Magnetic Printing Technology

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1. Introduction

Hard disk drives (HDDs) are equipped in most personal computers as peripheral storage equipment and the worldwide annual production of HDDs is expected to reach 200 million units (in 2001). In recent years, HDDs also have come to be installed in so-called network household appliances such as information appliances and digital home electronic equipment (the latest of which includes car navigation devices, digital TVs, and VCRs with built-in HDDs). This trend is creating another new market equal to or greater than the personal computer market. Aiming at these markets, Fuji Electric has been promoting the research and development project of magnetic disks for HDDs since 1999. Fuji Electric's projects cover such diverse topics as the development of new material substrate alternatives to aluminum, perpendicular recording media for high-density recording, and technology to lower the cost of embedding information into magnetic disks. The above-mentioned last technology aims to embed into magnetic disks such information as servo patterns used in HDDs and security data indispensable to network household appliances.

As part of the above-mentioned technologies, this paper will present our servo pattern and the magnetic printing technology, which is a new technique for embedding patterns into magnetic disks, and describe the major practical results achieved by the development thus far. This magnetic printing technology has been developed for the mass production of magnetic disks, based on research by Matsushita Electric Industrial Co., Ltd., and in cooperation with Fuji Electric's customer HDD manufacturers.

2. Magnetic Head Positioning Mechanism and Servo Pattern

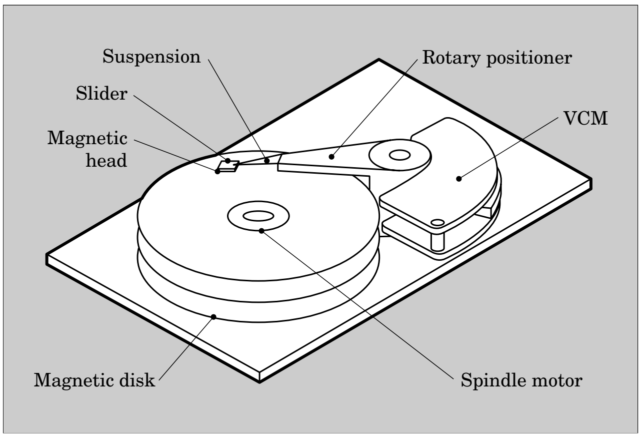
2.1 Magnetic head positioning mechanism in HDD

Figure 1 shows a schematic illustration of the structure of a magnetic head positioning mechanism in the HDD. The magnetic disk as a recording medium rotates at a high-speed of several thousand r/min by a spindle motor. When reading or writing data, the magnetic head flies about 10 nm above the rotating magnetic disk with a surfacing mechanism referred to as a slider. The slider is fixed to a rotary positioner via a suspension and the magnetic head can be moved to and positioned at an arbitrary track on the magnetic disk by a rotating action of the rotary positioner.

2.2 Servo pattern

In an HDD, the position information (which is referred to as the servo pattern) for detecting the position of the magnetic head relative to the target track on magnetic disk is written in advance onto the magnetic disk. As shown in Fig. 2 (a), servo zones written with servo patterns and data zones for reading/writing data are alternately aligned at fixed intervals in the circumferential direction. Thus, the magnetic head can detect its own position at every fixed time while reading/writing data (this method is referred to as the sector servo method and is utilized widely in HDDs.). Figure 2 (b) shows an example servo pattern written in a servo zone. The servo zone contains a servo clock, an address pattern, and a position detection pattern. The position detection pattern in the figure is a checker pattern utilized in many HDDs, and detects the position based on the difference in amplitude of a read signal waveform.

Fig.1 Magnetic head positioning mechanism in HDD



3. Servo Writing

3.1 Conventional servo writing method by STW

In conventional HDDs, an equipment referred to as the servo track writer (STW) writes servo patterns (see Fig. 3). After building in the magnetic disk in the HDD, a pushpin is inserted into the HDD case in order to mechanically hold the rotary positioner in the drive. Based on an encoder in the STW, the STW's fine rotary mechanism is moved to cause slight movement of the above-mentioned pushpin and rotary positioner, and to successively write the servo pattern corresponding to each track. A 20 Gbyte-per-plate class magnetic disk requires about ten minutes or more for servo writing.

Fig.2 Servo pattern

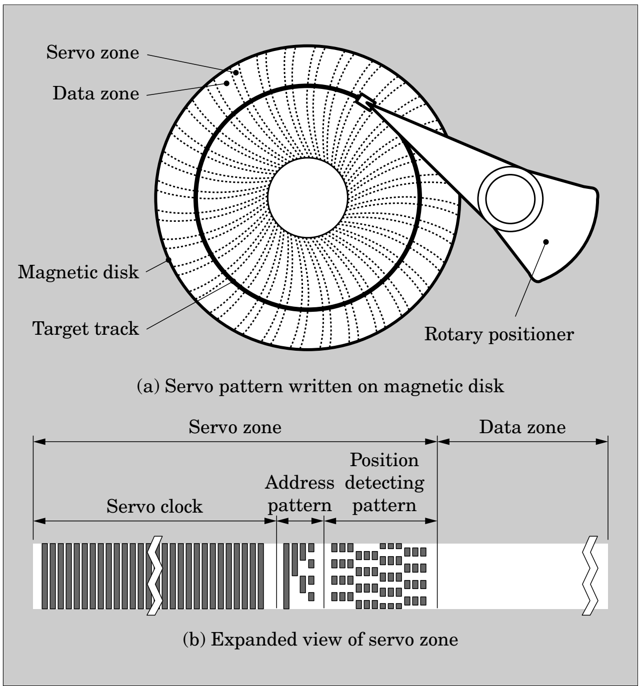
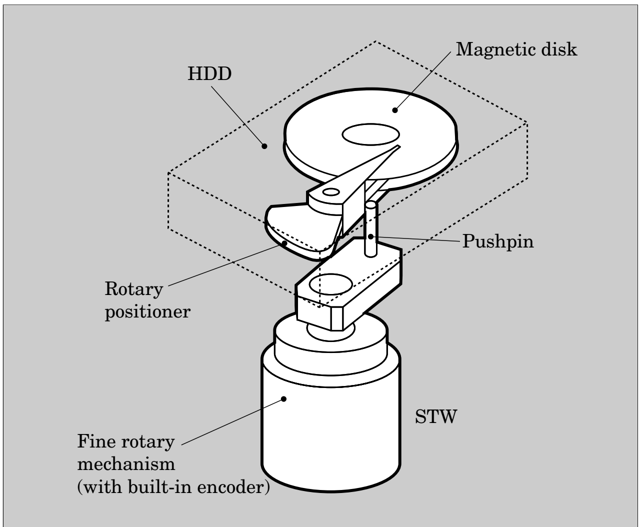


Fig.3 Servo writing by STW



As the track recording density increases, the number of the tracks increases, and accordingly, the servo writing time also increases. In addition, a higher accuracy is required for the STW mechanism, since the track pitch becomes narrower. Parallel servo writing with multiple expensive STWs provided in a clean room may provide a temporary solution, but imposes a heavy financial burden.

3.2 Servo writing by magnetic printing

As a low-cost and speedy servo writing measure alternative to the above-mentioned STW, Fuji Electric focused attention on the magnetic printing technology that copies magnetic patterns from an original recording disk (referred to as the master disk) to another magnetic disk in block.[(1) to (3)] In this magnetic printing technology, a reference servo pattern is written in advance to a magnetic disk, then based on the reference servo pattern, the HDD writes a finer servo pattern on itself (this is referred to as self servo writing). The time required for magnetic printing of one magnetic disk is less than six seconds and is much less than the STW's executing time. Since self servo writing can be implemented outside of a clean room, it has the effect of extensively reducing the investment in clean rooms.

Figure 4 shows the principle of the magnetic printing process. First, an external magnetic field is brought close to the magnetic disk to magnetize the recording layers of the magnetic disk in one direction (DC erasing). Next, a magnetic field is applied from above the master disk in the direction opposite to the DC erasing, while bringing the master disk into close contact with the magnetic disk. The master disk is a silicon substrate, in which slots of several hundred nm in width are formed corresponding to the servo pattern, and soft magnetic material (Co) is embedded in the slots. In the gaps between the soft magnetic material, magnetic flux leaks in the direction opposite to the DC erasing magnetic field. On the magnetic disk, areas that have been in contact with parts of the master disk part containing no soft magnetic material are magnetized in the direction opposite to the DC erasing magnetic field, and the DC erased condition is retained at areas that have been in contact with the parts containing soft magnetic material. Thus, the servo pattern data of the master disk is printed on the magnetic disk. Lastly, contact between the master disk and the magnetic disk is released. Figure 5 shows an external view of the master disk.

In mass production, the keys to achieving uniform printing of signals over the entire disk surface are the technologies to ensure good contact between the master disk and the magnetic disk and to maintain the cleanliness of both disks while in close contact. The former technology is achieved by configuring the master disk to have alternating land parts that form the servo patterns and groove parts that function as

Fig.4 Magnetic printing process (longitudinal recording)

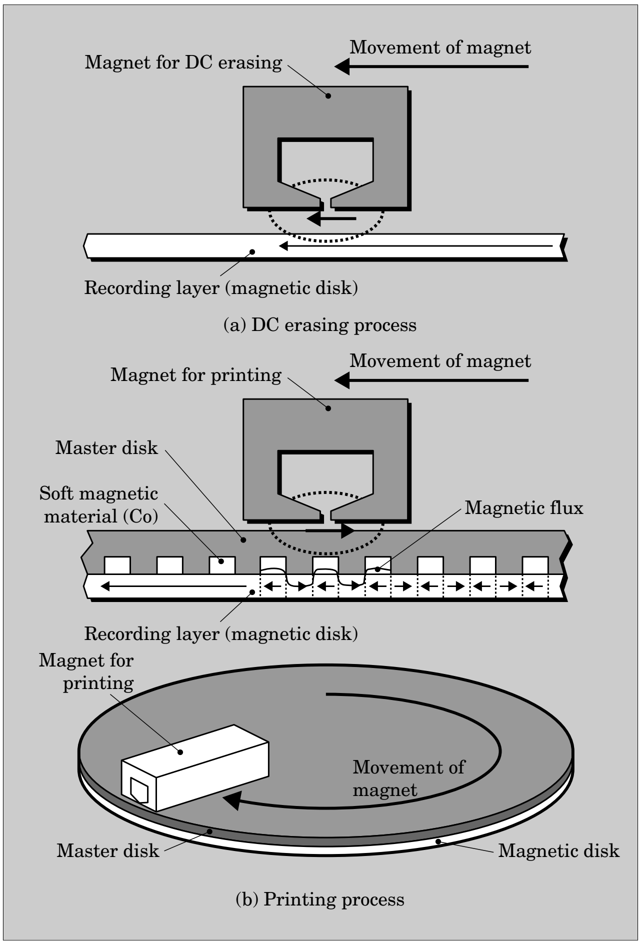
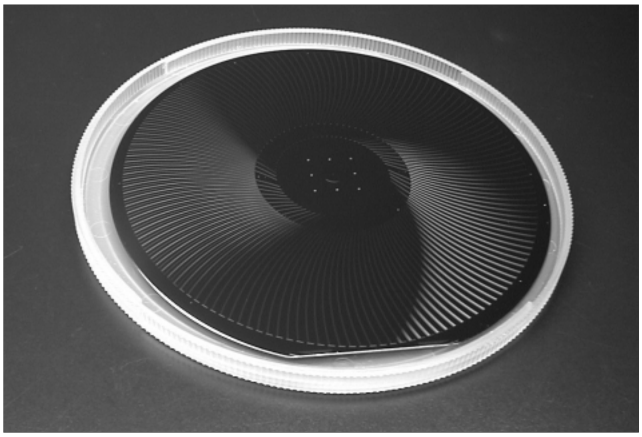


Fig.5 Outer view of master disk



air flow channels, for controlling the pressure of the air flow through the grooves. Measures for achieving the latter technology are as follows:

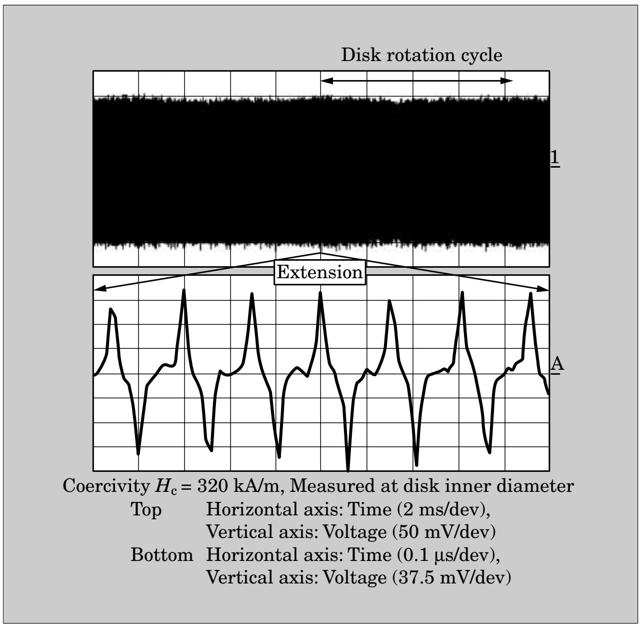
(1) Perform a magnetic disk surface inspection just before the magnetic printing process.

(2) Provide a continuous downward flow of air to maintain cleanliness in the vicinity of the magnetic printing process to below Class 1.

(3) Periodically clean the master disk.

Figure 6 shows an example of a servo signal waveform read from a magnetic-printed servo pattern. It is evident from the figure that a uniform envelope is achieved around the circumference of a track.

Fig.6 Servo signal waveform from magnetic printing disk (longitudinal recording)



4. Practical Results of Development

4.1 Mass production of magnetic printing disk

In July 2001, Fuji Electric started to mass-produce magnetic disks with servo patterns recorded by magnetic-printing (hereafter referred to as magnetic printing disks). At present, magnetic printing disks with recording capacity of 40 Gbyte-per-plate class are being shipped to HDD manufacturers. These disks are for use in personal computers and the number of disks shipped in 2001 is expected to reach 2.5 million units. Before shipping, quality checks associated with the cleanliness of the magnetic disks (including the tests for amplitude stability, ion contamination, corrosion, and organic contamination) are implemented. The results have verified that application of the cleaning technology described above enables magnetic printing to be performed without causing any damage or contamination on the magnetic disk surface.

4.2 Application to next generation disks

An experimental trial of magnetic printing for high-coercivity magnetic disks and perpendicular recording disks has been implemented ahead of time. The results of the basic experiment confirmed that the magnetic printing technology could be applied to both disks.

4.2.1 High-coercivity disk

The recording layer coercivity, H_c, of magnetic disks is increasing year after year and is expected to reach 480 kA/m (6,000 Oe) in 2003. As a result of the

Fig.7 Servo signal waveform from high-coercivity magnetic printed disk (longitudinal recording)

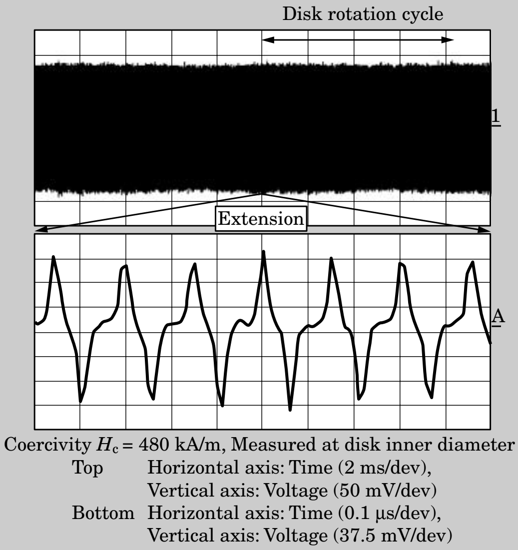
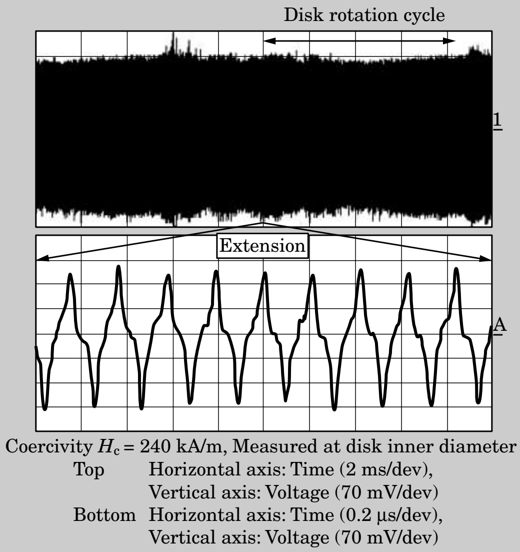


Fig.8 Servo signal waveform from perpendicular magnetic printing disk



magnetic printing basic experiment for magnetic disks with recording layer coercivity H_c of over 480 kA/m, it could be verified that a signal output level equal to that of current media with $H_c \approx$ 320 kA/m (4,000 Oe) can be achieved. Figure 7 shows an example of a servo signal waveform.[(4)]

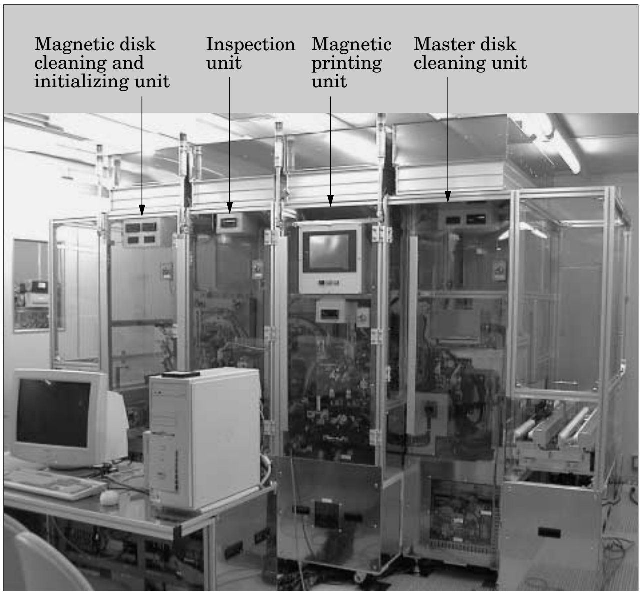
4.2.2 Perpendicular recording disk

For areal densities greater than 100 Gbits/in^2, the recording method is expected to shift from the current longitudinal recording method to the perpendicular recording method. The basic experiment of magnetic printing was implemented for the perpendicular recording disk. Using an external magnet and a master disk equivalent to those used for longitudinal recording, the perpendicular components of magnetic leakage flux from the edge of the soft magnetic material on the master disk perform the perpendicular recording. Figure 8 shows an example of a servo signal waveform. It was verified that a signal output level equal to that of a longitudinal disk can be achieved.[(5)]

4.3 Development of next generation magnetic printing equipment

Figure 9 shows an external view of the next generation magnetic printing equipment developed by Fuji Electric. This equipment has newly been developed to support magnetic printing to not only conventional aluminum-substrate longitudinal recording magnetic disks but also to disks for which demand is expected to increase such as glass-substrate magnetic disks, perpendicular magnetic printed disks, and magnetic disks with high-coercivity recording layers. This next generation magnetic printing equipment contains a magnetic disk cleaning and initializing unit with tape burnishing function for removing particles attached to the disks using a burnishing (polishing) tape and a DC erasing function for magnetic disks, a surface inspection unit for detecting attached particles smaller than 1 μm in size, a magnetic printing unit for implementing the magnetic printing while limiting the eccentricity between the master disk and the magnetic disk to less than 10 μm, and a master disk cleaning unit for removing particles attached to the master disks with the tape burnishing function. The equipment has been designed for ease of maintenance and each unit can operate independently. By placing the magnetic disk cleaning/initializing unit and the sur-

Fig.9 External view of next generation magnetic printing equipment



face inspection unit just in front of the magnetic printing unit, the cleanliness of the magnetic disk to be inserted into the magnetic printing unit can be strictly controlled. Additionally, the magnetic printing unit ensures a cleanliness level of Class 1 by placing the magnetic printing mechanism at the top of the disk handling mechanism to constantly maintain a downward flow of clean air. The main specifications are listed in Table 1.

4.4 Development of servo tester

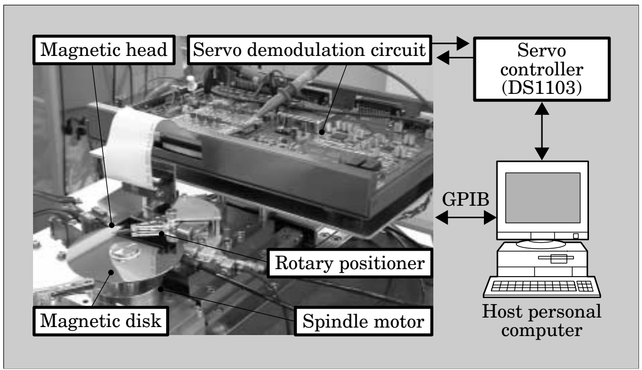
A servo tester has been developed, incorporating a servo signal test function that automatically measures the servo signal quality of the magnetic printing disk, and a track following test function that, based on the servo signal, performs positioning control of the magnetic head on an arbitrary track and measures the positioning accuracy. The former function is helpful as a measure for evaluating details of the signal quality, and the latter function is effective as a measure for comprehensive evaluating the servo signal.

Figure 10 illustrates the structure of the track following test function system, which is based on a commercially available spinstand (a specific tester for magnetic disks and heads consisting of a spindle motor for rotating a magnetic disk and a stage mechanism for moving and positioning a magnetic head). The system includes a rotary positioner for positioning a magnetic head on a target track rapidly, a servo demodulation circuit for acquiring a position error signal from a servo track, a servo controller (DS1103 made by dSPACE) for controlling the rotary positioner's positioning based on a position error signal, and a host personal computer. This allows the track following test to be performed on the spinstand, for a magnetic printing disk on which a servo pattern has been recorded. The VCM (voice coil motor) type rotary positioner commonly equipped with the HDD is used here. Figure 11 shows an example of the magnetic head positioning accuracy measured on a magnetic printing disk. It is evident that the accuracy is within ±0.1 μm, which is nearly equal to 1/10 of the track width.

Table 1 Specifications of next generation magnetic printing equipment

Item	Specification
Printing throughput	600 plates/hour
Eccentricity	< 10 μm
Magnetic disk size	2.5/3.5 inch
Substrate	Aluminum/Glass
Coercivity H_c	< 640 kA/m
Recording method	Longitudinal/Perpendicular
Setup time	< 4 hours
Cleanliness	Class 1 (below 0.1 μm)
Master disk cleaning	Yes (tape burnishing method and purpose-built cleaning disk method)
Magnetic disk cleaning	Yes (tape burnishing method)
Availability factor	> 96 %
Size	3,300 width×1,400 depth ×2,000 height (mm)

Fig.10 Structure of track following test function



5. Future Plans

Because the HDDs equipped in network household appliances are expected to be used daily for recording or replaying movies, greater recording density per magnetic disk will be required as in the case of personal computer use. Figure 12 shows a yearly trend forecast of the track recording density (TPI: Track per inch).

To further enhance magnetic printing technology, Fuji Electric plans to achieve a track recording density of 150 kTPI (equal to twice the current value) within the year of 2002 by promoting the formation of finer servo patterns on the master disk, optimization of the magnet for an external magnetic field using magnetic simulations, and improvement of the servo pattern.

The magnetic printing technology can be applied not only to the servo pattern, but also to data or

Fig.11 Measured positioning accuracy of magnetic head when track-following

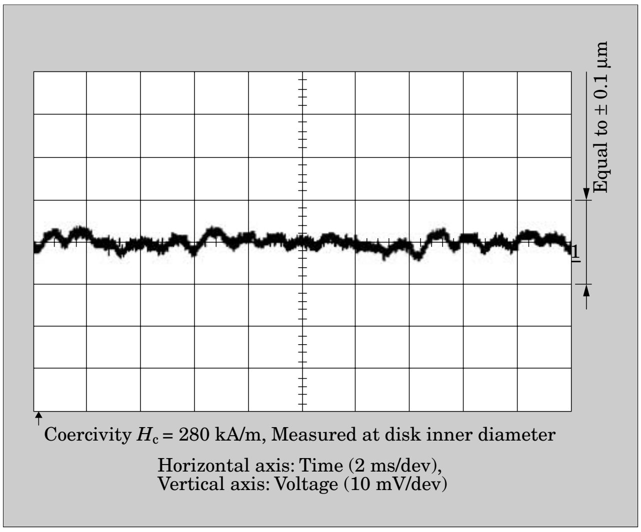
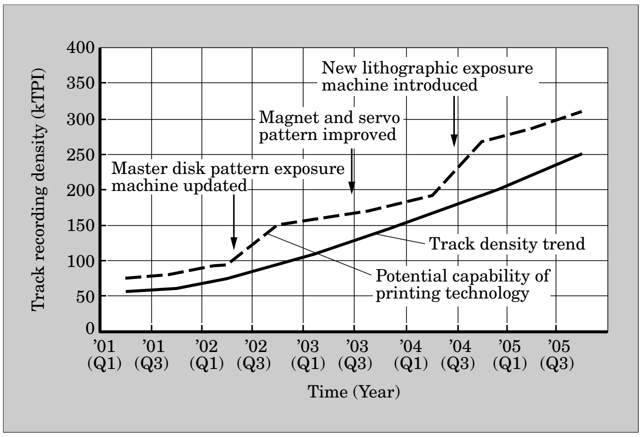


Fig.12 Trend forecast of HDD track recording density



software embedding. Another study is planned into the feasibility of new applications such as a security magnetic disk with security data embedded, which will become a key technology in network household appliances.

6. Conclusion

This paper has presented a servo pattern for positioning the HDD magnetic head, its new writing method, and magnetic printing technology, and has reported Fuji Electric's principal developmental results and future plans. The magnetic printing technology is receiving attention from HDD-related manufacturers as a potential technology for extensively reducing the cost of the servo writing process in HDD production. Fuji Electric expects that the number of manufacturers adopting this technology increases and that the technology becomes the de facto standard for servo writing in the future.

References

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