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(54) **WEAR REDUCTION IN FDB BY ENHANCING LUBRICANTS WITH NANOPARTICLES**

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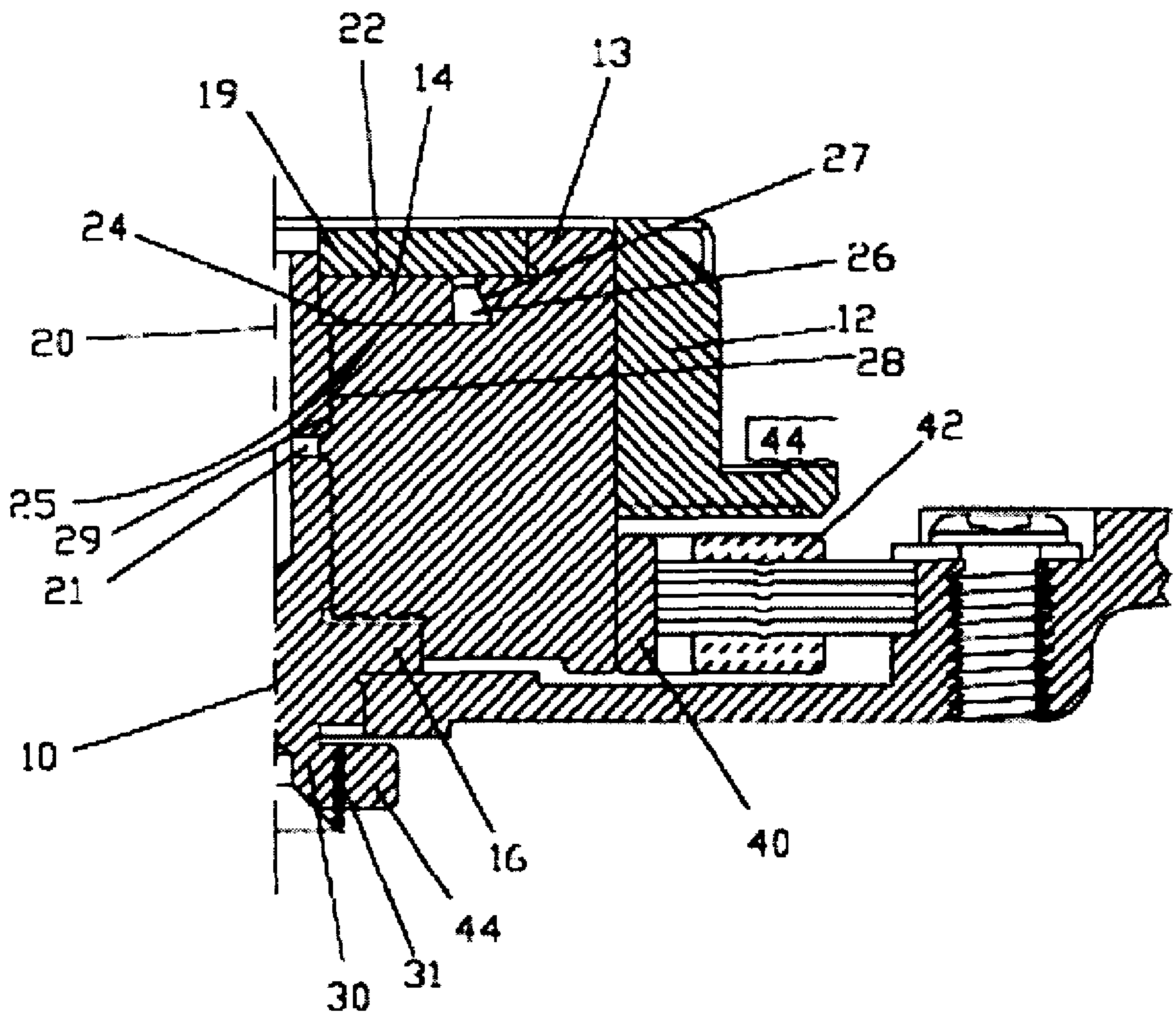
(57) **ABSTRACT**

An embodiment of the invention relates to a spindle motor of a magnetic recording storage device, the spindle motor comprising a fluid dynamic bearing comprising a lubricant comprising at least one of an organic and inorganic nanomaterial.



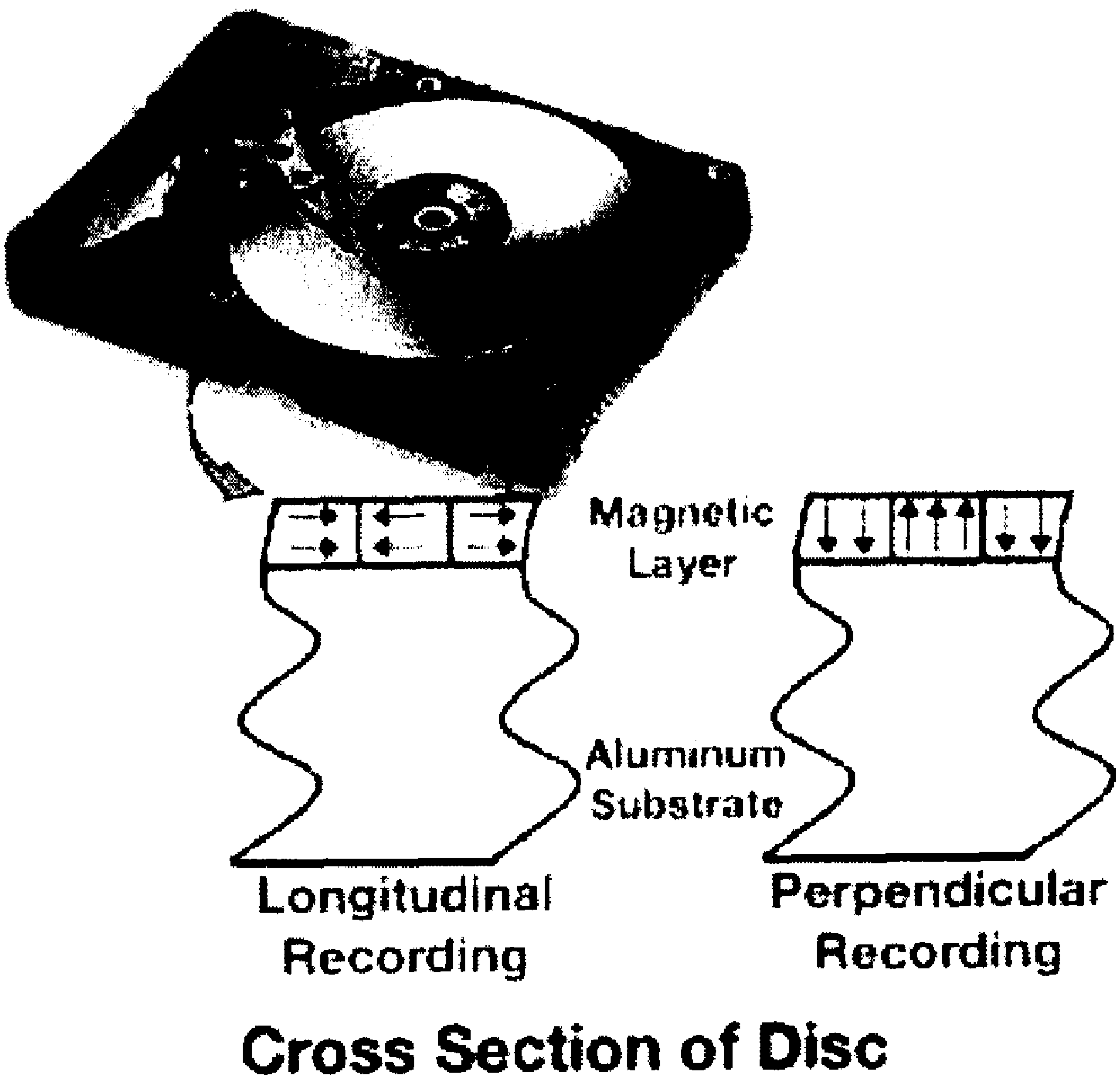

Magnetic
Layer
Aluminum
Substrate
Longitudinal
Recording
Perpendicular
Recording
Cross Section of Disc

Figure 1

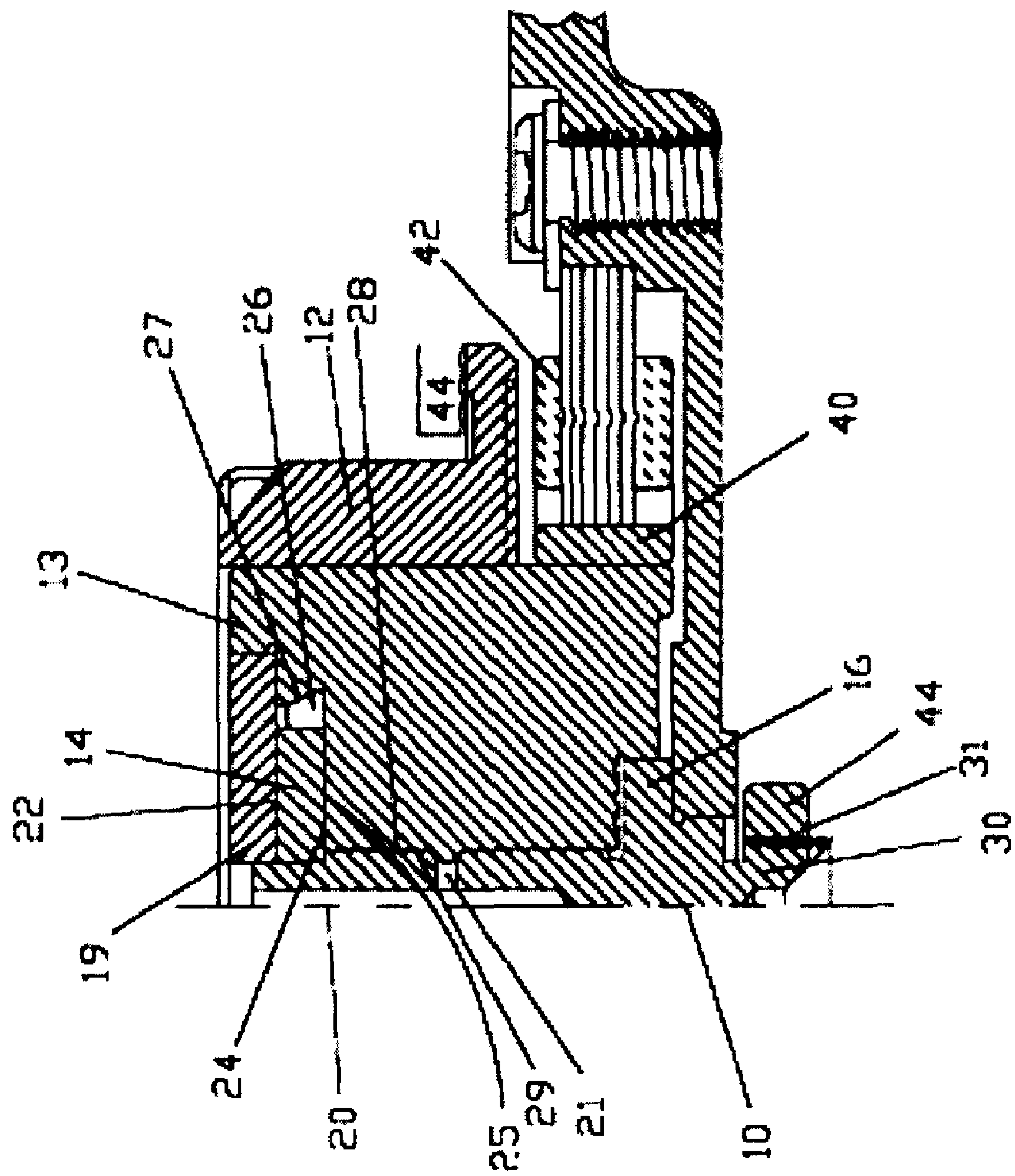


Figure 2

WEAR REDUCTION IN FDB BY ENHANCING LUBRICANTS WITH NANOPARTICLES

RELATED APPLICATION

[0001] None.

BACKGROUND

[0002] Magnetic discs with magnetizable media are used for data storage in most all computer systems. Current magnetic hard disc drives operate with the read-write heads only a few nanometers above the disc surface and at rather high speeds, typically a few meters per second. Because the read-write heads can contact the disc surface during operation, a layer of lubricant is coated on the disc surface to reduce wear and friction.

[0003] FIG. **1** shows a disk recording medium and a cross section of a disc showing the difference between longitudinal and perpendicular recording. Even though FIG. **1** shows one side of the non-magnetic disk, magnetic recording layers are sputter deposited on both sides of the non-magnetic aluminum substrate of FIG. **1**. Also, even though FIG. **1** shows an aluminum substrate, other embodiments include a substrate made of glass, glass-ceramic, NiP/aluminum, metal alloys, plastic/polymer material, ceramic, glass-polymer, composite materials or other non-magnetic materials.

[0004] Lubricants in a disc drive are applied on the spindle motor as well as on the disc surface. A lubricant fluid such as oil is typically filled in the bearing space which is created in the gap between the bearing sleeve and the shaft bush of a fluid dynamic bearing. On the other hand, a lubricant is applied to the disc surface by dipping the disc in a bath containing the lubricant or spraying the lubricant to the disc surface.

[0005] The lubricant film on the spindle motor or hard discs provides protection to the underlying materials by preventing wear. In addition, it provides protection against corrosion of the underlying materials. Reliability of hard disk drive is depends on the durability of the spindle motor and thin film media. Lubrication plays unquestionably an important role.

[0006] There are many common kinds of lubricants presently used in different kinds of fluid dynamic bearing but very few kinds are appropriate for disk drive application. It has been found that disk drive is very sensitive to the type and the amount of chemicals used in different components it is made from. Thus, it is desirable to develop a novel lubricant that would be appropriate for fluid dynamic bearing of disk drive application such that the lubricant exhibits compatibility with disk-head interface.

SUMMARY

[0007] An embodiment of the invention relates to a spindle motor of a magnetic recording storage device, the spindle motor comprising a fluid dynamic bearing comprising a lubricant comprising at least one of an organic and inorganic nanomaterial.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will be better understood by reference to the Detailed Description of the Invention when taken together with the attached drawings, wherein:

[0009] FIG. **1** shows a magnetic recording medium.

[0010] FIG. **2** shows a fluid dynamic bearing spindle motor.

DETAILED DESCRIPTION OF THE INVENTION

[0011] As used in the specification and claims, the singular forms "a", "an" and "the" include plural references unless the context clearly dictates otherwise.

[0012] The invention is directed to a lubricant for a disc and to a spindle motor containing the lubricants of the embodiments of the invention. Lubricants typically are liquid and contain molecular weight components that range from several atomic mass unit (AMU) to thousands of AMU including diesters, polyol esters, synthetic hydrocarbon, perfluoropolyether (PFPE) etc.

[0013] A "nanomaterial" as used herein refers to a structure, a device or a system having a dimension at the atomic, molecular or macromolecular levels, in the length scale of approximately about 1 to about 500 nanometer range. Preferably, a nanomaterial has properties and functions because of the size and can be manipulated and controlled on the atomic level. Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at the nano-scale this is often not the case. Size-dependent properties are observed such that the properties of materials could change as their size approaches the nanoscale. For example, the bending of bulk copper (wire, ribbon, etc.) occurs with movement of copper atoms/clusters at about the 50 nm scale. Copper nanoparticles smaller than 50 nm are considered super hard materials that do not exhibit the same malleability and ductility as bulk copper. The interesting and sometimes unexpected properties of nanoparticles are partly due to the aspects of the surface of the material dominating the properties in lieu of the bulk properties. The percentage of atoms at the surface of a material becomes significant as the size of that material approaches the nanoscale. For bulk materials larger than one micrometre the percentage of atoms at the surface is minuscule relative to the total number of atoms of the material. Suspensions of nanoparticles in liquid such as lubrication oil are possible because the interaction of the particle surface with the solvent is strong enough to overcome differences in density, which usually result in a material either sinking or floating in a liquid. Nanoparticles often have unexpected visible properties because they are small enough to scatter visible light rather than absorb it. For example gold nanoparticles appear deep red to black in solution. At the small end of the size range, nanoparticles are often referred to as clusters. Metal, dielectric, and semiconductor nanoparticles have been formed, as well as hybrid structures (e.g., core-shell nanoparticles). Nanospheres, nanorods, and nanocups are just a few of the shapes that within the embodiments of the invention.

[0014] FIG. **2** shows a fluid dynamic bearing spindle motor. FIG. **2** is a vertical sectional view of a single thrust plate hydrodynamic bearing motor design of a type which is already established in this technology. The basic structure of the motor shown in this figure includes a stationary shaft **10** and a hub **12** supported from a sleeve **13** for rotation around the shaft. The shaft **10** includes a thrust plate **14** at one end, and terminates in a shoulder **16** at the opposite end. The sleeve **13** supports a counterplate **19** at one end, for rotation over the thrust plate **14**. The counterplate **19** and thrust plate **14** are separated by a sufficient gap **22** to allow movement of lubricating fluid to lubricate the hydrodynamic bearing through the central hole or reservoir **20**, through the gap **22**, through the reservoir **26** defined between the end of the thrust plate **14** and an interior surface **27** of the sleeve **13**, and between the lower surface **24** of the thrust plate **14** and an upper surface **25** of the sleeve **13**, and between an inner surface **28** of the sleeve and the exterior surface **29** of the fixed shaft. The fluid path is completed to reservoir **20** primarily through a central bore **21**. In order to promote the flow of fluid over the bearing surfaces which are defined between the thrust plate **14** and the counterplate **19**; between the thrust plate **14** and the sleeve **13**, and between the shaft **10** and the sleeve **13**, typically one of the two opposing surfaces of each such assembly carries sections of grooves as is well known in this technology.

[0015] The fluid flow between the bearing surfaces creates hydrodynamic pressure, resulting in stiffness. Circulation of fluid is maintained through central hole **20** of the shaft to the other bearing surfaces by the appropriate designing of geometry and grooving patterns of the baring surfaces. The remainder of the structure of significance which is used to complete the motor design include shaft extension **30** which ends in threaded region **31** which is threaded into a portion of the base **44**. A stator **42** cooperates with magnets **40** which are supported from the sleeve **13**, with energization of the stator windings **42** causing rotation of the sleeve **18** and the hub **12** about the stationary shaft.

[0016] As used in a disc drive motor, this system supports one or more discs **44** for rotation. Because the transducers and disc drives fly at extremely low heights over the surface of the disc, it is essential that there not be wobble or vibration of the hub and disc as it rotates. Moreover, it is also important that should such wobble occur, that there is no touch down between the surfaces of the thrust plate **14** and the opposing surface of the counterplate **19** and sleeve **13**. However, as explained above, in a cantilever type bearing such as shown in FIG. **2**, where the load carrying surface which is thrust plate **14** is located far from the center point about which any pivoting would occur in the event of vibration or wobble, there is a much greater chance of a touch down or contact between the facing surfaces, which would result in both wear of the surfaces over the long term, and a slow down of the rotational speed of the disc in the short term.

[0017] Lubricants in a disc drive are applied on the spindle motor as well as on the disc surface. A lubricant fluid such as oil is typically filled in the bearing space which is created in the gap between the bearing sleeve and the shaft bush of a fluid dynamic bearing. On the other hand, a lubricant is applied to the disc surface by dipping the disc in a bath containing the lubricant or spraying the lubricant to the disc surface.

[0018] The lubricant film on the spindle motor or hard discs provides protection to the underlying materials by preventing wear. In addition, it provides protection against corrosion of the underlying materials. Reliability of hard disk drive is depends on the durability of the spindle motor and thin film media. Lubrication plays unquestionably an important role.

[0019] Conventional lubricant additives that reduce the friction and wear are organic compounds and their effectiveness is dependent on a tribo-chemical reaction leading to a tribological film formation having some harmful byproducts. The embodiments of the present invention relate to lubricant containing nanomaterials such as carbon nanotubes, onions and/or inorganic fullerene (IF) in which no chemical reaction is generally required to achieve low friction in lubricant. According to the embodiments of the invention, the nanomaterials are active as friction and wear reducers of the lubricant even at ambient and low temperatures.

[0020] Lubricants can include Di-Octyl Sebacate, Di octyl Azelate, Di octyl suberate, Dioctyl Pimelate, Di-octyl adipate, which are the reaction products of 2-Ethyl-I-hexanol (Isooctyl alcohol) and the dibasic acids of C10 (10 carbon), C9, C8, C7 and C6 respectively (named—sebacic acid, azelaic acid, Suberic acid, Pimelic acid and adipic acid). The lubricants may also include the polyol ester, synthetic hydrocarbon, PFPE etc. The lubricants of the embodiments may also contain other additives like anti-oxidant, corrosion inhibitors etc. to enhance the overall lubricant life. The lubricants of the embodiments of the invention further comprise organic and/or inorganic nanomaterials.

[0021] The nanoparticles of the embodiments of the invention can be nanotubes, fullerenes, onions, etc. A "nanotube" refers either a carbon nanotube or an inorganic nanotube. The carbon nanotube refers to a fullerene molecule having a cylindrical or toroidal shape. A "fullerene" refers to a form of carbon having a large molecule consisting of an empty cage of sixty or more carbon atoms. Carbon nanotubes are allotropes of carbon. A single wall carbon nanotube is a one-atom thick graphene sheet of graphite (called graphene) rolled up into a seamless cylinder with diameter of the order of a nanometer. This results in a nanostructure where the length-to-diameter ratio exceeds 10,000. Such cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. Carbon nanotubes are members of the fullerene structural family, which also includes buckyballs. Whereas buckyballs are spherical in shape, a nanotube is cylindrical, with at least one end typically capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is in the order of a few nanometers (approximately 50,000 times smaller than the width of a human hair), while they can be up to several millimeters in length. There are two main types of nanotubes: single-walled nanotubes and multi-walled nanotube.

[0022] An inorganic nanotube is a cylindrical molecule often composed of metal oxides, and morphologically similar to a carbon nanotube. Inorganic nanotubes have been observed to occur naturally in some mineral deposits. Inorganic nanotubes can be synthesized of inorganic materials, such as vanadium oxide and manganese oxide. Inorganic nanotubes can also be constructed from main group elements, boron nitride (borazine) being a prime contender. Being as borazine is isoelectronic with benzene, the substance could logically form sheets, fullerene analogs and nanotube analogs.

[0023] As the nanomaterials of the embodiments of the invention have a very large surface to volume ratio, the friction value in lubricated system of the embodiments of the invention can come down significantly even with a small addition of the nanomaterials of the invention. The amount of nanomaterials in the lubricant of the embodiments of the invention can be in the range of about 0.01 to about 5 percent by volume of the lubricating oil, more preferably in the range of about 0.02 to about 1 percent by volume of the lubricating oil, and most preferably in the range of about 0.05 to about 0.5 percent by volume of the lubricating oil.

[0024] It is desirable that the lubricant has a relatively narrow molecular weight distribution of molecular components. In practice, the narrower the distribution the easier it will be to maintain a steady-state concentration of one or more components in the vapor. For example, if the highest and lowest molecular weight components in the lubricant have very similar molecular weights, their vapor pressures will also be very similar. The lubricant can also be the mixture of two or more lubricants which will contain the nano materials as additives.

[0025] The viscosity range of the lubricant can be 3 to 50 cst @ 40° C. and 1 to 10 cst @ 100° C. and more preferably 5-15 cst @ 40° C. and 2 to 8 cst @ 100° C.

EXAMPLES

[0026] The following ester-containing lubricants were prepared by the reaction of an acid a dioctyl alcohol:

Acid	Dioctyl alcohol	Ester
Adipic acid (6 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-2-ethyl hexyl adipate
Pemelic acid (7 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-2-ethyl hexyl pimelate
Phthalic acid (8 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-octyl phthlate
Suberic acid (8 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-2-ethyl hexyl suberate
Azelaic acid (9 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-octyl azelate
Sebacic acid (10 carbon)	2-ethyl hexyl alcohol (8 carbon)	Di-octyl sebacate

[0027] The lubricants embodiment of the invention can be prepared by mixing these ester-containing lubricants with carbon nano tubes and onions like Ni/Y based single wall carbon nano tubes, Fe-based multiwall carbon nano tubes or metal free multiwall nano tubes and inorganic nanoparticles such as inorganic fullerene (IF), e.g., IF-MoS_2, IF-WS_2, IF-NbS_2 can be added in an amount ranging from about 0.01 to about 5.0 weight percent to form the lubricants of the embodiments of the invention.

[0028] In this application, the word "containing" means that a material comprises the elements or compounds before the word "containing" but the material could still include other elements and compounds. This application discloses several numerical ranges in the text and figures. The numerical ranges disclosed inherently support any range or value within the disclosed numerical ranges even though a precise range limitation is not stated verbatim in the specification because this invention can be practiced throughout the disclosed numerical ranges.

[0029] The above description is presented to enable a person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the preferred embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the invention. Thus, this invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein. The implementations described above and other implementations are within the scope of the following claims.

What is claimed is:

1. A spindle motor of a magnetic recording storage device, the spindle motor comprising a fluid dynamic bearing comprising a lubricant comprising at least one of an organic and inorganic nanomaterial.

2. The spindle motor of magnetic recording storage device of claim **1**, wherein the lubricant has a single phase composition.

3. The spindle motor of magnetic recording storage device of claim **1**, wherein the lubricant comprises a mineral base hydro carbon, synthetic hydrocarbon containing compound, or combinations thereof.

4. The spindle motor of magnetic storage device of claim **1**, wherein the lubricant comprises about 0.01 to about 5.0 percent by weight of the organic or inorganic nanomaterial.

5. The spindle motor of magnetic storage device of claim **1**, wherein the lubricant comprises about 0.02 to about 2.0 percent by weight of the organic or inorganic nanomaterial.

6. The spindle motor of magnetic storage device of claim **1**, wherein the lubricant comprises about 0.05 to about 1.0 percent by weight of the organic or inorganic nanomaterial.

7. A spindle motor of a magnetic recording storage device of claim **1**, wherein the lubricant comprises di-2-ethyl hexyl suberate.

8. The spindle motor of magnetic recording storage device of claim **1**, wherein the lubricant comprises an ester selected from the group consisting of diester, monoester, simple ester, compound ester and combinations thereof.

9. The spindle motor of magnetic recording storage device of claim **8**, wherein the lubricant comprises an additive.

10. The spindle motor of magnetic recording storage device of claim **1**, wherein the lubricant comprises di-2-ethyl hexyl pimelate.

11. The spindle motor of magnetic recording storage device of claim **1**, wherein the organic nanomaterial comprises carbon nano tubes, onions, or combinations thereof.

12. The spindle motor of magnetic recording storage device of claim **11**, wherein the onions are Ni/Y based single wall carbon nano tubes, Fe-based multiwall carbon nano tubes, metal free multiwall nano tubes, or combinations thereof.

13. The spindle motor of magnetic recording storage device of claim **1**, wherein the inorganic nanomaterial comprises inorganic fullerene (IF) comprising IF-MoS_2, IF-WS_2, IF-NbS_2 or combinations thereof.

14. A lubricant comprising (a) an organic or inorganic nanomaterial and (b) a mineral base hydro carbon, synthetic hydrocarbon containing compound, or combinations thereof.

15. The lubricant of claim **14**, wherein the lubricant comprises 0.01 to 5.0 percent by weight of the organic or inorganic nanomaterial.

16. The lubricant of claim **14**, wherein the inorganic nanomaterial comprises carbon nano tubes, onions, or combinations thereof.

17. The lubricant of claim **14**, wherein the onions are Ni/Y based single wall carbon nano tubes, Fe-based multiwall carbon nano tubes, metal free multiwall nano tubes, or combinations thereof.

18. The lubricant of claim **14**, wherein the inorganic nanomaterial comprises IF-MoS_2, IF-WS_2, IF-NbS_2 or combinations thereof.

19. A spindle motor of a magnetic recording storage device, the spindle motor comprising a fluid dynamic bearing comprising a lubricant comprising an organic liquid and an inorganic nanomaterial, wherein the inorganic nanomaterial and the organic liquid form a suspension such that the inorganic nanomaterial does not settle out from the suspension.

20. The spindle motor of magnetic recording storage device of claim **19**, wherein the inorganic nanomaterial comprises IF-MoS_2, IF-WS_2, IF-NbS_2 or combinations thereof.

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