

Nearline TDMR HDDs with Industry's Largest Capacity of 16 Tbytes

As a consequence of the rapid expansion and growing prevalence of cloud services, the volume of data generated is increasing. This, in turn, is fueling demand for large-capacity hard disk drives (HDDs) for data centers.

To meet this industry requirement, Toshiba Electronic Devices & Storage Corporation released the MG08 series of 3.5-inch nearline HDDs in January 2019. The MG08 series has achieved the industry's largest capacity of 16 Tbytes^(*) for a conventional magnetic recording (CMR) HDD. In order to increase the recording density, we applied two-dimensional magnetic recording (TDMR) technology for the first time in our HDDs. In addition, this series incorporates many other innovations to increase recording density, including improved head architecture, an optimized media material to enhance the signal quality, enhanced spacing control between the head element and the media surface, and improved servo control technology and suspension to improve the head positioning accuracy.

1. Introduction

The growing prevalence of cloud services, expansion of the surveillance camera and artificial intelligence (AI) markets, and the development of self-driving car technology using fifth-generation (5G) mobile wireless networks are spurring the exponential growth in the volume of data generated. In this situation, the demand for high-capacity 3.5-inch HDDs, particularly for nearline HDDs for data centers, is increasing. To meet this demand, Toshiba Electronic Devices & Storage Corporation has developed the MG08 series, which is the eighth generation of 3.5-inch nearline HDDs and the second generation of helium-filled HDDs. The MG08 series provides a

capacity of 16 Tbytes, the industry's highest for a CMR HDD, which was realized by using TDMR technology, improving the head positioning accuracy, and optimizing the designs of major components. Furthermore, the MG08 series incorporates servo control technology and a write reordering mechanism that optimizes the order in which the queued write commands are executed, increasing random write performance.

This report provides an overview of the MG08 series as well as the technologies that have been newly developed to realize the industry's highest-capacity HDDs.

(*) As of January 2019 for 3.5-inch HDDs with a height of 26.1 mm (as surveyed by Toshiba Electronic Devices & Storage Corporation)

2. Product highlights

Table 1 shows the key specifications of the newly developed MG08 series of 3.5-inch HDDs.

The MG08 series is available in two types of models having different interfaces: models with Serial Advanced Technology Attachment 3.3 (SATA-3.3) and those with Serial Attached Small Computer System Interface 3 (SAS-3). To provide a roughly 14% higher recording capacity than the previous MG07 series without increasing the number of either magnetic heads or platters, the MG08 series is designed with higher linear recording and track densities, achieving an average areal recording density of 1,770 Mbits/mm². The MG08 series also provides a maximum continuous data transfer rate of 262 Mibytes/s (Mibyte: mebi (2²⁰) bytes). In addition, the MG08 series provides a roughly 18% higher power consumption efficiency^{(*)2} than the MG07 series, contributing to a reduction in the power consumption of storage systems.

3. Mechanical design

We commercialized the MG07 series, the world's first helium-filled HDD series containing nine platters and 18 magnetic heads in the industry's standard 3.5-inch HDD enclosure with a height of 26.1 mm^{(*)3}. Based on the enclosure of the MG07 series, the newly developed MG08 series incorporates a TDMR head and the related components (**Figure 1**).

Since the TDMR head has two read head elements, the number of its terminals connected to head preamplifiers has increased from 9 to 11 (**Figure 2**). To accommodate this increase, we have shrunk the size of the layout dimension of

Table 1. Main specifications of MG08 series 3.5-inch nearline HDDs

Characteristic	Specification	
	MG08ACA16TA MG08ACA16TE	MG08SCA16TA MG08SCA16TE
Interface	SATA-3.3	SAS-3
Interface speed	6 Gbits/s	12 Gbits/s
Storage capacity	16 Tbytes	
Number of platters	9	
Number of magnetic heads	18	
Average linear recording density	102.7 kbits/mm	
Average track density	17,200 tracks/mm	
Average areal recording density	1,770 Mbits/mm ²	
Buffer size	512 Mibytes	
Rotation speed	7,200 rpm	
Maximum continuous data transfer rate	262 Mibytes/s (typical)	
MTTF	2,500,000 h	
Power consumption (in idle mode)	4.00 W	4.46 W
External dimensions (W x D x H)	101.85×147.0×26.1 mm	
Weight	720 g (maximum)	

MTTF : mean time to failure

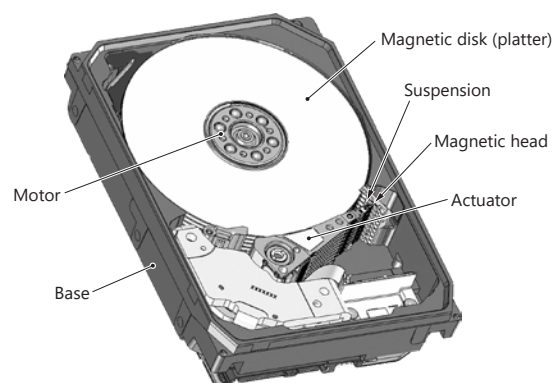


Figure 1. Internal structure of MG08 series

We have newly developed a magnetic head, a magnetic disk, an actuator, and a suspension assembly to realize the industry's highest capacity of 16 Tbytes.

(*)2) Power consumption in low-power idle mode divided by storage capacity

(*)3) As of December 2017 for 3.5-inch HDDs with a height of 26.1 mm (as surveyed by Toshiba Electronic Devices & Storage Corporation)

the flexible printed circuit (FPC) board that connects magnetic heads with head preamplifiers, improved the layout of the FPC, and optimized its bonding conditions. As a result, we have realized an actuator for the TMDR head with the same size as that of the MG07 series.

Furthermore, to increase the recording density, we have reduced the size of magnetic clusters and newly developed major components, including a magnetic disk that allows a reduction in head magnetic spacing and a head suspension assembly that provides higher head positioning accuracy. We have also optimized thermal design to make it possible to increase the data transfer rate and performance.

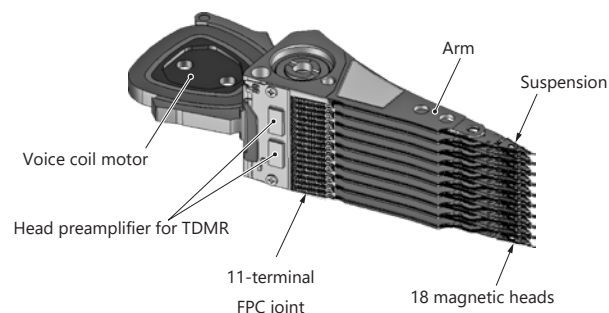


Figure 2. Actuator newly developed for TDMR

We have newly developed an FPC and a suspension assembly with high head positioning accuracy.

4. Increasing the recording density

The MG08 series has an average linear recording density of 102.7 kbits/mm in the track direction and a track density of 17,200 tracks/mm in the radial direction. An average areal recording density of 1,770 Mbits/mm² has been achieved by the increase in linear recording and track densities.

To increase the recording density, it is generally necessary to reduce the size of write and read head elements. However, reducing the width of head elements reduces the disk write capability, leading to degradation in the quality of the read signal from the HDD. Reducing the spacing between data tracks increases adjacent track interference (ATI), also leading to degradation in the quality of the read signal. To solve these problems, we have adopted TDMR technology for the MG08 series.

We have also enhanced the head positioning accuracy to increase the track density.

4.1 TDMR technology to achieve high recording density

TDMR is a novel data read technology that combines two signals simultaneously picked up from the same sector in a given data track of the platter.

Furthermore, we have modified the structure of write head elements to enhance the data write capability; optimized the amplitude of the output write signal on a bit-by-bit basis to enhance the write quality; changed the magnetic disk material to enhance the quality of the read signal; improved the technology to control the spacing between the head elements and disk surface; and enhanced the data formatting efficiency. As a result of these innovations, the MG08 series has achieved an increase in capacity.

The following subsections detail the major technologies that have been employed to increase the HDD capacity: TDMR technology to increase the recording density and the technology for the enhancement of the head positioning accuracy to achieve high track density.

The conventional magnetic head consists of one write head element and one read head element whereas the TDMR head consists of one write head element and two read head

elements (**Figure 3**). As shown in the enlarged image of Figure 3, the two read head elements are placed back-to-back in the track direction of the platter.

The characteristics of the two signals from these read head elements differ, depending on the read head elements' characteristics. In addition, the two read signals have a different amount of noise and a time skew according to the relative positions of a data track and the read head elements. Therefore, the two signals picked up simultaneously from the

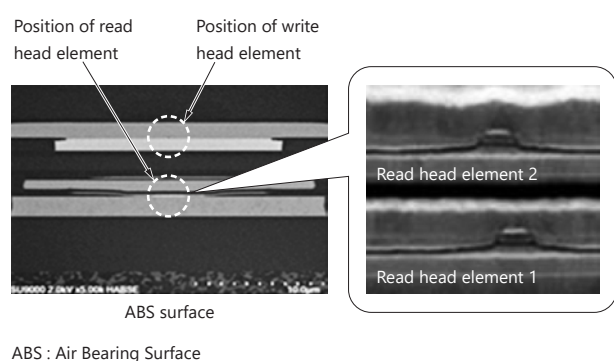


Figure 3. Scanning electron microscope (SEM) images of magnetic head elements

The magnetic head has two read head elements to simultaneously pick up two signals from the magnetic disk.

4.2 Enhancing head positioning accuracy to achieve high track density

To achieve high track density, it is necessary to improve head positioning accuracy. The control bandwidth is one of the measures of the ability to control the head positioning. To increase the control bandwidth, we have shortened the servo sampling period and improved the resonance characteristics of the actuator assembly. As a result, the MG08 series provides a roughly 14% higher control bandwidth (compressed frequency band) than the MG07 series.

The servo sampling period of an HDD is determined by its rotation speed and the number of servo codes recorded on a magnetic disk at an equal interval as a magnetization pattern. Reducing this period helps to realize faster servo control operations, enhancing head control performance. Accordingly, we have increased the number of servo codes and reduced the servo sampling period of the MG08 series by

same sector are not identical. Head amplifiers and read channels compensate for such noise and head skew. A two-dimensional (2D) equalizer subsequently combines the two signals into a single data stream (**Figure 4**). The 2D equalizer enhances the signal components from the tracks with high correlation and reduces interference between data from adjacent tracks to improve the quality of the read signal. TMDR technology helps increase linear recording and track densities, increasing the areal recording density.

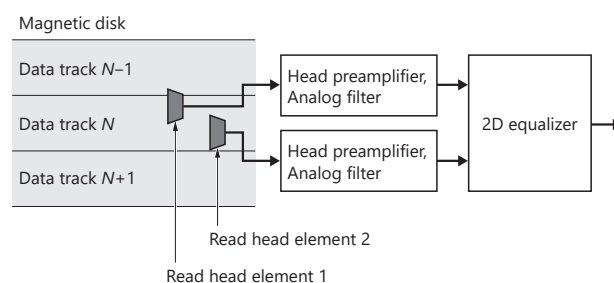


Figure 4. Schematic diagram of TMDR technology

The two signals picked up from two read head elements are processed by a 2D equalizer to enhance the read signal quality.

roughly 13% compared with that of the MG07 series.

However, increasing the number of servo codes increases the disk area occupied by the servo codes, leaving less area where user data can be recorded. It is therefore important to minimize the length of a region required by each servo code field. For this purpose, we have divided part of the servo codes into multiple regions and placed them dispersedly across a disk to reduce the amount of information per servo code while adopting a technique to reconfigure servo codes with firmware, in order to increase the user data area. This technique was employed for the MQ04 series of 2.5-inch HDDs for the first time. In adopting it for the MG08 series, we have theoretically optimized the division of the servo codes to modify the reconfiguration algorithm, further increasing the write data area and enhancing reliability.

The MG08 series incorporates a dual-stage servo system using a microactuator of the suspension assembly. The resonance characteristics of the microactuator have been improved to further enhance its control performance. We have optimized the microactuator design based on that of the MG07 series in order to improve the resonance characteristics in the high-frequency region that are affected mainly by the torsional mode of the head suspension and support. This enabled the controller of the MG08 series to suppress disturbances over a wider frequency range than that of the MG07 series.

Consequently, the MG08 series achieves a roughly 10% higher head positioning accuracy than the MG07 series (**Figure 5**), considerably contributing to the increase in track density. Although an increasing number of applications use HDDs in harsh environments with intensive vibration, the enhanced head positioning accuracy helps to ensure stable HDD operations.

5. High performance

The MG08 series provides a roughly 6% higher maximum continuous data transfer rate than the MG07 series since the MG08 series can fit more data in a track because of the increased linear recording density.

In addition, we have increased the number of internal queued commands^(*) and improved the reordering control method in order to enhance random write performance. Generally, random write performance cannot be improved simply by increasing the number of queued commands because doing so increases the period of time required to search for the commands to be reordered (i.e., to determine the order in which they are executed). To solve this problem, we have developed a group search reordering technique by which the data recording areas of the entire HDD are grouped according to their physical locations to manage a set of write commands for nearby physical areas together. This technique prioritizes the execution of the commands in the same group as the command being executed in order to improve the

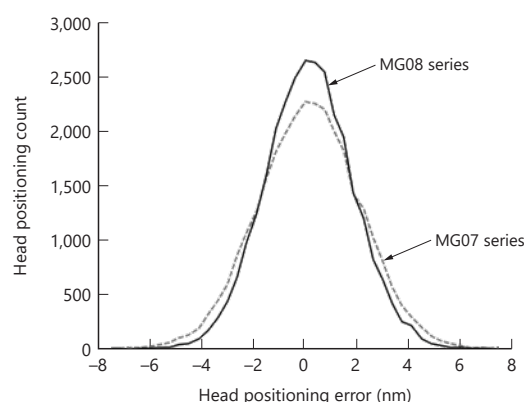
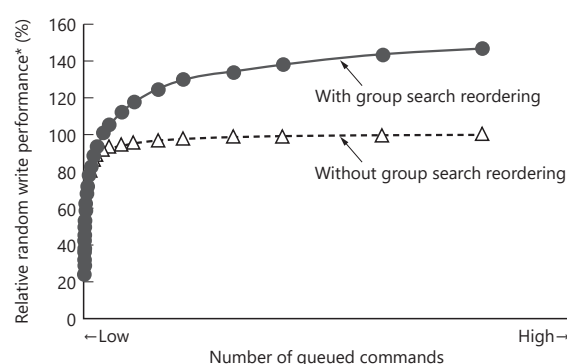


Figure 5. Comparison of head positioning accuracy

The MG08 series provides a rough 10% higher head positioning accuracy (less variation in positioning errors) than the previous MG07 series.

efficiency of a command search for reordering, enhancing random write performance (**Figure 6**).



* Maximum performance without group search reordering = 100 on a comparable index

Figure 6. Results of evaluation of random write performance by group search reordering

Increasing the number of queued commands using a group search reordering technique improves random write performance.

(*) Queue of multiple commands issued by the host system sorted in the order of data writes to a magnetic disk

6. Conclusion

We have employed TDMR technology, improved the head positioning accuracy, and optimized the designs of major components to develop the MG08 series of 3.5-inch nearline HDDs that provide the industry's highest capacity of 16 Tbytes for a CMR HDD.

The capacity of nearline HDDs will continue to increase, and

the market for high-capacity nearline HDDs is expected to continue to grow further.

As a cyber-physical system (CPS) technology enterprise, we will expand our portfolio of high-capacity nearline HDDs to satisfy customer needs, thereby contributing to the strengthening of the foundation of the information society.