CONICAL HYDRODYNAMIC BEARING WITH TWO INDEPENDENT CIRCULATION PATHS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on U. S. Provisional Patent Application, Serial No. 60/034,265, filed December 20, 1996, assigned to the assignee of this application and incorporated herein by reference. This structure is preferably assembled using the method described in Attorney Docket No. A-64158/JAS, U.S. Patent Application Serial No. _____, filed _____, by Addy et al., assigned to the assignee of this application and incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to disc drive storage systems, and more specifically, the present invention relates to a hydrodynamic fluid bearing for use in a disc drive storage system.

BACKGROUND OF THE INVENTION

Magnetic disc drives are used for magnetically storing information. In a magnetic disc drive, a disc rotates at high speed and a transducing head "flies" over a surface of the disc. This transducing head records information on the disc surface by impressing a magnetic field on the disc. Information is read back using the head by detecting magnetization of the disc surface. The transducing head is moved radially across the surface of the disc so that different data tracks can be read back.

Over the years, storage density has tended to increase and the size of the storage system has tended to decrease. This trend has led to greater precision and lower tolerance in the manufacturing and operating of magnetic storage discs. For example,

to achieve increased storage densities the transducing head must be placed increasingly close to the surface of the storage disc. This proximity requires that the disc rotate substantially in a single plane. A slight wobble or run-out in disc rotation can cause the surface of the disc to contact the transducing head. This is known as a "crash" and can damage the transducing head and surface of the storage disc resulting in loss of data.

From the foregoing discussion, it can be seen that the bearing assembly which supports the storage disc is of critical importance. One typical bearing assembly comprises ball bearings supported between a pair races which allow a hub of a storage disc to rotate relative to a fixed member. However, ball bearing assemblies have many mechanical problems such as wear, run-out and manufacturing difficulties. Thus, there has been a search for alternative bearing assemblies for use with high density magnetic storage discs.

One alternative bearing design which has been investigated is a hydrodynamic bearing. In a hydrodynamic bearing, a lubricating fluid such as air or liquid provides a bearing surface between a fixed member of the housing and a rotating member of the disc hub. In addition to air, typical lubricants include oil or ferromagnetic fluids. Hydrodynamic bearings spread the bearing interface over a large continuous surface area in comparison with a ball bearing assembly which comprises a series of point interfaces. This is desirable because the increased bearing surface reduces wobble or run-out between the rotating and fixed members. Further, improved shock resistance and ruggedness is achieved with a hydrodynamic bearing.

However, hydrodynamic bearings themselves suffer from a number of disadvantages. These disadvantages include a low stiffness-to-power ratio and a

likelihood of damage due to gyroscopic precession. These problems lead to a high sensitivity of the bearing to external loads or shock.

A desirable solution to this problem would be to have the spindle motor attached to both the base and the top cover of the disc drive housing. This would increase overall drive performance. A motor attached at both ends is significantly stiffer than one held by only one end.

Typically, hydrodynamic motor designs provide no method for top cover attachment. The reason for this is that in order to have top cover attachment, the motor would need to be opened on both ends. Opening a motor at both ends greatly increases the risk of oil leakage out of the hydrodynamic bearing. This leakage is caused by small differences in flow rate created by differing pumping grooves in the bearing. If all of the flows within the bearing are not carefully balanced, a net pressure rise toward one or both ends will force fluid out through the capillary seal. Balancing the flow rates in conventional, known thrust plate bearing designs is difficult because the flow rates created by the pumping grooves are a function of the gaps defined in the hydrodynamic bearing, and the gaps, in turn, are a function of parts tolerances. Thus, a need exists for a new approach to the design of a hydrodynamic bearing based motor to optimize motor performance stiffness and damping.

It is also desirable to design a hydrodynamic bearing which is open at both ends for other purposes than fixing both ends of the shaft to the base and cover of a housing. For example, with such an open-ended design, either end (or both) could be extended beyond the sleeve to be coupled to a driver or load, or for other purposes.

SUMMARY OF THE INVENTION

Thus, it is an object of the present invention to create an improved hydrodynamic bearing which is relatively insensitive to changes in load and rotational speed.

Yet another objective of the present invention is to provide a hydrodynamic bearing motor in which the bearing is open at both the upper and lower ends.

A related objective of the invention is to provide a hydrodynamic bearing open at both ends in which the balance of fluid flow within the bearings is maintained.

Another objective of the invention is to provide a hydrodynamic bearing useful in a spindle motor or the like which is stiffer than known standard spindle motors which are supported only at one end.

A further objective of the invention is to design a hydrodynamic bearing useful in a spindle motor or the like in which the motor could be attached to both the top cover and the base of the housing for the spindle motor.

These and other objectives of the present invention are achieved by providing a hydrodynamic bearing useful as a bearing cartridge or as the cartridge may be incorporated into a spindle motor or the like, where the bearing includes a shaft and two independent bearings at either end of the shaft, comprising a top cone and a bottom cone. More specifically, the bearing includes a sleeve rotating around and surrounding the shaft, a top cone and a bottom cone, separated by a portion of the shaft, and a pair of sealing plates which seal off the ends of the bearing and are located along the shaft beyond the cones. Separate flow paths are established, one around the top cone and one around the bottom cone. A reservoir is provided along a central axis of the shaft, connected by lateral bores to the gap between the shaft and the sleeve. The bores are

located near the center of the shaft segment and at or near the distal end of each cone to establish each of the paths. By providing two independent paths, the flow rates do not have to be the same in each conical flow path for the bearing seals to function properly. Thus, when the load or RPM changes, the flow rates may change but the function of the bearing and its ability to provide stiffness and stability to the system will not be impeded.

The bearing and bearing cartridge embodiments are also characterized by ease of assembly of the conical bearing spaced from each other along the shaft.

The hydrodynamic bearing assembly, and bearing cartridge, as disclosed herein used in a spindle motor, provides enhanced stiffness within the cartridge system.

Other features and advantages of the present invention will become apparent to a person of skill in the art who studies the present invention disclosure, given with respect to the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of a magnetic disc storage system which may incorporate the hydrodynamic bearing cartridge and spindle motor in accordance with the present invention.

Figures 2A and 2B are vertical sectional views of prior art hydrodynamic bearing cartridges.

Figure 3 is a vertical sectional view of a hydrodynamic bearing cartridge in accordance with the present invention incorporated in a spindle motor.

Figure 4 is a vertical sectional view of a spindle motor incorporating the present invention;

Figures 5A and 5B are perspective views of portions of the upper conical bearing illustrating the groove patterns available on this bearing; and Figures 5C and 5D are perspective views of the conical portion of the lower conical bearing illustrating the available grooving patterns on this portion of the bearing.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Figure 1 is an exploded perspective view of a magnetic disc drive storage system in which the present hydrodynamic bearing cartridge could be used. In the example to be discussed below, the use of the hydrodynamic bearing and associated cartridge will be shown in conjunction with a spindle motor. Clearly, this bearing cartridge is not limited to use with this particular design of a disc drive, which is shown only for purposes of the example. Given the many advantages which this invention achieves, it could also potentially be used to support the actuator for rotation. The bearing cartridge also has numerous other uses outside the field of disc drives.

In this particular example, the storage system 10 includes a housing base 12 having spindle motor 14 which carries storage discs 16. An armature assembly 18 moves transducers 20 across the surface of the discs 16. The environment of discs 16 is sealed by seal 22 and cover 24. In operation, discs 16 rotate at high speed while transducers 20 are positioned at any one of a radially differentiated track on the surface of the discs 16. This allows the transducers 20 to read and write magnetically encoded information on the surfaces of discs 16 at selected locations. The discs rotate at very high speeds, several thousand RPM, in order to maintain the transducer flying over the surface of the disc. In present day technology, the spacing distance between the

transducer and the rotating disc surface is measured in microinches; thus it is absolutely essential that the disc does not tilt or wobble.

Figure 2A is a cross sectional view of a further prior art drive spindle assembly of a type which is open only at one end; it can be supported only from the base of the housing of the system using the hydrodynamic bearing cartridge; in this case the system is a disc drive assembly. The figure is taken from U.S. Patent No. 5,559,651, which is assigned to the assignee of the present application and is incorporated herein by reference.

In Figure 2A, the cartridge 40 which includes the hydrodynamic bearing is shown incorporated in a spindle motor 50 which is usable to drive the discs in the disc drive 10 of Figure 1. The design includes a drive rotor or hub 14 rotatably coupled to the shaft 52. The shaft 52 includes an upper hemisphere or convex portion 54 and a lower hemisphere or convex portion 56 received in sleeve 58 which rotates relative to the shaft. The shaft 52 is fixedly attached to the base 60, which may be incorporated in or supported from the housing base 12 described with respect to Figure 1. The sleeve 58 receives the journal 62 of shaft 52 and has upper hemisphere shaped, concave receptacle 64 and lower hemisphere shaped concave receptacle 66. A fill hole 68 is also provided to a reservoir 59 in fixed shaft member 52 to provide bearing fluid to the hydrodynamic bearing, and rotor 14 includes a counterplate 70 which is used to close off one end (as drawn the upper end) of the hydrodynamic bearing to the atmosphere. In operation, the bearings shown in this figure comprise a hydrodynamic bearing in which a lubricating fluid such as oil circulates through gaps between the fixed member which is the shaft and the rotating member which in this case is the sleeve. Rotation of the rotating member causes the lubricating fluid to circulate.

As further shown in Figure 2A, oil is trapped in the hydrodynamic bearing by a diverging capillary seal 72. However, as can also be seen from an inspection of this Figure, this design is not adaptable to being opened to the atmosphere at both ends, as the counterplate 70 is provided at one end to close off the hydrodynamic bearing to the atmosphere, the counterplate 70 rotating with the sleeve. Figure 2B is a variation of the design shown in Figure 2A. This Figure, also taken from the '651 patent, illustrates the use of a central reservoir 86. Spindle 60 includes a rotor hub 71 which carries disc 73 and is rotatably coupled to shaft 75. Shaft 75 includes upper hemisphere 68 and lower hemisphere 70 received in cartridge sleeve 72. Sleeve 72 receives journal 74 of shaft 75. The top portion of shaft 75 is sealed with seal plate 76, and journal 74 extends therethrough. Hub spacer 78 is coupled to rotor hub 71, and carries permanent magnets 80. Shaft 75 is received in base 82, and includes fill hole 84. Fill hole 84 connects to passageway or reservoir 86, which extends through the center of shaft 75. Passageway 86 connects to center passageway or bore 88 and distal bores 90. In operation, oil flows into bore 86 through center bore 88 and out distal bores 90. This is indicated by arrows shown in bore 86. Again, in this embodiment, the fluid circulation paths in the hydrodynamic bearing are sealed off from the outer atmosphere by seal plate 76.

The present invention to be described with respect to Figures 4, 5 and 6, provides the improvement of allowing both the top and bottom ends of a hydrodynamic bearing to be open to the atmosphere. Thus, in a fixed shaft motor which incorporates the present invention, both upper and lower ends of the shaft could be fastened to the base and top cover of the housing, so that the stiffness of the motor and its resistance to shock as well as its alignment to the rest of the system is enhanced and maintained.

Referring next to Figure 3, the basic approach of the present invention is to create a bearing with two independent flow paths, designated in this case path 101 and path 102, which travel around two independent conical bearings, generally indicated at 104, and 106 and are separated by a portion 108 of the shaft. A sleeve 110 surrounds the upper conical bearing 104, lower conical bearing 106 and shaft 108 and is separated by a narrow gap from each of these surfaces to define axial elements of fluid flow paths 101, 102. A pair of sealing plates 112, 114 are provided, one at each end of the cartridge, adjacent radial surfaces 113, 115 of each conical bearing and separated by gap to establish radial elements of the fluid flow paths. These sealing plates 112, 114 also lie flush against radial surfaces 210, 212 of the sleeve 110 to prevent leakage of the bearing fluid away from the fluid paths 101, 102. Thus, two separate flow paths 101, 102 are defined, one over the upper bearing 104 and one over the lower conical bearing 106 as well as over shaft 108, all as will be explained in greater detail below. As the load or RPM changes, the flow rates through these paths may change. The flow rates do not have to be the same in each flow path for the bearing seals to function properly, since the paths are separated.

A further advantage of this design over the current thrust plate designs is that inward pumping spiral grooves, to be discussed more fully below, are defined on the surfaces 116, 118, of the respective cones 104, 106. These inwardly pumping spiral grooves effectively circulate the fluid through the bearing.

The dual cone design will provide substantially increased stiffness over designs of the type shown in Figure 2, which use a long shaft and perpendicularly disposed thrust plates. The increased structural strength and stiffness of the bearing of the present invention is due to several factors;

one, the stiffness can be enhanced by this design by fastening it at both the top and bottom of the shaft;

two, the stress is now distributed over the length of the bearing, rather than being concentrated on one end;

three, the narrow portion of the shaft 108 (which is also the journal center) is shorter than in prior art designs as shown in Figure 2;

four, the conical regions, which occupy in the preferred embodiment more than half the length of the overall design widen to a point of being approximately twice as thick as the shaft, thus allowing the system to be assembled without distortion of any element even though the margins between the shaft and sleeve can be made very close.

In order to provide the recirculating flow paths, a central reservoir 120 is incorporated extending up through the center of the shaft. In the embodiment shown herein, one end 121 of the reservoir terminates near to the end of the conical bearing as defined by the radially extending surface 113; the other end is closed off by a septum 126. The use of this septum 126 provides a means through which a needle may be inserted to fill the reservoir with fluid after which the needle is withdrawn and the reservoir is closed off to the outside atmosphere. Other means of filling the reservoir 120 may be provided, and this invention is not limited to designs where this filling approach is taken, or where the reservoir end is so defined.

To provide return path from each conical bearing to the reservoir 120, a bore 130 connects the reservoir to the short major shaft region 108, and the section of each circulation path 101, 102 that it defines. In a preferred embodiment, no grooves are provided on this section 108 of the shaft, although grooves could be provided either on

the shaft or the sleeve wall it faces to enhance the fluid flow from either conical surface 116, 118 towards this center bore 130.

One end of the reservoir 120 is provided with a bore 150 which runs from at or near to the end point of the reservoir 120 to the outside of the conical bearing 104. Preferably, this bore extends substantially parallel to the outer conical surface 116 of the cone, and terminates where the radial base surface 113 of the conical bearing meets an extended portion 151 of the central shaft. In addition to the bore 150 ending at this corner, this same corner may include a small recess 154 to enhance the fluid flow out through the bore 150 and into the flow path 101. The flow of the fluid out of the reservoir 120 and bore 150 is enhanced by a pattern of spiral grooves as shown in Figure 5A or herringbone grooves as shown in Figure 5B imposed on the conical bearing surface 116. The grooves are substantially as shown in the Figures, to accommodate the counterclockwise direction of rotation of the sleeve 110 around the shaft. The flow of lubricating fluid path 101 as enhanced by the rotation of the grooved surface, then continues over the outer surface of the cone 116, through the gap defined by the outer surface 160 of the central shaft portion 108 and the facing inner surface of sleeve 110, and into the center bore to return to the reservoir 150 and continue its flow as indicated by the arrow.

The opposite end of the shaft is similarly designed with a diagonal groove or bore 170 extending to a recess 172 at the corner defined by the radial base surface 115 of the conical bearing and the extended portion 161 of the shaft. It can be seen from reviewing Figure 3 that the fluid also flows out through this bore 170 up over the outer surface of the conical bearing 106, through the gap between the outer surface of the

shaft and the inner surface of sleeve 110, and into the center bore 130 which is the only common portion of the two circulation paths 101, 102.

As described above, the circumferential sealing plates 112, 114 are provided to cooperate with the radial surfaces of the conical bearings to form the circulation paths 101, 102, and held in place inside a shoulders 206,208 of the sleeve 110. The axially inner surface 210, 212 of each sealing plate is pressed tightly against a mating, radially extending surface 214, 216 of the sleeve 110. In order to prevent the escape of any fluid between these two surfaces, sealing rings 220, 221 is pressed in place in associated grooves 222, 223 of sleeve 110. Provision of the sealing rings 220, 221 ensures that the fluid is confined to the recirculating paths 101, 102, and cannot escape between sleeve 110 and plate 112.

It is readily apparent from an inspection of Figure 3 that this design also lends itself to ease of assembly. That is, the sleeve 110 could be slipped over the portion of shaft comprising central shaft 108 and conical bearing 104. Then the opposite conical bearing 106 which is integrated with sleeve 260 could be attached to the shaft by bonding, press fitting ,swaging, threading, laser welding or the like. The septum 126 is pressed in place inside the sleeve 260. These steps having been completed, the rings 220, 221 would be inserted in their respective grooves, and the sealing plates 114, 112 pressed into place inside the shoulders 206, 207.

Prior to assembly, the appropriate groove patterns as shown in Figures 5A-D are applied to the outer surfaces of the cone. Obviously, the patterns could also be applied to the inner mating surfaces of the sleeves, but grooving of the outer surfaces of the cones is preferred. The use of a spiral (502, 504 shown in Figures 5A and 5C), rather than a herringbone (506, 508 shown in Figures 5B, 5D) pattern, is also preferred

for maintaining the fluid flow through each of the two bearing circulation paths, since the fluid must be forced both over the surface of the cone and up along a portion of the shaft 108 to reach the center bore 130 to begin its return path through the reservoir.

Figure 3, of course, only shows a discrete cartridge. This cartridge is useful in many environments. However, the preferred embodiment of the present invention incorporates the cartridge in a spindle motor to support the discs in a magnetic disc drive as shown in Figure 4. Figure 4 shows a hub 400 pressed in place on the outer surface of the sleeve 110. The top end or step portion 402 of the shaft 404 which extends beyond the upper conical bearing 104, is attached directly to the cover 406 of the disc drive by a screw 407 or any similar attachment. The opposite end of the shaft, which is in this embodiment is formed by the sleeve 260 of the shaft is fixed in the base 408 so that the entire hydrodynamic bearing cartridge structure to be incorporated in the spindle motor is stably supported in place. To complete the assembly of a spindle motor, it is only necessary to add laminations 410 and coil or windings 412 which can be supported from an extension 414 of the base 408 and below the hub 300. The windings 412 are aligned with magnet 416 which is supported on sleeve 110 below the hub 400. The windings 412 cooperate with the magnet 416 to rotate the sleeve 110, the hub 400 and the disc 416 supported thereon.

As can be seen from a review of the Figures, especially Figure 4 of the present invention, the interface of the hydrodynamic bearing of the present invention is extended over a greater area and supported from a thicker portion of the shaft than in prior art designs, providing increased bearing stiffness and stability. Further, as is apparent from an inspection of the drawings and the description above, that the surfaces provided facilitate smooth operation and reduce the effect of external loads or shock or

precession. It is also apparent that this design is less likely to be damaged than a prior art thrust plate extending out radially from an end of a rotating shaft, a design in which a small tilt of the drive shaft could cause the tip of the long level arm of the thrust plate to travel a relatively large distance. Again, the restoring moment which measures the stability of the design is determined based upon the length of the line which extends from the center of the journal to an outer edge of the bearing member. In typical prior art thrust plate designs, the hydrodynamic bearing interfaces at a large or perpendicular angle with the axis of rotation. However, in the present invention, an angle between the interface and the axis of rotation is acute, i.e. not parallel. This is achieved by making the bearing having a narrow width at an inner side and widen towards an outer edge of the bearing. This further establishes the stability of the present design. Finally, the ability to mount the design at either end from the housing in which the cartridge is used provides stability not achieved in prior designs.

Of course, the design is not limited the environments where the shaft is mounted at both ends, or even a fixed shaft. For example, in the embodiment of Figure 3, either end of the shaft could be extended beyond the sleeve and either driven in rotation or used as a driver or as a bearing, while the sleeve 110 is fixed or still. In fact the sleeve 110 could even be rotating at a different speed than the shaft, or in the same or opposite direction.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. Therefore, the scope of the present invention is defined by the following claims.

CLAIMS

WHAT IS CLAIMED IS:

1. A hydrodynamic bearing cartridge comprising a fixed central shaft carrying first and second conical bearings separated by a central circular shaft portion of said shaft and lubricated by first and second circulation paths circulating through a central reservoir in said shaft, the first and second conical bearings tapering outwardly from said central shaft along defined surfaces, said conical bearings at ends distal from said central shaft having radially extending surfaces which extend back toward said shaft, said bearing cartridge further comprising

a sleeve which rotates relative to the fixed shaft around a central axis of rotation defined by a central axis of said shaft, the sleeve including a first concave bearing surface rotatably overlying a convex surface of the first conical bearing and forming a first gap of said first path, the sleeve further including a second concave bearing surface rotatably overlying a convex surface of said second bearing and forming a first gap of said second path, the sleeve further including a circular surface extending between the first and second convex bearings and receiving the fixed central circular shaft portion therethrough and forming a second gap therewith, sections of said second gap being included in each of said first and second circulation paths, said shaft further including a reservoir extending along said central axis of said fixed shaft and communicating with said second gap defined between said sleeve and said central shaft section through a first central bore which is included in both of said first and second circulation paths, said reservoir further communicating with said first and second convex bearings through second and third bores extending from said reservoir toward said radially extending surfaces,

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lubricating fluid flowing from said reservoir through each of said second and third bores and through said gaps over said first and second conical bearing surfaces and between said central shaft portion and said sleeve and through said first bore to said central reservoir, so that first and second independent circulation paths are established over each of said first and second convex bearings so that said shaft may be fixed at both ends.

2. A hydrodynamic bearing cartridge as claimed in claim 1 further comprising first and second radial sealing plates supported by said sleeve axially adjacent said radially extending surfaces, said sealing plates forming a gap for said lubricating fluid flow from said second and third bores toward said conical bearing surfaces, so that said first and second independent fluid circulation paths are reliably established in said bearing cartridge.

3. A hydrodynamic bearing cartridge as claimed in claim 1 wherein each of said second and third bores extend from said reservoir angularly toward said first and second sealing plates, so that fluid flow in said first and second independent circulation paths is from said reservoirs, through said bore, between said first and second radially extending surfaces and said first and second sealing plates, and over said convex bearing surfaces toward said central bore of said fixed shaft.

4. A hydrodynamic bearing cartridge as claimed in claim 3 wherein said bore extends at a acute angle from said central reservoir towards said sealing plate and said gap between said sealing plate and said radially extending first and second surfaces.

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5. A hydrodynamic bearing cartridge as claimed in claim 4 wherein said sleeve further includes first and second shoulders supporting said sealing plates on said sleeve radially spaced from axial extensions of said shaft, a recess adjacent each of said first and second shoulders, and a sealing ring captured in said recess between said sleeve and said sealing plate to prevent leakage of said hydrodynamic bearing fluid between said sealing plate and said sleeve.

6. A hydrodynamic bearing cartridge as claimed in claim 5 further including a recess defined in the region where said first and second radially extending surfaces of said first and second conical bearings meet said axially extended portions of said sleeve to enhance fluid flow through said bore and into said gap between said radially extending surface and said sealing plate.

7. A hydrodynamic bearing cartridge as claimed in claim 1 wherein separate non-overlapping sections of said second gap are included in each of said first and second circulation paths.

8. A hydrodynamic bearing cartridge as claimed in claim 1 wherein said convex surfaces are substantially flat.

9. A hydrodynamic bearing cartridge as claimed in claim 1 wherein said convex surfaces are substantially spherical.

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10. A magnetic disc storage system comprising a housing for said disc drive,

means for supporting one or more discs for constant speed rotation, and means for accessing data storage locations on each of said discs,

said means for supporting comprising fluid-filled hydrodynamic bearing means for enabling a hub supporting said one or more discs to rotate relative to a shaft supported in said housing.

11. A disc drive comprising a disc, a motor, and connected to said disc and said motor a means for fluidically coupling said discs and said motor to achieve a constant rotational speed.

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