bearing surfaces 78 and 80 by about 0 microns to 2.0 microns. The edge steps 76 are positioned along each rail, between leading edges 86 and trailing edges 88, to form the hour glass shapes of the air bearing surfaces 78 and 80. When the slider 70 flys at a skew angle ø (shown in Figure 5), the recessed surfaces accumulate additional pressure that prevents the slider 70 from losing flying height. This results in a more even flying height for varying skew angles ø.

In addition to flying height another critical flying characteristic is roll. At varying skew angles, sliders tend to roll about their longitudinal axes. Roll is caused by shifts in the pressure distributions across the air bearing surfaces 78 and 80 relative to the slider pivot point. To reduce roll and to obtain overall optimum flying characteristics, the dimensions of the air bearing surfaces 78 and 80 and the edge steps 76 must be adjusted to minimise shifts in pressure distribution. For example, the edge steps 76 on the inner and outer edges of each rail may be formed asymmetrically, with the inside surfaces wider, or having a larger indentation, than the outside surfaces. It should be known that the recessed inside and outside surfaces may be formed with different dimensions and may vary from one rail to the other.

In Figure 6, breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing

This is the replacement sheet

Date: 22 SEP 1998

edges 88. The breaks 82 and 84 preferably are spaced from the leading edges 86 by approximately one third the length of the slider 70. Positioning of the breaks 82 and 84 may be varied in alternative embodiments (not shown) to vary flying characteristics, such as pitch. Pitch is measured by an angle between the disk surface and a plane generally defined by the air bearing surfaces 78 and 80.

When the slider has a positive pitch, the leading edges 86 typically fly at greater distances from the disk surface than the trailing edges 88. Increasing the pitch angle provides for faster take off when the disk begins to rotate. Positive pitch also reduces the risk of a "head crash". When the leading edges 86 fly at greater distances from the disk surface than the trailing edges 88, the air bearing surfaces 78 and 80 tend to resist a negative pitch in which the leading edges 86 will crash into the disk surface. However, too large a positive pitch adversely affects stiffness or stability of the trailing edges 88. A small positive pitch increases the stiffness of the trailing edges 88. Since transducers, such as the transducers 35 and 37 (shown in Figure 2b) are typically positioned on the trailing edges 88, increased stability will increase performance of read and write operations. If the slider 70 flys with too small a positive pitch, a bump may cause the slider to rotate into a negative pitch and crash into the disk surface.

Pitch much be accurately controlled to achieve optimum flying characteristics. The pitch angle is adjusted by varying the pressure gradients along the air bearing surfaces 78 and 80. The breaks 82 and 84 may be positioned closer to either the leading edges 86 or the trailing edges 88 to vary pressure distribution along the air bearing surfaces 78 and 80. Typical pitch angles range from about 100 micro-radians to about 300

This is the replacement sheet

Date: 22 SEP 1998

micro-radians.

As the disk 14 drags air (wind 16) beneath the rail 72 and 74, skin friction along the air bearing surfaces 78 and 80 causes the air pressure to increase. The breaks 82 and 84 divide the air bearing surface 78 and 80 into forward surfaces and rearward surfaces. The forward surfaces are adjacent the leading edges 86 and rearward surfaces are adjacent the trailing edges 88. Positioned between the forward and rearward surfaces are central surfaces, which are adjacent the breaks 82 and 84. Since the central surfaces have narrower air bearing surfaces than the forward surfaces, a portion of the air pressure bleeds off at the breaks 82 and 84. This portion is not available to pressurise the rearward air bearing surfaces. This results in greater air pressure towards the leading edges 86 and less air pressure towards the trailing edges 88, which causes the slider 70 to increase pitch angle. To reduce the pitch angle, the breaks 82 and 84 are positioned closer to the leading edges 86 than to the trailing edges 88. The resulting pressure distribution reduces the pressure on the forward air bearing surface areas and thereby reduces the pitch angle.

Since the air pressure bleeds off near the breaks in the hour glass rails, the average flying height of an hour glass catamaran slider (with breaks) drops from that of a catamaran slider of the same width. Therefore, the air bearing surfaces 78 and 80 are formed to be wider near the leading and trailing edges 86 and 88 than the air bearing surfaces 38 and 39 of the conventional catamaran slider 30 shown in Figure 2c. The edge steps 76 do not fully extend from the breaks 82 and 84 to the leading and trailing edges 86 and 88 but terminate prior to the leading and trailing edges. Terminating the edge steps 76 prior to the leading and trailing edges 86 and 88 maximises the width of the air

This is the replacement sheet

Date: 22 SEP 1998

bearing surfaces 78 and 80 near the leading and trailing edges. The wider surfaces build up more air pressure and prevent the slider 70 from flying too close to the disk surface. The wider air bearing surfaces 78 and 80 also create more room to secure transducers on the trailing edges 88, such as the transducers 35 and 37 shown in Figure 2b.

Typically, a gimbal spring connects the slider 70 to an actuator arm, such as the arm 12 shown in Figure 2a. The gimbal spring includes a dimple that provides a pivot about which the slider 70 can pitch and roll while following the topography of the disk surface. The hour glass shape of each rail improves pitch stiffness of the air bearing about the point at which the dimple contacts the slider. Because the air pressure bleeds off near the breaks 82 and 84, the "area elements" of the air bearing surfaces 78 and 80 having vertical stiffness (formed by positive pressure) are concentrated near the leading and trailing edges 86 and 88 of the slider 70, remote from the pivot point. Thus, the vertical stiffness of each area element is "multiplied" by a longer moment arm to give a higher pitch stiffness.

Creating the hour glass shapes by applying the edge steps 76 to each rail such that they terminate prior to the leading and trailing edges 86 and 88 also improves, or reduces, flying height sensitivity to crown height variations. The air bearing surfaces 78 and 80 are not perfectly flat from the leading edges 86 to the trailing edges 88, but are slightly convex. There are two causes for the convex shape. First, manufacturing errors in the process of securing the slider 70 to the gimbal cause deformation of the slider. Second, designers intentionally "round" the air bearing surfaces 78 and 80 to reduce wear on the surfaces. The crown height is a measure of the degree of roundness and can vary from one slider to the next. An increase in crown

This is the replacement sheet
22 SEP 1998
Date:

height causes the pressure to increase near the mid-sections of the air bearing surfaces 78 and 80, which causes an increase in flying height. However, the edge steps 76 counter-act this effect. Since the edge steps 76 cause the air pressure to bleed off near the mid-sections, an increase in crown height has a negligible effect on the air pressure near the mid-sections. Therefore, the hour glass shapes reduce the flying height sensitivity to crown height variations. The hour glass shapes also reduce flying height sensitivity to low frequency disk waviness, since the disk waviness effect pressure on the air bearing surfaces 78 and 80 similar to crown height variations.

Figure 7 to 10 are greatly enlarged sectional views of a rail, such as the rail 74, taken along the lines 7 - 7 of Figure 6 and illustrate alternative edge step embodiments. Figure 7 illustrates an embodiment in which the edge step 76 are "true" steps. Figure 8 illustrates an alternative embodiment in which the edge steps 76 are chamfered. Figure 9 illustrates an alternative embodiment in which the edge steps 76 are wide, shallow chamfers between the air bearing surface 80 and the inside and outside edges of the rail 74. Figure 10 illustrates another alternative embodiment in which the edge steps 76 are shallow edge blends. It should be understood that any of these embodiments, or a combination of them, may be used within the scope of the present invention.

Figure 11 illustrates an hour glass slider similar to the slider 70 shown in Figure 6, but having a cross-rail. Sliders having cross-rails are typically called negative pressure air bearing (NPAB) sliders, as opposed to catamaran sliders which do not have cross-rails. An hour glass NPAB slider 110 includes rails 112 and 114 having air bearing surfaces 116 and 118 respectively. A cross-rail 120 extends between the rails 112 and 114.

This is the replacement sheet

Date: 22 SEP 1998

In the preferred embodiment, the cross-rail 120 is positioned closer to the leading edge 121 than the trailing edge 123.

During operation, the cross rail 120 creates a negative pressure area 122, which counter-acts the positive pressure built along the air bearing surfaces 116 and 118 and increases slider stability and stiffness. The negative pressure area 122 is created between the rails 112 and 114 and between the cross-rail 120 and the trailing edge 123.

The slider 110 further includes edge steps 125. The cross-rail 120 and edge steps 125 may be etched to approximately 0 microns to 2.0 microns below the air bearing surfaces 116 and 118. The edge steps 125 are relatively shallow compared to the negative pressure area 122, which is etched to about 10 microns below the air bearing surfaces 116 and 118. The edge steps 125 are drawn out of scale and actually look similar to the edge steps 76 shown in Figure 8. To maximise the slider stiffness, the edge steps 125 are applied to each rail, such that they terminate prior to the leading and trailing edges 142 and 124. This maximises the air bearing surface area that develops positive pressure near the ends of the rails 112 and 114 while maximising the negative pressure area 122 near the centre of the slider 110. As a result, the counter-action between the positive and negative pressure is maximised to improve the slider stiffness.

The shallow edge steps 125 accumulate additional pressure. When the slider 110 flys at a skew angle $\emptyset$, the additional pressure that accumulates on the edge steps 125 reduces the effect of the skew angle on fly height by reducing shifts in the pressure distributions across the air bearing surface areas 116 and 118. The result is a more constant fly height for varying skew angles $\emptyset$. The slider 110 is also relatively insensitive

This is the replacement sheet

Date: 22 SEP 1998

to crown height variation and disk waviness (see the discussion above with reference to Figure 6).

Figure 11 illustrates an alternative rail geometry that may be used with or without the cross-rail 120. Elongated breaks 126 and 128 divide the air bearing surfaces 116 and 118 into three portions. The air bearing surface 116 is divided into a forward surface 130, a central surface 132, and a rearward surface 134. Similarly, the air bearing surface 118 is divided into a forward surface 136, a central surface 138, and a rearward surface 140. The breaks 126 and 128 are spaced from the leading edges 142 by about approximately one third the length of the slider 110. As a result, the forward surfaces 130 and 136 are smaller than the rearward surfaces 134 and 140. The central surfaces 132 and 138 have generally rectangular shapes.

The negative pressure area 122 created by the cross-bar 120 reduces flying height senstivity to tangential disk velocity. As the disk rotates, the air velocity beneath the air bearing surfaces is greater at the outer radius of the disk than at the inner radius. Therefore, the positive pressure built along the air bearing surface is greater at the outer radius than at the inner radius. However, the negative pressure also increases at the outer radius. The increase in negative pressure counter-acts the increase in positive pressure to reduce changes to flying height caused by changes in air velocity.

The hour glass air bearing surfaces 116 and 118 further reduce changes in flying height caused by changes in air velocity. At higher air speeds, increases in positive pressure are greater than increases in negative pressure. Since the air bearing surfaces 116 and 118 are narrower at the central surfaces 132 and 138 the positive pressure bleeds off into the negative pressure cavity 122 to reduce increases in positive

This is the replacement sheet

Date: 22 SEP 1998

pressure. The positive pressure is even further reduced since the area of greatest negative pressure, the central region of the negative pressure area 122 is adjacent the central surfaces 132 and 138. Therefore, the negative pressure area 122 draws more air off the central surfaces 132 and 138 to further reduce increases in positive pressure. As a result, changes in positive and negative pressure remain substantially equal over varying tangential disk velocities.

The slider having hour glass rails according to the present invention provides a near constant air bearing surface area and pressure distribution while flying at varying skew angles and disk velocities. As a result, the slider having hour glass rails has improved flying characteristics over the prior art.

This is the replacement sheet

Date: 22 SEP 1998

CLAIMS

1. An air-bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk, said slider comprising:

a slider body (50,70,110) having a leading edge (51,121), a trailing edge (52,123) and first and second edges therebetween; and

first and second side rails (42,44; 72,74; 112,114) disposed on the side of the slider which is opposed to the disk, extending respectively adjacent said first and said second side edges, each of said side rails forming an air bearing surface (46,48; 78, 80; 116,118) with an inside edge and an outside edge extending between the leading edge and the trailing edge wherein

a portion of the inside and outside edges converge together toward a central region of the air bearing surfaces to form intermediate surfaces (76,125), characterised in that the intermediate surfaces are raised above the slider body and are recessed from the air bearing surfaces to form shallow steps which, when the slider is in use, accumulate additional pressure on the rails if the slider flys at a skew angle.

2. A slider according to claim 1 characterised in that the air bearing surface of each of the first and second side rails has a forward surface portion (130,136) extending from the leading end thereof to the narrowed surface portion and a rearward surface portion (134,140) extending from the trailing end thereof to the narrowed surface portion, and in that the forward surface portion has a smaller area than the rearward surface portion.

3. A slider according to claim 1 or 2 characterised in that the narrowed surface portion of the air bearing surface of each of the first and second side rails is spaced from the leading end thereof by about one third of the length between the leading and the trailing ends thereof.

4. A slider according to any of claims 1 to 3 characterised in that the narrowed surface portion has a substantially rectangular shape.

* C L M S *

This is the replacement sheet

Date: 22 SEP 1998

5. A slider according to any of claims 1 to 4 characterised in that the air bearing surface of each of the first and second side rails has substantially the same width adjacent the leading and trailing ends thereof, and in that the narrowed surface portion has a width which is substantially half said width adjacent the leading and trailing ends.

6. A slider according to any preceding claim characterised in that said converging inside and outside edge portions extend substantially the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

7. A slider according to any of claims 1 to 5 characterised in that said converging inside and outside edge portions extend less than the full length between the leading and trailing ends of the air bearing surface of each of the first and second side rails.

8. A slider according to any preceding claim characterised in that said converging inside and outside edge portions form edge steps.

9. A slider according to any preceding claim characterised in that said converging inside and outside edge portions comprise chamfers.

10. A slider according to any of claims 1 to 8 characterised in that said converging inside and outside edge portions comprise edge blends.

11. A slider according to any preceding claim characterised in that said converging inside and outside edge portions adjoin recessed inside and outside surfaces, which are set back from the air bearing surfaces by about 0 microns to 2.0 microns.

12. A slider according to claim 11 characterised in that the recessed inside surfaces have different dimensions from the recessed outside surfaces.

This is the replacement sheet

Date: 22 SEP 1998

* C L M S *

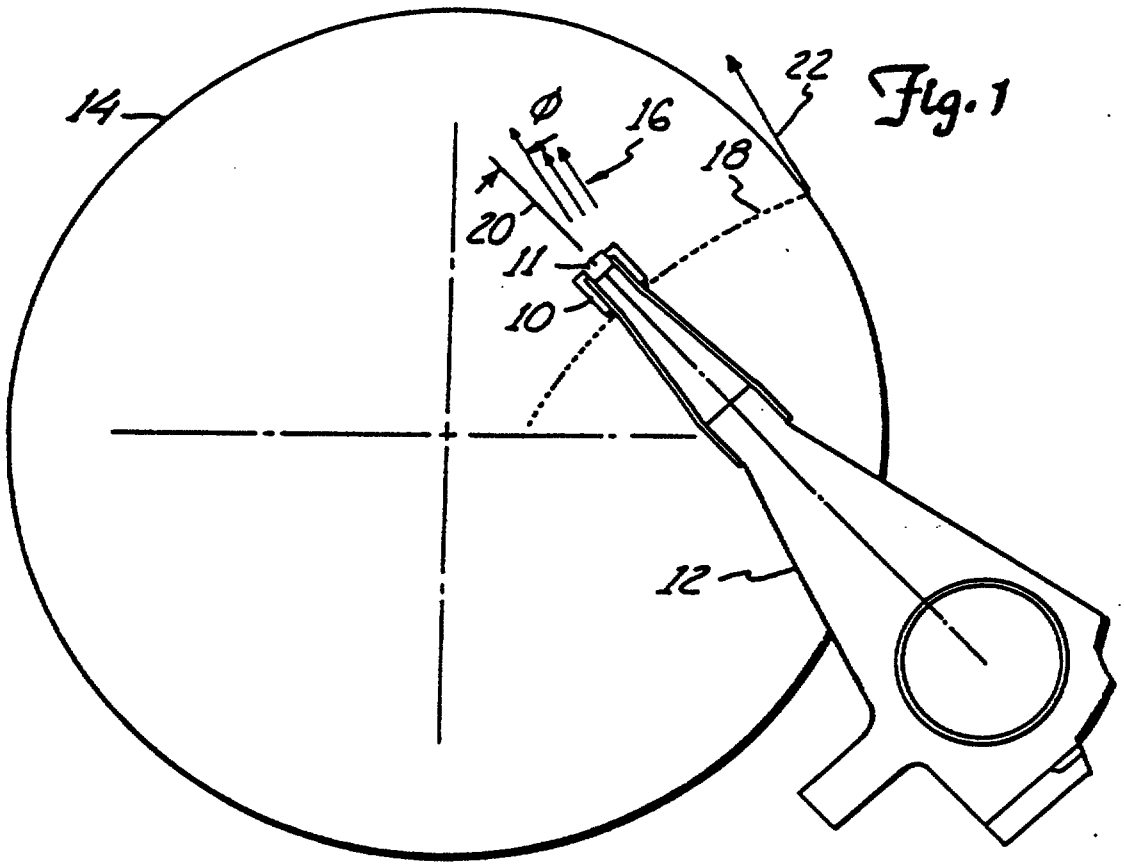


Fig. 1

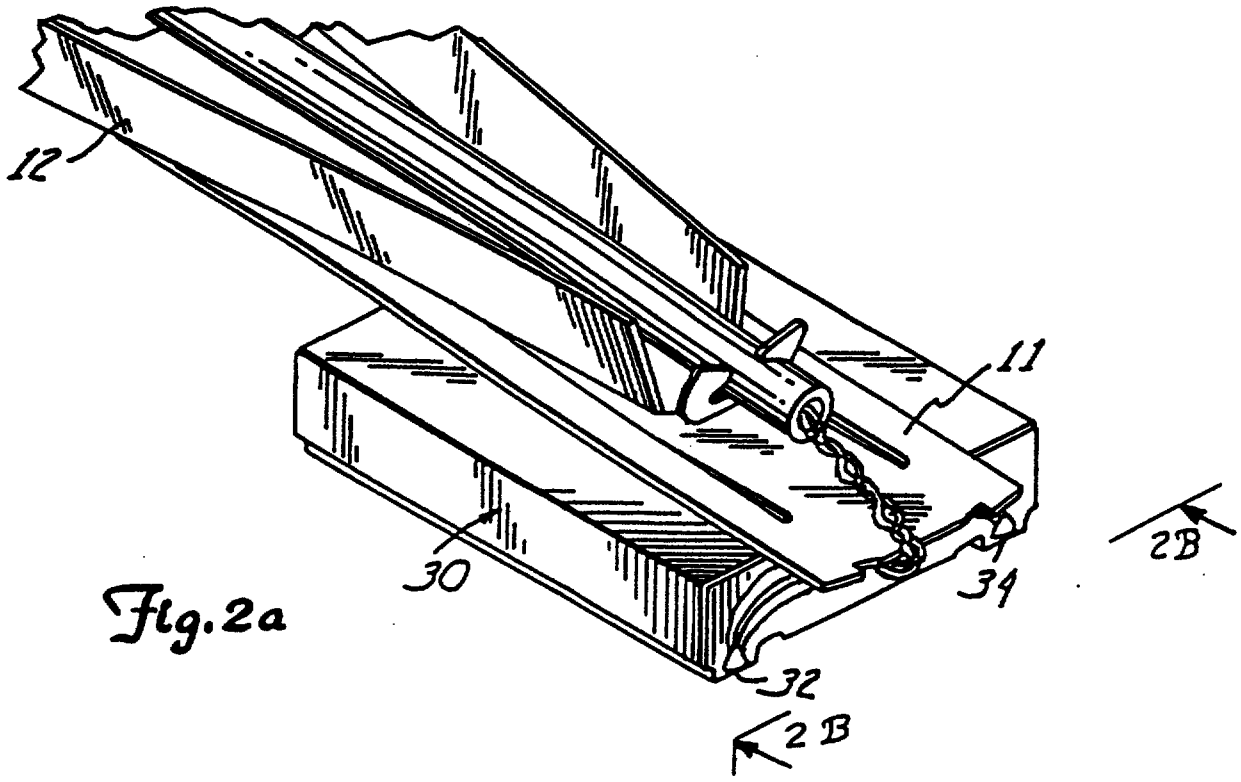


Fig. 2a

This is the replacement sheet

Date: 22 SEP 1990

Fig. 2b

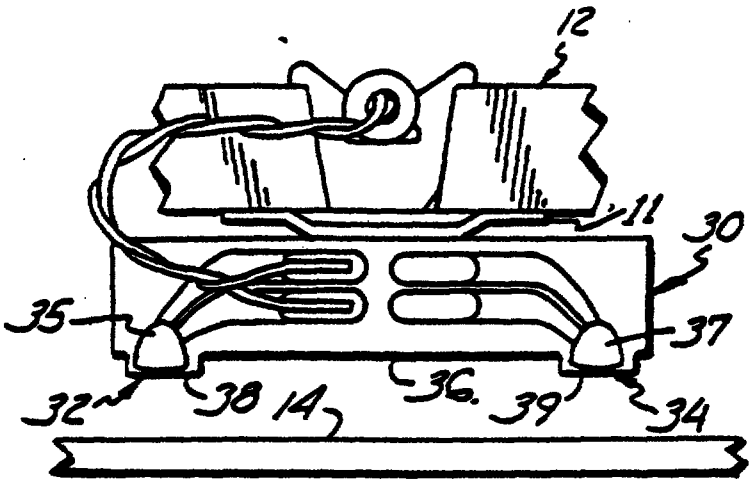
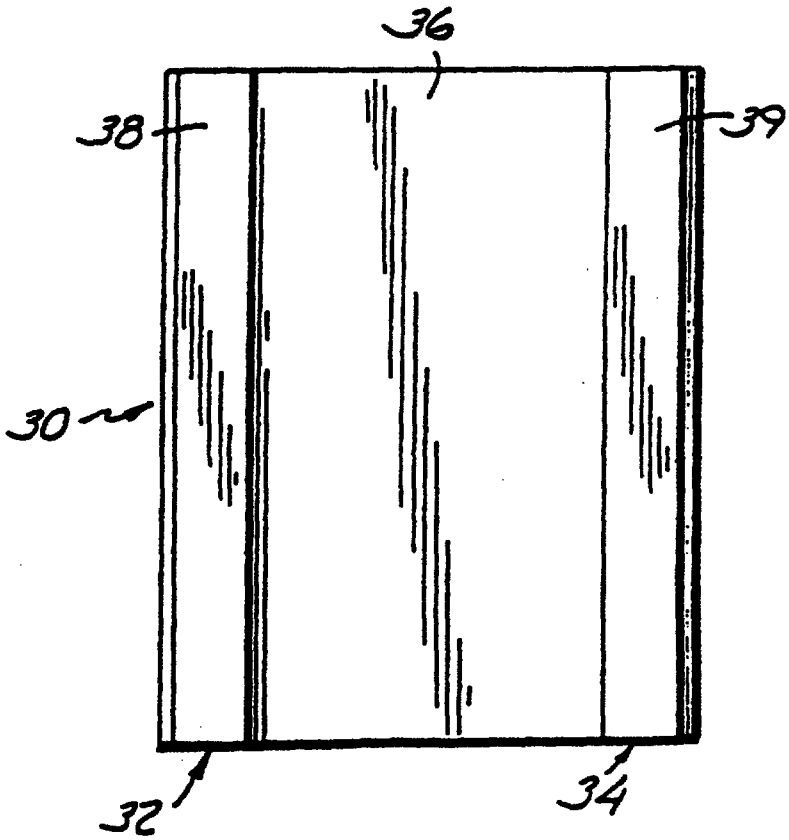


Fig. 2c



This is the replacement sheet

Date: 22 SEP 1998

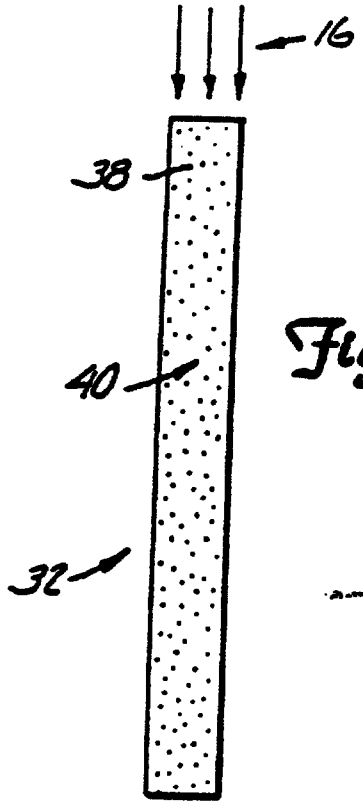


Fig.2d

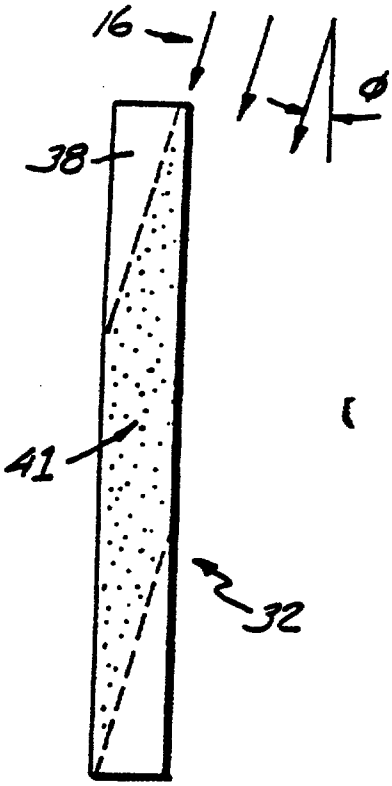


Fig.2e

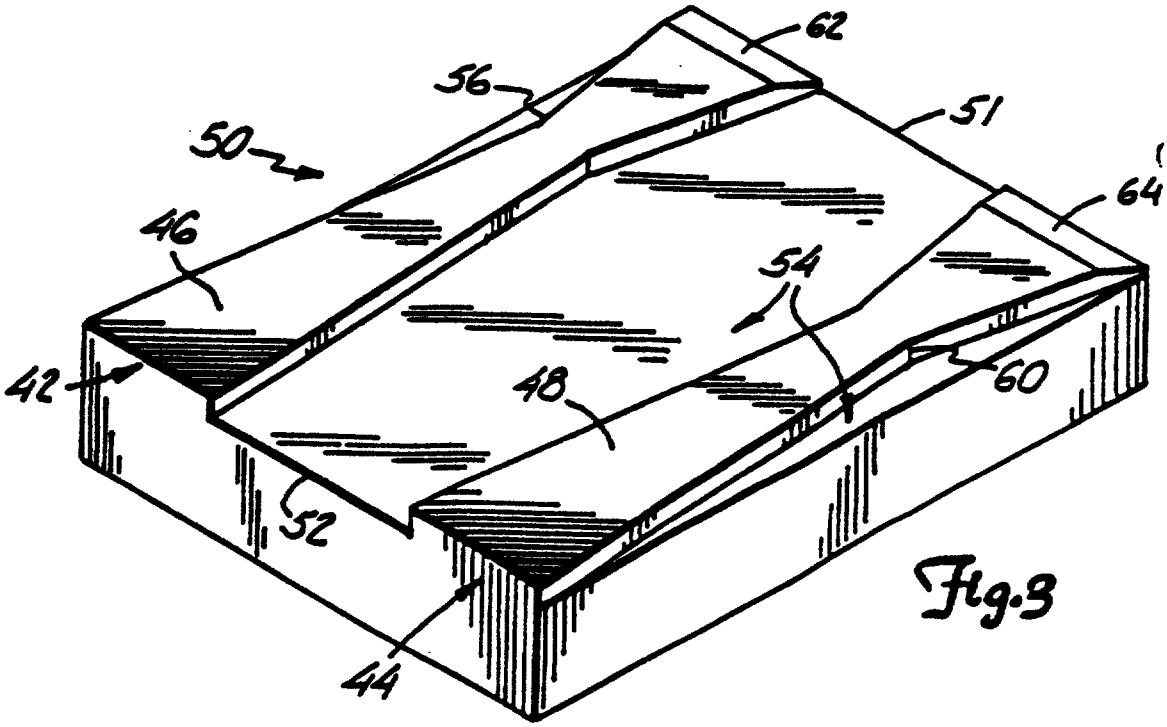


Fig.3

This is the replacement sheet

Date: 22 SEP 1998

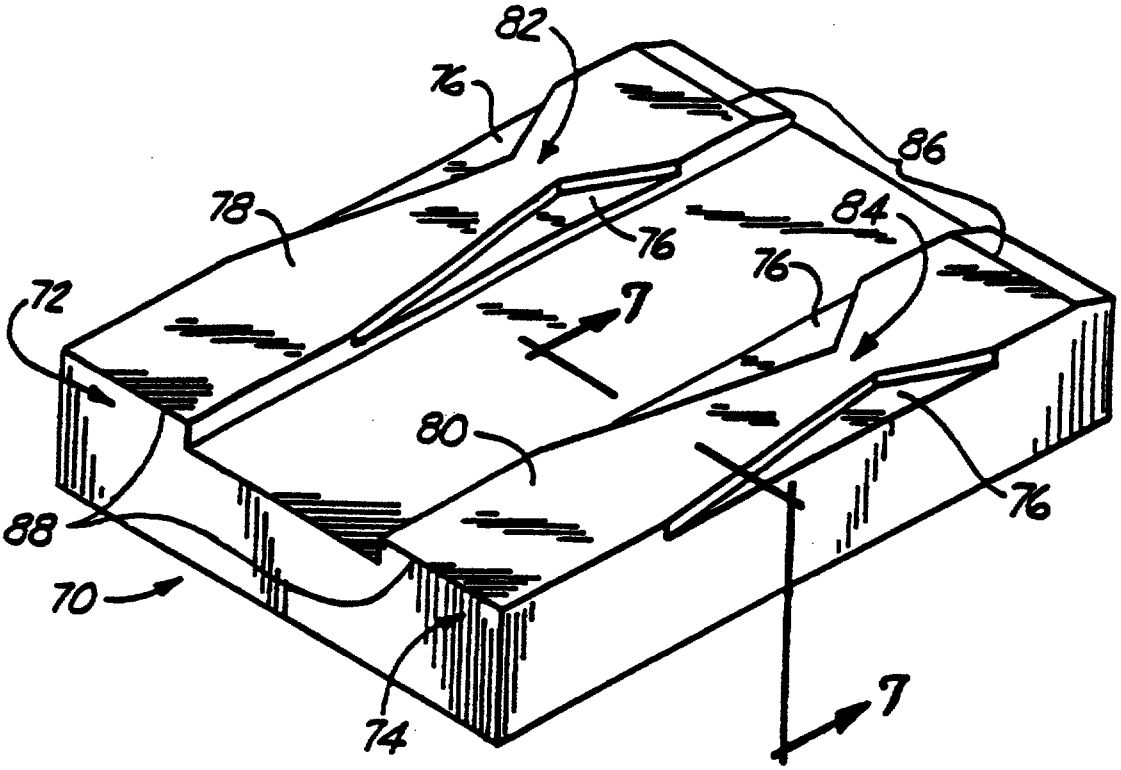


Fig. 6

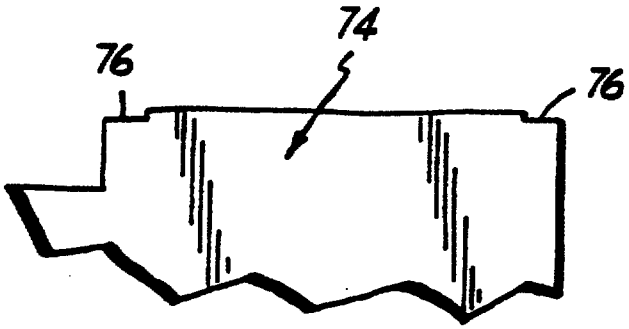


Fig. 7

This is the replacement sheet

Date: 22 SEP 1998

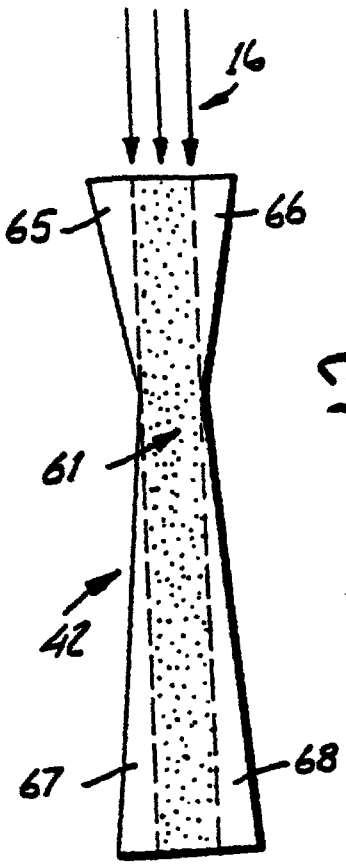


Fig. 4

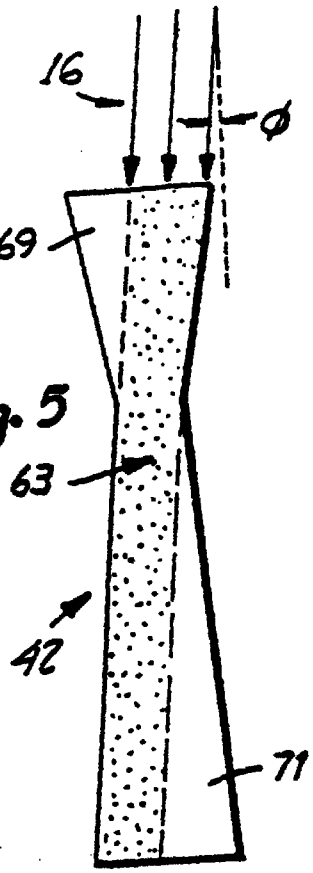


Fig. 5

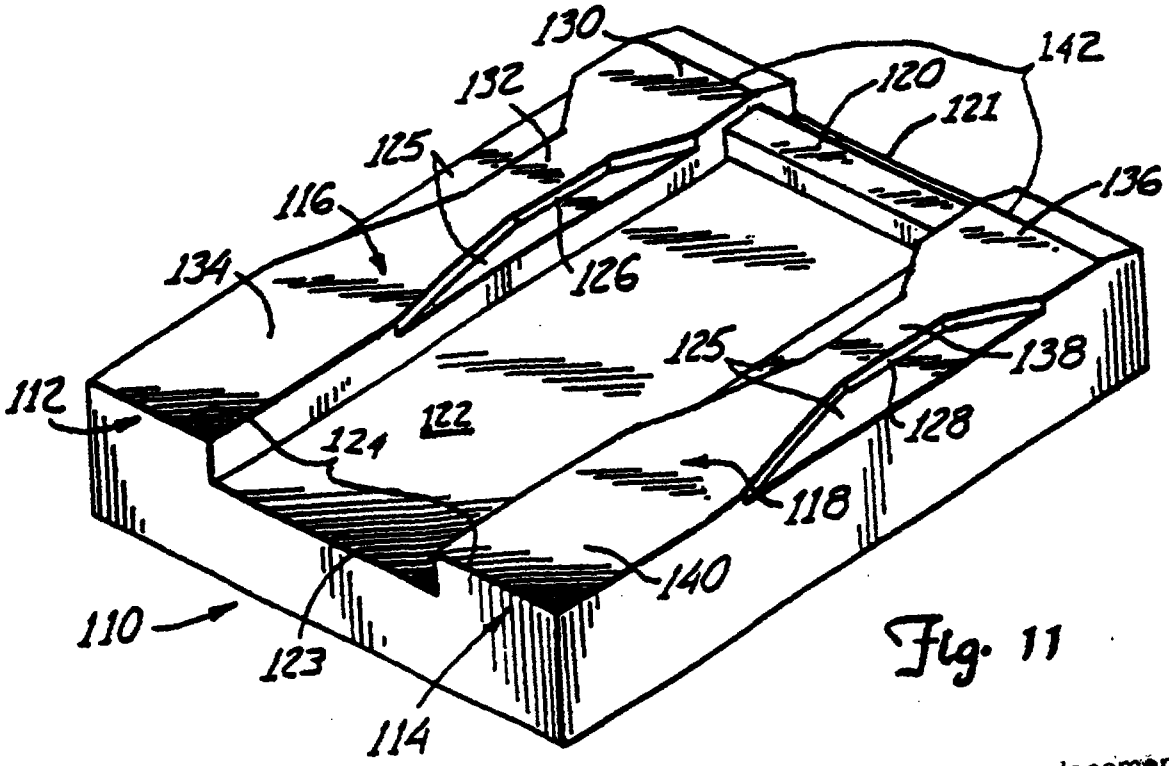


Fig. 11

This is the replacement sheet

Date: 22 SEP 1998

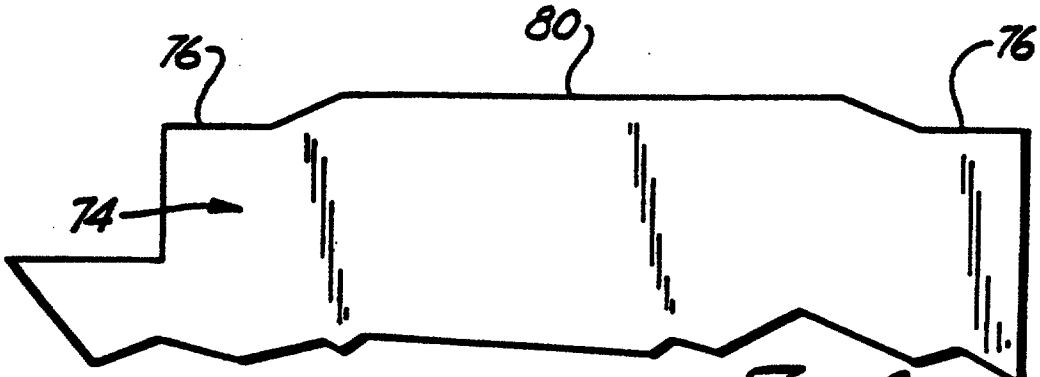


Fig. 8

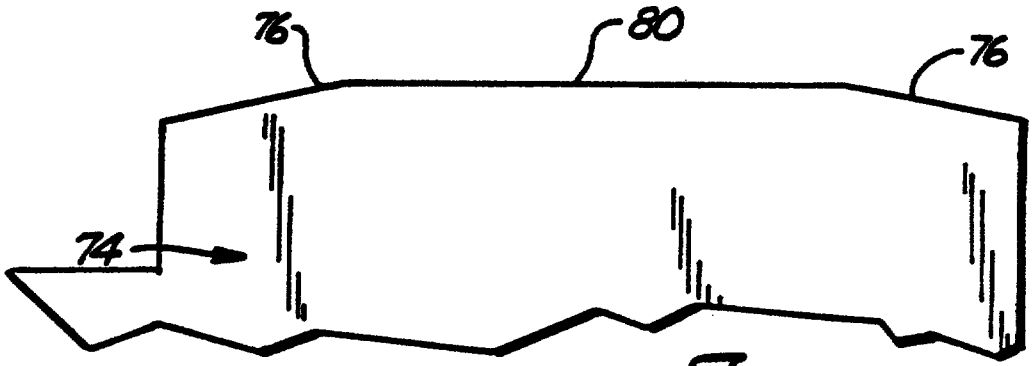


Fig. 9

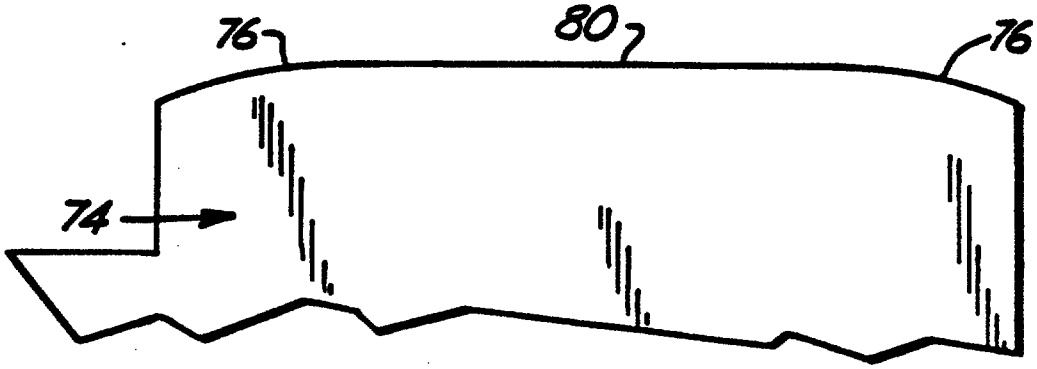


Fig. 10

This is the replacement sheet

Date: 22 SEP 1998

REPLACEMENT SHEET
08 MAR 1999

ABSTRACT

AIR BEARING DISK HEAD SLIDER

The invention provides an air bearing disk head slider for supporting an electro-magnetic transducer proximate a rotating magnetic disk. The slider comprises a slider body (50) having a leading edge (51), a trailing edge (52), and first and second side edges therebetween, and first and second side rails (42, 44) extending adjacent the first and second side edges, respectively. Each of the side rails forms an air bearing surface (46, 48) having a narrowed surface portion located between a leading end and a trailing end of the rail. Each air bearing surface has inside and outside edges, which converge towards the narrowed surface portion.

[Figure 3]