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SPINDLE MOTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a spindle motor provided with a damping means adapted to absorb vibrations at a position where maximum strain energy is generated, thereby being capable of minimizing a non-repeatable runout to increase the magnetic track density of a disk.

2. Description of the Prior Art

For a drive means used in miniature disk recording appliances such as hard disk drivers or floppy disk drivers, a spindle motor is mainly used.

Various kinds of spindle motors are known which are manufactured for a variety of purposes by various manufacturers. Spindle motors are being improved in terms of performance and speed.

Fig. 1 illustrates an example of a general spindle motor. As shown in Fig. 1, the spindle motor includes a coil 112 and a permanent magnet 131. As is well known, the spindle motor is driven by an electromagnetic force generated in accordance with a co-operation between an electric field created by current flowing through the coil 112 and a magnetic field created by the permanent magnet 131. This will be described in more detail.

When current flows through the coil 112 serving as a stator, an electromagnetic force is generated between the coil 112 and the permanent magnet 132 facing the coil 112. The electromagnetic force serves to rotate the permanent magnet

132. By virtue of the rotating force of the permanent magnet 132, a rotor 130, to which the permanent magnet 132 is attached, is rotated.

Spindle motors are classified into those of an outer wheel rotation type and those of an inner wheel rotation type in accordance with a construction to which a ball bearing 140 is applied.

In the outer wheel rotation type construction, a bearing is interposed between a spindle and a rotor in such a fashion that the rotor rotates together with an outer wheel of the bearing. On the other hand, in the inner wheel rotation type construction, a bearing is interposed between a spindle and a support housing of a motor base plate so that the spindle and rotor rotate together with the inner wheel of the bearing.

This will be described in more detail. In the outer wheel rotation type construction, a spindle is centrally fixed to a base plate. A bearing is interposed between the fixed spindle and a support housing for a rotor in such a fashion that the rotor rotates along with the outer wheel of the bearing by an electromagnetic force generated between the coil and permanent magnet.

In the inner wheel rotation type construction, as shown in Fig. 1, a spindle 120 is integrally coupled to a rotor casing 121. A ball bearing 140 is mounted on the spindle 120 in such a fashion that its inner wheel 141 is tightly fitted around the spindle 120. A support housing 101 integrally formed with a base plate 100 is mounted on the ball bearing 140 in such a fashion that it is tightly fitted around an

outer wheel 142 of the ball bearing 140 at its inner peripheral surface. When an electromagnetic force is generated between the coil 112 and permanent magnet 132, the spindle 120 and rotor 130 rotate simultaneously along with the inner wheel 142 of the bearing 140.

In such a spindle motor to which a ball bearing is applied, fine vibrations are generated in an axial direction and in a radial direction perpendicular to the axial direction while the spindle motor is driven. Such vibrations, which cause disks to wobble or exhibit displacement in an axial direction, are called "runout".

Such runout, which is generated at the bearing, may be transferred to the disk via the hub. Otherwise, it may be transferred to the disk via the hub after being transferred to the spindle.

After measuring such runout and analyzing the frequency components of the measured runout, it can be found that runout consists of frequency components periodically generated during the rotation of the motor or frequency components irregularly generated during the rotation of the motor.

Runout consisting of frequency components periodically generated in a repeatable fashion is called "repeatable runout" whereas runout consisting of frequency components other than periodic frequency components is called "non-repeatable runout".

The point of time when repeatable runout is generated can be estimated through repeated tests because such repeatable runout is periodically generated during every rotation of the

motor. In this regard, servo control systems, which serve to shift the position of a head at the point of time when repeatable runout is generated, have been used in order to compensate for the displacement of a disk.

However, non-repeatable runout cannot be practically controlled because it is impossible to estimate the point of time when such non-repeatable runout is generated.

In particular, the degree of non-repeatable runout determines the degree of distortion in the rotation trace of the disk. For this reason, non-repeatable runout serves as a cause of a limitation on the magnetic track density of the disk. To this end, there has been a regulation in the manufacture of spindle motors to restrict the degree of non-repeatable runout to a certain level. For instance, for hard disk drivers, there is a regulation to restrict non-repeatable runout to about 5% of the track pitch. In accordance with this regulation, in the case of 3.5-inch hard disk drivers, the disk track pitch should be 3.6μm, and the non-repeatable runout should not exceed 0.18μm in order to obtain a magnetic track density of 7,000 TPI.

However, the current demand associated with an increase in the capacity and track density of disks cannot be satisfied by the above mentioned method for simply restricting non-repeatable runout.

Although it is possible for disks to have a higher track density by reducing the track pitch thereof, this is restricted because there is a limitation in reducing the non-repeatable runout adversely affecting an increase in the track

density of disks. For this reason, it is impossible for the head to write data onto a disk at an increased density unless an improvement in non-repeatable runout is directly made.

In order to obtain a high magnetic track density of disks, it is most important to reduce non-repeatable runout generated at spindle motors as much as possible.

Recently, a construction for reducing vibrations generated at spindle motors has recently been proposed. Referring to Fig. 2, an example of such a construction is illustrated. As shown in Fig. 2, a clamp 1, which serves to cover a disk while preventing displacement of the disk, is mounted to the upper end of a spindle 4 by means of a bolt 5. A vibration attenuating means is interposed between the clamp 1 and the upper end of the shaft 4. The vibration attenuating means comprises a soft tape 2 attached to a mass 3.

In such a construction, however, only an indirect control for the runout of the disk is achieved because only the runout transferred through the shaft and clamp 1 is reduced by the tape 2 and mass 3.

Furthermore, since the clamp 1 is installed outside the spindle motor, it is impossible to control runout directly transferred through the rotor directly coupled to the shaft 4 and on which the disk is seated, even though the construction is easily applied to the spindle motor. For this reason, there is a problem in that it is difficult to expect a substantial reduction in non-repeatable runout.

As mentioned above, it is yet hardly possible to achieve a control for the non-repeatable runout generated at spindle

motors. Thus, non-repeatable runout serves a main cause of preventing a substantial increase in the track density of disks.

SUMMARY OF THE INVENTION

Therefore, the present invention has been made in view of the above mentioned problems, and an object of the invention is to provide a spindle motor provided with a damping means arranged at an area on which strain energy is concentrated, thereby greatly reducing disk runout , in particular, non-repeatable runout.

Another object of the invention is to provide a spindle motor capable of minimizing a frequency response function of disks to increase the magnetic track density of those disks, thereby enabling a fabrication of disks with a high track density.

Another object of the invention is to provide a spindle motor which is applicable to both the inner wheel drive type system and outer wheel drive type system.

In order to accomplish the above objects, the present invention provides a spindle motor provided with damping means arranged at areas where strain energy excited by ball bearings supporting a shaft of the spindle motor are concentrated. The damping means greatly reduces repeatable runout of a rotor and non-repeatable runout generated at the motor.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and aspects of the invention will become apparent from the following description of embodiments with reference to the accompanying drawings in which:

Fig. 1 is a vertical sectional view illustrating a conventional spindle motor;

Fig. 2 is an enlarged vertical sectional view illustrating a vibration reduction construction applied to conventional motors;

Figs. 3 and 4 are vertical sectional views respectively illustrating spindle motors of different types according to a first embodiment of the present invention;

Figs. 5 and 6 are vertical sectional views illustrating respective half portions of the spindle motors according to the first embodiment of the present invention, in which a reinforcing plate is coupled to a damping means;

Figs. 7 and 8 are vertical sectional views respectively illustrating spindle motors of different types according to a second embodiment of the present invention;

Figs. 9 and 10 are vertical sectional views illustrating respective half portions of the spindle motors according to the second embodiment of the present invention, in which a reinforcing plate is coupled to a damping means;

Figs. 11 and 12 are vertical sectional views respectively illustrating spindle motors of different types according to a third embodiment of the present invention;

Figs. 13 and 14 are vertical sectional views illustrating respective half portions of the spindle motors according to the third embodiment of the present invention, in which a reinforcing plate is coupled to a damping means;

Fig. 15 is a vertical sectional view illustrating a spindle motor according to a fourth embodiment of the present

invention;

Figs. 16 and 17 are vertical sectional views respectively illustrating a half portion of the spindle motor according to the fourth embodiment of the present invention, in which a reinforcing plate is coupled to a damping means;

Fig. 18 is a vertical sectional view illustrating a spindle motor according to a fifth embodiment of the present invention;

Figs. 19 and 20 are vertical sectional views respectively illustrating a half portion of the spindle motor according to the fifth embodiment of the present invention, in which a reinforcing plate is coupled to a damping means;

Figs. 21 and 22 are output waveform diagrams of runout generated in a spindle motor at certain intervals of time and at certain intervals of frequency under the condition in which no disk is loaded on the spindle motor, respectively;

Fig. 23 is a histogram of non-repeatable runout generated under the condition of Figs. 21 and 22;

Figs. 24 and 25 are output waveform diagrams of runout generated in a spindle motor at certain intervals of time and at certain intervals of frequency under the condition in which disks are loaded on the spindle motor, respectively;

Fig. 26 is a histogram of non-repeatable runout generated under the condition of Figs. 21 and 22;

Figs. 27 and 28 are output waveform diagrams of runout generated at certain intervals of time and at certain intervals of frequency when a spindle motor rotates at a rated velocity under the condition in which no disk is loaded on the

spindle motor, respectively, depending on whether or not a damping means is provided;

Figs. 29 and 30 are output waveform diagrams of runout generated at certain intervals of time and at certain intervals of frequency when a spindle motor rotates at a rated velocity under the condition in which disks are loaded on the spindle motor, respectively, depending on whether or not a damping means is provided; and

Fig. 31 is an output waveform diagram of frequency response characteristics of disks depending on whether or not a damping means is provided.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

After measuring strain energy generated at a motor along a transmission path thereof by use of a finite element method, it can be found that great strain energy is generated at the surface of the rotor contacting the upper bearing (0.00857 - 1.353), the upper end of the outer wheel of the upper bearing (0.0112 - 0.381), the facing inner wheel ends of the upper and lower bearings (0.00489 - 1.604), and the spacer (0.00837 - 0.612).

The strain energy is indicative of the magnitude of output energy per unit input energy, and its actual value is expressed in the unit of 10^{-3}.

In accordance with a preferred embodiment of the present invention, respective damping members 70 are installed at areas of a motor, where great strain energy is generated, based on the result of the measurement, in order to greatly reduce non-repeatable disk runout.

Figs. 3 and 4 are vertical sectional views respectively illustrating spindle motors according to a first embodiment of the present invention. Fig. 3 shows an inner wheel drive type spindle motor whereas Fig. 4 shows an outer wheel drive type spindle motor. In Figs. 3 and 4, the reference numeral 10 denotes a base plate, 20 a shaft, 30 a stator, and 40 a rotor.

In accordance with this embodiment of the present invention, the shaft 20 may be a rotating spindle as in the case of Fig. 3, or may be a fixed spindle fixedly mounted to the base plate 10 as in the case of Fig. 4.

The stator 30 includes a core 31, and a winding coil 32 wound around the core 31. The stator 30 may be fixedly mounted to a support housing 11 integrally formed with the base plate 10 in the case of Fig. 3, or may be directly fixed to the base plate 10 in the case of Fig. 4.

The stator 30 serves to create an electric field by virtue of electric power received from an external power source.

The rotor 40 is arranged around the stator 30 in such a fashion that it covers the stator 30 while defining an air gap therebetween.

The rotor 40 includes a rotor housing 41, and a permanent magnet 42 attached to an inner peripheral surface of the rotor housing 41 facing the stator 30. The permanent magnet 42 is spaced from the stator 30 to define an air gap therebetween.

The support housing 11 of Fig. 3 is protruded from the base plate 10 in such a fashion that it has an inner diameter larger than that of the outer peripheral surface of the shaft

20. On the other hand, in the case of Fig. 4, a support housing 43 is protruded from the rotor 40 in such a fashion that it has an inner diameter larger than that of the outer peripheral surface of the shaft 20. In either case, a ball bearing unit 50, which includes an upper bearing 51 and a lower bearing 52, is fitted between the outer peripheral surface of the shaft 20 and the inner peripheral surface of the support housing 11 or 43.

The upper bearing 51 of the ball bearing unit 50 has an inner wheel 51a, an outer wheel 51b, and a plurality of balls 53 arranged between the inner and outer wheel 51a and 51b. Similarly, the lower bearing 52 of the ball bearing unit 50 has an inner wheel 52a, an outer wheel 52b, and a plurality of balls 53 arranged between the inner and outer wheel 51a and 51b.

The configurations mentioned above in conjunction with Figs. 3 and 4 are the same as those of conventional inner and outer wheel drive type spindle motors, respectively.

The embodiment of the present invention illustrated in Figs. 3 and 4 is characterized in that the upper and lower bearings 51 and 52, which are arranged between the shaft-20 and the support housing 11 or 43, are spaced from each other to define a desired gap therebetween, and a damping means 70 is interposed in the gap between the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 in such a fashion that it is tightly in contact with the outer wheels 51b and 52b.

That is, in either case of Fig. 3 or Fig. 4, a desired

gap is defined between the upper and lower bearings 51 and 52. In the gap, the damping means 70 is interposed between the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 in such a fashion that it is tightly in contact with the facing end surfaces of the outer wheels 51b and 52b.

The damping means 70 not only serves as a damper, but also serves as a spacer for spacing the upper and blower bearings 51 and 52 from each other. To this end, it is preferred that the damping means 70 be made of a harder material, but its surfaces being in contact with respective outer wheels 51b and 52b of the upper and lower bearings 51 and 52 be made of a material capable of absorbing impact transferred from the upper and lower bearings 51 and 52.

In particular, the damping means 70 may be slightly spaced from at least one of the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 to define a fine gap in which a reinforcing plate 80 made of a material harder than that of the damping means 70 is arranged, as shown in Figs. 5 and 6.

In accordance with the first embodiment of the present invention, it is possible to effectively absorb vibrations generated between the upper and lower bearings 51 and 52 by the damping means 70 interposed between those bearings, thereby greatly reducing the degree of runout in the rotor 40.

Figs. 7 and 8 are vertical sectional views respectively illustrating spindle motors according to a second embodiment of the present invention. Fig. 7 shows an inner wheel drive type spindle motor whereas Fig. 8 shows an outer wheel drive

type spindle motor. In Figs. 7 and 8, elements respectively corresponding to those in Figs. 3 and 4 are denoted by the same reference numerals.

The second embodiment has the same configuration as the first embodiment in that it includes a base plate 10, a shaft 20, a stator 30, a rotor 40, and a ball bearing unit 50, which have the same construction as those of the first embodiment.

That is, in accordance with the second embodiment of the present invention, the stator 30 is fixed to the base plate 10. The shaft 20 is a rotating spindle in the inner wheel drive type construction, and a fixed spindle in the outer wheel drive type construction. The ball bearing unit 50, which includes an upper bearing 51 and a lower bearing 52, is tightly fitted between the shaft 20 and the support housing 11 or 43.

The second embodiment of the present invention is characterized in that a spacer 60 is arranged in the gap defined between the upper and lower bearings 51 and 52 while being spaced from the outer wheels 51b and 52b of the upper and lower bearings 51 and 52, and a pair of damping means 70 are interposed in gaps defined between the spacer 60 and respective outer wheels 51b and 52b of the upper and lower bearings 51 and 52.

That is, in accordance with the second embodiment of the present invention, vibrations generated at the upper and lower bearings 51 and 52 are absorbed by the spacer 60 arranged between the upper and lower bearings 51 and 52, and the damping means 70 interposed between the spacer 60 and

respective outer wheels 51b and 52b of the upper and lower bearings 51 and 52.

Where a pair of damping means 70 are arranged at the upper and lower bearings 51 and 52, respectively, as mentioned above, it is possible to more effectively reduce non-repeatable disk runout because the damping means 70 more effectively disperse and absorb vibrations generated at the upper and lower bearings 51 and 52.

Alternatively, a reinforcing plate 80 made of a material harder than that of the damping means 70 are fixed to at least one side of the damping means 70, as shown in Figs. 9 and 10, in order to firmly hold the damping means 70.

A pair of hard reinforcing plates 80 may be arranged at the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 facing the damping means 70 as in the case of Fig. 9, or may be arranged at opposite sides of the bearing spacer 60 facing the damping means 70 as in the case of Fig. 10.

Figs. 11 and 12 are vertical sectional views respectively illustrating spindle motors according to a third embodiment of the present invention. Fig. 11 shows an inner wheel drive type spindle motor whereas Fig. 12 shows an outer wheel drive type spindle motor. In Figs. 11 and 12, elements respectively corresponding to those in Figs. 3 and 4 are denoted by the same reference numerals.

The third embodiment has the same configuration as the above mentioned embodiments in that it includes a base plate 10, a shaft 20, a stator 30, a rotor 40, and a ball bearing unit 50, which have the same construction as those of the

above mentioned embodiments.

That is, in accordance with the third embodiment of the present invention, the stator 30 is fixed to the base plate 10. The shaft 20 is a rotating spindle in the inner wheel drive type construction, and a fixed spindle in the outer wheel drive type construction. The ball bearing unit 50, which includes an upper bearing 51 and a lower bearing 52, is tightly fitted between the shaft 20 and the support housing 11 or 43.

In the inner wheel drive type construction, accordingly, the rotor 40 rotates along with the shaft 10. On the other hand, only the rotor 40 rotates in the outer wheel drive type construction.

The third embodiment of the present invention is characterized in that a bearing spacer unit 60, which includes a first bearing spacer 61 and a second bearing spacer 62, is arranged in the gap defined between the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 while being spaced from each other, and a damping means 70 is interposed between the first and second bearing spacers 61 and 62.

That is, in accordance with the third embodiment of the present invention, the first and second bearing spacers 61 and 62 are arranged in the gap defined between the upper and lower bearings 51 and 52 in such a fashion that they are in surface contact with the outer wheels 51b and 52b of the upper and lower bearings 51 and 52 while being spaced from each other to define a gap.

The damping means 70 is interposed between the gap

defined between the first and second bearing spacers 61 and 62.

In accordance with this embodiment, vibrations generated at the upper and lower bearings 51 and 52 are absorbed as they are transferred to the damping means 70 via the first and second bearing spacers 61 and 62. Accordingly, it is possible to minimize impact resulting from vibrations transferred via the bearings.

It is preferred that a reinforcing plate 80 made of a material harder than that of the damping means 70 be arranged on at least one side of the damping means 70 between the first and second bearing spacers 61 and 62.

The reinforcing plate 80 may be interposed between the damping means 70 and the first bearing spacer 61, as shown in Fig. 13, or may be interposed between the damping means 70 and the second bearing spacer 62, as shown in Fig. 14. Alternatively, a pair of reinforcing plates 80 may be provided which are arranged on opposite sides of the damping means 70 in such a fashion that they are in contact with the first and second bearing spacers 61 and 62, respectively.

The reinforcing plate 80 serves to allow the softer damping means 70 to be easily inserted into the gap between the first and second bearing spacers 61 and 62 while maintaining the inserted state of the damping means 70.

In accordance with this embodiment, vibrations transferred to the rotor 40 are greatly reduced by the damping means 70 firmly supported by the reinforcing plate 80, so that non-repeatable runout of disks is minimized.

Fig. 15 is a vertical sectional view illustrating a spindle motor according to a fourth embodiment of the present invention. This embodiment is applied only to the inner wheel drive type construction. In Fig. 15, elements respectively corresponding to those in Fig. 3 are denoted by the same reference numerals.

In accordance with the fourth embodiment of the present invention, a stator 30 is fixed to the base plate 10, in particular, the outer peripheral surface of a support housing 11 protruded from the base plate 10. A shaft 20 is integrally coupled to a rotor 40. A ball bearing unit 50, which includes an upper bearing 51 and a lower bearing 52, is tightly fitted between the support housing 11 and the shaft 20.

When an electromagnetic force is generated between a winding coil 32 of the stator 30 and a permanent magnet 42 of the rotor 40, inner wheels 51a and 52a of the upper and lower bearings 51 and 52 rotate along with the shaft 10 and the rotor 40.

The fourth embodiment of the present invention is characterized in that a damping means 70 is interposed between the inner wheel 51a of the upper bearing 51 and a portion of the rotor casing 41 facing the inner wheel 51a.

That is, this embodiment provides a configuration for absorbing vibrations transferred between the shaft 20 and rotor 40, which are rotating elements of the motor, and the inner wheel 51a of the upper bearing 51 using the damping means 70.

A reinforcing plate 80 made of a material harder than

that of the damping means 70 may be arranged at one side of the damping means 70 in accordance with the fourth embodiment. The reinforcing plate 80 may be interposed between the damping means 70 and the upper bearing 51, as shown in Fig. 16, or may be interposed between the damping means 70 and the rotor case 41, as shown in Fig. 17.

The reinforcing plate 80 serves to allow the damping means 70 to be easily inserted between the rotor case 41 and the inner wheel 51a of the upper bearing 51 while firmly maintaining the inserted state of the damping means 70. By this configuration, vibrations transferred to the rotor 40 are continuously reduced.

Fig. 18 is a vertical sectional view illustrating a spindle motor according to a fifth embodiment of the present invention. This embodiment is applied only to the outer wheel drive type construction. In Fig. 18, elements respectively corresponding to those in Fig. 4 are denoted by the same reference numerals.

In accordance with the fifth embodiment of the present invention, a shaft 20 is fixed to a base plate 10. Around the shaft 20, a stator 30, which includes a core 31 and a winding coil 32, is fixed to the base plate 10. A rotor 40 is arranged above the stator 30. The rotor 40 includes a rotor casing 41 arranged around the stator 30 in such a fashion that it covers the stator 30 while defining an air gap therebetween, and a permanent magnet 42 fixed to the inner wall surface of the rotor casing 41.

A support housing 43 is downwardly protruded from a

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central portion of the rotor 40 in such a fashion that it is integral with the rotor 40. A ball bearing unit 50, which includes an upper bearing 51 and a lower bearing 52, is fitted between the outer peripheral surface of the shaft 20 and the inner peripheral surface of the support housing 43. Each of the upper and lower bearings 51 and 52 has an inner wheel, an outer wheel, and a plurality of balls arranged between the inner and outer wheels.

The above configuration is substantially similar to that of conventional outer wheel drive type constructions. The fifth embodiment of the present invention is mainly characterized in that a damping means 70 is interposed between the base plate 10 and the inner wheel 52a of the lower bearing 52.

In accordance with this embodiment, an attenuation of vibrations is achieved in a more stable state because the damping means 70 is arranged between fixed members, namely, the base plate 10 and the inner wheel 52a of the lower bearing 52 which are fixed to the shaft 20.

This will be described in more detail. Where the damping means 70 is arranged between rotating members, it is rotated when the rotating members rotate. As a result, it is very difficult to control rotation vibrations. Where rotation vibrations are controlled at a fixed position on the ball bearing unit 50 as in the above embodiment of the present invention, it is possible to absorb such vibrations in a stable state. Therefore, the configuration of the fifth embodiment is more effective in terms of a vibration

attenuation.

A reinforcing plate 80 may be arranged at one side of the damping means 70 between the base plate 10 and the inner wheel 52a of the lower bearing 52 in order to firmly support the damping member 70.

The reinforcing plate 80 is made of a material harder than that of the damping means 70.

The reinforcing plate 80 may be interposed between the damping means 70 and the lower bearing 52, as shown in Fig. 19, or may be interposed between the damping means 70 and the base plate 10, as shown in Fig. 20.

As described in the above mentioned embodiments, the present invention is mainly characterized in that vibrations generated by the ball bearings during the driving of the motor are prevented from being transferred to the rotor 40.

In order to evaluate such characteristics of the present invention, runout occurring in the spindle motor was measured using a separate testing device. Under the condition in which no disk is loaded on the spindle motor, the total indicated runout, repeatable runout, and non-repeatable runout of the spindle motor alone were measured at certain intervals of time and at certain intervals of frequency, respectively. The results of the measurement are shown in Figs. 21 and 22. The statistical characteristics of the measured runout are shown in the following Table 1.

Table 1

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	Deviation between Max. and Min. Values (μm)	Standard Deviation (μm)
TIR	3.1280	1.1927
RRO	3.0907	1.1927
NRRO	0.0521	0.0072

In Table 1, "TIR" represents the total indicated runout, "RRO" represents the repeatable runout, and "NRRO" represents the non-repeatable runout.

Fig. 23 is a histogram depicting the measured non-repeatable runout. In Fig. 23, the solid line is indicative of a normal distribution involving mean and standard deviations, as in the measured non-repeatable runout. Referring to Fig. 23, it can be understood that non-repeatable runout is a normal distribution.

On the other hand, under the condition in which two disks were loaded on the above mentioned spindle motor, the runout of the disks was measured at certain intervals of time and at certain intervals of frequency. The results of the measurement are shown in Figs. 24 and 25. The statistical characteristics of the measured runout are shown in the following Table 2.

Table 2

	Deviation between Max. and Min. Values (μm)	Standard Deviation (μm)
TIR	22.2520	7.7800
RRO	22.0214	7.7798

NRRO	0.3113	0.0451

Referring to Table 2, it can be found that the total indicated runout, repeatable runout, and non-repeatable runout are increased by about 7 times, as compared to those of Table 1.

This is because an exciting force from the ball bearings is added to motions of the disks during its transfer, so that the resultant force is amplified.

Fig. 26 is a histogram depicting the results of the above measurement. After analyzing the histogram of Fig. 26, it can be found that the distribution of non-repeatable runout is a normal distribution with a mean of 0.

On the other hand, a runout measurement was conducted for a conventional spindle motor and a spindle motor provided with the damping means according to the present invention, respectively. Different results were obtained in accordance with different arrangements of the damping means. The results of the measurement are shown in the following Table 3.

Table 3

	Normal	Upper Bearing Damping	Bearing Spacer Damping
1st Mode	994 Hz	986 Hz	990 Hz

As apparent from Table 3, the measurement was conducted for three cases, namely, a normal case, an upper bearing

damping case in which the damping means 70 is arranged at the upper bearing 51, and a bearing spacer damping case in which the damping means 70 is arranged between the upper and lower bearings 51 and 52.

Non-repeatable runout was measured for the above three cases, at certain intervals of time and at certain intervals of frequency, respectively. The results of the measurement are shown in Figs. 27 and 28.

On the other hand, under the condition in which disks were loaded, the same measurement was conducted for the conventional product and products respectively provided with the damping means 70 at different positions. The results of the measurement are shown in the following Table 4.

Table 4

	1st Mode	2nd Mode	3nd Mode
Normal	554 Hz	700 Hz	1,043 Hz
Upper Bearing Damping	533 Hz	685 Hz	1,073 Hz
Bearing Spacer Damping	554 Hz	696 Hz	1,035 Hz

Also, non-repeatable runout was measured at certain intervals of time and at certain intervals of frequency under the condition in which the disks rotate at a rated velocity of 70 Hz. The results of the measurement are shown in Figs. 29 and 30, respectively.

After analyzing the above measurement results, it can be understood that the construction provided at the bearing with the damping means exhibits a great reduction in non-

repeatable runout as compared to the construction provided with no damping means. It can also be found that among the various constructions provided with the damping means, the upper bearing damping case, in which the damping means is arranged at the upper bearing as in the fourth embodiment of the present invention, exhibits the greatest reduction of non-repeatable runout caused by ball defects in the ball bearing. In particular, it can be found that most of non-repeatable runout are eliminated at a frequency of 300 Hz or less.

Although an increase in some non-repeatable runout components is exhibited just after disks are loaded on the spindle motor, most of non-repeatable runout components are eliminated. Accordingly, a reduction in non-repeatable runout is totally achieved.

Where the damping means 70 is arranged between the upper and lower ball bearings 51 and 52 as in the first to the third embodiments, non-repeatable runout caused by inner wheel defects of the ball bearings increases even though non-repeatable runout caused by ball defects of the ball bearings is reduced as in the fourth embodiment. This is considered to be caused by the position of the damping means. Similar results are exhibited in a disk-loaded state. Thus, the total non-repeatable runout is greatly reduced.

In particular, where the damping means 70 is interposed between the upper bearing 50 and the rotor 40 in accordance with the present invention, the standard deviation of non-

repeatable runout is reduced to 11.9 nm, as compared to 16 nm in conventional cases. Accordingly, the non-repeatable runout reduction rate of about 26% is obtained, as compared to conventional cases. Where the damping means 70 is interposed between the upper and lower bearings 51 and 52, the standard deviation of non-repeatable runout is greatly reduced to 10.5 nm. Accordingly, the non-repeatable runout reduction rate of about 34% is obtained. Thus, the case in which a damping is established between the upper and lower bearings 51 and 52 is more effective.

This will be described in more detail. Where a damping is established between the rotor casing 41 and the upper bearing 51, only the energy transferred from the inner wheel 51a of the upper bearing 51 to the rotor casing 41 is absorbed. However, in the construction adapted to establish a damping between the upper and lower bearings 51 and 52, all vibrations transferred via both the upper and lower bearings 51 and 52 are absorbed. In the latter case, accordingly, the quantity of energy being absorbed is larger than that of the former case. Thus, the latter case exhibits an increased non-repeatable runout reduction effect.

It is considered that the reason why an increased non-repeatable runout reduction effect is exhibited in the disk-loaded state, as compared to the state in which no disk is loaded, is because the quantity of strain energy consumed by the damping means 70 increases due to an increase in inertia resulting from the loading of disks.

Since the damping means 70 is arranged at areas, where a maximum quantity of strain energy is exhibited, in accordance with the present invention, it is possible to greatly reduce the deviation of runout control.

Fig. 31 is an output waveform diagram of frequency response characteristics of disks depending on whether or not the damping means is provided. Referring to Fig. 31, it can be found that an improvement in the frequency response characteristics of disks is obtained by the damping means 70 according to the present invention.

In particular, where the reinforcing plate 80 is attached to the damping means 70, the assembling of the damping means 70 can be easily and conveniently achieved. In this case, it is also possible to disperse various components of frequencies with a high amplitude by virtue of the reinforcing plate 80. Accordingly, an improvement in amplitude uniformity is totally obtained, thereby enhancing the reduction of non-repeatable runout.

As apparent from the above description, in accordance with the present invention, the damping means 70 is installed at portions of the motor, where a maximum quantity of strain energy is generated, thereby greatly reducing non-repeatable runout components of runout generated at the motor, which components are difficult to be controlled.

In accordance with the present invention, the damping means cuts off the transfer of vibrations at areas, where a maximum quantity of strain energy is generated, and absorbs the vibrations, thereby causing the rotating trace of the

disk to be approximate to a true circle.

As the non-repeatable runout components restricting the magnetic track density of disks is minimized in accordance with the present invention, a higher magnetic track density can be obtained.

For instance, the magnetic track density of disks can be increased to 25,000 TPI in accordance with the present invention. Thus, the present invention is very useful in that it enables the manufacture of high density disk drivers.

Although the preferred embodiments of the invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.

WHAT IS CLAIMED IS:

1. A spindle motor comprising:

a shaft;

a stator including a core and a winding coil;

a rotor arranged around said stator in such a fashion that an air gap is defined between said rotor and said stator, said rotor including a rotor casing and a permanent magnet fixed to an inner wall surface of said rotor casing;

a ball bearing unit arranged between an outer peripheral surface of said shaft and an inner peripheral surface of said support housing, said ball bearing unit including an upper bearing and a lower bearing, each of said upper and lower bearings having an inner wheel, an outer wheel, and a plurality of balls arranged between said inner and outer wheels; and

damping means arranged between said outer wheels of said upper and lower bearings and adapted to substantially attenuate vibrations generated at said motor.

2. The spindle motor in accordance with Claim 1, further comprising a reinforcing plate attached to at least one side of said damping means and made of a material harder than that of said damping means.

3. A spindle motor comprising:

a shaft;

a stator including a core and a winding coil;

a rotor arranged around said stator in such a fashion that an air gap is defined between said rotor and said stator, said rotor including a rotor casing and a permanent

magnet fixed to an inner wall surface of said rotor casing;

a ball bearing unit arranged between an outer peripheral surface of said shaft and an inner peripheral surface of said support housing, said ball bearing unit including an upper bearing and a lower bearing, each of said upper and lower bearings having an inner wheel, an outer wheel, and a plurality of balls arranged between said inner and outer wheels;

a bearing spacer arranged between said outer wheels of said upper and lower bearings in such a fashion that a fine gap is defined between said bearing spacer and at least one of said outer wheels; and

damping means inserted in said gap defined between said bearing spacer and said at least one wheel, said damping means serving to substantially attenuate vibrations generated at said motor.

4. The spindle motor in accordance with Claim 3, further comprising a reinforcing plate attached to at least one side of said damping means and made of a material harder than that of said damping means.

5. A spindle motor comprising:

a shaft;

a stator including a core and a winding coil;

a rotor arranged around said stator in such a fashion that an air gap is defined between said rotor and said stator, said rotor including a rotor casing and a permanent magnet fixed to an inner wall surface of said rotor casing;

a ball bearing unit arranged between an outer

peripheral surface of said shaft and an inner peripheral surface of said support housing, said ball bearing unit including an upper bearing and a lower bearing, each of said upper and lower bearings having an inner wheel, an outer wheel, and a plurality of balls arranged between said inner and outer wheels;

a bearing spacer unit including a first bearing spacer being tightly in contact with said outer wheel of said upper bearing, and a second bearing spacer being spaced from said first bearing spacer to define a fine gap therebetween, said second bearing spacer being tightly in contact with said outer wheel of said lower bearing; and

damping means inserted in said gap defined between said first and second bearing spacers, said damping means serving to substantially attenuate vibrations generated at said motor.

6. The spindle motor in accordance with Claim 5, further comprising a reinforcing plate attached to at least one side of said damping means and made of a material harder than that of said damping means.

7. A spindle motor comprising:

a shaft;

a stator including a core and a winding coil;

a rotor arranged around said stator in such a fashion that an air gap is defined between said rotor and said stator, said rotor including a rotor casing fixed to one end of said shaft, and a permanent magnet fixed to an inner wall surface of said rotor casing;

a ball bearing unit tightly fitted between an outer peripheral surface of said shaft and an inner peripheral surface of said support housing, said ball bearing unit including an upper bearing and a lower bearing, each of said upper and lower bearings having an inner wheel, an outer wheel, and a plurality of balls arranged between said inner and outer wheels; and

damping means arranged between said inner wheel of said upper bearing and said rotor casing and adapted to substantially attenuate vibrations generated at said motor.

8. The spindle motor in accordance with Claim 7, further comprising a reinforcing plate attached to at least one side of said damping means and made of a material harder than that of said damping means.

9. A spindle motor comprising:

a base plate;

a shaft fixed to said base plate;

a stator including a core and a winding coil;

a rotor arranged around said stator in such a fashion that an air gap is defined between said rotor and said stator, said rotor including a rotor casing fixed to one end of said shaft, and a permanent magnet fixed to an inner wall surface of said rotor casing;

a ball bearing unit tightly fitted between an outer peripheral surface of said shaft and an inner peripheral surface of said support housing, said ball bearing unit including an upper bearing and a lower bearing, each of said upper and lower bearings having an inner wheel, an outer

wheel, and a plurality of balls arranged between said inner and outer wheels; and

damping means arranged between said base plate and said lower bearing and adapted to substantially attenuate vibrations generated at said motor.

10. The spindle motor in accordance with Claim 9, further comprising a reinforcing plate attached to at least one side of said damping means and made of a material harder than that of said damping means.