Magnetoresistive (MR) Head Technology

A Quantum White Paper

Across the spectrum from network servers to personal computers and desktop workstations to notebook systems, the capacity demands placed on hard disk drives are increasing faster than ever before. Because lower costs per megabyte are also desired, the conventional method of adding disks and heads is less and less appropriate. Instead the primary engineering challenge is to continue increasing areal densities, or bits of data per square inch of disk surface.

To date, drive manufacturers have successfully doubled capacities every 12 to 18 months by increasing areal density. But pushing areal densities higher results in smaller recorded patterns on the disk, and therefore, weaker signals generated by the read head. Several methods can compensate for these weaker signals. For example, read/write heads can fly closer to the disk. Today, heads typically fly two to three microinches over the disk — a distance much smaller than a human hair or dust particle. Another method uses improved read channels such as PRML (Partial Response Maximum Likelihood). First used in digital communications, PRML read channels are more recently being applied in hard disk drives. Drive engineers may also compensate for the weaker read signals by adding more turns to the inductive heads used in most drives. All of these solutions, however, are rapidly reaching the limits of their usefulness.

The consensus then, is that a major transition in head technology is on the horizon in order to continue the swift pace of areal density improvements seen today. That transition — from the inductive head technology used since the first disk drive was introduced to new, magnetoresistive (MR) head technology — is necessary if magnetic random-access storage is to remain the storage medium of choice over the course of the next decade. Laboratory tests have demonstrated that MR heads can deliver four times the areal densities possible with thin-film inductive heads. The MR technology permits continued reductions in the cost of stored data and has several advantages over thin-film inductive heads, including: separate read and write elements, high signal output, low noise and velocity-independent output.

The following sections briefly describe inductive head technology and its limitations, and introduce MR head technology and its fundamental advantages that can lead to the areal density requirements of both current and future generations of disk drives.

Inductive heads: reaching their limit

Spurring the need for a new head technology is a simple fact: as areal densities increase, the bit patterns recorded on the surface of the disk grow smaller, which weakens the signal generated by the head. That, in turn, makes it difficult for the disk drive’s read channel electronics to identify the bit patterns that produced the signal.

Until now, drive designers have circumvented this problem by using several methods to produce a stronger read signal. These techniques may include flying the head closer to the disk or adding turns (the number the number of wraps of the thin copper wire that is coiled around the magnetic core of the head). The read signal is directly proportional to the number of turns. Adding turns increases the read signal sufficiently for accurate determination of the magnetic pattern recorded on the disk.

The downside of this approach is that increasing turns increases the head’s inductance (an electrical current’s equivalent to momentum). There is a limit to the amount of inductance a head can tolerate to effectively perform data write operations. Since thin-film inductive heads use the same head element for both reading and writing, an “inductance compromise” is necessarily involved.
During a data write, electrical current flows from the disk drive’s write circuitry to the wire coils around the head. This produces the magnetic field used to record data on the surface of a disk. As areal densities continue to increase, the concomitant increase in inductance associated with the number of turns limits the frequency with which the current reversals can occur for write operations.

During a data read, the process is reversed: flux changes on the disk induce a current in the coil. The high inductance of a high-turn head will also limit the frequency of operation for sensing these magnetic transitions.

Disk drive manufacturers have also improved read signal strength by increasing the linear speed at which recorded data bits move under the head. With thin-film inductive heads, the faster the speed, the stronger the signal. But here again limitations apply. The faster rotational speeds also increase the data frequencies — the rate at which the magnetic transitions (which encode the data) pass the head. As previously mentioned, high-inductance heads cannot perform at the high frequencies. In addition, high data frequencies are limited by read channel electronics.

As disk drives decrease in size, their linear speed naturally slows, and the read signal’s amplitude can diminish to the point where the signal is no longer discernible from background electrical noise. Drive vendors have often boosted the revolutions per minute (RPM) of their products to maintain the needed velocity (and subsequently reach desired areal densities). While some of today’s high-capacity 3.5-inch drives operate at speeds up to 7,200 RPM, higher rotational speeds are less acceptable in 2.5-inch drives used in power-conservative notebook systems, where low power consumption and low acoustics are desirable.

**The MR edge: two Heads are better than one**

One characteristic of MR head technology, which is also one of its greatest advantages, is that it employs two closely spaced but separate write and read elements: a thin-film inductive element for recording data, and a magnetically sensitive thin-film resistive element for detecting data bits written on the disk surface. Each of the two separate elements can be optimized to perform its particular function — reading or writing data. With an MR head, the number of wire turns associated with the write element can be as few as 10, resulting in an optimally low level of inductance for write operations. That compares with as many as 50 turns for thin-film inductive heads used in today’s high-performance, high-capacity drives. The lower inductance of the MR write element makes it easier to write the signal at very high data frequencies.

The use of separate read and write elements in MR heads can also reduce the noise problems and the degradation of read signal quality associated with head misalignments over tightly-spaced data tracks. During read operations, the disk drive’s servo system positions the head so that it is accurately placed over the center line of the data track that has just been written. Because of the electromechanical nature of these servo systems, some misalignment is unavoidable. As drive vendors increase areal densities by packing data tracks closer together, head misalignment can cause the head to pick up noise from adjacent tracks, and thereby produce a read signal with an unacceptably low signal-to-noise ratio.

With thin-film inductive heads, even slight misalignments can offset the head from the written track, reducing signal amplitude and adding noise. With MR heads, the separate read element can be fabricated to be narrower than the written track (see Figure 1). As a result, the read element can remain entirely over a written track even when the head is slightly misaligned. The original read signal amplitude is maintained and no noise is added, resulting in a high signal-to-noise ratio.

Figure 1. Write Wide/Read Narrow
An equally significant advantage of MR heads is that the resistive read element can produce a strong signal even when reading bits that are spaced just ten millionths of an inch apart and one hundred millionths of an inch wide, regardless of linear disk speed. This velocity-independent signal output permits drive vendors to increase areal densities without spinning the disks faster to prevent read signal degradation. By using MR heads, RPM rates can be held constant (or even reduced) allowing use of less expensive read channel electronics. Alternatively, in high-performance disk drives, where latency (the length of time needed for the data to reach the location of the head) needs to be minimized and data rates maximized, MR heads will excel. The low inductance of the MR read element permits the use of very high frequencies.

**MR head design**

With either a thin-film inductive head or an MR head, most of the head’s mass and size comes from the slider and the suspension mechanisms, which are the aerodynamic components that permit the head to fly over a disk. The head’s active element(s) are extremely small by comparison.

The write element of an MR head is designed much the same way as a thin-film inductive head. It consists of two magnetic-pole pieces that are typically made of permalloy, a soft magnetic material. These pole pieces are connected at the ends that point away from the disk’s surface. Coiled through the middle of the pole pieces is the deposited-layer copper wire. When an electrical current runs through the coil, it produces a magnetic field that jumps across the gap between the two inner ends of the pole pieces, at the surface of the head. The magnetic fringe field associated with that gap is used to write data onto a disk by reversing the direction of the magnetic fields on the disk’s surface (called magnetic flux changes or transitions).

The MR head’s separate read element consists of a minute stripe of a permalloy material placed next to one of the write element’s magnetic-pole pieces. The electrical resistance of the permalloy changes by a few percent when it is placed in the vicinity of a magnetic field, or when it is exposed to a magnetic field in a certain direction. This change in the material’s resistance allows the MR head to detect the magnetic flux transitions associated with recorded bit patterns.

During an MR head read operation, specially fabricated pre-amplifier circuitry generates a small direct current through the stripe of resistive material. As the MR stripe is exposed to the magnetic field from the disk, the pre-amplifier measures the resulting voltage drop.
across the stripe. That measurement determines the change in resistance of the MR stripe — an increase or decrease depending on the direction of the magnetic fields. This is where the term magnetoresistance comes from. The pre-amplifier then generates a read signal whose voltage is proportional to the resistance-change value.

Figure 2. The MR Head*

Another component of the MR read element plays a critical role. Called a soft adjacent layer (SAL), this component consists of a small piece of soft, non-magnetoresistive, permalloy-like material that lies next to the MR stripe. When an electric current flows through both the MR stripe and the SAL, a magnetic field is produced around both of these materials. The SAL’s presence serves to angle or “bias” the direction of the MR stripe’s magnetization. (See Figure 2.)

The bias step ensures an accurate read signal. If the direction of the MR stripe’s magnetic field remains unaltered, the material’s resistance will “sit” at the nominal peak of a sine wave-like curve. In that case, the changes in the material’s resistance that occur during a data read will always register as a decrease, regardless of the direction of the magnetic fields to which the read element is exposed. The resulting signal generated by the MR head will not reflect the actual pattern of 1’s and 0’s recorded on the disk. Biasing the stripe’s magnetic field neatly solves this problem and produces an accurate read signal.

A combined approach for further areal density improvements

Quantum-owned MR head development and manufacturing resources have provided the company a time-to-market advantage: Quantum started shipping its 3.5-inch Quantum Capella™ drives with MR heads in the fourth quarter of 1994. As the first independent drive manufacturer to ship drives with MR heads, Quantum has gained valuable experience incorporating this technology into drives. The company’s newest highest-capacity products, the Quantum Atlas™ II and the Quantum Empire™ II drives, will also incorporate MR heads.

While advanced MR heads alone can increase capacity per disk, areal density potential improves dramatically when MR heads are combined with PRML read channel technology. (See white paper: Quantum’s PRML Read Channel: How Sophisticated Read Channel Technology Improves Disk Drive Performance and Increases Capacity, 10/93.) Quantum has shipped PRML read channels in its high-capacity hard disk drives for more than two years and is on its third generation of the technology — a 90Mbit per second, single-chip implementation.
The Quantum Empire II drive is the company’s first announced product to combine MR heads with PRML read channels. Later in the year, Quantum will introduce additional 3.5-inch and 2.5-inch drives that incorporate both key technologies. MR heads and PRML read channels ensure Quantum’s OEM and distribution customers a source for disk drives that will meet the current and future areal density requirements of all computer systems ranging from mainframes to notebook PCs.