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FLYING HEAD SLIDER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a flying head slider with a magnetic transducer head for recording to or reproducing from, for example, a magnetic disc, a magneto-optical disc, or the like.

2. Description of the Related Art

Conventionally, a hard disc drive that is included in or connected to a computer or the like has a structure as shown in, for example, Fig. 24.

In Fig. 24 a hard disc drive 1 has a two-sided magnetic disc 2 that is rotated at a constant angular velocity by a spindle motor (not shown), an arm 3, and a head slider 4 that is disposed at the head of the arm 3.

One end of the arm 3 is swingably fixed around a vertical axis 3a, while the other end is provided with the head slider 4 by a suspension 3b connected therebetween.

In this arrangement the magnetic disc 2 is rotated at a constant velocity by the spindle motor (not shown). When the arm 3 is rotated around the vertical axis 3a, the head slider 4 disposed in the other end is substantially moved in the radial direction of the magnetic disc 2, so that a magnetic transducer head 5 mounted on the head slider 4

performs a seek operation with respect to the magnetic disc 2. Thereby, information is recorded to or is reproduced from a predetermined track on the magnetic disc 2.

The head slider 4 is formed as shown in Fig. 25. The head slider 4 has rails 4a and 4b which act as air bearing surfaces on a couple of longitudinal parts of its bottom surface as a main surface. The upstream ends of these rails 4a and 4b have taper portions 4c and 4d serving as inclined portions that have a gentle inclination at θ_1, for example, a taper angle of not more than 1 degree. A magnetic transducer head 5 is mounted on the side of the downstream end of the rail 4a.

In accordance with the shape of the head slider 4, when the head slider 4 approaches the surface of the magnetic disc 2 that is rotating, an airflow, caused by the rotation of the magnetic disc 2, streaming between the rails 4a, 4b of the head slider 4 and the surface of the magnetic disc 2 forms a floating force acting on the head slider 4.

This floating force causes the head slider 4 and the magnetic transducer head 5 mounted thereon to float and travel at a minute distance (lift distance) from the surface of the magnetic disc 2. Therefore, the head slider 4 is designed to prevent the magnetic disc 2 from being abraded and damaged by direct contact of the magnetic transducer head 5 with the surface of the magnetic disc 2.

In accordance with the flying head slider 4 having such a structure, even when the surface of the magnetic disc 2 is slightly uneven, the lift distance of the head slider 4 having the magnetic transducer head 5 from the surface of the magnetic disc 2 is maintained at approximately a constant value.

In recent years, as hard disc drives have increasingly smaller sizes and larger storage capacities, high-density recording is in greater demanded. Thus, recent hard disc drives have begun to employ a so-called zone-bit-recording method.

This zone-bit-recording method is formed such that the data region of a magnetic disc is separated into several zones, and recording is performed at a higher frequency as the zone is located closer to the outer circumference of the disc, thereby the recording capacity of the whole disc is increased. Consequently, in order to effectively utilize this zone-bit-recording method, the lift distance of the head slider on which a magnetic transducer head is mounted needs to be maintained at a constant value above the whole data regions of the magnetic disc.

As the lift distance of the head slider decreases, the inclination position (so-called roll) of the head slider, having its longitudinal direction as an axis of rotation, significantly affects the reliability of the head slider.

In other words, the large roll when the head slider normally floats causes a high possibility of the head slider colliding with a projection or adhering to the surface of the magnetic disc. Such a collision is called a clash. To prevent such a clash, the roll when the head slider normally floats needs to be reduced. The large roll angle of the head slider also causes a large change in the roll of the head slider in the seek condition, and similarly, the possibility of the clash becomes higher. Accordingly, the roll angle needs to be reduced.

However, in the flying head slider 4 having such a structure, when the magnetic disc 3 is rotated at a constant angular velocity, a linear velocity at the outer circumference is greater than a linear velocity at the inner circumference. Therefore, the lift distance of the head slider 4 varies with the outer and inner circumferences, showing a relatively large change. In other words, a linear velocity at the outer circumference of the magnetic disc 2 is greater than a linear velocity at the inner circumference, and thus the lift distance corresponding to this linear velocity is obtained, so that a so-called static change in the lift distance is generated.

To the contrary, when the arm 3 turns around the vertical axis 3a, the head slider 4 radially moves in the form of an arc, not linearly, above the surface of the

magnetic disc 2. Accordingly, the head slider 4 shifts as its center line becomes off from the tangential direction to a track of the magnetic disc 2, and therefore, as shown in Fig. 26, a so-called skew angle is formed. This skew angle varies with the position of the head slider 4 from the center of the magnetic disc 2. In other words, when the skew angle increases, the conversion efficiency from a dynamic pressure into a floating force between the surface of the magnetic disc 2 and the head slider 4 decreases to reduce the lift distance, as shown in Fig. 27. By considering this point, a most ideal head slider that has a lift distance characteristic as shown in, for example, Fig. 27 with a solid line A is obtained.

A general flying head slider shows a floating characteristic as shown with a solid line B in Fig. 27. When a skew angle at the magnetic transducer head is ±5 degrees, the head lift distance characteristic is represented by a solid line C.

Consequently, the lift distance d that increases greater as the head slider is located closer to the circumference decreases due to the skew angle. In this case a change in the lift distance d caused by a linear velocity is linear, while a decrease in the lift distance d caused by the skew angle is quadratic and non-linear. Accordingly, as long as the conventional head slider 4 as shown in Fig. 26,

it is difficult to keep the balance of the linear velocity and the skew angle θs over the whole radial range of the magnetic disc 2.

The range of the peripheral velocity and skew angle in the magnetic disc 2 is characteristic values of the hard disc drive 1, which values are determined when the drive 1 is designed. The spring load of the suspension 3b with respect to the head slider 4 is determined when the drive 1 is designed. Thus, with respect to these conditions, as parameters capable of changing the lift distance of the head slider 4 the widths of the rails 4a and 4b are used.

The widths of the rails 4a and 4b determine the affection to the lift distance by the peripheral velocity and by the skew angle. Accordingly, the widths of the rails 4a and 4b are automatically determined based on the characteristic conditions of the hard disc drive 1, and the affection to the lift distance by the skew angle is determined.

As obvious from Fig. 27, regarding a certain rail width, with respect to the extremely limited range of skew angles, the constant lift distance characteristics of the flying head slider 4 are obtained, however, in other conditions the constant lift distance characteristics, which are preferred, are not obtained. With regard to control of the roll angle, the roll angle of the head slider is

adjusted by shifting a load-point, however, only by shifting a load-point, it is difficult to control the roll angle to zero. Consequently, the conventional flying head slider hardly maintains sufficient reliance obtained when the lift distance decreases.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a flying head slider in which the constant lift distance thereof is obtained over the whole data zones of a recording medium, and in which the roll angle thereof is reduced, in accordance with unspecified floating conditions such as the peripheral velocity, the skew angle, and so forth.

In accordance with an aspect of the present invention, the foregoing object is achieved through the provision of a flying head slider comprising: two side-rails disposed on a surface of a slider body facing a recording medium so as to extend in parallel along the direction from the upstream side to the downstream side of the slider body; an inclined portion or a step portion formed on a part of the surface to the upstream side; a transducer mounted on the downstream side; and a cross-rail disposed on the surface so as to connect the upstream ends of the two side-rails, the two side-rails each having at least one bending point between

the upstream end and the downstream end thereof, and each side-rail extending inward along the longitudinal direction of the surface between the upstream end and the bending point, and extending outward along the longitudinal direction between the downstream end and the bending point.

Each side-rail may have a width-extended portion whose width is extended inward or outward in the vicinity of the downstream end.

The cross-rail may have a separation groove in the center thereof.

Each side-rail may have a parallel rail portion extending from the cross-rail along the longitudinal direction of the surface.

The transducer may be mounted on a part of the downstream side positioned perpendicular to either of the side-rails.

The flying head slider further comprises a projecting air-guide portion formed so as to diverge toward the downstream side in the vicinity of the center of the downstream region of the surface.

The transducer may be mounted on a part of the downstream side perpendicular to the projecting air-guide portion.

The bending portion of each side-rail extending to the innermost of the surface from the upstream end may have a

bending angle θ with respect to the longitudinal side of the surface, such angle being defined by the following range: 10 degrees $\leq \theta \leq$ 30 degrees.

The bending portion of each side-rail extending to the innermost of the surface from the upstream end may have a bending angle θ with respect to the longitudinal side of the surface, such angle being defined by the following range: 20 degrees $\leq \theta \leq$ 30 degrees.

The bending portion of each side-rail may satisfy the following relation: $0.30 \leq L/R \leq 0.70$, where L represents the distance between the bending portion closest to the upstream end and the downstream end; and R: the distance between a point at which the bending portion starts and the downstream end.

The bending portion of each side-rail satisfies the following relation: $0.40 \leq L/R \leq 0.70$, where L represents the distance between the bending portion closest to the upstream end and the downstream end; and R: the distance between a point at which the bending portion starts and the downstream end.

In accordance with another aspect of the present invention, the foregoing object is achieved through the provision of a magnetic disc drive comprising: a magnetic disc used as a recording medium; driving means for rotating

the magnetic disc; a turning actuator swingably supported with respect to the magnetic disc rotated by the driving means; a flying head slider mounted on the head of the turning actuator; a magnetic transducer head mounted on the flying head slider for recording to or reproducing from the magnetic disc; and a driving mechanism for swinging the turning actuator, in which the flying head slider has: two side-rails disposed on a surface of a slider body facing a recording medium so as to extend in parallel along the direction from the upstream side to the downstream side of the slider body; an inclined portion or a step portion formed on a part of the surface to the upstream side; a transducer mounted on the downstream side; and a cross-rail disposed on the surface so as to connect the upstream ends of the two side-rails, the two side-rails each having at least one bending point between the upstream end and the downstream end thereof, and each side-rail extending inward along the longitudinal direction of the surface between the upstream end and the bending point, and extending outward along the longitudinal direction between the downstream end and the bending point.

As described above, in the head slider according to the present invention, having the side-rails which are bent inward so as to each have at least one bending portion, the affection to the lift distance by the peripheral velocity

and the affection to the lift distance by the skew angle are reduced, and therefore, the lift distance of the head slider is maintained at a constant value.

In addition, the roll of the head slider can be controlled to approximately zero even when the skew angle changes.

Hence, in accordance with the present invention, in response to unspecified conditions such as the peripheral velocity, the skew angle and so forth, the lift distance over the whole data zones of the recording medium is maintained at a constant value, and the roll angle is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view illustrating the construction of a hard disc drive that includes a flying head slider according to the present invention.

Fig. 2 is a schematic bottom view illustrating a flying head slider according to a first embodiment of the present invention.

Fig. 3 is a sectional view illustrating the condition in which the head slider shown in Fig. 2 floats with respect to a magnetic disc.

Fig. 4 is a graph showing the relationship between the peripheral velocity and the lift distance of the head slider

shown in Fig. 2 in which a bending angle θ is a parameter.

Fig. 5 is a graph showing the relationship between the skew angle and the lift distance of the head slider shown in Fig. 2 in which the bending angle θ is a parameter.

Fig. 6 is a graph showing the relationship between the skew angle and the lift distance of the head slider shown in Fig. 2 in which the position of a bending point, L/R, is a parameter.

Fig. 7 is a graph showing the relationship between the skew angle and the roll of the head slider shown in Fig. 2 in which the bending angle θ is a parameter.

Fig. 8 is a graph showing the relationship between the skew angle and the roll of the head slider shown in Fig. 2 in which the position of the bending point, L/R, is a parameter.

Fig. 9 is a graph showing the relationship between the bending angle θ and lift distance characteristics with regard to the head slider shown in Fig. 2.

Fig. 10 is a graph showing the relationship between the position of the bending point L/R and the lift distance characteristics with regard to the head slider shown in Fig. 2.

Fig. 11 is a schematic bottom view illustrating a flying head slider according to a concrete embodiment of the

present invention.

Fig. 12 is a graph showing the relationship between the position of the head and the lift distance of the head slider shown in Fig. 11.

Fig. 13 is a graph showing the relationship between the position of the head and the roll of the head slider shown in Fig. 11.

Fig. 14 is a graph showing the relationship between the skew angle and the lift distance in a plurality of models of flying head sliders according to the present invention, obtained by computer simulation.

Fig. 15 is a graph showing affection by the skew angle with respect to the bending angle θ in each model shown in Fig. 14.

Fig. 16 is a graph showing the relationship between the skew angle and the roll in each model shown in Fig. 14.

Fig. 17 is a graph showing a change in the roll with the bending angle θ in each model shown in Fig. 14.

Fig. 18 is a graph showing the lift distance with respect to the peripheral velocity in each model.

Fig. 19 is a graph showing affection by the peripheral velocity with respect to the bending angle θ in each model.

Fig. 20 is a schematic perspective view illustrating a flying head slider according to a second embodiment of the

present invention.

Fig. 21 is a schematic bottom view illustrating a flying head slider according to a third embodiment of the present invention.

Fig. 22 is a schematic perspective view illustrating a flying head slider according to a fourth embodiment of the present invention.

Fig. 23 is a schematic perspective view illustrating a flying head slider according to a fifth embodiment of the present invention.

Fig. 24 is a perspective view illustrating the construction of an example of a conventional hard disc drive.

Fig. 25 is a perspective view illustrating the head slider in the hard disc drive shown in Fig. 18.

Fig. 26 is a schematic chart showing a change in the skew angle with regard to the head slider shown in Fig. 25.

Fig. 27 is a graph showing a change in the lift distance caused by the skew angle with regard to the head slider shown in Fig. 25.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

By referring to Figs. 1 to 23, preferred embodiments of the present invention will be described below.

These embodiments are detailed and preferred examples

of the present invention, and therefore they are provided with technically preferred, various limitations. However, the scope of the present invention is not limited to these embodiments unless the following explanation includes a particular description to limit the present invention.

Fig. 1 is a perspective view illustrating the whole of a hard disc drive that is provided with a flying head slider according to the present invention.

The hard disk drive 10 has a two-sided magnetic disc 11 that is rotated at a constant angular velocity by a spindle motor (not shown), an arm 12, and a head slider 13 that is disposed at the head of the arm 12.

One end of the arm 12 is swingably fixed around a vertical axis 12a, while the other end is provided with the head slider 13 by a suspension 12b connected therebetween.

In this arrangement the magnetic disc 11 is rotated at the constant velocity by the spindle motor (not shown). When the arm 12 is rotated around the vertical axis 12a, the head slider 13 mounted on the other end is substantially moved in the radial direction of the magnetic disc 11, so that a magnetic transducer head 14 mounted on the head slider 13 performs a seek operation with respect to the magnetic disc 11. Thereby, information is recorded to or is reproduced from a predetermined track on the magnetic disc 11.

In Fig. 2 a bottom view of the flying head slider according to a first embodiment of the present invention is illustrated, in other words, the detailed structure of the flying head slider 13 is shown.

The flying head slider 13 is formed into a rectangular parallelepiped that is wholly flat. The bottom surface of the head slider 13 includes two side-rails 15 and 16 acting as air bearing surfaces, and a cross-rail 17 connecting these side-rails.

The respective side-rails 15 and 16 are disposed in two parts of the bottom surface to the longitudinal sides so that they extend along the direction from the upstream side to the downstream side of the head slider 13. The rails 15 and 16 form a negative-pressure groove 18 therebetween. The cross-rail 17 is disposed so as to connect the side-rails 15 and 16 on the upstream ends thereof.

As shown in Fig. 2, the cross-rail 17 is provided with a separation groove 17a in the center.

The head slider 13 includes a taper portion serving as an inclined portion having an inclination, or a step portion 19 serving as a step (the step portion is shown in Fig. 2) in a part of the bottom surface to the upstream side.

This step portion 19 is parallel to the air bearing surfaces formed by the side-rails 15, 16 and the cross-rail 17, and has a predetermined difference in level with respect

to the surface.

The side-rails 15 and 16 are formed so as to include, sequentially from the upstream side, parallel rail portions (parallel portions) 15a and 16a which extend along the longitudinal direction from the cross-rail 17, first bending portions 15b and 16b which extend inward along the longitudinal direction, and second bending portions 15c and 16c which extend outward along the longitudinal direction. The first bending portions 15b, 16b and the second bending portions 15c and 16c form bending points 15d, 16d in the center of both first and second portions.

The second bending portions 15c and 16c include flared portions 15e and 16e serving as width-extended portions which are gradually flared inward or outward in the downstream ends.

In accordance with the flying head slider 13, as shown in Fig. 3 when the flying head slider 13 approaches the surface of a rotating magnetic disc D, as shown in Figs. 2 and 3, an airflow that enters from the upstream side of this flying head slider 13 streams from the step portion 19 across the cross-rail 17, between the side-rails 15, 16 and the surface of the magnetic disc D, and the airflow streams between the negative-pressure groove 18 formed by the side-rails 15, 16 and the magnetic disc D.

The lift distance of the head slider 13 at the cross-

rail 17 is normally approximately 0.3 to 0.5 μm, while the lift distance at the negative groove 18 is, for example, approximately 5 μm. Consequently, the airflow rapidly expands to generate a suction force F1 caused by the negative pressure. Also, the airflow that streams between the side-rails 15, 16 and the magnetic disc D generates a floating force acting on the flying head slider 13.

Accordingly, the head slider 13 and the magnetic transducer head 14 mounted on the downstream side of the head slider 13 float and travel at a minute distance (lift distance) from the surface of the magnetic disc D, because of the floating force and the suction force, and a balance of the spring-load with regard to the suspension 12b of the arm 12. Therefore, the head slider 13 is designed to prevent the magnetic disc D from being abraded and damaged by direct contact of the magnetic transducer head 14 with the surface of the magnetic disc D.

The lift distance of the flying head slider 13 is determined by a peripheral velocity and an skew angle at each point on the magnetic disc D. However, as the peripheral velocity in the flying head slider 13 increases, the suction force as well as the floating force increase, which thus suppresses the affection to the lift distance by the peripheral velocity. Therefore, an increase in the lift in the vicinity of the circumference of the magnetic disc D

is reduced. The lift distance of the flying head slider 13 can be controlled by the depth of and area of the negative pressure groove 18, and also changed by the bending angle θ with respect to the longitudinal direction of the bending portions 15b and 16b.

For example, as shown in Fig. 4, when θ is small ($\theta <$ 10 degrees), in other words, when $\theta = 0$ degrees, the lift distance increases with an increase in the peripheral velocity. This is because, when θ is small, the side-rails extend almost in parallel with respect to the longitudinal direction, and as a result, the side-rails 15 and 16 cause a relatively large positive pressure to be generated. To the contrary, when θ is extremely large, for example, when $\theta =$ 37.9 degrees, the width of the negative pressure groove 18 at bending positions 15d and 16d narrows, and the airflow in the negative pressure 18 hardly streams, which thus suppresses the negative pressure to be generated.

When $10 \leq \theta \leq 30$ degrees, for example, when $\theta = 10$ degrees, the positive pressure is sufficiently suppressed and the negative pressure is sufficiently generated. Thus, the affection to the lift distance by the peripheral velocity is sufficiently reduced.

The affection to the lift distance by the skew angle is

controlled by the bending angle θ and the bending positions 15d and 16d, in other words, it is controlled by a distance L from the bending position to the downstream end.

The side-rails 15 and 16 have the bending positions 15d and 16d, respectively, and are bent inward. Thus, when an skew angle is formed, the airflow streams along the direction from the first bending portion 15b to the second bending portion 16c, or the airflow streams along the direction from the second bending portion 15c to the first bending portion 16b. Consequently, in relatively wide skew angles, a sufficiently large lifting force is obtained.

Accordingly, as shown in Fig. 5, it is obvious that as the skew angle θ increases, the affection to the lift distance by the skew angle becomes reduced. In particular, when the skew angle is not less than 20 degrees, the lift distance is not affected by the skew angle to form a constant value.

Further, for example, as shown in Fig. 6, as the bending positions 15d and 16d are moved closer to the upstream side ($L/R > 0.5$) than to the downstream side ($L/R < 0.5$), a characteristic curve showing the affection to the lift distance by the skew angle changes from a downwardly convex shape to an upwardly convex shape. In particular, when $L/R \approx 0.5$, the lift distance is not affected by the skew angle to form a constant value.

As described, by reducing the affection to the lift distance by the peripheral velocity and the skew angle, the lift distance of the head slider 13 is maintained approximately at a constant value. Consequently, in the hard disc drive 10, when the flying head slider 13 moves from an inner circumference to an outer circumference of the magnetic disc 1 in the head seek condition, if the peripheral velocity and the skew angle acting on the head slider 13 sequentially change, the lift distance, which is approximately constant, is obtained.

When a linear actuator is used instead of the arm 12 as a turning actuator in the hard disc drive 10, head seeking is performed at a constant skew angle (normally zero), and only the peripheral velocity of the head slider 13 sequentially changes. In such a case, the lift distance of the head slider 13 is not affected by the peripheral velocity to form a constant value.

In the whole area above which the flying head slider 13 is lifted, the roll of the flying head slider 13 is remarkably reduced to approximately zero by the bending angle θ and the length L from the position closest to the upstream side or the bending position to the downstream side.

For example, as shown in Fig. 7, as θ increases, the side-rail 15 positioned to the inner circumference of the

magnetic disc D tends to be lifted at a positive skew angle, and the roll of the flying head slider 13 gradually changes. In particular, in the range of 20 degrees $\leq \theta \leq 30$ degrees, the roll is not affected by the skew angle to form a constant value.

Further, for example, as shown in Fig. 8, as the bending points 15d and 16d are moved closer to the upstream side than to the upstream side, the roll increases from a large negative value to the neighborhood of zero once, and decreases to a large negative value again in positive skew angles. In particular, when $L/R \approx 0.5$, the roll is not affected by the skew angle to form a constant value.

As described above, preferred roll characteristics close to approximately zero are obtained. Consequently, in the hard disc drive 10, when the skew angle in the head slider 13 sequentially changes in the head seek condition in which the head slider 13 moves from the inner to the outer circumference of the magnetic disc 11, the roll of the flying head slider 13 is not affected by the skew angle, and is controlled approximately to zero in the whole area above which the flying head slider 13 is lifted.

When a liner actuator is used instead of the arm 12 as a turning actuator 12 in the hard disc drive 10, the skew angle is constant (normally zero), and thus, the roll characteristics expressed by approximately zero are obtained

in the whole area above which the head slider 13 is lifted.

As described above, in accordance with the above embodiment, by forming the bending positions 15d and 16d on the almost parallel side-rails 15 and 16, and optimizing the bending angle θ of the first bending portions 15b and 15b and the distance L from the bending points 15d and 16d, preferred constant lift distance characteristics and the roll characteristics expressed by zero in the hard disc drive 10 are obtained.

Figs. 9 and 10 show the optimal range of the bending angle θ and the position L defined by the bending positions 15d and 16d in the flying head slider 13 according to the above embodiment.

In other words, in Fig. 9, as already mentioned from the viewpoints of both the affection to the lift distance by the peripheral velocity and the affection to the roll by the skew angle, the preferred range of the bending angle θ is expressed as $10 \text{ degrees} \leq \theta \leq 30 \text{ degrees}$. In particular, in order to reduce, to 5 nm, a change caused by the affection to the lift distance by the peripheral velocity and the skew angle, and the affection to the roll by the skew angle, the most preferred range of the bending angle θ is expressed as $20 \text{ degrees} \leq \theta \leq 30 \text{ degrees}$.

In Fig. 10, the preferred range of the bending-point position L is expressed as $0.3 \leq L/R \leq 0.7$, from the affection to the lift distance by the peripheral velocity and the skew angle, and the affection to the roll by the skew angle. In particular, in order to reduce a change caused by the affection to the lift distance by the peripheral velocity and the skew angle and the affection to the roll by the skew angle, to 5 nm, the most preferred range is expressed as $0.4 \leq L/R \leq 0.6$.

Fig. 11 illustrates a flying head slider according to a concrete embodiment of the present invention.

The flying head slider 20 has the same structure as the flying head slider 13 shown in Fig. 13. The flying head slider 20 is formed into a rectangular parallelepiped that is wholly flat. The bottom surface of the head slider 20 includes two side-rails 21 and 22 acting as air bearing surfaces, and a cross-rail 23 connecting these side-rails.

The respective side-rails 21 and 22 are disposed in two part of the bottom surface to the longitudinal side so that they extend along the direction from the upstream side to the downstream side of the head slider 20. The rails 21 and 22 form a negative-pressure groove 24 therebetween. The cross-rail 23 is disposed so as to connect the side-rails 21 and 22 on the upstream end thereof.

As shown in Fig. 11, the cross-rail 23 includes a

separation groove 23a in the center.

The head slider 20 includes a taper portion serving as an inclined portion having an inclination, or a step portion 25 serving as a steps (the step portion is shown in Fig. 11) in a part of the bottom surface to the upstream side.

This step portion 25 has a predetermined angle, for example, a gentle angle of inclination of not more than 1 degree with respect to the air bearing surfaces formed by the side-rails 21, 22 and the cross-rail 23.

The side-rails 21 and 22 are formed so as to include, sequentially from the upstream side, parallel rail portions (parallel portions) 21a and 22a which extend along the longitudinal direction from the cross-rail 17, first bending portions 21b and 22b which extend inward along the longitudinal direction, and second bending portions 21c and 22c which extend outward along the longitudinal direction. The first bending portions 21b, 22b and the second bending portions 21c and 22c form bending points 21d, 22d in the center of both first and second portions.

The second bending portions 21c and 22c include flared portions 21e and 22e serving as width-extended portions which are gradually flared inward in the vicinity of the downstream ends.

The whole head slider 20 is made of alumina-titanium carbide. To form the head slider 20, its whole surface is

coated with urethane resist, only the side-rail portions 21, 22 and the cross-rail portion 23 are masked, and ultraviolet rays are irradiated onto the resist to be hardened. Subsequently, after the photo-hardening, a resist mask is formed in a necessary area on the surface of the head slider 20 by removing a portion which is not hardened in the resist with a developer. For example, by removing the alumina-titanium carbide on the slider surface with a method such as ion-milling, a negative-pressure groove 24 is formed. Further, by mounting the head slider 20 on the suspension 12b with an adhesive, a head-gimbal-assembly is assembled.

The head slider 20 has a total length of 2050 μm and a total width of 1600 μm. The first bending portions 21b and 22b of the side-rails 21 and 22 have a bending angle of 25 degrees. A distance L from bending points 21d and 22d of the side-rails 21 and 22 to the downstream side is 700 μm. A distance R from the bending-start points of the first bending portions 21b and 22b to the downstream side is 1400 μm. A magnetic transducer head 26 is mounted on, for example, the downstream side perpendicular to the side-rail 21.

When the flying head slider 20 formed in the above manner is included in, for example, a 3.5-inch hard disc drive, the lift distance of the head slider 20 with respect to positions in the radial direction of the magnetic disc is

shown in Fig. 12. The roll of the head slider 20 with positions in the radial direction of the magnetic disc is shown in Fig. 13. Accordingly, it is understood that preferred constant floating characteristics and constant roll characteristics expressed by approximately zero are obtained in accordance with the above-described flying head slider 20.

The computer simulation of a change in the lift distance obtained when two parameters of the bending angle θ and the bending point position L are changed in the flying head slider 20 is described below.

At first, four models A, B, C and D are considered. Model A is a case in which the bending-point position L = 600 μm, L/R = 0.43 and the bending angle = 20 degrees. Model B is a case in which the bending-point position L = 600 μm, L/R = 0.43 and the bending angle = 30 degrees. Model C is a case in which the bending-point position L = 800 μm, L/R = 0.57 and the bending angle = 20 degrees. Model D is a case in which the bending-point position L = 800 μm, L/R = 0.57 and the bending angle = 30 degrees.

According to these models A to D, the lift distance with respect to the skew angle is expressed as shown in Fig. 14. The affection to the lift distance by the skew angle with respect to the bending angle θ in which L/R = 0.5 is expressed as shown in Fig. 15. In Fig. 14 a curve E

represents the characteristic of the above-mentioned flying head slider 20 shown in Fig. 11.

According to these models A to D, the roll with respect to the skew angle is expressed as shown in Fig. 16. The roll with respect to the bending angle θ in which L/R = 0.5 is expressed as shown in Fig. 17.

To the contrary, according to these models A to D, the lift distance with respect to the peripheral velocity is expressed as shown in Fig. 18. The affection to the lift distance by the peripheral velocity with respect to the bending angle θ in which L/R = 0.5 is expressed as shown in Fig. 19.

By comparing these conditions to the optimal condition (θ = 25 degrees, and L = 700 μm), it is found that a maximum change in the affection to the lift distance by the peripheral velocity is approximately 7 μm, a maximum change in the affection to the lift distance by the skew angle is approximately 8 nm, a maximum change in the roll is approximately 12 μm, and as a result, almost constant preferred characteristics of the lift distance are obtained.

Fig. 20 is a perspective view illustrating a flying head slider according to a second embodiment of the present invention.

The flying head slider 30 is formed into a rectangular

parallelepiped that is wholly flat. The bottom surface of the head slider 30 includes two side-rails 31 and 32 acting as air bearing surfaces, and a cross-rail 33 connecting these side-rails.

The respective side-rails 31 and 32 are disposed in two parts of the bottom surface to the longitudinal side so that they extend along the direction from the upstream side to the downstream side of the head slider 30. The rails 31 and 32 form a negative-pressure groove 34 therebetween. The cross-rail 33 is disposed so as to connect the side-rails 31 and 32 on the upstream ends thereof.

In this embodiment the cross-rail 33 does not include a separation groove.

The head slider 30 includes a taper portion 35 in a part of the bottom surface to the upstream side.

This taper portion 35 has a predetermined angle, for example, a gentle angle of inclination of not more than 1 degree with respect to the air bearing surfaces formed by the side-rails 31, 32 and the cross-rail 33.

The side-rails 31 and 32 are formed so as to include, sequentially from the upstream side, first bending portions 31a and 32a which extend inward along the longitudinal direction from the cross-rail 17, and second bending portions 31b and 32b which extend outward along the longitudinal direction. The first bending portions 31a, 32a

and the second bending portions 31b and 32b form bending points 31c, 32c in the center of both first and second portions.

In this embodiment the second bending portions 31b and 32b are formed so that their widths are constant, and does not have flared portions.

The flying head slider 30 having such a structure operates similarly and shows the same advantages as the flying head slider 13 shown in Fig. 2.

Fig. 21 is a view illustrating the bottom of a flying head slider according to a third embodiment of the present invention.

The flying head slider 40 is formed into a rectangular parallelepiped that is wholly flat. The bottom surface of the head slider 40 includes two side-rails 41 and 42 acting as air bearing surfaces, and a cross-rail 43 connecting these side-rails.

The respective side-rails 41 and 42 are disposed in two parts of the bottom surface to the longitudinal sides of the head slider 40 so that they extend along the direction from the upstream side to the downstream side of the head slider 40. The rails 41 and 42 form a negative-pressure groove 44 therebetween. The cross-rail 43 is disposed so as to connect the side-rails 41 and 42 on the upstream end thereof.

In this embodiment the cross-rail 43 includes a separation groove 43a in the center to the downstream side.

The head slider 40 includes a taper portion 45 in a part of the bottom surface to the upstream side.

This taper portion 45 has a predetermined angle, for example, a gentle angle of inclination of not more than 1 degree with respect to the air bearing surfaces formed by the side-rails 41, 42 and the cross-rail 43.

The side-rails 41 and 42 are formed so as to include, sequentially from the upstream side, parallel rail portions 41a and 42a which extend along the longitudinal direction from the cross-rail 43, first bending portions 41b and 42b which extend inward along the longitudinal direction, and second bending portions 41c and 42c which extend outward along the longitudinal direction. The first bending portions 41b, 42b and the second bending portions 41c and 42c form bending points 41d, 42d in the center of both first and second portions.

The flying head slider 40 having such a structure operates similarly and shows the same advantages as the flying head slider 13 shown in Fig. 2.

Fig. 22 is a view illustrating the bottom surface of a flying head slider according to a fourth embodiment of the present invention.

The flying head slider 50 has almost the same structure

as the flying head slider 20 shown in Fig. 20, except for having a step portion instead of the taper portion 35. In other words, the flying head slider 50 is formed into a rectangular parallelepiped that is wholly flat. The bottom surface of the head slider 50 includes two side-rails 51 and 52 acting as air bearing surfaces, and a cross-rail 53 connecting these side-rails.

The respective side-rails 51 and 52 are disposed in two parts of the bottom surface to the longitudinal sides so that they extend along the direction from the upstream side to the downstream side of the head slider 50. The rails 51 and 52 form a negative-pressure groove 54 therebetween. The cross-rail 53 is disposed so as to connect the side-rails 51 and 52 on the upstream end thereof.

In this embodiment the cross-rail 53 does not include a separation groove.

The head slider 50 includes a step portion 55 in a part of the bottom surface to the upstream side.

This step portion 55 are parallel to the air bearing surfaces formed by the side-rails 51, 52 and the cross-rail 53, and has a predetermined difference in level with respect to the surfaces.

The side-rails 51 and 52 are formed so as to include, sequentially from the upstream side, first bending portions 51a and 52a which extend inward along the longitudinal

direction from the cross-rail 53, and second bending portions 51b and 52b which extend outward along the longitudinal direction. The first bending portions 51a, 52a and the second bending portions 51b and 52b form bending points 51c and 52c in the center of both first and second portions.

In this embodiment the second bending portions 51b and 52b are formed so that their widths are constant, and do not include flared portions.

The flying head slider 50 having such a structure operates similarly, and shows the same advantages as the flying head slider 15 shown in Fig. 2.

Fig. 23 is a perspective view illustrating a flying head slider according to a fifth embodiment of the present invention.

The flying head slider 60 has almost the same structure as the flying head slider 30 shown in Fig. 20, except for a flow-conducting portion formed in the center to the downstream side. In other words, the flying head slider 60 is formed into a rectangular parallelepiped that is wholly flat. The bottom surface of the head slider 50 includes two side-rails 61 and 62 acting as air bearing surfaces, and a cross-rail 63 connecting these side-rails.

The respective side-rails 61 and 62 are disposed in two parts of the bottom surface to the longitudinal sides so

that they extend along the direction from the upstream side to the downstream side of the head slider 60. The rails 61 and 62 form a negative-pressure groove 64 therebetween. The cross-rail 63 is disposed so as to connect the side-rails 61 and 62 on the upstream end thereof.

In this embodiment the cross-rail 63 does not include a separation groove.

The head slider 60 includes a taper portion 65 in a part of the bottom surface to the upstream side.

This taper portion 65 has a predetermined angle, for example, a gentle angle of inclination of not more than 1 degree, with respect to the air bearing surfaces formed by the side-rails 61, 62 and the cross-rail 63.

The side-rails 61 and 62 are formed so as to include, sequentially from the upstream side, first bending portions 61a and 62a which extend inward along the longitudinal direction from the cross-rail 63, and second bending portions 61b and 62b which extend outward along the longitudinal direction. The first bending portions 61a, 62a and the second bending portions 61b and 62b form bending points 61c, 62c in the center of both first and second portions.

In this embodiment the second bending portions 61b and 62b are formed so that their widths are constant, and do not include flared portions.

The flying head slider 60 includes a projecting air-guide portion 66 in the center on the bottom surface to the downstream side.

A magnetic transducer head 67 is mounted on the downstream side perpendicular to the projecting air-guide portion 66.

The projecting air-guide portion 66 is divergently formed toward the downstream side so that its end to the upstream side has a point. In this formation the airflow that streams in a negative pressure groove is separated right and left by the projecting air-guide portion 66, and the separated flows streams out.

The flying head slider 60 having such a structure operates similar and shows the same advantages as the flying head slider 16 shown in Fig. 2.

In the above embodiment the taper portion or the step portion is formed in a part of the bottom surface to the upstream side. However, it is obvious that the step portion instead of the taper portion, or the taper portion instead of the step portion may be formed. In the flying head sliders 13, 20, 30, 40, 50 and 60 according to the respective embodiments, each side-rail has only one bending position, however may have a plurality of bending points. In this case, by satisfying the above-mentioned condition with the bending angle θ of the bending portion closest to

the upstream side, the bending start point R closest to the upstream side, and the bending point position L closest to the upstream side, the affection to the lift distance by the peripheral velocity and the affection by the skew angle are suppressed, and a change in the roll is reduced, and thereby constant floating characteristics are obtained.

In the above embodiments concrete values are shown in connection with the widths and lengths of the side-rails. However, the side-rails formed almost in parallel along the longitudinal direction may have at least one bending point positioned inward. Its lengths and arrangement should be optimized corresponding to a hard disc drive in which the side-rails are included. Accordingly, the side-rails should not be limited to the shapes, arrangement and so forth shown in the above embodiments. It does not need saying that to the shapes, arrangement and so forth can be combined.

In the above embodiments the flying head sliders for hard disc drives for recording to or reproducing from a magnetic disc have been described, however, the present invention does need to be limited to such purpose, and can obviously be applied to, for example, flying head sliders for disc drives in which another type of disc such as a magneto-optical disc is used as a recording medium.

WHAT IS CLAIMED IS:

1. A flying head slider comprising:

two side-rails disposed on a surface of a slider body facing a recording medium so as to extend in parallel along the direction from the upstream side to the downstream side of said slider body;

an inclined portion or a step portion formed on a part of said surface to the upstream side;

a transducer mounted on the downstream side; and

a cross-rail disposed on said surface so as to connect the upstream ends of said two side-rails,

said two side-rails each having at least one bending point between the upstream end and the downstream end thereof,

and each side-rail extending inward along the longitudinal direction of said surface between the upstream end and said bending point, and extending outward along the longitudinal direction between the downstream end and said bending point.

2. A flying head slider according to Claim 1, wherein each side-rail has a width-extended portion whose width is extended inward or outward in the proximity of the downstream end.

3. A flying head slider according to Claim 1, wherein said cross-rail has a separation groove in the center thereof.

4. A flying head slider according to Claim 1, wherein each side-rail has a parallel rail portion extending from said cross-rail along the longitudinal direction of said surface.

5. A flying head slider according to Claim 1, wherein said transducer is mounted on a part of the downstream side positioned perpendicular to either of said side-rails.

6. A flying head slider according to Claim 1, further comprising a projecting air-guide portion formed so as to diverge toward the downstream side in the vicinity of the center of the downstream region of said surface.

7. A flying head slider according to Claim 1, wherein said transducer is mounted on a part of the downstream side perpendicular to said projecting air-guide portion.

8. A flying head slider according to Claim 1, wherein the bending portion of each side-rail extending to the

innermost of said surface from the upstream end has a bending angle θ with respect to the longitudinal side of said surface, such angle being defined by the following range:

$$10 \text{ degrees} \leq \theta \leq 30 \text{ degrees}$$

9. A flying head slider according to Claim 1, wherein the bending portion of each side-rail extending to the innermost of said surface from the upstream end has a bending angle θ with respect to the longitudinal side of said surface, such angle being defined by the following range:

$$20 \text{ degrees} \leq \theta \leq 30 \text{ degrees}$$

10. A flying head slider according to Claim 1, wherein the bending portion of each side-rail satisfies the following relation:

$$0.30 \leq L/R \leq 0.70$$

where L represents the distance between the bending portion closest to the upstream end and the downstream end; and R: the distance between a point at which the bending portion starts and the downstream end.

11. A flying head slider according to Claim 1, wherein

the bending portion of each side-rail satisfies the following relation:

$$0.40 \leq L/R \leq 0.70$$

where L represents the distance between the bending portion closest to the upstream end and the downstream end; and R: the distance between a point at which the bending portion starts and the downstream end.

12. A magnetic disc drive comprising:

a magnetic disc used as a recording medium;

driving means for rotating said magnetic disc;

a turning actuator swingably supported with respect to said magnetic disc rotated by said driving means;

a flying head slider mounted on the head of said turning actuator;

a magnetic transducer head mounted on said flying head slider for recording to or reproducing from said magnetic disc; and

a driving mechanism for swinging said turning actuator,

wherein said flying head slider has:

two side-rails disposed on a surface of a slider body facing a recording medium so as to extend in parallel along the direction from the upstream side to the downstream side of said slider body;

an inclined portion or a step portion formed on a part

of said surface to the upstream side;

a transducer mounted on the downstream side; and

a cross-rail disposed on said surface so as to connect the upstream ends of said two side-rails,

said two side-rails each having at least one bending point between the upstream end and the downstream end thereof,

and each side-rail extending inward along the longitudinal direction of said surface between the upstream end and said bending point, and extending outward along the longitudinal direction between the downstream end and said bending point.

FLYING HEAD SLIDER

ABSTRACT OF THE DISCLOSURE

A flying head slider has: two side-rails disposed on a surface of a slider body facing a recording medium so as to extend in parallel along the direction from the upstream side to the downstream side of the slider body; an inclined portion or a step portion formed on the surface on the upstream side; a transducer mounted on the downstream side; and a cross-rail disposed on the surface so as to connect the upstream ends of the two side-rails, in which the two side-rails each has at least one bending point between the upstream end and the downstream end thereof, and in which each side-rail extends inward along the longitudinal direction of the surface between the upstream end and the bending point, and extends outward along the longitudinal direction between the downstream end and the bending point.

Figure 2

FIG. 1

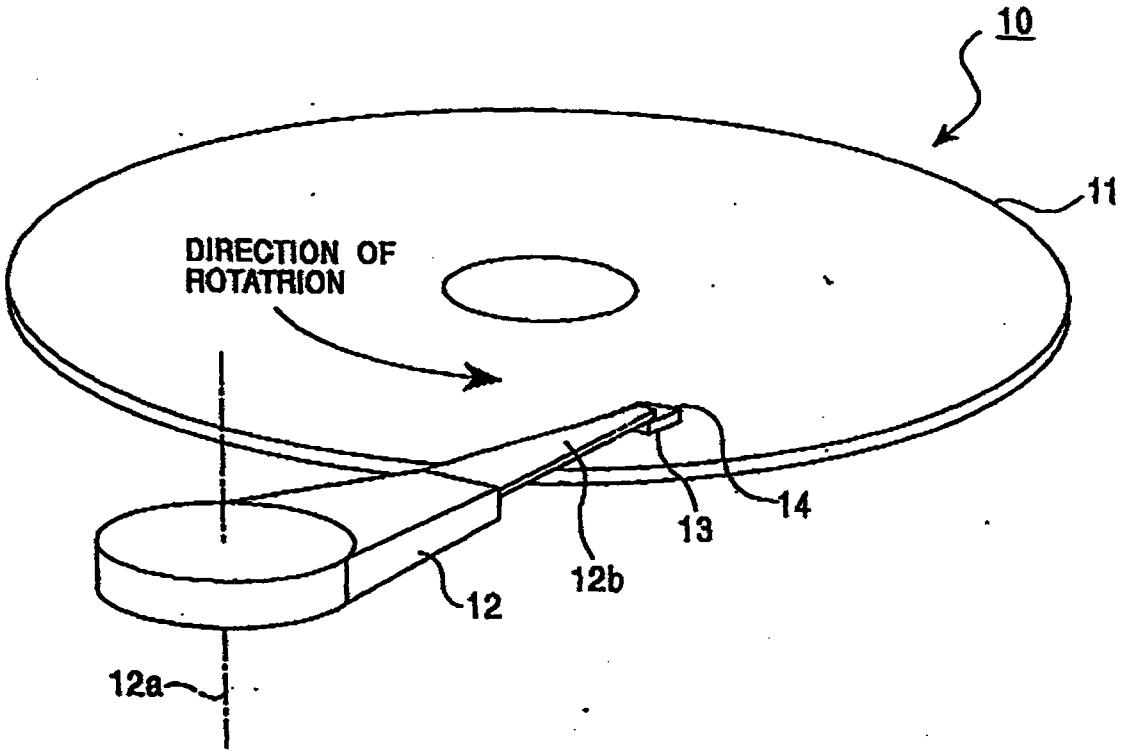


FIG. 2

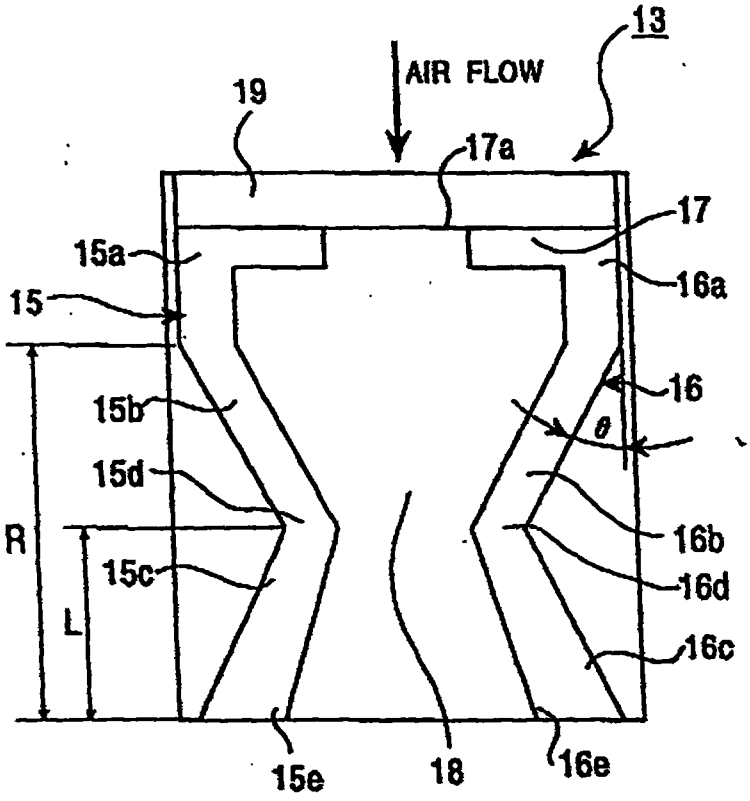

13
AIR FLOW
19
17a
17
15a
16a
15
16
θ
15b
15d
R
16b
15c
16d
L
16c
15e
18
16e

FIG. 3

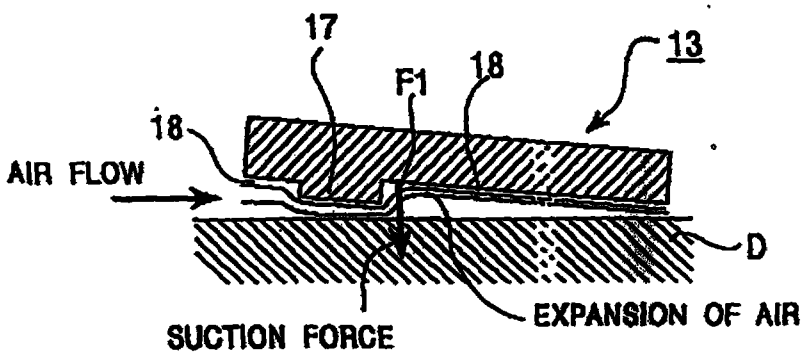

17
F1
18
13
18
AIR FLOW
D
SUCTION FORCE
EXPANSION OF AIR

FIG. 4

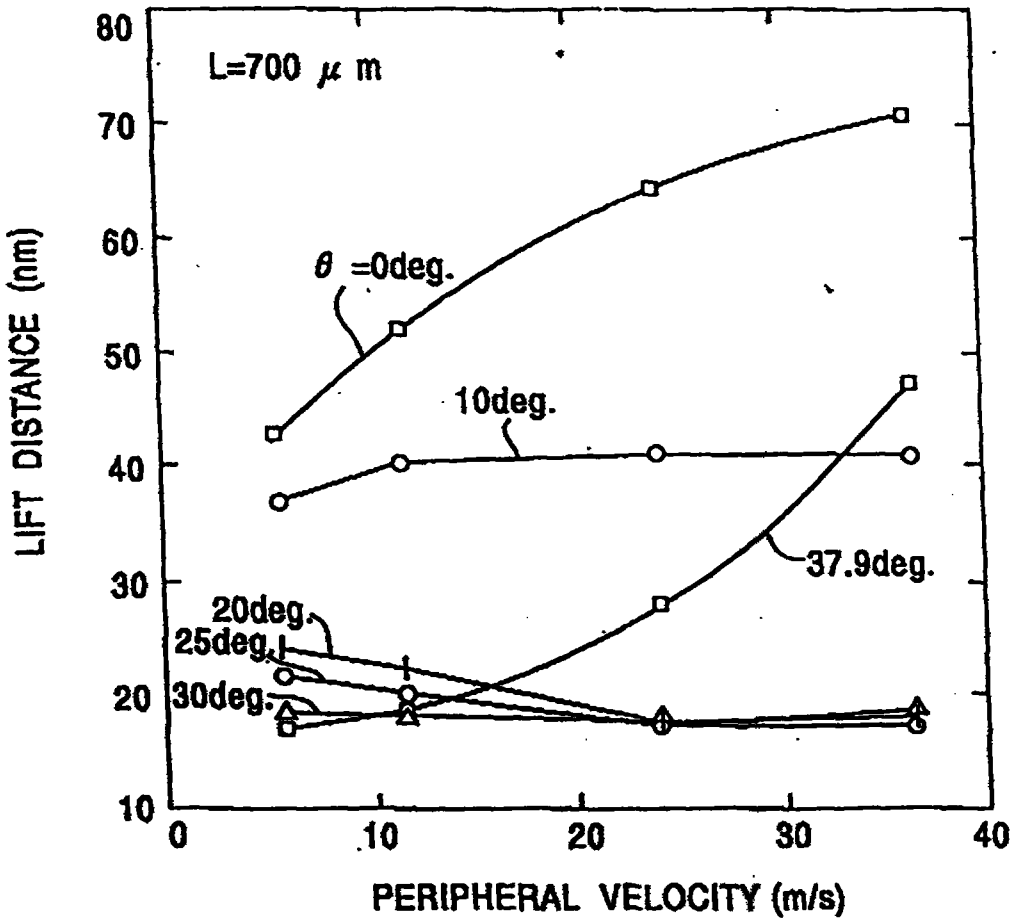

L=700 μ m
θ =0deg.
10deg.
37.9deg.
20deg.
25deg.
30deg.
LIFT DISTANCE (nm)
PERIPHERAL VELOCITY (m/s)
80
70
60
50
40
30
20
10
0
10
20
30
40

FIG. 5

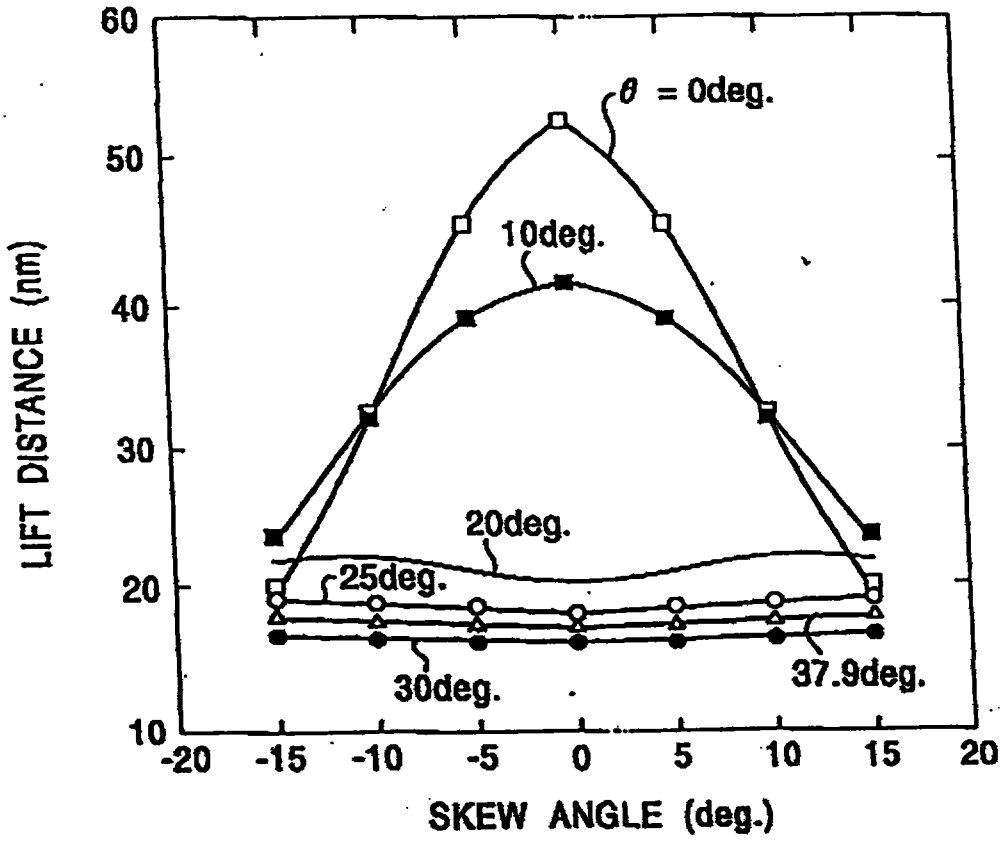

60
50
40
30
20
10
LIFT DISTANCE (nm)
θ = 0deg.
10deg.
20deg.
25deg.
30deg.
37.9deg.
-20
-15
-10
-5
0
5
10
15
20
SKEW ANGLE (deg.)

FIG. 6

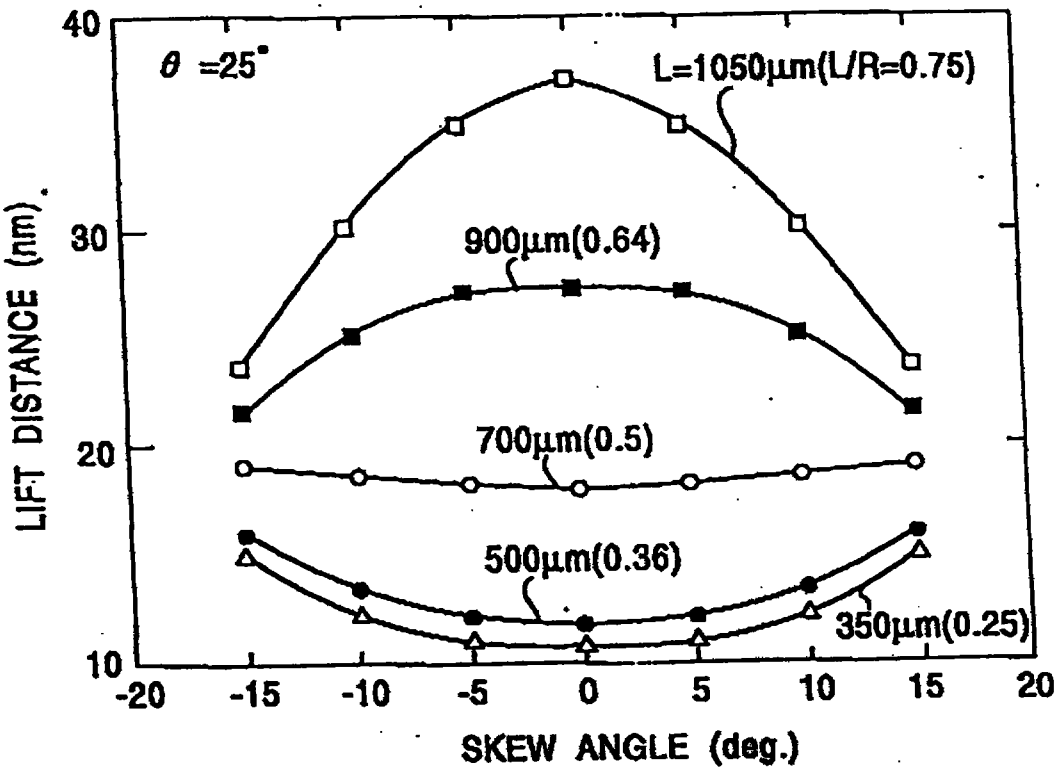

θ =25°
L=1050μm(L/R=0.75)
900μm(0.64)
700μm(0.5)
500μm(0.36)
350μm(0.25)
LIFT DISTANCE (nm)
SKEW ANGLE (deg.)
40
30
20
10
-20
-15
-10
-5
0
5
10
15
20

FIG. 7

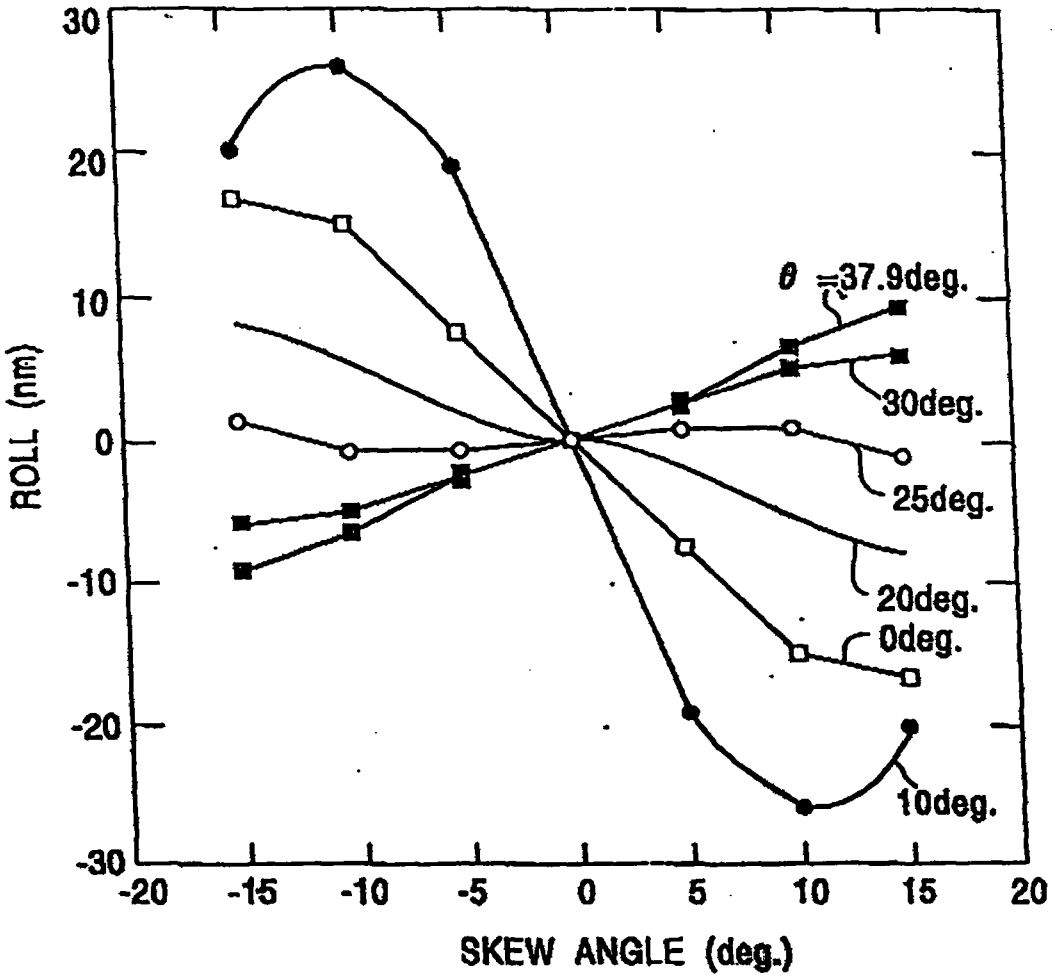

30
20
10
0
-10
-20
-30
ROLL (nm)
-20
-15
-10
-5
0
5
10
15
20
SKEW ANGLE (deg.)
θ =37.9deg.
30deg.
25deg.
20deg.
0deg.
10deg.

FIG. 8

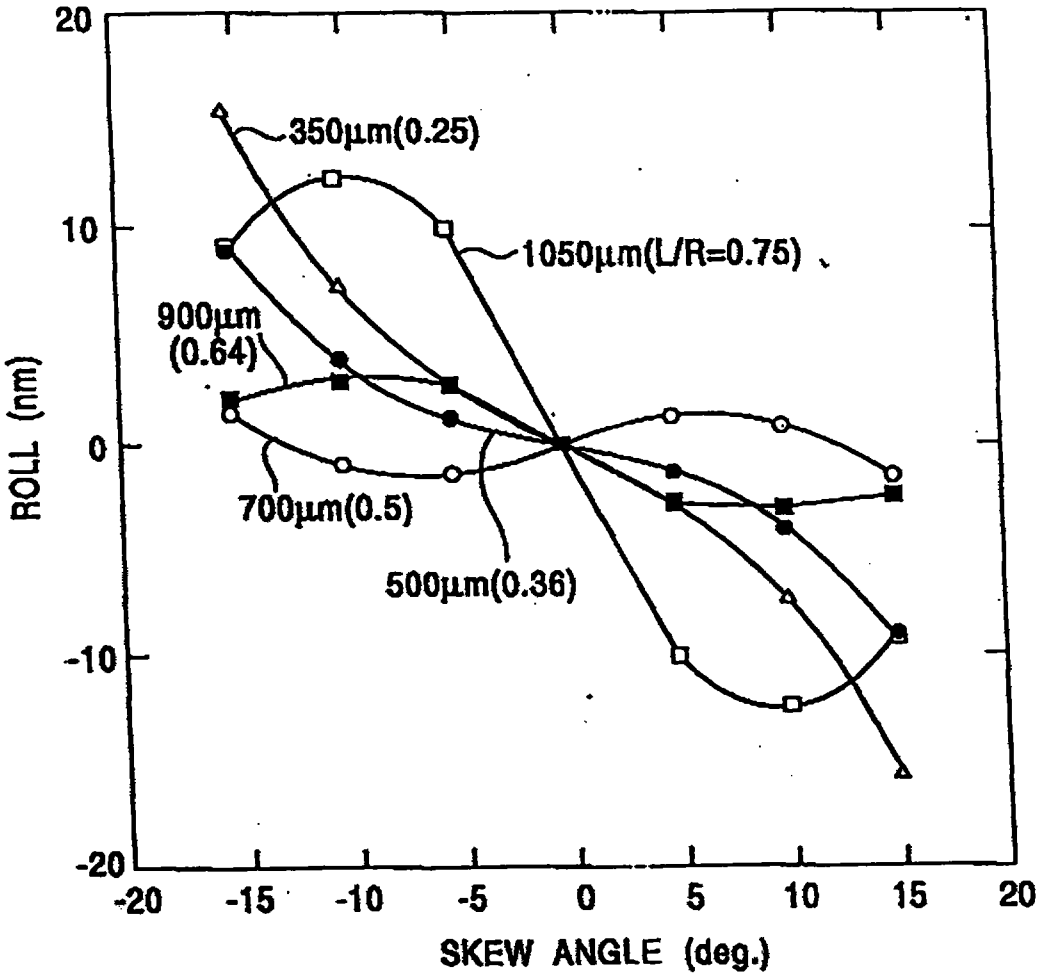

20
10
0
-10
-20
ROLL (nm)
-20
-15
-10
-5
0
5
10
15
20
SKEW ANGLE (deg.)
350μm(0.25)
1050μm(L/R=0.75)
900μm
(0.64)
700μm(0.5)
500μm(0.36)

FIG. 9

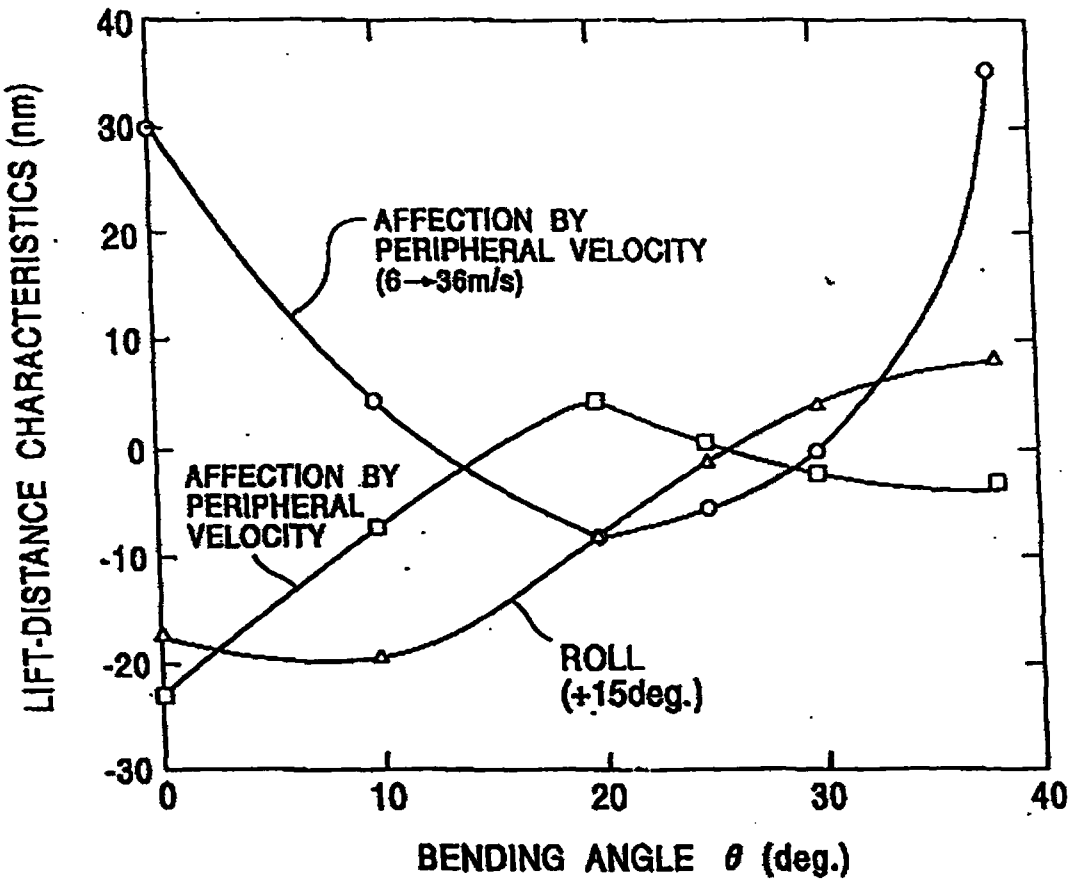

LIFT-DISTANCE CHARACTERISTICS (nm)
40
30
20
10
0
-10
-20
-30
0
10
20
30
40
BENDING ANGLE θ (deg.)
AFFECTION BY PERIPHERAL VELOCITY (6→36m/s)
AFFECTION BY PERIPHERAL VELOCITY
ROLL (+15deg.)

FIG. 10

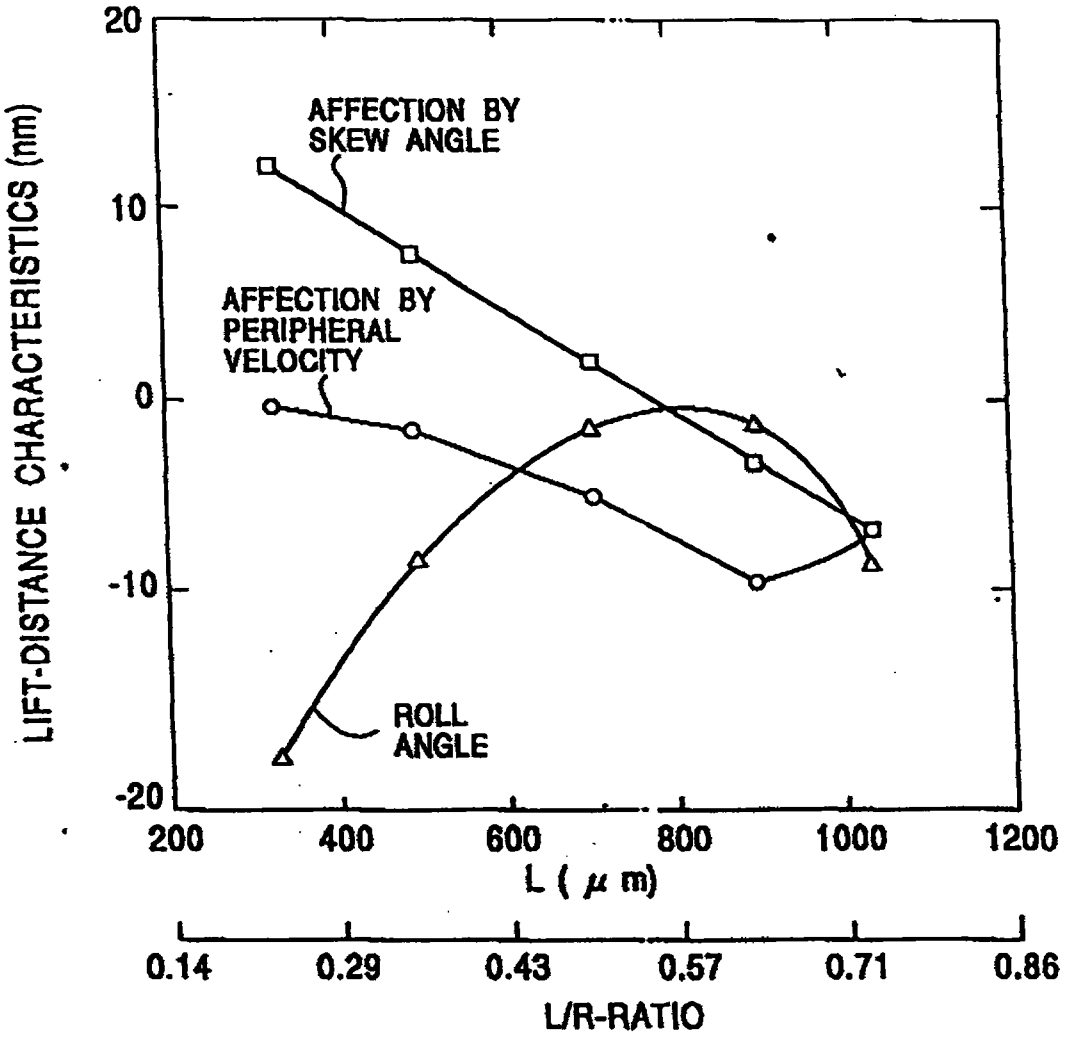

LIFT-DISTANCE CHARACTERISTICS (nm)
20
10
0
-10
-20
AFFECTION BY SKEW ANGLE
AFFECTION BY PERIPHERAL VELOCITY
ROLL ANGLE
200
400
600
800
1000
1200
L (μ m)
0.14
0.29
0.43
0.57
0.71
0.86
L/R-RATIO

FIG. 11

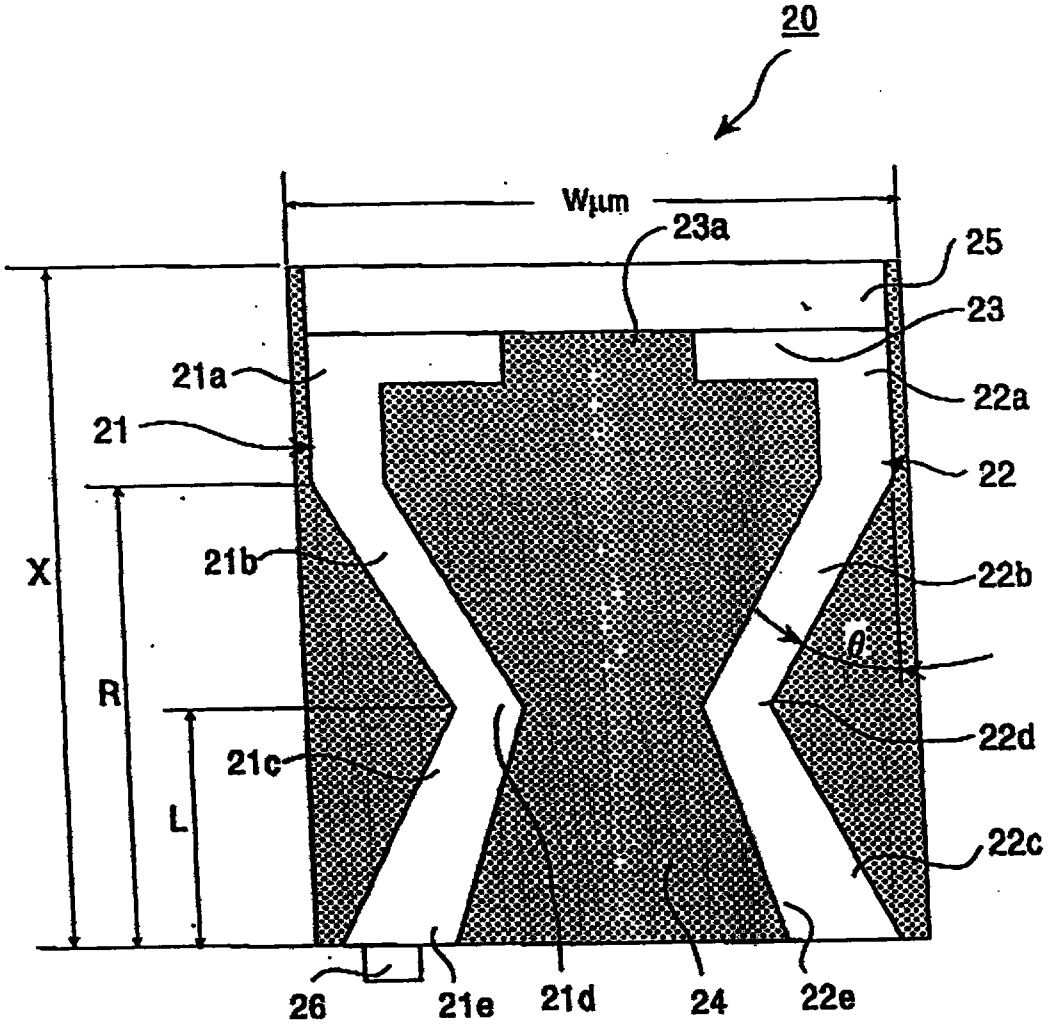

20
Wμm
23a
25
23
21a
22a
21
22
X
21b
22b
θ
R
22d
21c
L
22c
26
21e
21d
24
22e

FIG. 12

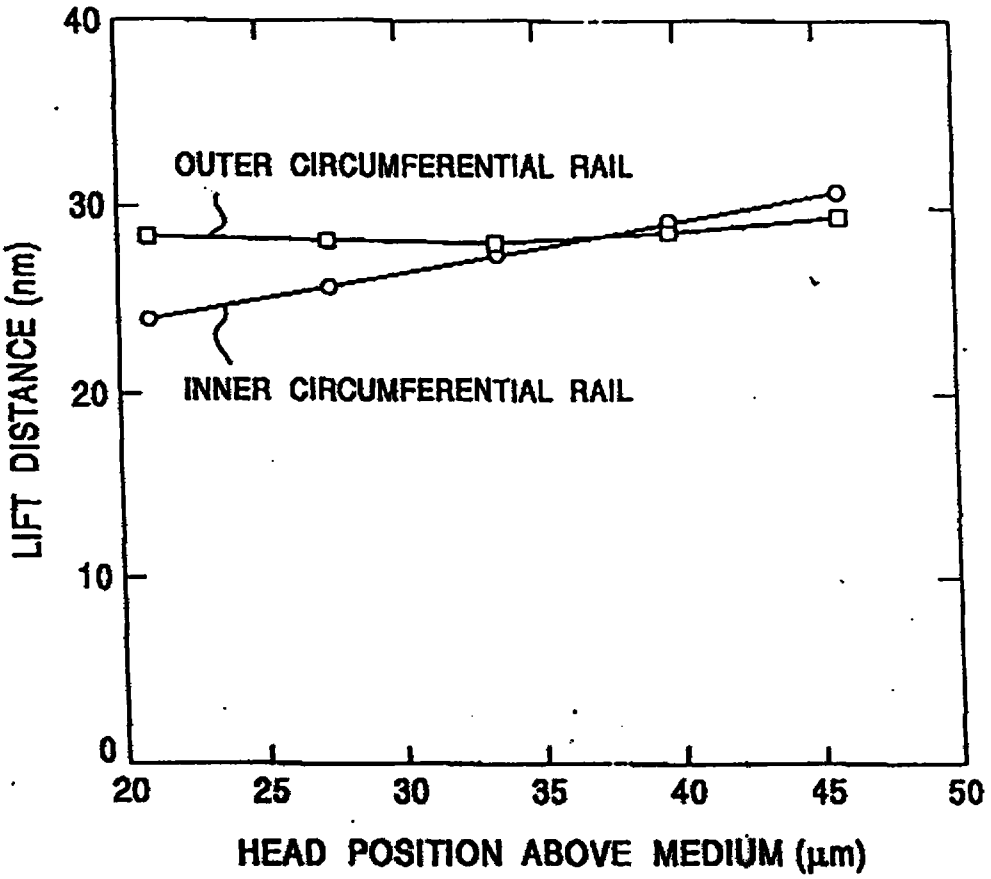

40
30
20
10
0
LIFT DISTANCE (nm)
OUTER CIRCUMFERENTIAL RAIL
INNER CIRCUMFERENTIAL RAIL
20
25
30
35
40
45
50
HEAD POSITION ABOVE MEDIUM (μm)

FIG. 13

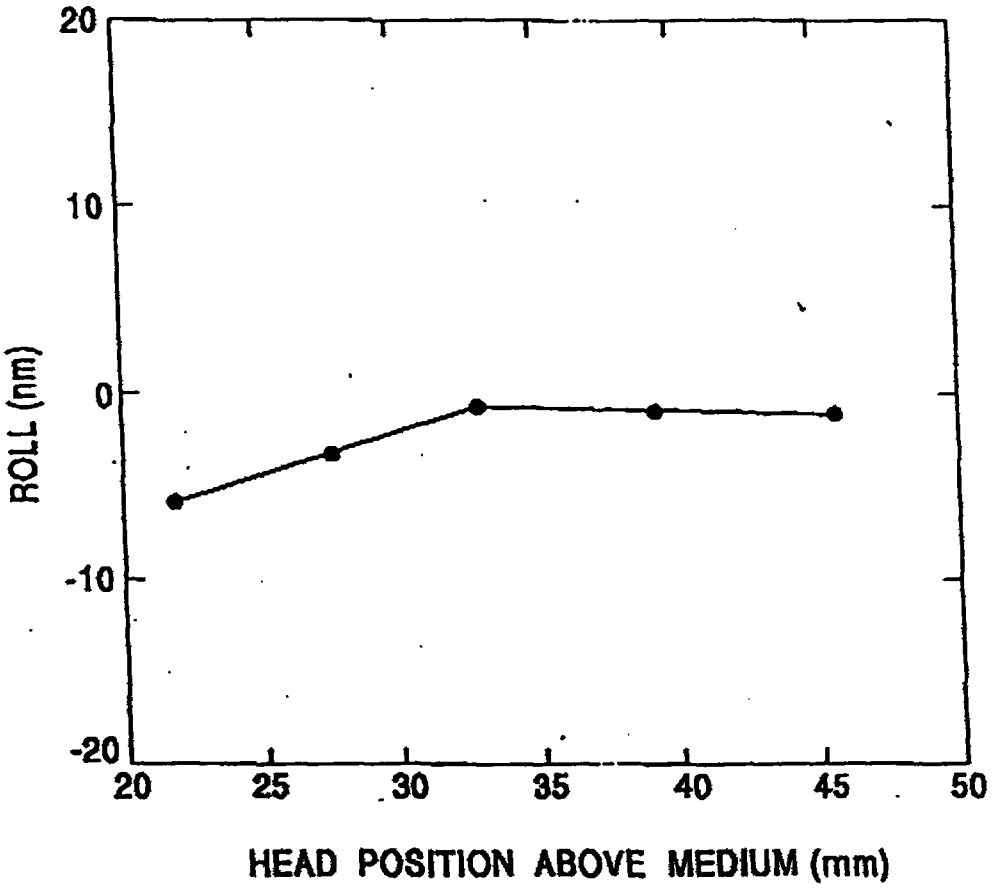

20
10
0
-10
-20
ROLL (nm)
20
25
30
35
40
45
50
HEAD POSITION ABOVE MEDIUM (mm)

FIG. 14

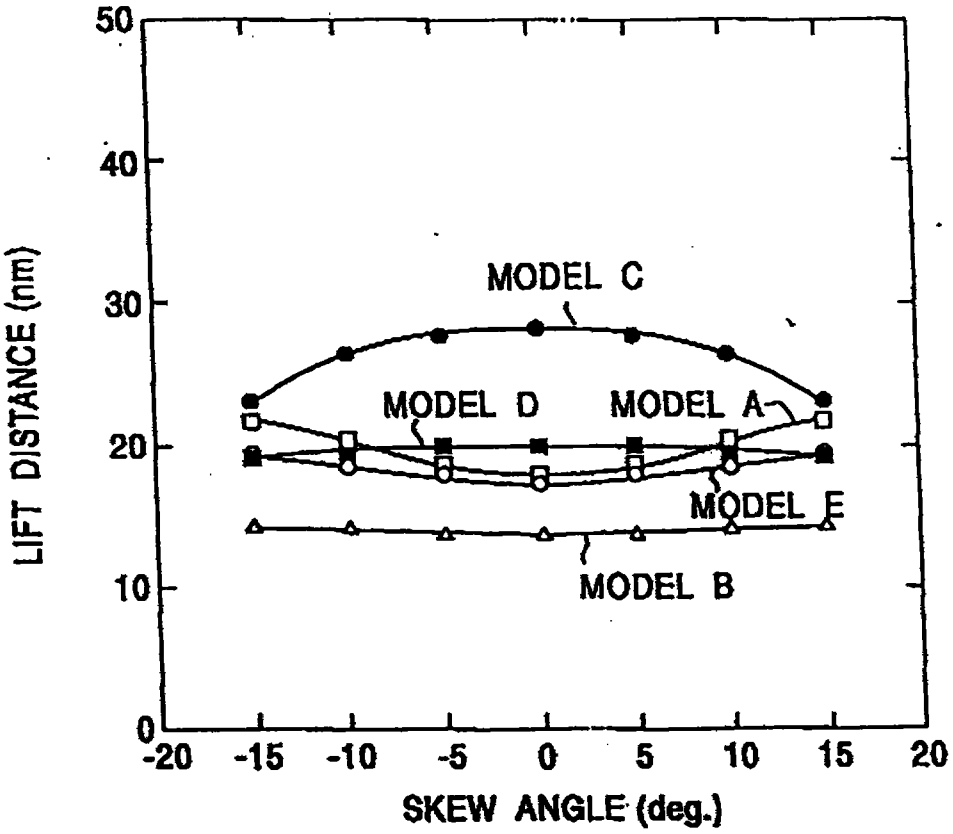

50
40
30
20
10
0
LIFT DISTANCE (nm)
MODEL C
MODEL D
MODEL A
MODEL E
MODEL B
-20
-15
-10
-5
0
5
10
15
20
SKEW ANGLE (deg.)

FIG. 15

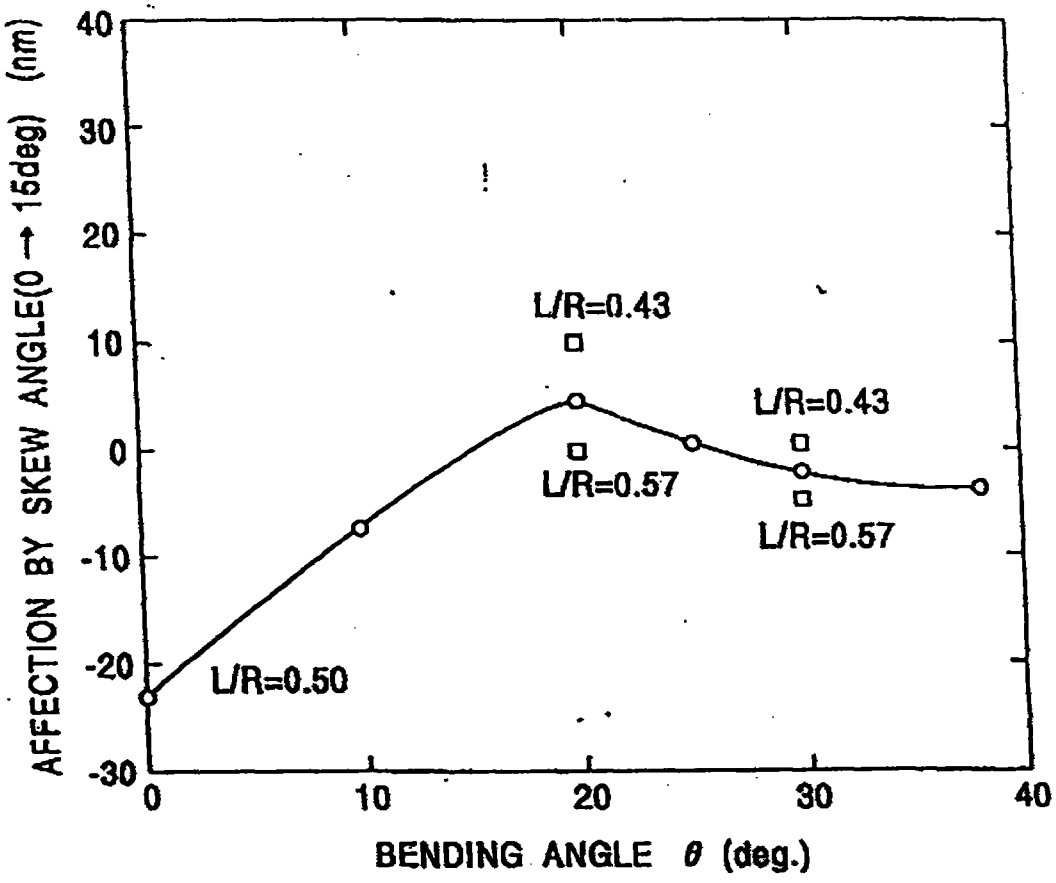

AFFECTION BY SKEW ANGLE(0 → 15deg) (nm)
40
30
20
10
0
-10
-20
-30
0
10
20
30
40
BENDING ANGLE θ (deg.)
L/R=0.43
L/R=0.43
L/R=0.57
L/R=0.57
L/R=0.50

FIG.16

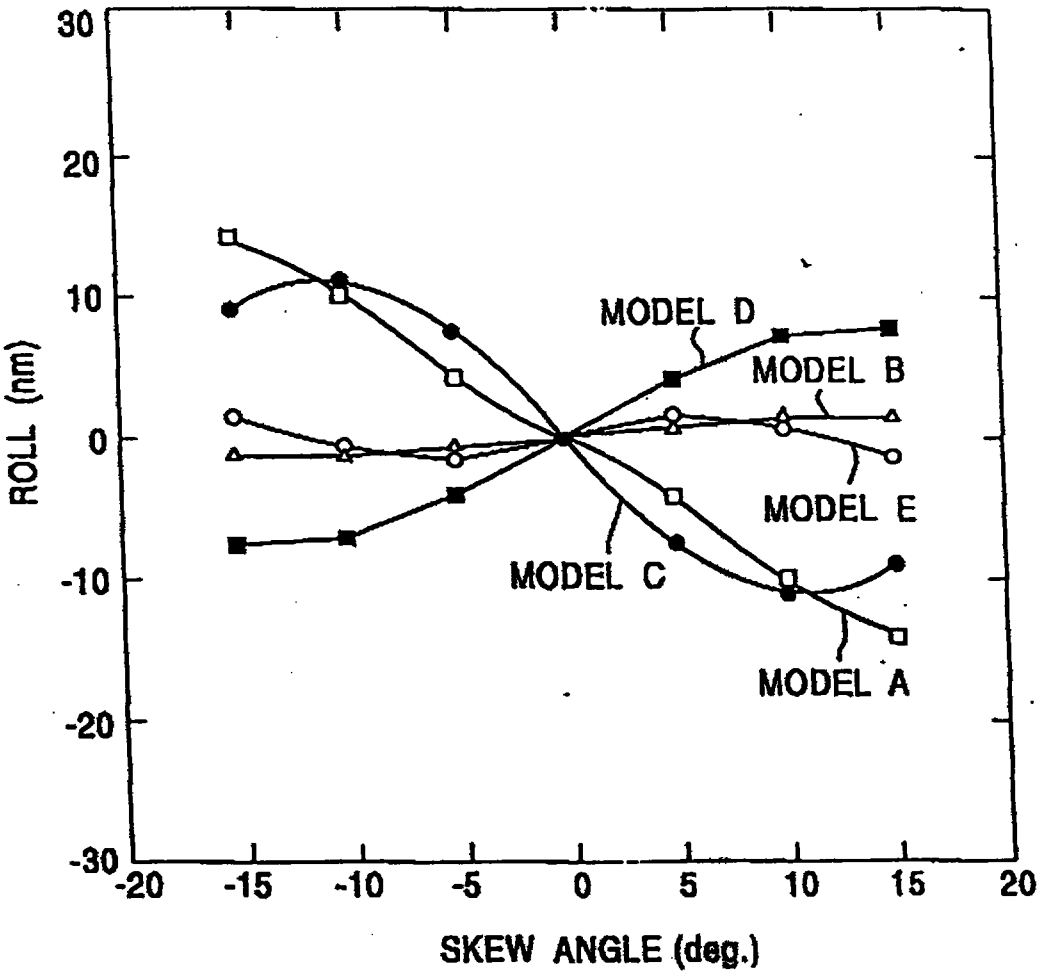

30
20
10
0
-10
-20
-30
-20
-15
-10
-5
0
5
10
15
20
ROLL (nm)
SKEW ANGLE (deg.)
MODEL D
MODEL B
MODEL E
MODEL C
MODEL A

FIG.17

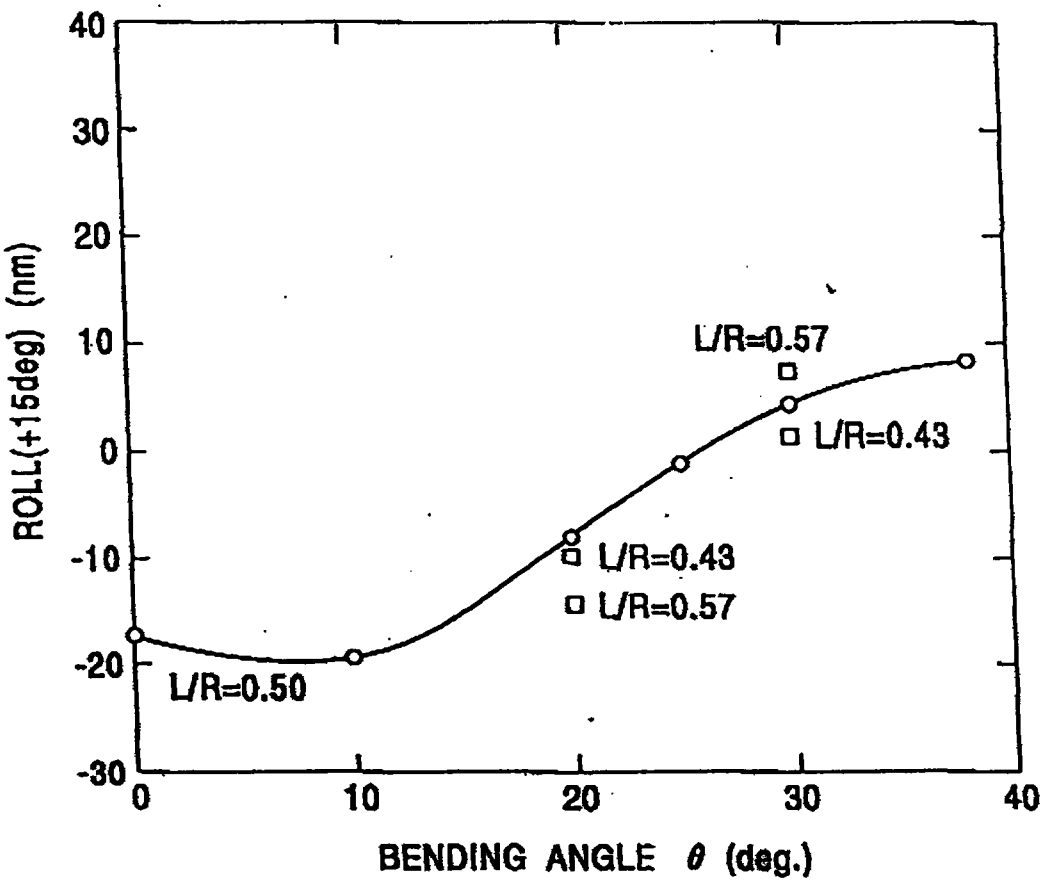

40
30
20
10
0
-10
-20
-30
0
10
20
30
40
ROLL(+15deg) (nm)
BENDING ANGLE θ (deg.)
L/R=0.57
L/R=0.43
L/R=0.43
L/R=0.57
L/R=0.50

FIG. 18

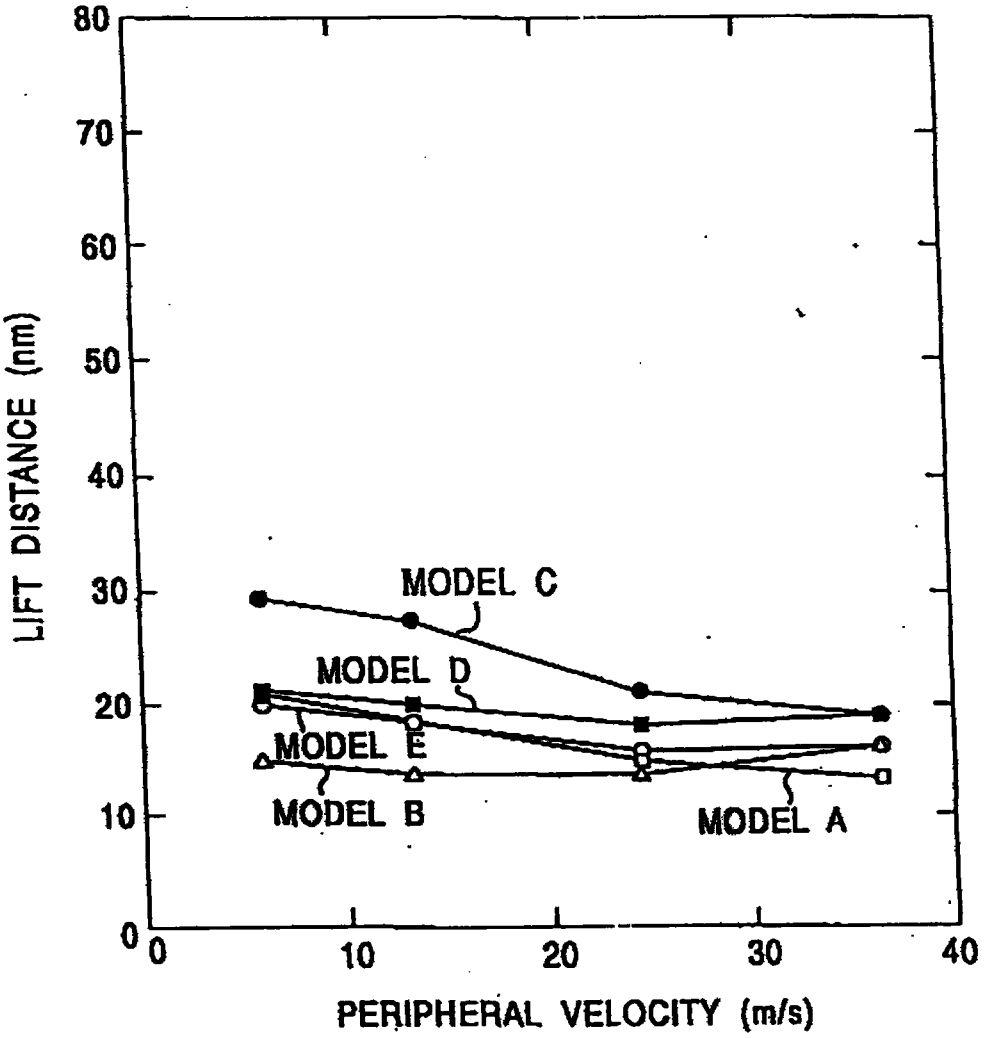

80
70
60
50
40
30
20
10
0
LIFT DISTANCE (nm)
0
10
20
30
40
PERIPHERAL VELOCITY (m/s)
MODEL C
MODEL D
MODEL E
MODEL B
MODEL A

FIG. 19

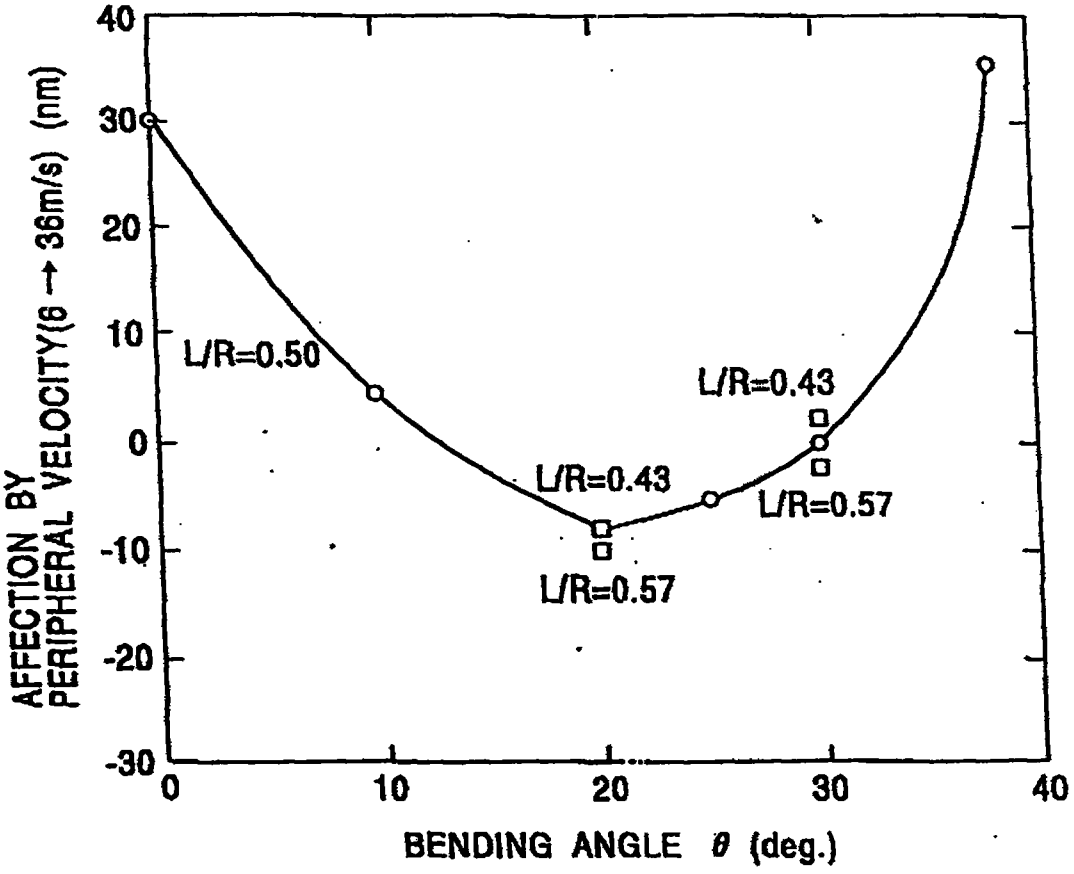

AFFECTION BY PERIPHERAL VELOCITY(6 → 36m/s) (nm)
40
30
20
10
0
-10
-20
-30
0
10
20
30
40
BENDING ANGLE θ (deg.)
L/R=0.50
L/R=0.43
L/R=0.57
L/R=0.43
L/R=0.57

FIG. 20

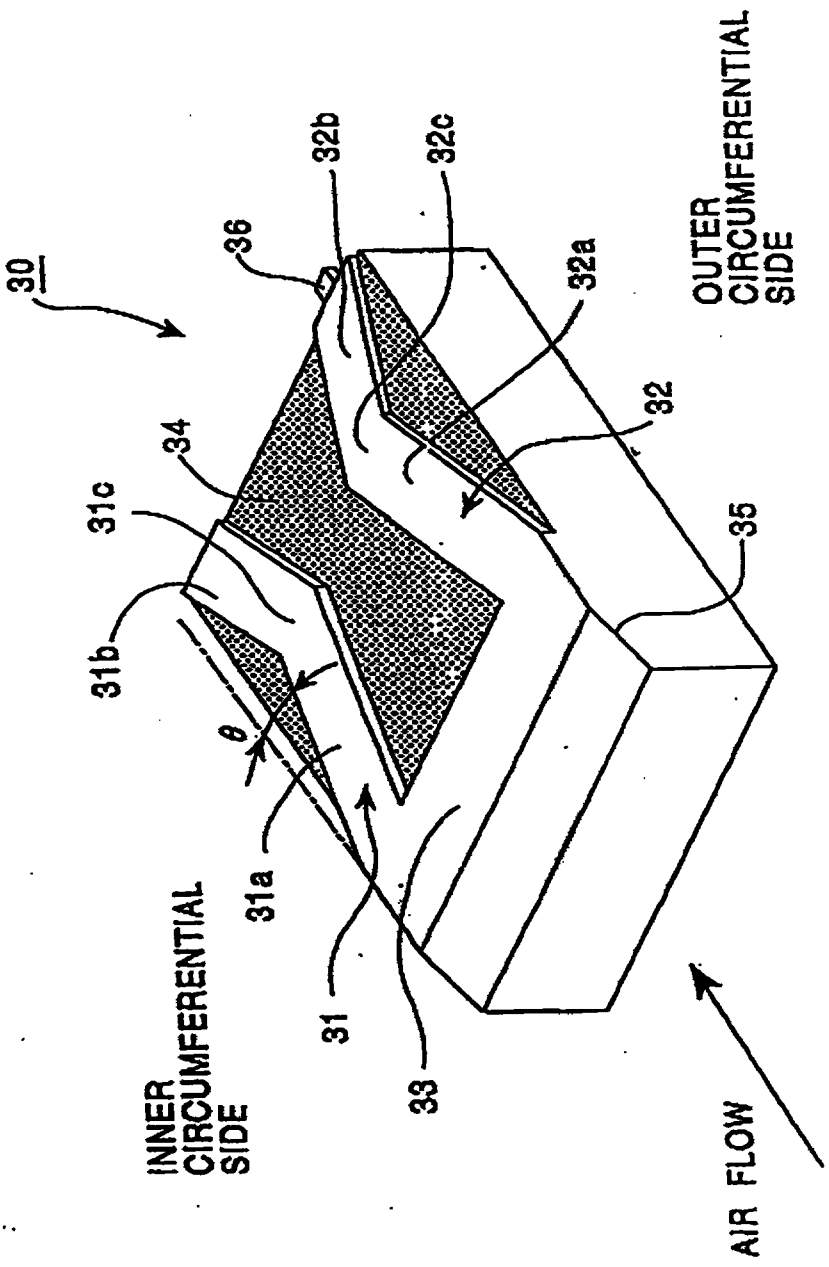

30
36
32b
32c
32a
OUTER CIRCUMFERENTIAL SIDE
32
34
31c
35
31b
θ
31a
INNER CIRCUMFERENTIAL SIDE
31
33
AIR FLOW

FIG. 21

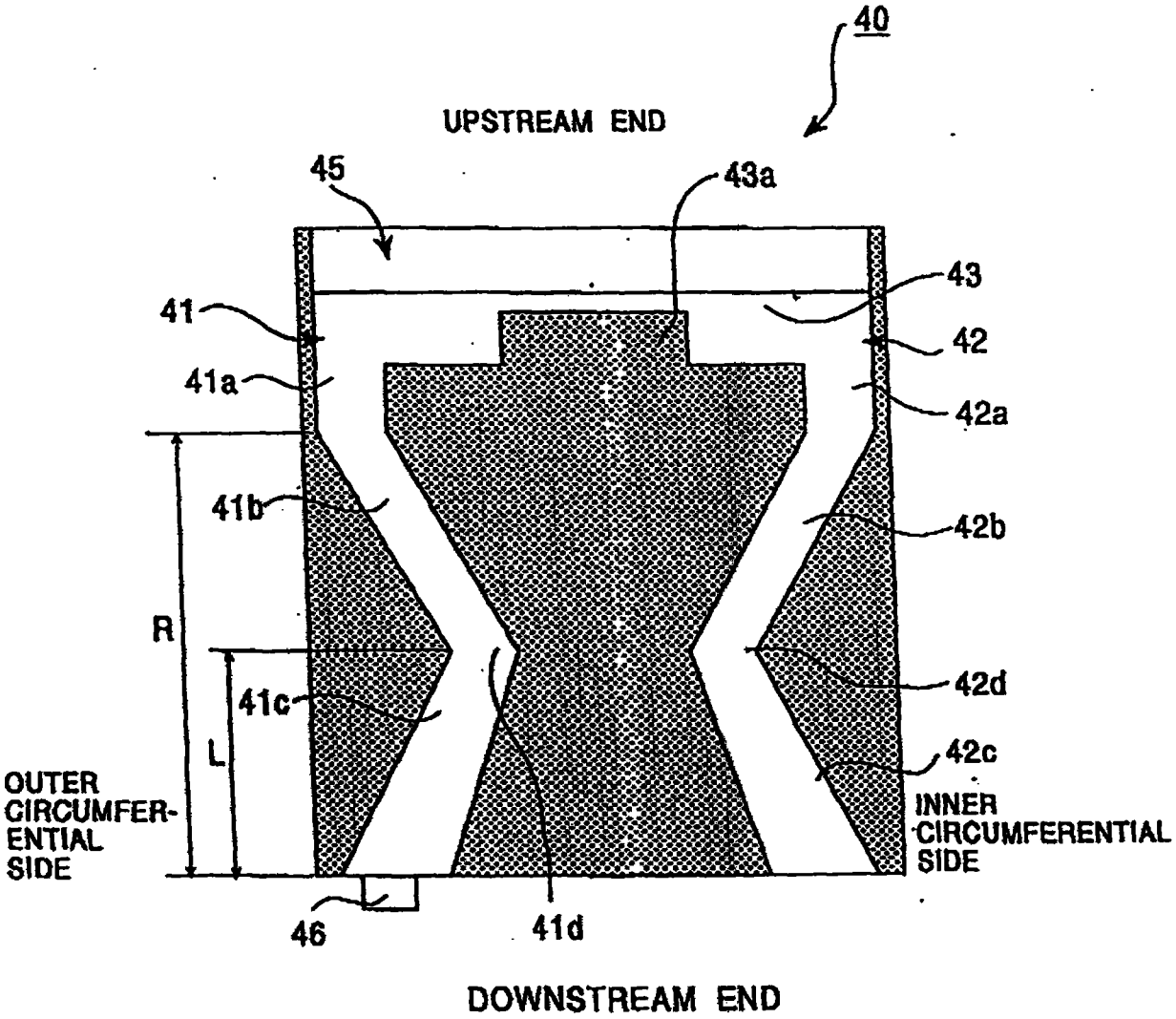

40
UPSTREAM END
45
43a
43
41
42
41a
42a
41b
42b
R
41c
42d
L
42c
OUTER CIRCUMFERENTIAL SIDE
INNER CIRCUMFERENTIAL SIDE
46
41d
DOWNSTREAM END

FIG. 22

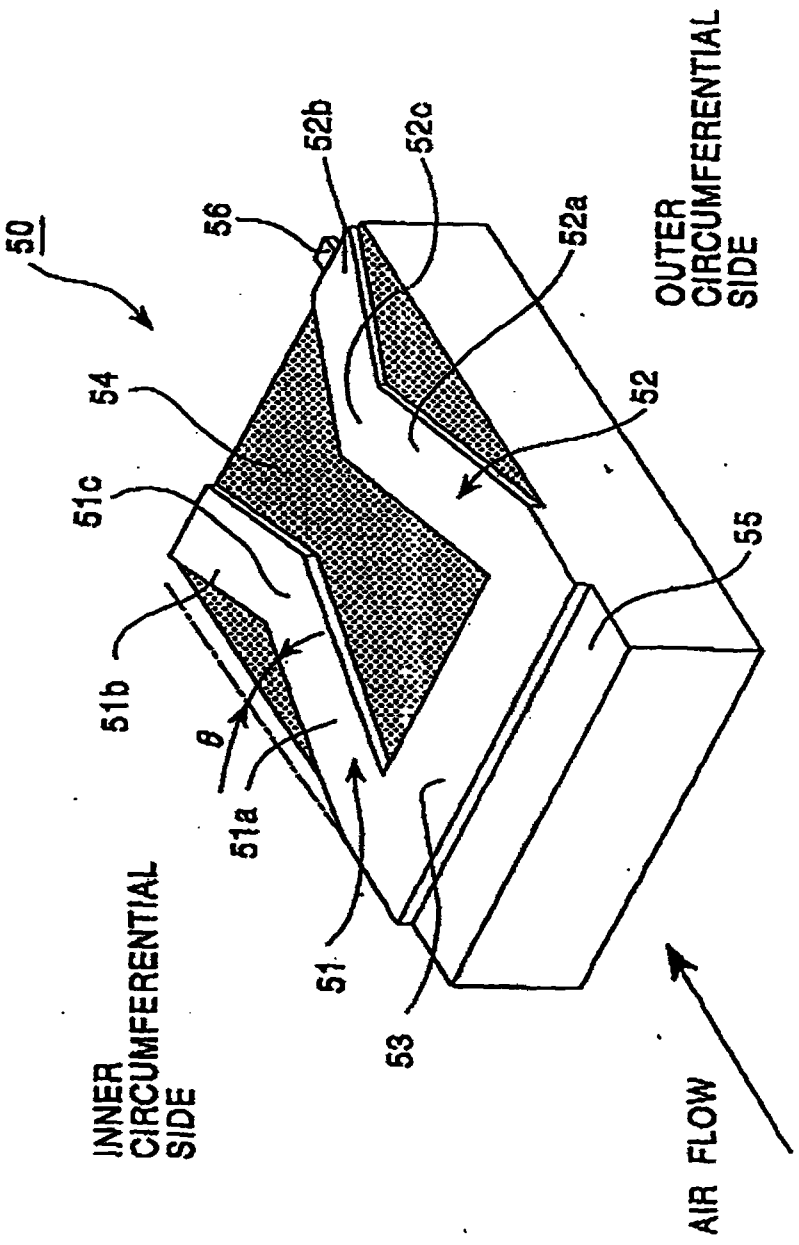

50
56
52b
52c
52a
OUTER CIRCUMFERENTIAL SIDE
54
52
51c
55
51b
θ
51a
51
53
INNER CIRCUMFERENTIAL SIDE
AIR FLOW

FIG. 23

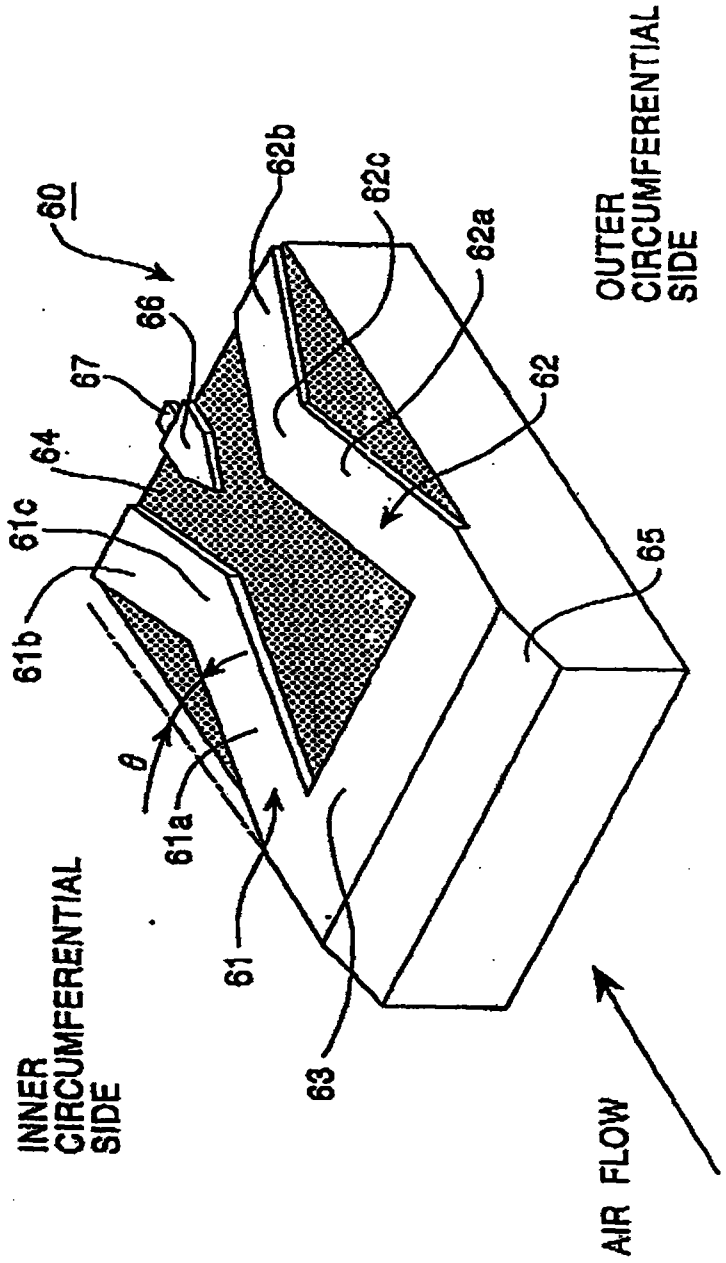

60
62b
62c
62a
62
OUTER CIRCUMFERENTIAL SIDE
66
67
64
61c
61b
65
θ
61a
61
63
INNER CIRCUMFERENTIAL SIDE
AIR FLOW

FIG. 24

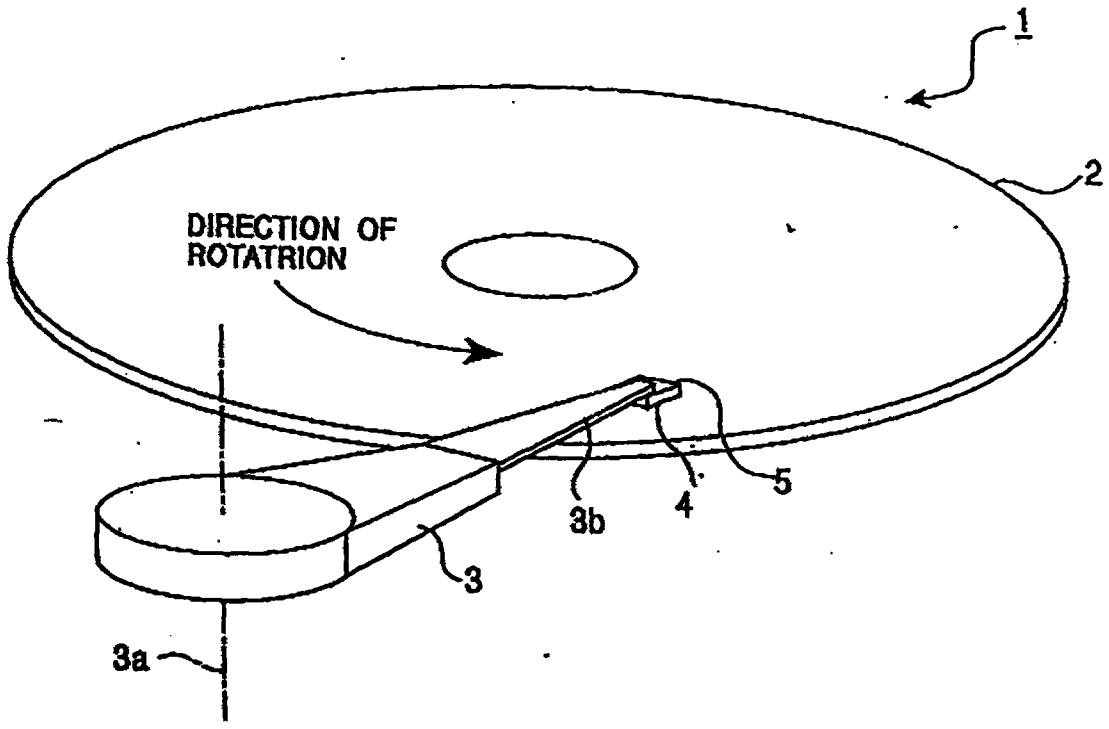


FIG. 25

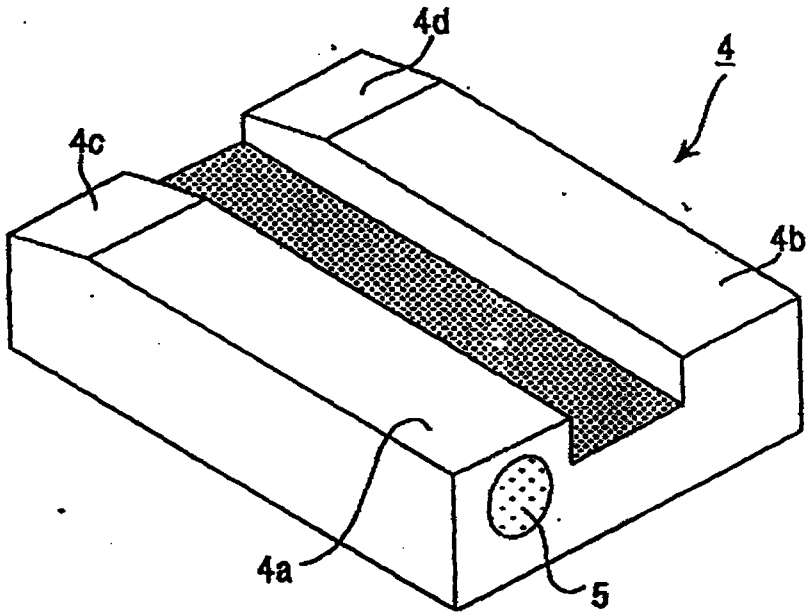


FIG. 26

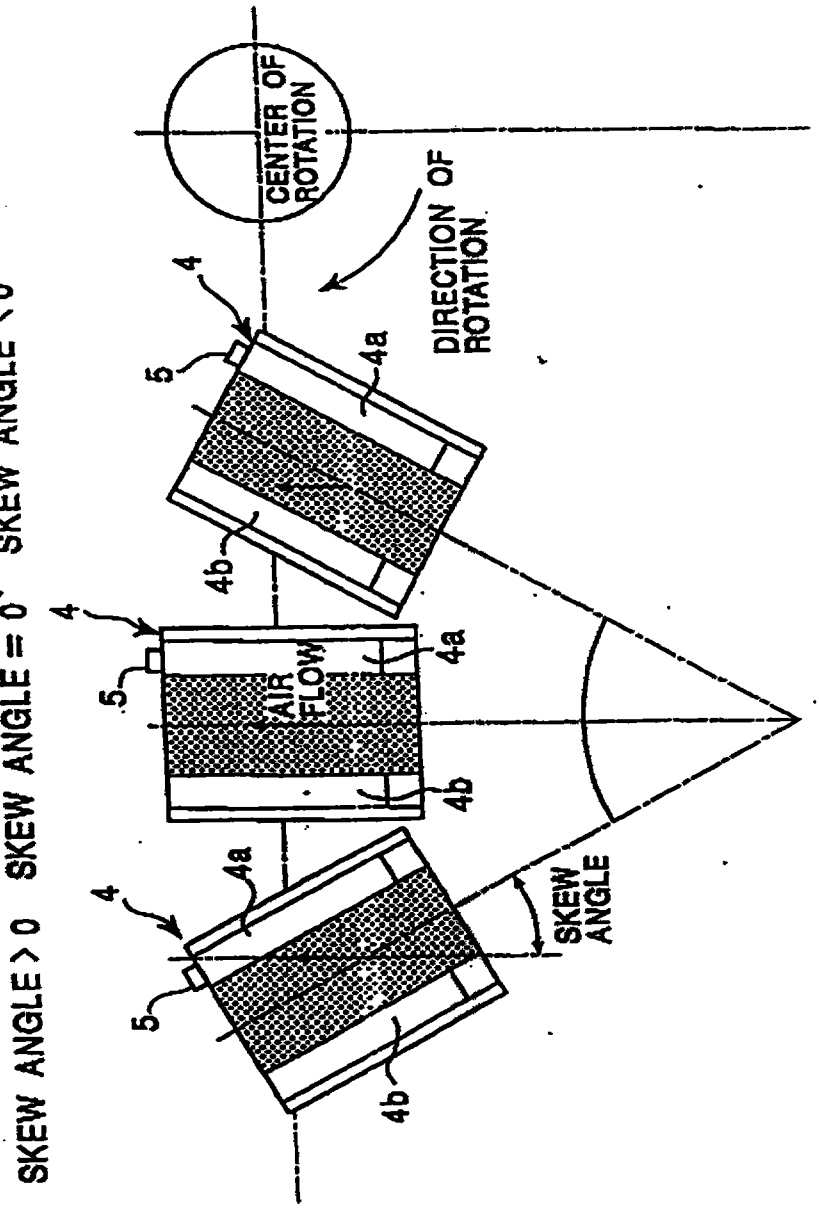
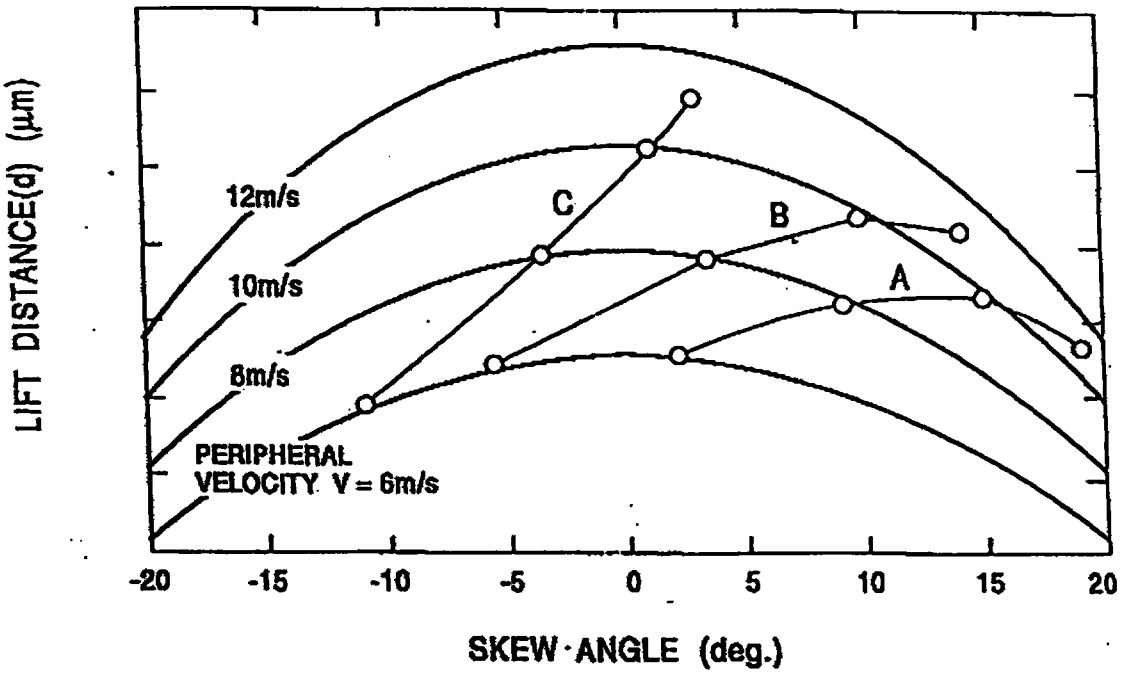

SKEW ANGLE > 0
SKEW ANGLE = 0°
SKEW ANGLE < 0
CENTER OF ROTATION
DIRECTION OF ROTATION
AIR FLOW
SKEW ANGLE
4
4a
4b
5

FIG. 27


LIFT DISTANCE(d) (μm)
12m/s
10m/s
8m/s
PERIPHERAL
VELOCITY V = 6m/s
C
B
A
-20
-15
-10
-5
0
5
10
15
20
SKEW·ANGLE (deg.)