Perpendicular Magnetic Recording Technology

HITACHI
Inspire the Next

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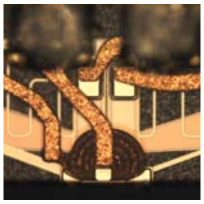
Executive summary

In 2006, an exciting new magnetic recording technology was introduced into hard drive storage. Perpendicular magnetic recording (PMR) offers the customer higher capacities, improved reliability and robustness, and a very positive outlook for the future growth in capacity and performance. Through the efforts of a company-wide taskforce, Hitachi's first PMR drive, the Travelstar® 5K160, achieved best-of-breed performance and quality and has since ramped seamlessly to high-volume production. Drive development incorporated a year-long field test that successfully demonstrated the viability of Hitachi's advanced design. Core technologies include second-generation trailing-shield heads and advanced granular cobalt-chromium-platinum (CoCrPt) oxide media. Jointly optimized head and media designs, as well as advanced system integration, resulted in very high performance with sharp write field gradients, resistance to stray fields, and excellent media magnetic and mechanical stability. Hitachi is an intellectual property leader in perpendicular magnetic recording and has more than fifty patent-pending technologies in the Travelstar 5K160.

Following on the successful implementation of the Travelstar 5K160, Hitachi subsequently announced the industry's first terabyte hard drive in January 2007. Built on Hitachi's industry-leading PMR technology, the Deskstar® 7K1000 brings customers the same performance and reliability as the Travelstar hard drive, as well as the highest-capacity available in a desktop hard drive.



1. Introduction

1.1 Hard Disk Drive (HDD) Storage Basics

All HDDs store the data as tiny areas of either positive or negative magnetization on the surfaces of the disks. Each tiny area represents a "bit" of information. The bits are written closely-spaced to form circular "tracks" on the rotating disk surface. Many such concentric tracks cover the surfaces of the disks. There are millions of bits on each track and many tens of thousands of tracks on each disk surface. The total storage capacity of a HDD depends directly on how small we can make the area needed to represent one bit of information: the smaller the bits—the greater the capacity.

1.2 Areal Density, Technology Growth, Thermal Limit

The product of bits per inch along the track times tracks per inch radially on the disk is areal density in bits per square inch. Areal density growth-rate is a frequently quoted measure of the rate of advance of the technology. In recent years the growth-rate has slowed because of a fundamental limit in magnetic recording. This limit relates to the fact that the magnetic material on the disk surface is necessarily composed of small grains. Because of the randomness of the grain shapes and sizes, each bit written on the disk must cover about 100 grains to ensure that the information is reliably stored. Unfortunately there is a lower limit to the size of a grain. Below this limit, there is a risk that the magnetization may spontaneously reverse just due to excitation by the thermal energy that is universally present in the environment, even at room temperature.

1.3 Perpendicular Recording Technology

Perpendicular recording addresses this "thermal" limit and allows continued advances in areal density. In conventional "longitudinal" magnetic recording (LMR), the magnetization in the bits is directed circumferentially along the track direction. In perpendicular recording, the "magnetic bits" point up or down perpendicular to the disk surface. Figure 1 contrasts how the recording media, the write head, and the read head are configured for a longitudinal and for perpendicular recording system.

The unique feature seen in the perpendicular system is the "soft magnetic underlayer" incorporated into the disk. This underlayer conducts magnetic flux very readily. When the write head is energized, flux concentrates under the small pole-tip and generates an intense magnetic field in the short gap between the pole-tip and soft underlayer. The recording layer that stores the data is directly in this gap where the field is most intense. Higher fields allow "higher coercivity" media to be used. Such media require higher fields to set the magnetization, but once set, the magnetization is inherently more stable.

The presence of the soft underlayer also strengthens the readback signals and helps decrease interference from adjacent tracks. Although the read head itself does not need to be changed very much, the waveforms that come out of the head are totally different and require new signal processing techniques in order to gain the most benefit.

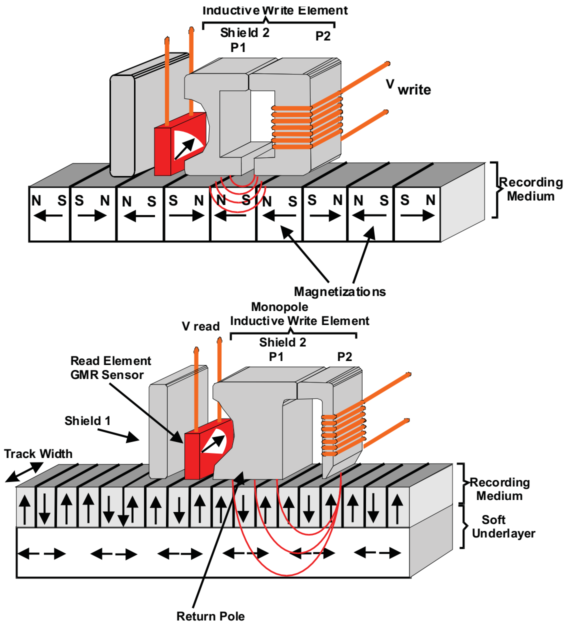


Figure 1: Longitudinal recording diagram (top) and perpendicular recording diagram (bottom)

1.4 Second-Generation Perpendicular Technology

Figure 1 refers to what we might call first-generation technology. This is similar to the technology deployed in Hitachi's field test in 2005. While this technology proved advantageous and reliable, even more benefit can be gained by further refinements to the head, media, and electronics. It is this second-generation technology that is being shipped in the Hitachi Travelstar 5K160 and Deskstar 7K1000. Second-generation technology involved changes to the write head, the recording medium, and the read/write electronics.

The write-head is modified by placing a "trailing-shield" spaced closely to the trailing-edge of the pole-tip where the data is recorded, as in Figure 2. This can impact the field-strength slightly but has a big advantage in that the fields die away very rapidly as the medium moves from under the pole-tip to under the shield. This rapid gradient in field means that the bits that are written can be much more sharply defined.

For ease of implementation, the first-generation media was created as a single uniform layer. However, it is very advantageous to tailor the properties differently through the thickness of the media. These are properties such as the magnetic moment (magnetization per unit volume), the anisotropy (the strength with which the magnetization like to align along a given direction), and the exchange (the level of atomic coupling between adjacent grains that tends to make the magnetization of adjacent grains point the same direction). These magnetic properties are a complex function of the materials used and the conditions under which the media is laid down.

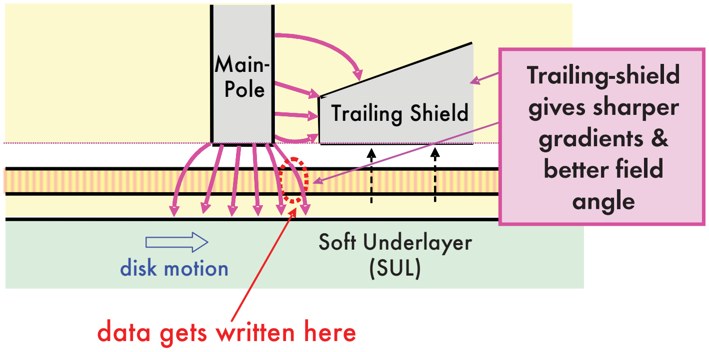


Figure 2: Cross-sectional schematic of a "trailing shield" head—a thin magnetic shield placed in the proximity of the trailing edge of the writing pole.

2. Head Technologies

In a conventional LMR head, the magnetic field for writing is generated from a thin non-magnetic gap in the ring head, and it has a higher longitudinal component than perpendicular component. In PMR, the media has magnetization oriented in the up-down direction. To achieve efficient writing, a PMR write head needs to generate fields having the perpendicular components higher than the longitudinal components. As illustrated in Fig. 1, a "single pole" PMR head combined with a soft-under-layer (SUL) offers a strong perpendicular write field, while the longitudinal component is much reduced. Rather than being generated from the gap, the field from a PMR write-head is generated from the pole surface and collected by the SUL. Fig. 3 shows the corners of a rectangular pole will cut into neighboring tracks when the head is operating at a skew angle. In modern drives, the head has a skew angle with respect to the track direction when the head operates at inner or outer radii. Fabricating a narrow trapezoidal pole with a well-controlled bevel angle is essential to prevent the fields from the pole surface erasing data in neighboring tracks.

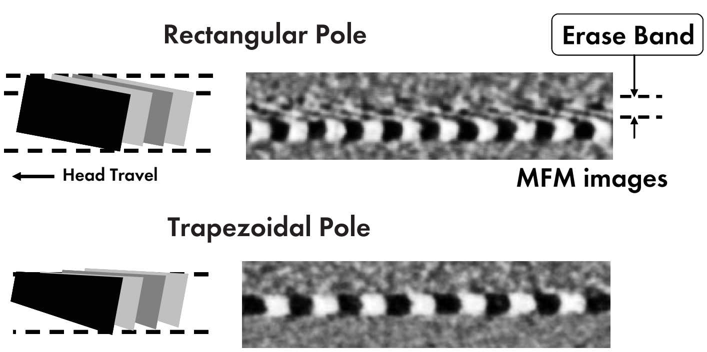


Figure 3: Trapezoidal pole shape in a PMR write head to avoid data erasure in neighboring tracks when the head is operated at a skew angle, e.g., at inner or outer radius.

The Hitachi second-generation PMR "trailing-shield" head has tight controls on the shield thickness and the gap between the trailing edge of the pole to intricately balance the interaction between the trailing shield and the main pole. Media matching for trailing shield heads is critical in order to take advantage of the high field gradient and more optimal field angle, and to tailor to the modified field strength. When writing on media with matching characteristics, trailing-shield heads write sharper bits. As a result, the drive delivers better bit-error rate performance and therefore a better reliability margin.

Besides the optimization of the head design for recording performance, there are other challenges that are also unique to perpendicular heads, such as "pole erasure" and "stray field erasure." Both issues can lead to data corruption if not treated properly. Pole erasure refers to the phenomenon where the writing pole continues to emit magnetic fields even when the write current is set to zero at the end of the write cycle. As a result, the data can be erased unintentionally. This phenomenon arises from the extremely small dimensions and the ferromagnetic nature of the perpendicular writing poles. Special efforts in thin film magnetic material selection and processes are necessary to ensure a pole-erasure free write head.

One of the earliest concerns with PMR was an inherent increased susceptibility to external magnetic fields when compared with longitudinal technology. The increased sensitivity to stray fields is originated from the interaction between the recording head and SUL. These external fields are a particular concern for mobile products, where, for example, a magnetic bracelet on someone's wrist can easily come within a few centimeters of the HDD in a laptop. Without special head designs, the external fields can greatly distort data writing and read-back signals and cause error events. In some extreme cases, the external field can even cause unrecoverable data erasure. With careful head and media designs, Hitachi has been able to bring the robustness of external fields up to a level equivalent to or better than current longitudinal drives.

Although introduction of a new technology enables new and exciting performance, the new technology often invokes new risks in reliability. Hitachi has carefully studied and addressed the potential problems that are uniquely associated with the new PMR technology. The Hitachi second-generation perpendicular heads offer excellent bit error rate performance at high density without compromising any reliability.

3. Media Technology

As longitudinal media approaches its lower limit for thermally stable bit size, the industry has been motivated to resolve the historically complex issues surrounding perpendicular media manufacturing. At Hitachi, the fundamental media structure developed for 2006 products is a type of "granular" media, comprised of magnetic alloys containing Cobalt, Chromium, and Platinum (CoCrPt) and an oxide grain-boundary segregant, as shown in Figure 4. By using an Hitachi-unique alloy combination and layer-deposition process, recording properties are graded through the media thickness to optimize signal-to-noise ratio while providing excellent writing characteristics and high mechanical quality. The media and head were co-developed to take advantage of features inherent in the trailing-shield write head design, the media soft magnetic underlayers, and the media hard magnetic layers. This rigorous joint head/media optimization is a key enabler of Hitachi's superior technology results.

Figure 4: Hitachi Perpendicular Media Structure

Before product development started in earnest, perpendicular media had lower mechanical reliability than longitudinal media. It took a concerted and coordinated effort by Hitachi's vast resources to understand and improve the reliability to the level of Hitachi's quality standards, while also advancing the magnetic performance and achieving production-level cycle times and yield. Perpendicular media development required rethinking of reliability metrics and anticipation of new potential failure mechanisms to help ensure the highest levels of corrosion resistance and mechanical robustness. As a result, Hitachi successfully engineered the high-density perpendicular media into one of the most reliable media in the industry. Furthermore, manufacturing of PMR media technology required a new sputter tooling paradigm with more deposition stations, more process capabilities and higher throughput. Using Hitachi's broad experience in process and equipment engineering, state-of-the-art perpendicular media was developed and transitioned to large scale manufacturing with impressive speed and stability.

4. Read/Write Electronics

The signals from a perpendicular recording system look dramatically different than those from a conventional longitudinal system (Figure 5). Every frequency component gets shifted by 90 degrees in phase (corresponding to the 90 degree rotation of magnetization from longitudinal to perpendicular). This totally alters the appearance of the waveforms. The signal processing in the Read/Write electronics must be modified to accommodate these waveforms. In addition to the phase-shift, there is also a lot more signal energy at low-frequencies. The new electronics in the Travelstar 5K160 and Deskstar 7K1000 takes advantage of this additional signal strength but is also careful to avoid the signal disturbances and noise that sometimes can occur in these low-frequency regions.

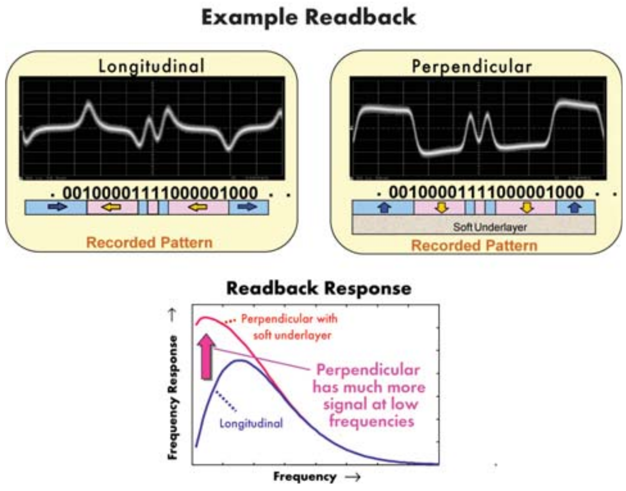


Figure 5: The readback waveforms change dramatically between longitudinal and perpendicular recording. The signal processing in the R/W channel must be able to accommodate these new waveforms and appropriately include some of the extra signal energy available at low frequencies.

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