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DISC DRIVE MOTOR HAVING BEARINGS LUBRICATED WITH NON-SPREADING LUBRICANT

BACKGROUND OF THE INVENTION

The present invention relates to disc drives.

5 More specifically, the present invention relates to a motor used in a disc drive.

A typical disc drive includes one or more magnetic discs mounted for rotation on a hub or spindle. A typical disc drive also includes one or more
10 transducers supported by a hydrodynamic air bearing which flies above each magnetic disc. The transducers and the hydrodynamic air bearing are collectively referred to as a data head. A drive controller is conventionally used for controlling the disc drive
15 system based on commands received from a host system. The drive controller controls the disc drive to retrieve information from the magnetic discs and to store information on the magnetic discs.

An electromechanical actuator operates within
20 a negative feedback, closed-loop servo system. The actuator moves the data head radially over the disc surface for track seek operations and holds the transducer directly over a track on the disc surface for track following operations.

25 Information is typically stored on the magnetic discs by providing a write signal to the data head to encode flux reversals on the surface of the magnetic disc representing the data to be stored. In retrieving data from the disc, the drive controller
30 controls the electromechanical actuator so that the data head flies above the magnetic disc, sensing the flux reversals on the magnetic disc, and generating a read signal based on those flux reversals. The read signal

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is then decoded by the drive controller to recover the data represented by flux reversals stored on a magnetic disc, and consequently represented in the read signal provided by the data head.

5 In current generation disc drive products, the most commonly used type of actuator is a rotary moving coil actuator. The discs themselves are typically mounted in a "stack" on the hub structure of a brushless DC spindle motor. The rotational speed of the spindle
10 motor is precisely controlled by motor drive circuitry which controls both the timing and the power of commutation signals directed to the stator windings of the motor. The hub structure is rotatably coupled to a shaft via a set of bearings. The hub includes a sleeve
15 or back iron portion which carries a magnet. Interaction between the magnet and the stator causes controlled rotation of the hub about the shaft.

 The bearings in the spindle motor are typically lubricated with a material that provides a
20 fluid film which separates the bearing surfaces. Such bearings are conventionally small, grease lubricated ball bearings, self-pumping hydrodynamic fluid bearings, or oil-saturated porous metal bushings.

 In a disc drive, the bearings in the spindle
25 motor have a limited oil supply which must last the lifetime of the drive. However, lubricating materials which have good lubricating properties also typically wet surfaces which they contact. Because of this, the lubricant tends to spread or migrate out of the bearings
30 under the influence of gravity or capillary attraction. Such a property is especially undesirable for small mechanisms, such as motors in disc drives, which must be lubricated only once for a single lifetime.

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In order to address the problem of oil leakage or migration from bearings in a rotating assembly, many purported solutions have been attempted. For instance, grease is often used because it provides a reservoir of liquid lubricant (the base oil in the grease) that is drawn into the lubricated zone as needed. However, because of capillary attraction combined with high mechanical shear or temperature, the liquid can be lost from the grease.

Therefore, capillary and labyrinth seals are used in some bearings in order to prevent migration. However, these seals do not effectively prevent leakage under all conditions. Further, rotary type seals, such as rubber bushings, are not useful in the disc drive industry because of the requirement that such seals have an extremely long lifetime, and also because such seals typically generate wear particles which rub off during use. These particles are extremely detrimental to the disc drive.

Films which are commonly referred to as "barrier films" have also been used in an attempt to control migration. Such films repel oil and are typically applied to surfaces where oil is not desired. However, barrier films are usually invisible and are therefore difficult to apply with any reasonable degree of control. Further, application of such films requires an additional manufacturing step, which is also undesirable.

Non-spreading oils referred to as "autophobic" oils are also known in other industries. These oils are principally used in the clock making industry. Autophobic oils do not readily wet their own films and therefore show much less tendency to spread. However, clock oils have relatively high viscosity and surface

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tensions and are formulated with natural oils containing polar compounds such as esters and fatty acids. These oils are not suitable for the lifetime lubrication of a computer disc drive spindle bearing due to the high power consumption associated with the high viscosity properties of the oils and because the oils are incompatible with the head disc interface.

SUMMARY OF THE INVENTION

A disc drive includes a disc and a motor having a rotatable portion and a fixed portion. The fixed portion and the rotatable portion are separated by a bearing, and the rotatable portion supports the disc. A data transducer is coupled to an actuator to move relative to the disc to access different portions of the disc. The bearing includes a lubricant having an additive of perfluoropolyether with a reactive end group.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of disc drive according to the present invention.

FIG. 2 is a side sectional view of one embodiment of a disc drive motor according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a block diagram of disc drive according to the present invention. Disc drive includes drive controller 12, servo control processor 14, power amplifier 16, actuator assembly 18, disc stack assembly 20, preamplifier 22, data and clock recovery circuit 24, and error detection circuit 26. Drive controller 12 is typically a microprocessor, or digital computer, and is coupled to a host system, or another drive controller which controls a plurality of drives.

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Disc stack assembly 20 includes spindle 28 which supports a plurality of coaxially arranged discs 30. The discs are mounted for rotation with spindle 28 about axis of rotation 29. Each of the discs 30 has a first surface 32 and a second surface 34. Surfaces 32 and 34 both include concentric tracks for receiving and storing data in the form of flux reversals encoded on the tracks. A group of tracks which includes one track per surface 32 and 34, wherein each track in the group is located a common radial distance from the inner diameter of the corresponding disc 30 upon which it resides, is referred to as a cylinder.

Actuator assembly 18 includes an actuator 36 supporting a plurality of actuator arms 38. Each of the actuator arms 38 is rigidly coupled to at least one head gimbal assembly 40. Each head gimbal assembly includes a load beam, or flexure arm, rigidly coupled to actuator arm 38 at a first end thereof, and to a gimbal at a second end thereof. The gimbal is, in turn, coupled to a hydrodynamic air bearing which supports a data head above the corresponding disc surface, 32 or 34, for accessing data within the tracks on the disc surface.

Actuator 36 is rotatably mounted with respect to discs 30. As actuator 36 rotates, it moves the transducers coupled to the head gimbal assemblies 40 either radially inward, toward an inner radius of the corresponding disc 30, or radially outward, toward an outer radius of the corresponding disc 30. In this way, actuator 38 positions the transducers on head gimbal assemblies 40 over a desired track (and cylinder) on the discs 30.

In operation, drive controller 12 typically receives a command signal from a host system which indicates that a certain portion of a disc 30 on disc

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stack assembly 20 is to be accessed. In response to the command signal, drive controller 12 provides servo control processor 14 with a position signal which indicates a particular cylinder over which actuator 36 is to position head gimbal assemblies 40. Servo control processor 14 converts the position signal into an analog signal which is amplified by power amplifier 16 and provided to actuator assembly 18. In response to the analog position signal, actuator 18 positions head gimbal assemblies 40 over a desired cylinder.

The command signal from drive controller 12 also indicates the particular sector to be read from or written to. If the particularly identified disc and sector are to be read, the read transducer on the corresponding head gimbal assembly 40 generates a read signal containing the data. The read signal is provided to a preamplifier 22 which amplifies the read signal and provides it to data and clock recovery circuit 24. Data and clock recovery circuit 24 recovers data, which is encoded on the disc surface when the data is written to the disc surface. The data is recovered from the read signal provided by preamplifier 22. Data and clock recovery circuit 24 operates in a known manner.

Once the data is recovered, it is provided to error detection circuit 26 which, in this preferred embodiment, is based on an error correction code (ECC), such as a Reed-Solomon code. Error detection circuit 26 detects whether any errors have occurred in the data read back from the disc.

During head positioning, drive controller 12 provides a position signal to servo control processor 14 causing actuator assembly 18 to position the head gimbal assemblies 40 over a selected cylinder (for coarse

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positioning), and at a desired relative position within a track (for fine positioning).

FIG. 2 is a side sectional view of a disc drive motor 42 according to the present invention. Drive motor 42 is used as a spindle motor to rotate spindle 28 and includes a base 44 and a shaft 46 fixedly attached to base 44. An axis of rotation 48 is generally defined by the longitudinal axis of shaft 46. Motor 42 also includes rotor assembly 50. Rotor assembly 50 includes bearings 52 and 54, bearing holder 56, hub 58 and magnet 60.

Bearings 52 and 54 are disposed about shaft 46 and are supported by bearing holder 56. Labyrinth seal 62 and Ferro-fluid seal 64 are disposed generally at opposite axial ends of bearing holder 56 and seal a bearing compartment 66 which holds bearings 52 and 54. Hub 58 is fixedly coupled to bearing holder 56 and has a flange 68. Flange 68 supports magnetic discs 30 for rotation about axis 48.

Bearing holder 56 includes a back iron or sleeve portion 70 which is generally cylindrical in shape and is preferably formed integrally with bearing holder 56. Seal holder 72 is formed of a non-magnetic material and is mounted to an inner surface of sleeve 70 to support Ferro-fluid seal 64.

Sleeve 70 has an outer periphery defined by a generally cylindrical surface 74. Magnet 76 is coupled to outer surface 74 of sleeve 70. Magnet 76 is a generally annular-shaped magnet disposed about outer surface 74.

Stator windings 78 are rigidly attached to base 44 and are selectively provided with commutation signals. Interaction between the magnetic field

generated by stator 78 and magnet 76 causes controlled rotation of rotor assembly 50 about shaft 46.

Bearings 52 and 54 are lubricated with one of a number of commercially available lubricants. The disc drive industry has developed several lubricants (liquids and greases, such as Multemp SRL) that have excellent properties in miniature bearings including excellent compatibility with the head-disc interface. These lubricants are based primarily on natural and synthetic hydrocarbons and synthetic ester lubricants. All show varying, but similar, tendency to migrate from bearings 52 and 54.

When such migration occurs on a flat surface, it is referred to as "spreading". The tendency of a lubricant to spread is typically tested by placing a small volume of the lubricant under test on a flat, clean block of the bearing construction materials, with various surface finishes. The area covered by oil from the lubricant is then measured over a period of time. For liquid lubricants, capillary migration is also tested by measuring the rise of fluid in a clean gas capillary. These tests together are predictive of the migration performance of lubricant from the bearings 52 and 54.

It has been found that certain types of synthetic lubricants referred to as perfluoropolyethers (PFPEs) reduce migration when added to other lubricants. The PFPEs that provide this benefit include reactive end groups. The reactive end group is a chemical structure that is intended to chemically bond to a surface, anchoring the PFPE molecule in place. Examples of PFPEs with reactive end groups are commercially available as a series of PFPEs under the commercial designation FOMBLIN Z produced by Montefluos SpA/Ausimont, of

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Morristown, New Jersey. Other PFPEs with reactive end groups are commercially available under the commercial designation DEMNUM from Daikin Chemical Company, of Osaka, Japan. The particular commercial designation, and the chemical structure, along with the typical characteristics of a number of the PFPEs are shown in Table 1.

The above PFPEs shown in Table 1 have been tested and adequately perform according to the present invention. Also, the above PFPEs are compatible with the head-disc interface in the disc drive.

In one example of the present invention, the additive FOMBLIN Z-DOL was blended into a commercially available refined paraffinic petroleum hydrocarbon that has otherwise been proven suitable as a hydrodynamic bearing fluid. The additive was blended in several amounts between, and including, about 0.05% by volume and 1% by volume of the additive with respect to the bulk lubricant material. The spreading and migration tendency of the mixture was greatly reduced over that of the original oil lubricant. The area covered by a droplet of the lubricant containing the additive after 96 hours at room temperature on a stainless steel block (surface finish to better than 5 microinches) was approximately 25% of that covered by the lubricant oil with no antimigration additive, under the same conditions. After one month, the area covered by the droplet containing the additive was less than 10% of the area covered by the droplet with no additive. Also, the fluid lubricant with the additive climbed a glass capillary only 50% as high as the fluid without the additive. At some higher concentrations, the PFPE formed an emulsion in the fluid, with the precipitate settling to the bottom of the container. When the fluid

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was decanted from over the precipitate, it was found that the antimigration properties of the fluid remained intact.

In another example of the present invention,
5 FOMBLIN AM-2001 was blended into the same refined paraffinic petroleum hydrocarbon. The results were the same as for the lubricant containing the FOMBLIN Z-DOL additive.

In yet another example of the present
10 invention, FOMBLIN AM-2001 was blended into a commercially available synthetic ester lubricant that has been found to be a superior fluid for use in miniature self-pumping hydrodynamic bearings. The fluid was found to have a slightly greater tendency to migrate
15 than did the refined paraffinic petroleum fluid containing the additive. However, significant improvement was obtained over lubricants containing no additive. A number of concentrations were mixed such that the additive made up between (and including) about
20 0.05% and 1% by volume of the bulk lubricant material. The area covered by a droplet containing the additive after 96 hours at room temperature on a stainless steel block (with a surface finished to better than 5 microinches) was only about 40% of that covered by the
25 oil with no antimigration additive under the same conditions. Also, the fluid with the additive climbed a glass capillary only 70% as high as the fluid without the additive.

In yet another example of the present
30 invention, FOMBLIN Z-Dol was blended into a commercially available synthetic ester lubricant that has been found to be a superior fluid for use in miniature self-pumping hydrodynamic bearings. The fluid was found to have a slightly greater tendency to migrate than did the

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refined paraffinic petroleum fluid containing the additive. However, significant improvement was obtained over lubricants containing no additive. A number of concentrations were mixed such that the additive made up
5 between (and including) about 0.05% and 1% by volume of the bulk lubricant material. The area covered by a droplet containing the additive after 96 hours at room temperature on a stainless steel block (with a surface finished to better than 5 microinches) was only about
10 40% of that covered by the oil with no antimigration additive under the same conditions. Also, the fluid with the additive climbed a glass capillary only 70% as high as the fluid without the additive.

In still another example of the present
15 invention, FOMBLIN Z-DOL was blended with a high quality, commercially known and available, synthetic ester-based grease presently used in computer hard disc ball bearing spindle motors. To test migration of the base oil from the grease, a small amount of grease
20 (approximately 0.1 to 3 milligrams) was placed on a highly polished stainless steel block in a 70°C oven for 24 hours. The grease without the additive showed oil spreading over an area equal to approximately 3-5 times the area covered by the grease. Substantially no base
25 oil spreading was observed for grease containing the Z-DOL additive. As with the above examples, various concentrations of the additive were tried in a range of about 0.05% to 1% by volume.

In all of the above examples, various
30 concentrations of the additive between (and including) 0.05% and 1% by volume were used with no material difference in the properties of the solution. It was observed that a range of 0.05% to approximately 0.5% by volume was preferred. Even more preferred was a

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concentration level for the additive of approximately 0.1% by volume added to the base lubricant material. At concentration levels above 5% by volume, the additive tended to come out of solution or phase separate, and at
5 concentrations above 1% , there was no significant improvement in performance and the properties of the bulk lubricant could be affected. Therefore, concentrations in excess of 1% were not needed.

While the present invention has been
10 illustrated in a spindle motor containing a Ferro-fluid seal, it is to be understood that the present invention could be used either in conjunction with, or in place of, the Ferro-fluid seal. Ferro-fluid seals are presently quite expensive and form a significant percent
15 of the total cost of the motor. With lubricants containing the present additive, depending on the sensitivity of the drive to contamination, and depending on the rotating speed of the drive, such seals may be substantially unneeded.

20 While a number of examples of an additive used according to the present invention have been provided, it should be understood that the additive could be any additive usable with synthetic lubricants that repels the lubricating oil, bonds to the appropriate solid
25 surfaces, and is compatible with the head disc interface.

It should also be noted that, while the present invention was illustrated herein with respect to a spindle motor, it could also be useful in other motors
30 within or without disc drives.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes

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may be made in form and detail without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A disc drive, comprising:
a disc;
a motor having a rotatable portion and a fixed portion, the fixed portion and the rotatable portion being separated by a bearing, the rotatable portion supporting the disc;
a data transducer; and
an actuator coupled to the data transducer to move the data transducer relative to the disc to access portions of the disc;
wherein the bearing includes a lubricant having an additive of perfluoropolyether (PFPE) with a reactive end group.
2. The disc drive of claim 1 wherein lubricant comprises no more than about 1.0% by volume of the PFPE additive.
3. The disc drive of claim 2 wherein the lubricant comprises about 0.05% to about 1.0% by volume of the PFPE additive.
4. The disc drive of claim 3 wherein the lubricant comprises about 0.1% by volume of the PFPE additive.
5. The disc drive of claim 1 wherein the motor further comprises:
a Ferro-fluid seal between the fixed and rotatable portions tending to seal the lubricant within the motor.
6. The disc drive of claim 1 wherein the motor further comprises:
a labyrinth seal between the fixed and rotatable portions tending to seal the lubricant within the motor.



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7. The disc drive of claim 1 wherein the bearing comprises one of a grease lubricated ball bearing, a hydrodynamic fluid bearing, and an oil-saturated porous metal bushing.

8. A disc drive, comprising:
a disc;
a motor having a rotatable portion and a fixed portion, the fixed portion and the rotatable portion being separated by a bearing, the rotatable portion supporting the disc;
a data transducer; and
an actuator coupled to the data transducer to move the data transducer relative to the disc to access portions of the disc;
wherein the bearing includes a lubricant having an additive which tends to repel lubricating oil and which tends to bond to solid surfaces.

9. The disc drive of claim 8 wherein the additive comprises a perfluoropolyether with a reactive endgroup.

10. The disc drive of claim 9 wherein the lubricant comprises a semi-solid lubricant.

11. The disc drive of claim 10 wherein the lubricant comprises grease.

12. The disc drive of claim 9 wherein the lubricant comprises a liquid lubricant.

13. The disc drive of claim 12 wherein the lubricant comprises one of a refined paraffinic petroleum hydrocarbon and a synthetic ester.

14. A motor for use in a disc drive, the motor comprising:

a movable portion;
a fixed portion; and



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a bearing separating the fixed portion and the movable portion, wherein the bearing includes a lubricant having an additive of perfluoropolyether (PFPE) with a reactive endgroup.