Dynamic characteristics of hard disk drive spindles supported by hydrodynamic bearings

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Abstract Most hard disk spindles currently used are supported by grease lubricated deep-groove ball bearings. However, in the trend of increasing spindle speed and reducing size and cost, the shortcomings of ball bearing spindles, such as high non-repeatable run out, high acoustic noise and short life time at high running speed, make them unsuitable for high performance hard disk drives (HDD). On the contrary, the dynamic characteristics of hydrodynamic bearing spindles are superior to that of ball bearing spindles. Therefore, they are considered to be the substitute of ball bearing spindles in HDD. In this paper, a simulative setup of HDD is build up. The dynamic characteristics of liquid lubricated spiral groove bearing(SGB) spindles are studied. The effects of both operating condition and bearing clearance are investigated. It is found that running speed of the spindle has significant influence on its dynamic performance, while the load has little influence. The effect of clearance is also evident.

Keywords: hard disk drive, spiral grooved bearing, spindle motor.

Hard disk spindle is one of the most important mechanical parts of hard disk drive. Its dynamic characteristics have great influence on HDD's performance. In recent years, hard disk drives have made great progress in increasing area density and capacity, and reducing both size and cost. It requires that hard disk spindles should have high speed, high accuracy and small size. However, hard disk drives, widely used nowadays, are supported by grease lubricated ball bearings. The shortcomings of ball bearing spindles[1], such as high non-repeatable run out(NRRO), high acoustic noise and short lifetime at high running speed, make them unsuitable for high performance hard disk drives. Recently, some drive companies and spindle motor manufacturers are looking for a substitute for ball bearings. Hydrodynamic bearing is the most promising candidate. The dynamic characteristics of hydrodynamic bearings are much more superior to the ball bearings because the fluid film provides a high damping[2]. According to the difference of lubricant, hydrodynamic bearings can be divided into air bearings, grease lubricated bearings, ferro-fluid bearings and liquid-film bearings, etc. Each kind of the hydrodynamic bearing has its own characteristics. Their advantages and disadvantages are listed in table 1.

Compared with air, grease and ferro-fluids, lubricating oils have great superiority on lubrication performance, stability and variety. Therefore, liquid-film bearings have been regarded to be the most important substitute of ball bearings. Some hard disk drive companies, such as IBM and Seagate, have paid attention to the study of liquid-film bearing spindle and tried to apply it in hard disk drive. But because of the commercial competition, the research results are seldom published. In this paper, a simulative setup of HDD is build up. The dynamic characteristics of liquid lubricated SGB spindles are studied. The effects of both bearing clearance and operating conditions are investigated.

Table 1 Advantages and disadvantages of four kinds of hydrodynamic bearings

	Advantages	Disadvantages
Air bearings[3]	• low NRRO • high running speed • no need to seal • can be used at both high and low temperature	• low load capacity • low rigidity • sensitive to operating position • high manufacturing cost • can not release the static electricity between disk and slider
Grease-lubricated bearings[4]	• low NRRO • good stability • high rigidity and load capacity • long life time • good seal performance	• high viscosity • high power consumption • running speed <10000rpm
Ferro-fluid bearings[5]	• low NRRO • good stability • high rigidity and load capacity • long life time • good seal performance	• relatively high viscosity • The stability and lubrication performance of ferro-fluid under high shear rate is not very clear.
Liquid-film bearings[6][7]	• low NRRO • good stability • high rigidity and load capacity • low power consumption • long life time	• difficult to seal

1 Experimental setup

The liquid-film spiral groove bearing spindle vibration test setup is shown in fig. 1. The spiral groove bearing is made up of upper spiral groove thrust bearing 6, spiral groove journal bearing 7 and lower spiral groove thrust bearing 12. They are mounted on the motor spindle and impacted by nut 5, and rotate together with the motor. There are clearances between the rotating parts and the bearing bush 13, which are filled with lubricating oil. There is no oil supply system. The oil is added at the beginning of the experiments and is confined in the clearance by its surface tension. The detail structure of SGB is shown in fig. 2.

In the setup, load is added by magnet 4, which can move up and down by adjusting micrometer 1. The magnetism between the magnet and the nut changes with the space between them. The value of the load is measured by a load sensor. Two optical fiber displacement probes are installed to measure the vibration of the upper thrust bearing in the directions of both radical and axial. The sensitivity of the probe in axial direction is 7.7μm/V and in radical direction is 14.2μm/V. The probes are mounted on the base to measure the relative displacement between the base and the bearing. The signals are recorded and analyzed on a computer.

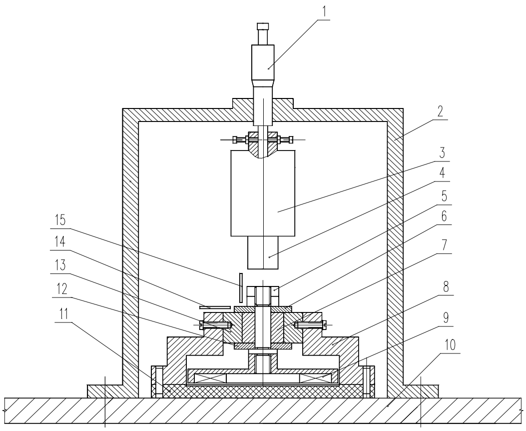

Fig. 1. Schematic of Spindle Vibration Test Setup. 1. micrometer 2. frame 3. load sensor 4.magnet 5.nut 6.upper thrust bearing 7.journnal bearing 8.bearing support 9.motor rotor 10.base 11.motor stator 12.lower thrust bearing 13.bearing bush 14&15.displacement probes.

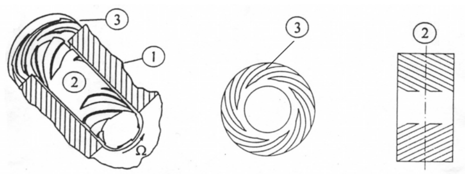

Fig. 2. Detail Structure of SGB.

2 Results and discussion

In this paper, the effects of running speed, load and bearing clearance on dynamic characteristics of SGB spindle are studied. The experimental conditions are as follows:

Running speed: 3000rpm ~ 10000rpm

Load: 0.5N, 0.9N, 1.5N

Clearance between upper thrust bearing 4 and bearing brush 13: 5μm, 7.5μm, 10μm

Lubricants: SI04, viscosity 12.01mPa.s(40°C), surface tension 20.58mN/m((40°C)

The signal recorded by the optical probe is total indicated runout(TIR), which is consisted of repeatable runout(RRO) and non-repeatable runout(NRRO). In hard disk drives, The repeatable runout can be corrected or eliminated by servo-systems. The non-repeatable runout is the main cause of the tracking error. The repeatable runout of a spindle is obtained by averaging the total indicated runout over N revolutions. The non-repeatable runout is then obtained through vector subtraction of the repeatable runout from an instantaneous total indicated runout record, i.e.,

$$RRO(t) = \frac{1}{N}\sum_{i=1}^{N} TIR(t),$$

$$NRRO(t) = TIR(t) - RRO(t),$$

where t denotes time. Fig. 3 shows the typical TIR, RRO and NRRO of the spindle in both radical and axial directions.

Each NRRO signal is a stationary random process. Its evaluation is generally done by statistical method. The standard deviation and the probability density function are calculated. And the standard deviation is used to compare the dynamic characteristics of the spindle under different

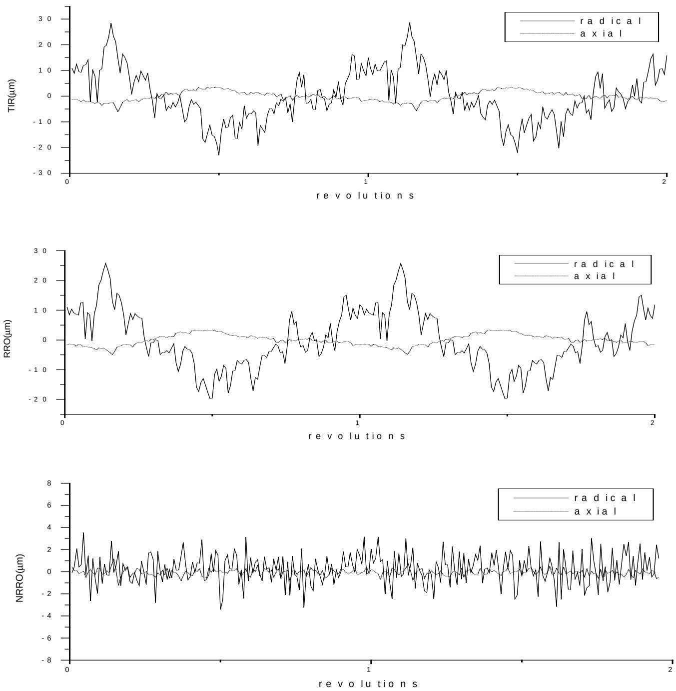

Fig. 3. The TIR, RRO and NRRO of the spindle in both axial and radical directions.

conditions. Fig. 4 shows the probability density functions of radical and axial NRRO for a spindle at 5000rpm, under the load of 0.9N, with the axial bearing clearance of 10μm. It can be observed that both the radical and axial NRRO probability density functions are similar to Gaussian distributions.

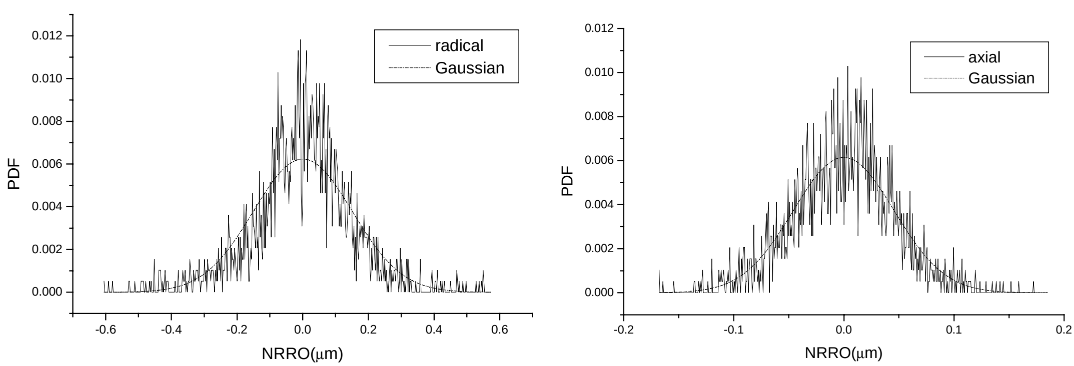

Fig. 4. Probability density functions of the radical and axial NRRO.

Fig. 5 shows the dependence of the standard deviation on spindle speed. From it we can see that the magnitude of both radical and axial standard deviation decrease with the increasing of the spindle speed. It indicates that the spindle has better dynamic characteristics at higher speed. The magnitude of radical standard deviation is much larger than that of axial standard deviation. The difference is caused by the imbalance of the spindle. In Fig.1 we can see that the rotating part of the spindle is consisted of the motor rotor, the lower thrust bearing, the journal bearing, the upper thrust bearing and the nut. Before doing the experiments, the lower thrust bearing, the journal bearing, the upper thrust bearing and the nut are demounted from the axis of the motor rotor for cleaning and adding oil. Because of this special structure, the dynamic imbalance of the spindle can not be eliminated completely. It will inevitably influence the dynamic characteristics of the spindle, especially the characteristics in radical direction.

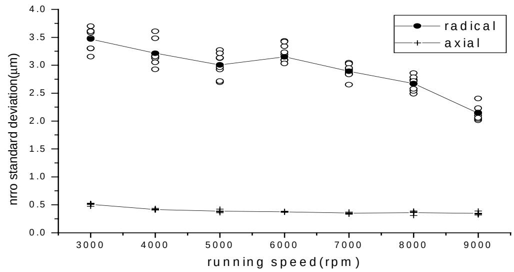

Fig. 5. Standard deviation versus spindle speed.

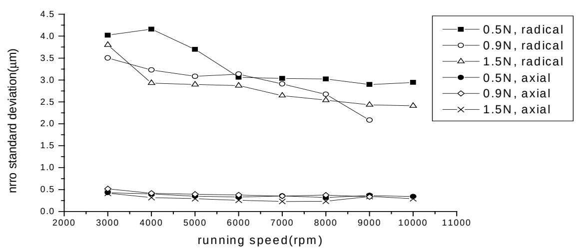

Fig. 6. The influence of the load on standard deviation.

Fig. 6 shows the influence of the load on spindle vibration. Three loads, 0.5N, 0.9N and 1.5N, are added. We note that the effect of the load on the dynamic characteristics of the spindle is not very obvious. As we know, the weight of one 5 inch disk is about 0.1N. Therefore, the load range, 0.5N to 1.5N, is large enough for a hard disk drive. But compared with the load capacity of the spiral grooved bearing, 0.5N, 0.9N and 1.5N all belong to the range of light load. So the variation of the load has little influence on the dynamic characteristics of the spindle.

The dependence of standard deviation on bearing clearance is shown in fig. 7. The axial clearances are 5μm, 7.5μm and 10μm respectively, while the radical clearance remains constant, which is 10μm. The load added is 0.9N. From fig. 7 we know that when the spindle runs at a speed which is lower than 8000rpm, both the radical and axial standard deviation keep decreasing

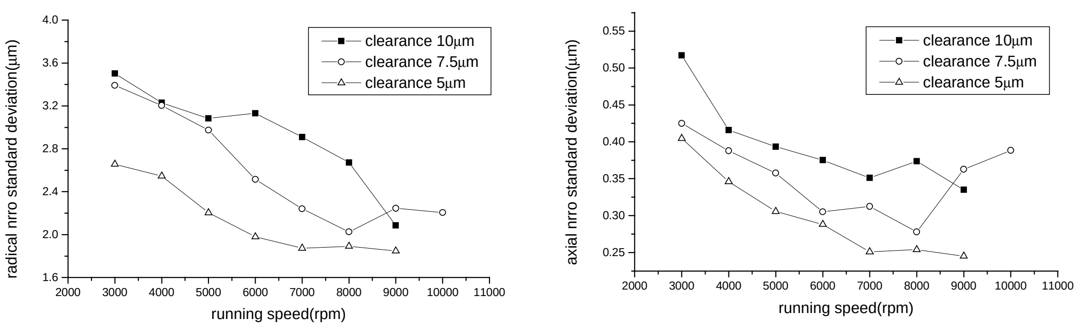

Fig. 7. The influence of the axial bearing clearance on standard deviation.

with the decrease of bearing clearance. This indicates that under the same load, the rigidity of the spindle increases with the decrease of the bearing clearance. However, there is not an apparent orderliness at higher speed. This is because that when the spindle is running at a low speed, the surface tension of the oil is larger than the centrifugal force. So the oil can be confined between the clearance. But with the increase of the speed, the centrifugal force increases as well. When it exceeds the surface tension, the oil between the clearance may be thrown out. This will greatly affect the dynamic characteristic of the spindle. In order to keep a good lubrication status, the oils with high surface tension should be adopted and the bearing clearance should be carefully designed.

3 Conclusions

In this paper, the radical and axial dynamic characteristics of the HDD spindle supported by SGB are studied. The effects of spindle speed, load and axial bearing clearance are investigated. Several conclusions are obtained:

1) Both radical and axial NRRO follow a Gaussian distribution. The magnitude of axial standard deviation is much smaller than that of radical standard deviation.

2) The spindle has better dynamic characteristics at higher speed, while the load has little effect on the dynamic characteristics of the spindle.

3) The bearing clearance has significant effects on dynamic characteristics of the spindle. When the spindle speed is lower than 8000rpm, the magnitude of radical and axial standard deviation decrease with the decrease of the bearing clearance. But at higher speed, there is no regulation.

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