MK3001GRRB 2.5-inch Hard Disk Drive for Enterprise Use with 300 Gbyte Capacity and 15,000 rpm Rotational Speed

●Toru IWAMOTO ●Akihiko MAKITA ●Tatsuro SASAMOTO ●Keiichi YORIMITSU

Hard disk drives (HDDs) for enterprise use are primary storage devices installed in mission-critical information systems such as servers and storage systems. In this capacity, HDDs should provide high reliability for long-term continuous workloads (24 hours a day, seven days a week), as well as high performance including a high data transfer rate and high-speed access. Low power consumption has also become increasingly important in recent years.
In response to the needs of the market, Toshiba has developed the MK3001GRRB 2.5-inch HDD for enterprise use with a capacity of 300 Gbyte and a rotational speed of 15,000 rpm. The MK3001GRRB achieves a high data transfer rate of 200 Mbit/s, a fast average seek time of 2.7 ms, and low power consumption of 4.0 W in idle state.

1. Introduction

As cloud computing becomes more widespread, faster transaction processing is needed in order to store and manage various types of information. As the main storage device in mission-critical information processing systems, enterprise-class HDDs ideally should have high performance (e.g., high data transfer rates and high-speed access) in addition to high reliability (to realize continuous operation for extended periods of time).

(1) High reliability
High reliability is required to ensure continuous operation (24 hours a day, 7 days a week) for about five years.

(2) High performance
High data transfer rates and high-speed access are essential for processing large amounts of data within a short period of time.

In addition, low-power consumption has become increasingly important in response to energy conservation efforts. With these concerns in mind,Toshiba has developed the MK3001GRRB 2.5-inch HDD. This product achieves high performance and high reliability with 15,000 rpm rotational speed, while delivering low power consumption at 4.0 W in idle state.

2. Drive Overview

Table 1 shows the brief specifications of Toshiba's MK3001GRRB 2.5-inch HDD. The drive has a rotation speed of 15,000 rpm and a storage capacity of 300 GB; enabling up to 200 MB/s sustained data transfer rates. It enables high-speed data access with an average seek time of 2.7 ms. Further, it achieves low power consumption, consuming only 4.0 W while in idle mode. For the interface, Toshiba employs SAS 2.0 (Serial Attached SCSI [Small Computer System Interface] 2.0), which is the mainstream HDD interface for enterprise use.

In addition to the MK3001GRRB, Toshiba offers the MK1401GRRB with storage capacity of 147 GB as well as encrypting models such as the MK3001GRRR and the MK1401GRRR in their product lineup. The basic specifications are listed in Table 1.

This paper describes the hardware and firmware technologies that Toshiba developed to enable both high reliability and high performance in these products.

Table 1 Main specifications of MK3001GRRB 2.5-inch HDD for enterprise use

Item			Specifications	
			MK3001GRRB	MK1401GRRB
Interface			SAS 2.0	
Interface speed (Gbit/s)		(Gbit/s)	6	
Storage capacity		(GB)	300	147
Disks		(QTY)	2	1
Heads		(QTY)	4 (Embedded HDI sensor)	2 (Embedded HDI sensor)
Power consumption (W)	Idle mode		4.0	3.8
	Low-RPM idle mode		3.0	2.8
Rotation speed		(rpm)	15,000	
Sustained data trans. rate		(MB/s)	147–200	
Avg. seek time (during read)		(ms)	2.7	
MTBF		(10^6 h)	1.6	

MTBF: Mean Time between Failures HDI: Head Disk Interface

3. Hardware Technologies

Figure 1 shows the drive's internal structure. The mechanical dimensions are compatible with SFF-8201/8223, the industry standard for 2.5-inch HDDs. Although drives for mobile PCs can be as thin as 9.5 mm, this drive is 15 mm thick in order to have a highly rigid base plate and top cover for high-speed rotation. Through computer aided engineering (CAE) using finite element method (FEM) analysis, Toshiba optimized mechanical architecture to enable high performance, low acoustic noise, and low power consumption.

Toshiba uses fluid dynamic bearings (FDB) due to their low vibration and acoustic noise properties. Bearings are a

critical mechanical component as they decisively influence HDD operating life and reliability. For this reason, the bearing design Toshiba uses is the same as field-proven conventional bearings. Toshiba uses glass substrate disks with an outer diameter of 57 mm and a plate thickness of 1.27 mm. An air stabilizer is placed between magnetic disks as indicated by the dotted line in Figure 1. Compared to Toshiba's conventional model, MBE2147RC, this air stabilizer, which covers 3/4 of the disk periphery, is able to reduce the disk vibration and windage generated by high speed disk rotation. Lower vibration and windage is able to reduce positioning errors (disturbance force) during the positioning control of the head over the target track.

Within the disk enclosure of the MK3001GRRB , four heads are mounted on a carriage. The carriage in turn is mounted on a base via a pair of small-sized ball bearings. The carriage is actuated by a voice coil motor (VCM), which includes a flat coil and magnets.

To achieve a storage capacity of 300 GB, the heads include a newly developed head disk interface (HDI) sensor which responds to subtle heat fluctuations between the head and disk, between which there is a very small clearance. In recent years, HDDs have included heaters which are embedded in the heads' read/write elements. By controlling heater power, the clearances between read/write elements and magnetic disk surfaces can be finely controlled, thereby achieving a high recording density. The HDI sensor is a functional element for controlling clearance accurately. When mounting the HDI sensor, as each head has a total of eight terminals—the existing six terminals for read, write, and heater plus two additional terminals—these terminals must be connected to the flexible printed circuit (FPC) with high precision. **Figure 2** shows a schematic drawing in which heads with HDI sensors are attached to the FPC, which in turn is mounted on the carriage.

To enable high speed seeking, it is important to design a high-performance actuator with both a powerful VCM and a lightweight and vibration-proof carriage. When designing the VCM, Toshiba optimized shapes and materials through magnetic field analyses. For the carriage design, Toshiba conducted a large-scale FEM analysis (**Figure 3**) for the entire piece of hardware and optimized the shapes and structures of the mechanical components to lessen undesirable vibrations and improve the damping of vibrations, particularly those caused by large VCM forces during the acceleration or deceleration of the carriage.

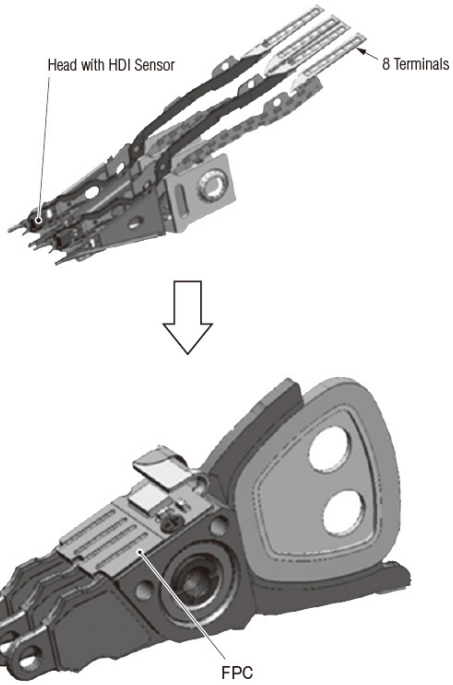

Figure 2 Connection of head-disk interface (HDI) sensor to flexible printed circuit (FPC) —
High-density connecting technology was used to implement the HDI sensors, which are functional elements to increase HDD capacity.

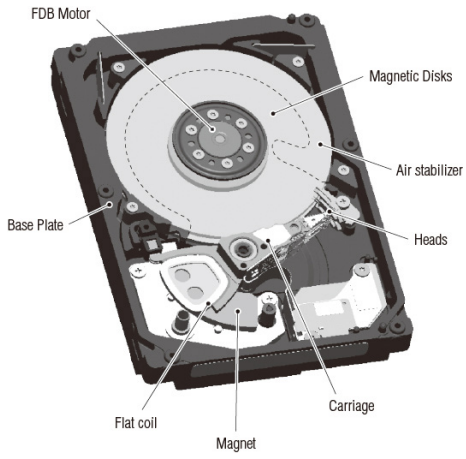

Figure 1 Internal structure of MK3001GRRB —
High reliability, high performance, low acoustic noise, and low power consumption were achieved by optimizing the design of the HDD's mechanical components.

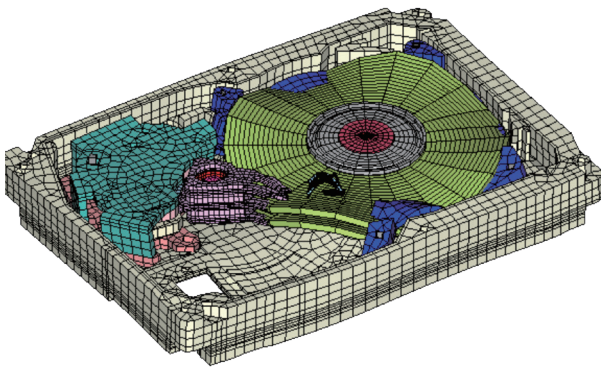

Figure 3 Example of finite element method (FEM) analysis —
By conducting large-scale FEM analysis of the entirety of the HDD's mechanical components, the shapes and structures of each component were optimized, enabling high actuator performance.

4. Firmware Technologies

The drive's firmware consists of the following two function structures:

(1) Servo control functions

Controls the FDB motor, the VCM for head positioning and seeking, etc.

(2) Controller firmware functions

Controls the interface that handles commands from the host as well as the interfaces with the servo control and cache control functions.

4.1. Servo control functions

The drive achieves an average seek time of 2.7 ms. The drive accelerates and decelerates the carriage with a maximum acceleration exceeding 200 G; its maximum speed reaches 3 ms. After such rapid acceleration and deceleration movements, the drive must quickly and stably follow the target track. Although the width of one track is only approximately 90 nm, the heads must be positioned exactly above the center of the tracks. For this reason, Toshiba had to significantly improve the servo feedback control loop gain. It also optimized the current waveforms during seeking by taking into consideration the resonance frequency of the actuator in order to reduce residual vibrations and carriage acoustic noise (**Figure 4**) compared to Toshiba's conventional model, MBE2147RC.

Toshiba also increased the sampling frequency of the servo controller, used faster processors, and optimized servo controller loop shapes.

When using enterprise class HDDs not only should the vibrations inside HDDs be considered but also the influence of external vibrations. In servers and storage systems, multiple built-in HDDs as well as the cooling fans may cause vibrations. To suppress the performance degradation caused by such vibrations, Toshiba used rotational vibration feed forward (RV-FF) technology to improve the above-mentioned actuator feedback control compared to Toshiba's conventional model, MBE2147RC, and expanded the RV-FF frequency band compared to Toshiba's conventional model, MBE2147RC. These two enhancements contribute to a significant improvement for the external vibration stress (**Figure 5**) compared to Toshiba's conventional model, MBE2147RC.

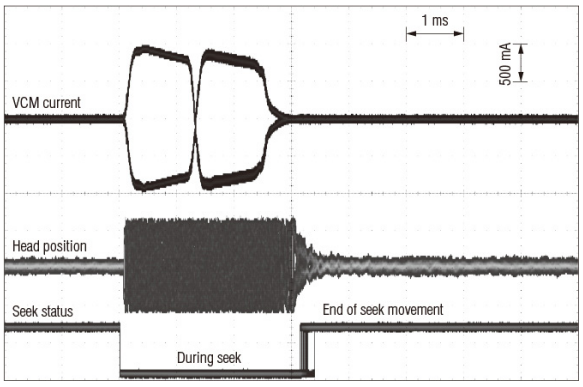

Figure 4 Seek waveform —
Alternate seek waveforms with 1/3 of the full stroke distances; maximum acceleration exceeding 200 G during seek operations.

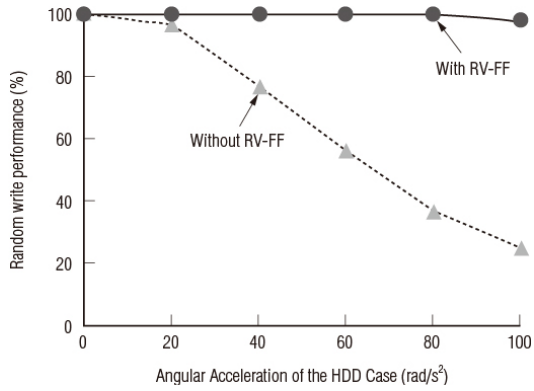

Figure 5 Comparison of Performance with/ without RV-FF Servo —
Without RV-FF, the performance degradation can be observed at 20 rad/s2 or more; with RV-FF, no performance degradation can be observed under 100 rad/s2. Anti-vibration performance is greatly improved.

Lower power consumption compared to Toshiba's conventional model, MBE2147RC, has been achieved by powering down circuits individually and reducing the rotation speed of the disks that are not carrying out read/write operations after the drive carries out seek movements or while it is in an idle state. Toshiba also optimized the FDB spin-up control, head loading and unloading controls, and reduced acoustic noise.

By adopting these technologies, Toshiba's MK3001GRRB provides high performance, low power consumption, and low acoustic noise.

4.2. Controller firmware functions

Toshiba's MK MK3001GRRB is compatible with the SAS 2.0 industry standard and enables an interface speed of up to 6 Gbits/s.

The following sections describe the drive's maintainability and high reliability as well as its high functionality, high performance, and low power consumption.

4.2.1. Maintainability and high reliability

The drive has a self-monitoring analysis reporting technology (SMART) function, which warns of critical HDD failures in advance, to realize a full-fledged implementation of a logging function for detailed failure analysis. The drive also has a self-test functionthat allows the status of the HDD to be diagnosed if needed.

End-to-end data protection (an error detection function executed upon any component failure) and a disk-surface defect avoidance function support data reliability at all times. Furthermore, the following processes are executed in the background to help improve reliability during continuous long-term operation.

(1) Background media scan (BMS) function

Performs a full scan of the data area at regular intervals to detect recoverable errors in advance and automatically recover them.

(2) System area (SA) saving function
Improves the log function by periodically saving system information on the HDD into the SA, which is isolated from the user-accessible areas.

4.2.2. High functionality, high performance, and low power consumption

Toshiba improved the following three basic HDD functions compared to its conventional model, MBE2147RC:

(1) Reordering function
Executes command processing in the shortest possible period of time by optimizing the execution order of received commands (up to 128 commands).

(2) Data queuing function
Reduces processing time by executing the write operations of several commands together after storing write data in the cache area.

(3) Cache function
Temporarily holds data to be read or written to/from magnetic disks, improve command responses, and optimizes processing in response to various access forms from the host.

By expanding the data buffer capacity from 16 MB of the previous model to 32 MB, Toshiba improved cache hit rates and realized higher performance.

Furthermore, Toshiba realized both higher performance and lower power consumption by introducing a multi-level automatic power saving algorithm and command-driven forcible power saving as power saving functions.

An optional self-encryption drive (SED) function, which allows the HDD itself to internally encrypt data, and a data integrity field (DIF) function, which allows data protection to be controlled at the system level, are supported.

5. Conclusion

Toshiba has developed a high-performance 2.5-inch enterprise class HDD with a rotation speed of 15,000 rpm and an average seek time of 2.7 ms. During development, Toshiba employed new technologies for the mechanical components, servo control section, and controller firmware section to enable high reliability and high performance. Going forward, Toshiba will continue to push forward with the development of HDDs for the enterprise market featuring both higher performance and higher quality.

* Maximum read and write speed may vary depending on the host device, read and write conditions, and file size. For purposes of measuring read and write speed in this context, 1 megabyte or MB=1,000,000 bytes.


Toru IWAMOTO
Storage Products Div.


Akihiko MAKITA
Storage Products Div.


Tatsuro SASAMOTO
Storage Products Div.


Keiichi YORIMITSU
Storage Products Div.