HDI Technology for Perpendicular Magnetic Recording Media

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ABSTRACT

To reduce the magnetic spacing and improve media characteristics, (1) a thinner carbon protective film and thinner lubricant layer, and (2) a lower magnetic head flying height are necessary. However, reducing the thickness of the protective film and the lubricant layer causes a significant deterioration in such reliability-related characteristics as corrosion resistance and durability. Thus, Fuji Electric controls the film properties of the protective layer so as to improve the corrosion resistance and sliding durability simultaneously with a reduction in the thickness. By controlling the molecular weight and composition of the PFPE (perfluoropolyether) used in the lubricant layer, and developing additives and post-processing technology, a thinner film with higher reliability can be realized. Additionally, while developing technology for evaluating the flying characteristics of the HDI (Head Disk Interface), Fuji Electric has been reducing the magnetic spacing.

1. Introduction

The hard disk drive (HDD) is an inexpensive storage device capable of handling large amounts of information quickly, and a market has been established for HDDs as external storage for computers. This market, which is also driven by new applications, is expected to expand more and more in the coming years.

The magnetic recording media provided in HDDs has achieved remarkable increases in density. Fuji Electric, in 2009, mass-produced media having a storage capacity of 500 GB per 3.5-inch disk, and then in 2010, developed 750 GB capacity media which will be released to the market.

At the HDI (Head Disk Interface) between the magnetic head and media surface, the main functions of the carbon protective film and the lubricant layer, which are important elements in the media, are to prevent corrosion of the magnetic layer and the like, and to protect the magnetic layer from wear due to the magnetic head. Additionally, the lubricant layer is also required to suppress lubricant pick-up by the magnetic head, enable lower flying height of the magnetic head and to improve flying stability. To support the rapidly increasing high recording densities of the future, the magnetic spacing (flying height+lubricant layer thickness+carbon protective film thickness), i.e., the distance between the magnetic head element and the magnetic layer surface, must be reduced as much as possible. Incidentally, the flying height is 2.5 to 3.0 nm for a 500 GB capacity disk at 3.5 inch disk, and 2.5 nm or less for a 750 GB capacity disk. To reduce the magnetic spacing and increase the recording density, (1) the carbon protective film and the lubricant film must be made thinner, and (2) the flying height of the head must be reduced. In attempting to do so, however, the following problems and issues arise.

If the protective layer is made thinner, the corrosion inhibiting function decreases. The technical challenges to overcome in order to solve this problem include devising more appropriate deposition conditions for the carbon protective layer, and increasing the film density of the carbon protective film structure.

If the lubricant layer is made thinner, the frictional durability with respect to the magnetic head deteriorates significantly. Therefore, advancing the development of lubricant additives for improving frictional durability, and reducing the amount of lubricant pick-up by the magnetic head slider surface, which results in a trade-off with the ensuring of durability, are important issues.

Moreover, in recent HDDs, not only has the flying height of the slider been reduced, but the magnetic heads employ technology whereby thermal expansion causes just the magnetic head element to approach the media side. This technology is known as DFH (Dynamic Flying Height) technology, TFC (Thermal Flying-height Control) technology, FOD (Flying on Demand) technology, and so on. In this paper, however, the technology discussed is called as FOD.

In accordance with Fuji Electric's recent field tests, a thinner lubricant layer was found to be especially effective for making the magnetic head element protrude farther with FOD technology.

This paper introduces recent approaches for attaining higher recording densities from the perspective of HDI technology, and the development status of the increasingly sophisticated carbon protective film and lubricant layer, and the development status of HDI evaluation technology (flyability, reliability) from the perspective of ensuring reliability technology which involves a trade-off with higher recording densities.

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2. Carbon Protective Film Technology

2.1 Goals and challenges of carbon protective film

Carbon protective film provides three representative functions: (1) corrosion resistance, (2) shock resistance (surface hardness), and (3) sliding wear durability. These are important functions for protecting the magnetic layer and the like. If the carbon protective film is made thinner in order to reduce the magnetic spacing, its function will deteriorate. Carbon protective film development faces challenges including achieving a uniform distribution of the thickness of the carbon protective film, realizing the high-rate of deposition required for mass-production processes, and reducing particles, etc.

2.2 Carbon protective film development status

Carbon protective film has a two-layer construction consisting of a high-density layer and a stabilization layer. The high-density layer formed on the magnetic layer functions to protect the magnetic layer, and the stabilization layer formed on the high-density layer functions to stabilize the lubricant layer. By making the high-density layer more dense and making the stabilization layer thinner, corrosion resistance and sliding durability have been improved and the magnetic spacing has been reduced.

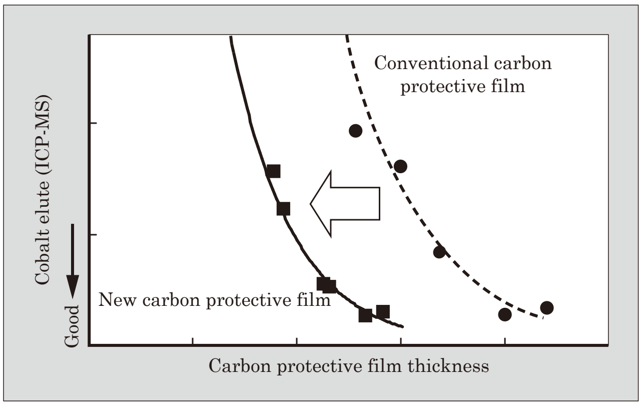

Fig.1 Test and evaluation results of cobalt elution by acid

The high-density layer in the carbon protective layer is fabricated by plasma CVD (Chemical Vapor Deposition). Carbon film formed by CVD exhibits excellent coverage of the magnetic layer and this is especially important because of the surface reaction that accompanies the film fabrication. Additionally, the film quality can be controlled by controlling the ion energy. By optimizing the deposition process, denser and harder film can be formed. Moreover, in the fabrication of the stabilization layer, a new process for improving adhesion with the lubricant was used to realize a thinner film.

The results of a comparison between the newly developed carbon protective film and existing carbon protective film are listed below.

(1) Corrosion resistance

One way to evaluate corrosion resistance is to drop dilute nitric acid onto the media surface, and use ICPMS (Inductively Coupled Plasma-Mass Spectrometry) to measure the small amount of cobalt that elutes from the magnetic layer or the like. The results of evaluation of the amount of cobalt elution from the dilute nitric acid extract are shown in Fig. 1. The new carbon protective film exhibits excellent corrosion resistance, and can be made thinner than conventional carbon protective film.

(2) Surface hardness

Fig. 2 shows the results of using nanoindentation and evaluating the residual mark depth caused by a diamond indenter when a constant load is applied. The new carbon protective layer has a shallow indentation even as a thin film, and therefore is understood to be difficult to deform plastically and to be a hard film.

(3) Sliding durability

To evaluate the sliding durability, a reduced-pressure sliding test was carried out using an actual magnetic head. The results are shown in Fig. 3. The reduced-pressure sliding test is a test to evaluate sliding durability and uses the fact that the magnetic head flying height decreases at reduced pressure to simulate a low flying height state with a HDD. The new carbon protective layer exhibits several times the sliding path durability number of a conventional protective layer,

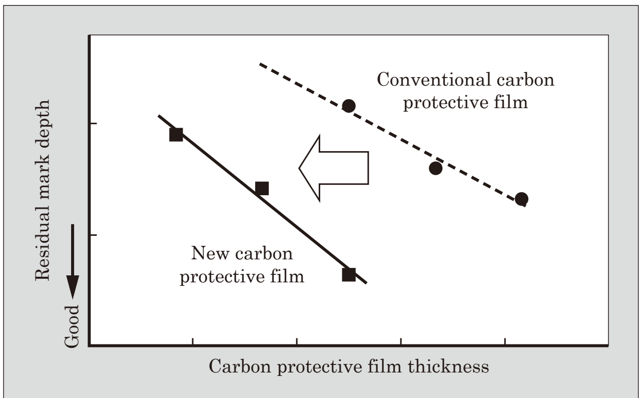

Fig.2 Nanoindentation evaluation results

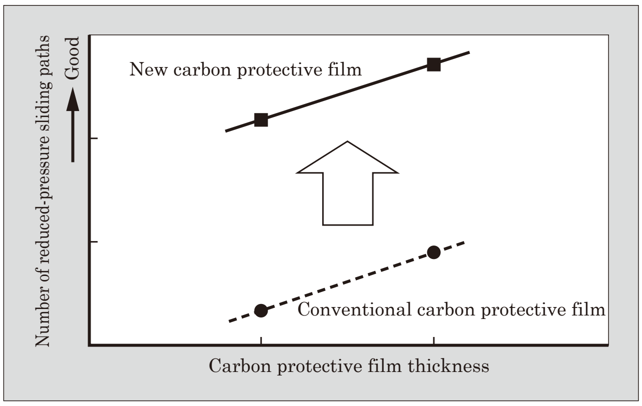

Fig.3 Reduced pressure sliding evaluation results

and the carbon protective surface is found to provide improved carbon film surface durability.

The newly developed carbon protective layer exhibits excellent corrosion resistance, surface hardness and sliding durability, and enables the carbon protective film to be made thinner and the magnetic spacing to be reduced.

3. Lubricant Layer Technology

3.1 Lubricant layer: Objective and challenges

The lubricant layer is fabricated by applying an approximate 1 nm-thick coating of a perfluoropolyether (PFPE)-based liquid lubricant having (-CF_2O-) repeating structural units onto the carbon protective film. The PFPE-based lubricant provides high heat resistance and low friction and low wear properties. Also, the end structure of the PFPE-based lubricant is terminated with a hydroxyl group (-OH). This functional group chemically bonds to the surface of the carbon protective layer to form a stable lubricant layer. For the magnetic head to fly stably over the magnetic media, the lubricant layer is indispensible. Moreover, if the magnetic recording media and the magnetic head make contact, the lubricant layer also functions to protect the surface of the magnetic recording media.

The thickness of the aforementioned lubricant layer, as is the thickness of the carbon protective layer, is a factor that determines the magnetic spacing. The relationship between variation in the lubricant layer thickness and the variation in the magnetic spacing is shown in Fig. 4. When field tests were performed using two types of lubricant agents, the magnetic spacing increased when the lubricant layer become thicker, and the amount of that increase was nearly equal to the thickness of the lubricant layer. That is, the lubricant layer thickness directly increases the magnetic spacing.

Additionally, the lubricant layer thickness also relates to the amount of protrusion of the FOD magnetic head element. Fig. 5 shows the relationship between lubricant layer thickness and the amount of protrusion of the element due to FOD. Increasing the lubricant layer thickness resulted in a reduced amount of protrusion. That is, due to the synergistic effect of the aforementioned reduction in spacing and the FOD projection, making the lubricant layer thinner was found to lead to improved electromagnetic conversion characteristics and higher recording density.

Fig. 6 shows the relationship between the lubricant

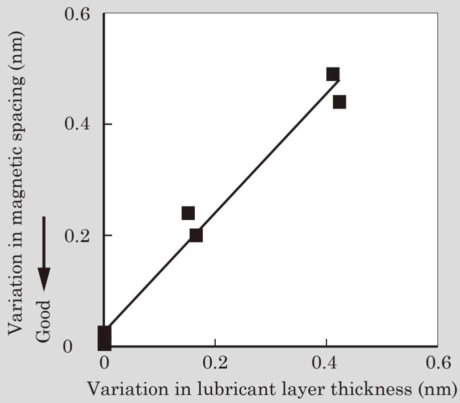

Fig.4 Relationship between lubricant layer thickness and magnetic spacing

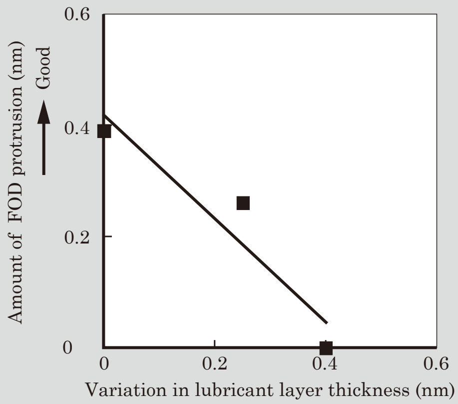

Fig.5 Relationship between lubricant layer thickness and FOD

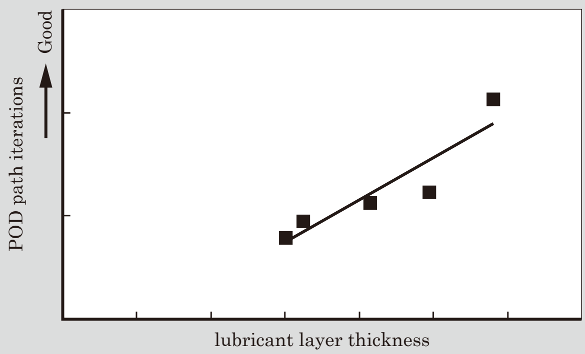

Fig.6 Relationship between lubricant layer thickness and POD path iterations

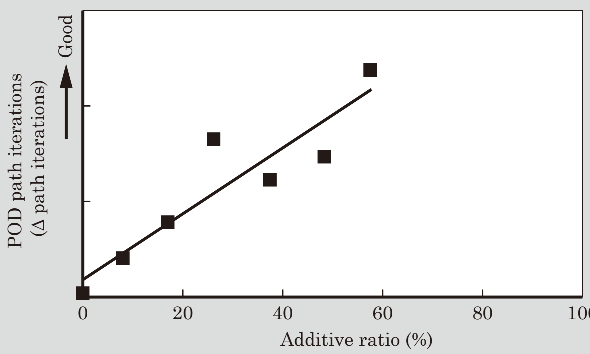

Fig.7 POD durability improvement according to additive ratio

layer thickness and durability. Here, the durability is evaluated based on the results of a POD (Pin On Disk) wear test in which an AlTiC ball is dragged over the surface of the media. As the lubricant layer becomes thinner, the number of drag path iterations decreases. That is, if the lubricant layer is made thinner in order to increase the recording density, the durability will decrease proportionally. So that durability can be maintained even if the recording layer is made thinner in order to increase recording density, improving the durability and reliability of the lubricant layer itself are important issues in lubricant layer development.

3.2 Lubricant layer development status

As described above, in the development work to make a thinner and more durable lubricant layer, the following topics are pursued simultaneously.

(a) Development of an additive that provides enhanced durability to the lubricant layer
(b) Development of material refining technology that appropriately adjusts the molecular weight and composition of the PFPE-based lubricant
(c) Development of techniques for post-processing after application of the lubricant coating

Of these topics, the additive technology of (a) is described below.

Materials having a phosphazene skeleton have been proposed as the additive.

For a mixed lubricant layer consisting of a hydroxyl-terminated PFPE-based lubricant and a phosphazene-based additive, Fig. 7 shows the relationship between the proportion of phosphazene-based additive and the number of drag path iterations in a POD wear test. If the proportion of phosphazene-based additive is increased, the number of path iterations increases. By adding the phosphazene-based additive, durability can be improved and the lubricant layer can be made correspondingly thinner. On the other hand, increasing the proportion of the phosphazene-based additive causes an increase in the lubricant pick-up volume transferred to the surface of the magnetic head slider, thereby inhibiting flying stability. The durability of the lubricant layer and the lubricant pick-up volume are highly dependent on the structure and properties of the phosphazene-based additive. To improve HDI (head disk interface) characteristics, the comprehensive design of a high reliability lubricant layer, including the development of new materials, is extremely important. Moreover, in addition to evaluating the magnetic recording media itself, evaluation of the HDD in various environments and the implementation of the lubricant layer design are also important.

4. HDI (Head Disk Interface) Evaluation Technology

4.1 Flyability test technology

FOD touchdown power measurement is introduced below as an example of a flyability test. FOD technology uses the thermal expansion of a heater built into the magnetic head near the read/write element to cause the element to approach the magnetic recording media surface. Here, the FOD read/write element (FOD element) is considered to protrude by an amount that corresponds to the amount of power applied to the heater. From the state in which the media is rotating and the magnetic head is floating, the FOD touchdown power is measured by gradually increasing the amount of applied power, and the applied power at the time when the FOD elements finally contact (touch down onto) the media surface is measured and evaluated. The larger the FOD touchdown power, the larger the amount of FOD element protrusion that is tolerable without the FOD element making contact with the media, and consequently, the FOD element is able to approach the media more closely. This leads to reduced magnetic spacing, improved electromagnetic conversion characteristics, and higher recording density.

The three main ways for assessing touchdown with this measurement are listed below.

(a) Use of AE (Acoustic Emission)
(b) Use of the saturation characteristics of the recording signal (TAA: Track Average Amplitude)
(c) Use of variations in the modulation of the recording signal

Here, the FOD touchdown power measurement method using AE will be described.

Fig. 8 shows the configuration of the measurement circuit.

The AE sensor detects elastic waves that propagate within a solid. For this measurement, an AE sensor having sensitivity at the vibration frequency (70 to 500 kHz) occurring at the time of touchdown is used. The AE sensor output signal is amplified by the AE preamp, narrowed down to the required frequency band by a bandpass filter, and unwanted noise is removed. Additionally, the AE sensor output signal voltage oscillates between positive and negative polarity, and is therefore difficult to use directly for touchdown detection. Thus, so that the strength of AE sensor output values that vary significantly at the time of touchdown can be expressed statistically using a detection circuit, the output signal is processed into a RMS (root mean square) value to convert it into a form that is easy to use for touchdown detection.

Fig. 9 is a graph showing the power applied to the

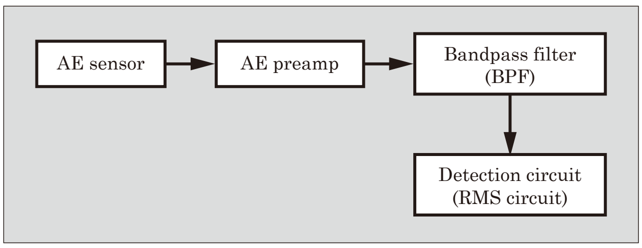

Fig.8 FOD touchdown measurement circuit configuration

heater of the magnetic head and the RMS value of the AE output. Measurement is carried out with the magnetic head floating at a position of radius 20 mm above 2.5-inch diameter media, the applied power is increased at a rate of 0.05 mW/ms, and contact between the FOD element and the media surface is monitored according to the time change of the AE signal. Despite the increase in power, while the FOD element is not in contact with the media, the AE output value remains constant at the noise signal level. When the FOD element contacts the media, the AE output value increases suddenly. A certain level above the non-contact noise signal level is set as a slice line, and when the AE output exceeds this level, touchdown is judged to have occurred and the applied power at that time is taken as the FOD touchdown power.

Fig. 10 shows the results of measurement of the FOD touchdown power for media in which the lubricant layer thickness is varied. As the lubricant layer is made thinner, the touchdown power increases. Therefore, making the lubricant layer thinner was found to be an effective means for increasing the amount of protrusion of the FOD element and reducing the magnetic spacing.

4.2 Durability test technology

An example of FOD applied to an accelerated durability evaluation of magnetic recording media is described below. When starting or stopping an actual HDD, the ramp load method for loading and unloading the magnetic head on a head retreating part, known as a ramp, that is provided beyond the outer periphery of the media is one method for operating the head. A load-unload accelerated test that combines a reduced-pressure environment and FOD was developed for accelerated testing with this method. In the basic operation, a magnetic head is repeatedly moved back and forth between a ramp and the outer periphery of the media, and this is a durability test for measuring the number of back-and-forth cycles (cycle durability) until scratches are visually observed on the media surface.

For magnetic recording media of the same conventional specifications, Fig. 11 compares the cycle durability in the case of a load-unload test performed in a reduced-pressure environment solely and in the case when FOD is used together. The testing in a reduced-pressure environment solely is an accelerated test, but when FOD is used together, the cycle durability is significantly less than in the case where FOD is not used. This means that the evaluation time can be reduced. Thus, in a load-unload test used for durability evaluation, the use of FOD was found to be effective for further accelerating the testing.

That a thinner lubricant layer is effective in reducing the magnetic spacing has already been described.

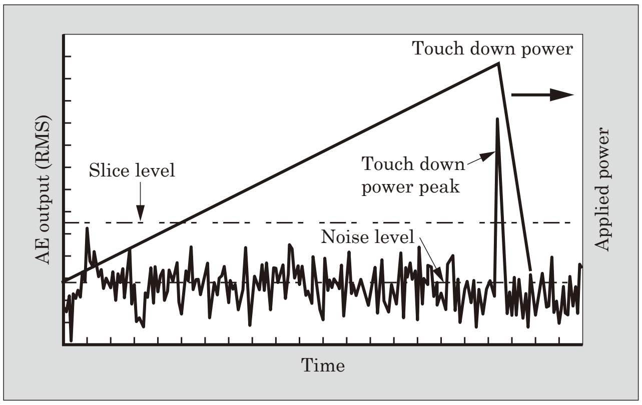

Fig.9 AE signal output vs. applied power

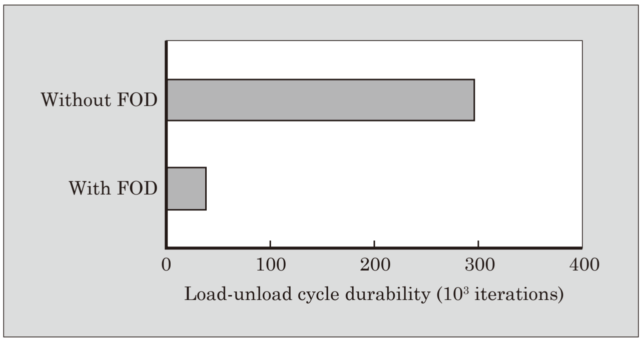

Fig.11 Comparative results with/without FOD in reduced-pressure load-unload test

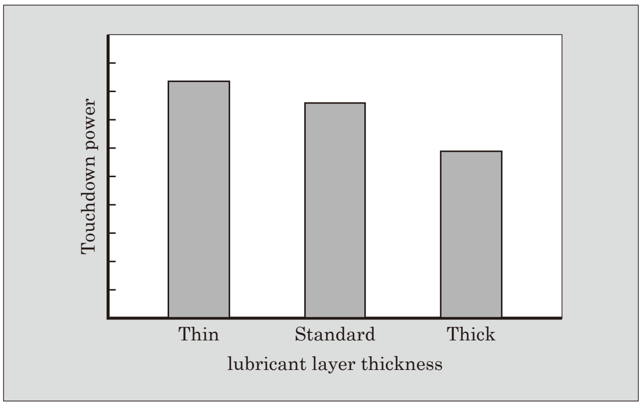

Fig.10 Dependence of touchdown power on lubricant layer thickness

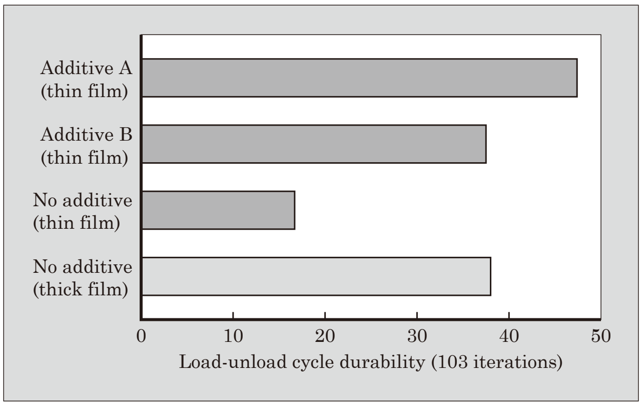

Fig.12 Comparative results of additives to lubricant layer in reduced-pressure load-unload test

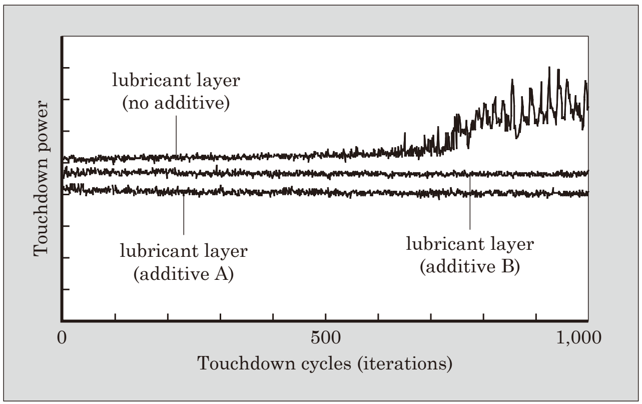

Fig.13 FOD element degradation test results

A thinner lubricant layer leads to degraded durability, however. To enhance the durability, a method of adding an additive to the lubricant has been used. Fig. 12 shows a comparison of magnetic recording media durability when an additive has been added to the lubricant layer using this test method. Without an additive, durability deteriorates when the lubricant layer is made thinner. The addition of an additive to a thinner lubricant layer was found to maintain the same level of durability as conventional media in a thinner lubricant layer. Additionally, durability can be improved further by varying the type of additive.

4.3 Reliability test technology

Lastly, the FOD element degradation test for long-term reliability evaluation is introduced below.

In some cases, depending on the operating environment of a HDD, the magnetic head and the media surface may suddenly come into contact. The part that makes contact first is the FOD element, and depending upon the surface condition of the magnetic recording media, FOD element wear or other damage may occur. If the FOD element becomes worn, the original amount of protrusion cannot be ensured, and moreover, the worn part may become corroded and have a significant adverse effect on the recording characteristics. An FOD element degradation test assesses damage that occurs due to contact between the FOD element and the media surface, and is a reliability test for the purpose of determining the design policy for high reliability recording media. The increase in power due to repeated touchdowns indicates wear of the FOD element, and therefore, measurement of the FOD touchdown power is repeated several thousands of times to evaluate the change in touchdown power.

Fig. 13 shows the FOD element degradation test results for magnetic recording media having a thin lubricant layer and for magnetic recording media that has both a thin lubricant layer and an additive. Magnetic recording media using a lubricant layer formed from a thin film and an additive exhibits stable touchdown power, without fluctuation, even after more than 1,000 touchdown iterations. On the other hand, for magnetic recording media that uses a thin lubricant layer and no additive, power was found to begin to gradually increase after 500 iterations. This suggests that the FOD element easily becomes worn by the magnetic recording media surface, and would likely inhibit recording in an actual HDD.

5. Postscript

So that magnetic recording media can attain even higher recording density, further reduction in the magnetic spacing is required. Therefore, further thinning of the carbon protective film in the protective layer and the use of high-durability lubricant materials in the lubricant layer are being studied, and research and development work is needed to ensure that high reliability (flying performance and durability) can be ensured with close magnetic spacing. Fuji Electric is committed to developing surface technology (carbon protective film and lubricant layer) suitable for 1 Tbit/in^2 recording density and to developing the corresponding reliability evaluation technology.