

Evaluation and Analysis Techniques for Perpendicular Magnetic Recording Media

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ABSTRACT

Hard disk drives have come to have large capacities as a result of the synergy between the evolution of recording and playback components, as represented by the magnetic head and magnetic recording media, and the advances in signal processing technology, tracking technology and other drive-related technologies. With perpendicular magnetic recording media, Read/Write characteristics, including those of the low-frequency region, are critically important. Also, the realization of tracking precision of up to approximately 1.3 nm paves the way for higher density recording. Additionally, disturbances in the recording magnetization in the vicinity of the side shield of the side shield head were visualized and evaluated to optimize the configuration of the media layer and to mitigate the disturbances.

1. Introduction

Hard disk drive (HDD) recording capacity has continued to grow rapidly at an annual rate of approximately 40%. The various techniques described below including realization of the perpendicular magnetic recording media method have contributed to this achievement. Representative improvements in HDI (Head Disk Interface) technology include a reduction in media noise and improvement in linear recording density resulting from miniaturization of the magnetic grain size in the magnetic recording media, the development of a magnetic head that narrows the writing pole, and a reduction in magnetic spacing (distance between the magnetic head and the magnetic layer of the magnetic recording media). Additionally, there is a diverse array of technologies such as tracking techniques (head positioning techniques) and signal processing techniques for HDDs. With the higher densities of magnetic recording media, new techniques are needed to evaluate the characteristics of those magnetic recording media. This paper describes the development status of Fuji Electric's evaluation and analysis techniques for electromagnetic conversion characteristics.

2. Evaluation Techniques for Electromagnetic Conversion Characteristics

2.1 Evaluation of signal quality in perpendicular magnetic recording and playback

The most significant change concerning HDD recording and playback in recent years is that perpendicular magnetic recording has replaced longitudinal magnetic recording. To make high density recording possible, the distance between bits must be reduced

in order to increase the linear recording density. Fig. 1 compares the interactions of two adjacent magnetizations having different orientations for longitudinal magnetic recording and perpendicular magnetic recording, and shows the relationship between the magnetic field generated by the left-side transition point magnetization and the right-side magnetization. With longitudinal magnetic recording, if the distance between bits is reduced, the magnetic field emanating from one bit will be opposite from the direction of magnetization of an adjacent bit. Thus, longitudinal magnetic recording has a weakness of unstable magnetization in a region of reversed magnetization. On the other hand, with perpendicular magnetic recording, if magnetization is reversed and the magnetization is oriented oppositely from that of an adjacent bit, the bit magnetization will be in the same direction as the magnetic field from an adjacent bit. Therefore, perpendicular magnetic recording has the characteristic of increasing stability as the interval between regions of reversed magnetization become narrower. Because of

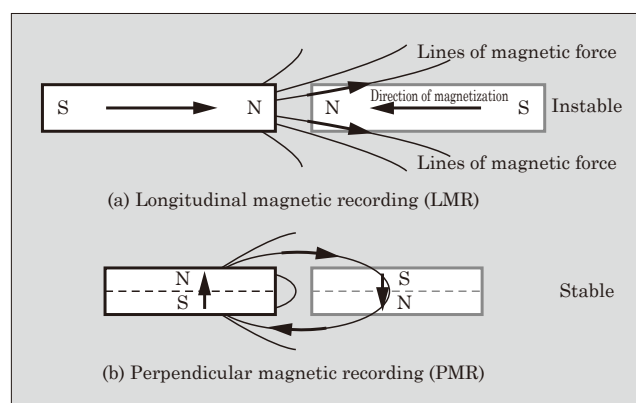


Fig.1 Difference in magnetic interaction between LMR and PMR

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this characteristic, perpendicular magnetic recording is more advantageous for high density recording.

The use of perpendicular magnetic recording has alleviated the stability problem during high-density recording. Reducing the size of magnetic grains in the recording layer of magnetic recording media and reducing the jitter (signal fluctuation) caused by variations in magnetic grain size are the main challenges for achieving even higher densities. Therefore, in perpendicular magnetic recording media, the SNR (signal to noise ratio) during high density recording, which is typically closely related to jitter, is considered to be important.

To increase the recording capacity of HDDs, the recording code has also been improved. Typically, in digital communications, a DC signal cannot be transmitted as-is and therefore the signal is continuously modulated with restrictions imposed on the continuation of the same code. Imposing stricter restrictions and modulating the signal into one where the same code interval is shorter will increase redundancy and lead to decreased transmission speeds. The loosening of restrictions concerning the same code interval and the ability to handle signals with lower redundancy contribute significantly to improvements in transmission speeds in recent years. For the magnetic record and playback signals in an HDD, efforts are underway to reduce the redundancy of data recorded on actual magnetic recording media⁽¹⁾ and a recording code that includes long-period signal components has been adopted. The recording of long-period signals, however, presents difficult challenges for perpendicular magnetic recording, and in addition to the aforementioned efforts for realizing higher recording densities, the realization of long-period signal recording is also sought.

The long-period signal recording performance in magnetic recording media is generally evaluated with a reverse overwrite (ROW) process. ROW is the ratio of the original recorded signal strength to the remaining signal strength when a high-density recording is overwritten with a low-density recording. A higher ROW value indicates that signals are easier to record. Although ROW is used to evaluate the ease of record-

ing, it is not necessarily correlated to an indication of actual recording and playback performance. Moreover, in the design of magnetic recording media, when attempting to increase the ROW value, a recording signal known as the magnetic writing width (MWW), which is correlated to a decrease in surface recording density, will increase in width and this trade-off makes it difficult to optimize the media design for high-density recording. Thus, the various characteristics of today's magnetic recording media have complicated interrelationships, and the direction of technical development for realizing higher densities is not easily discoverable.

Therefore, in order to provide a specific direction for development, assuming the recording and playback characteristics of an actual HDD and aiming for an appropriate improvement in media characteristics, Fuji Electric is presently evaluating media characteristics as follows.

First, single track recording and playback performance are evaluated with a focus on the following three characteristics.

- (a) MF-SpiSNR

SNR at 1/2 of the highest recording frequency, higher values indicate that higher density recording is possible
- (b) SNR with weighted noise spectrum

Assumes that signal processing is performed inside HDD
- (c) SNR during long-period signal recording

Fig. 2 shows the SNR dependency on recording frequency measured using experimental magnetic recording media. The SNR on the high-frequency side has been considered an important characteristic even for longitudinal magnetic recording, and is directly correlated to the resolving power of magnetization for media recording and playback. Regardless of the type of media, the SNR decreases at the high-frequency side. This is chiefly due to interference from oppositely coded signals when playing back signals that have been recorded with high density. The SNR on the low-frequency side is related to characteristics of long-period recording.

As mentioned above, with perpendicular magnetic recording, long-period recording characteristics have a tendency to deteriorate easily. The required bandwidth differs according to the HDD, and in recent

Table 1 Relationship between evaluated characteristics values and HDD characteristics results for the media shown in Fig. 2

Media	HDD characteristics ranking	Frequency-integrated SNR (New evaluation index)	MF-SpiSNR (Conventional index)
Media A	1	19.7 dB	14.3 dB
Media B	2	19.5 dB	14.9 dB
Media C	3	18.8 dB	14.1 dB

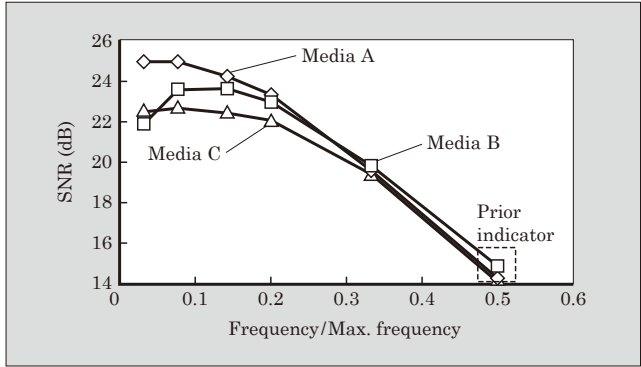


Fig.2 SNR frequency characteristics (horizontal axis is normalized by max. frequency)

years, in order to improve long-period recording characteristics, good recording performance that extends down to the low-frequency side is being required. Because actual HDDs require good recording and playback performance throughout the entire bandwidth, the SNR value weighted for each frequency is defined and evaluated as a comprehensive index for the SNR of the magnetic recording media. Table 1 shows the relationship between the evaluation results based on conventional evaluation criteria and the evaluated results based on the new evaluation index concerning the HDD characteristics results for media A through C of Fig. 2. With the conventional evaluation criteria (MF-SpiSNR), media B has a high SNR and appears to exhibit the highest performance. On the other hand, when compared to the new evaluation criteria (SNR value weighted for each frequency), media A is judged to have the highest performance, and this agrees with the ranking of characteristics in an actual HDD. As can be seen from Fig. 2, media A, which provides the best recording and playback performance based on the HDD characteristics, exhibits poor performance during high frequency (short-period) recording than media B, but exhibits excellent performance during low frequency (long-period) recording. Thus, in the evaluation of media characteristics leading to better HDD performance, it is effective to consider the recording performance down to the low-frequency side.

2.2 Evaluation of track pitch

In addition to evaluating the recording and playback performance of single tracks, evaluating track pitch is also important. With the current combination of magnetic recording media and magnetic heads in HDDs, high density recording is realized by optimizing

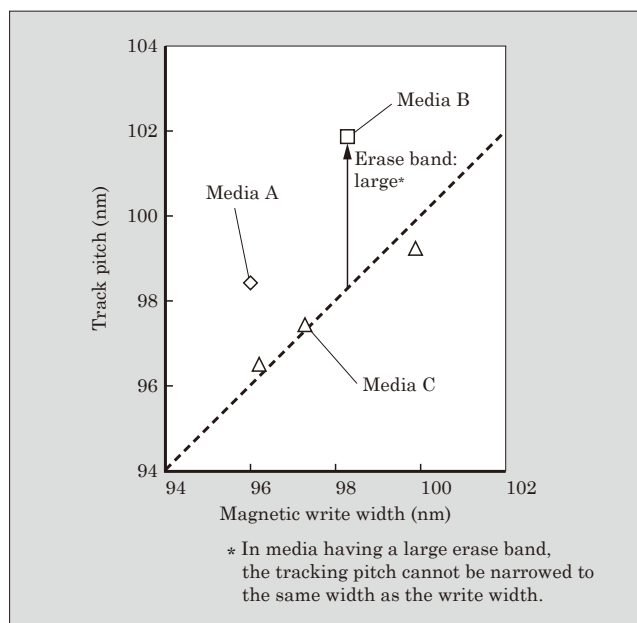


Fig.3 Difference in relationships between magnetic write width and track pitch according to media

both the linear recording density and the track density. The evaluation to estimate track density is becoming an increasingly important part of the evaluation of media for high density recording use.

Previously, track density was estimated by evaluating the write width. The write width is a value that indicates the actual average width of magnetic reversal occurring when a signal is written to a track. This value is closely correlated to the track density that could be realized in an actual HDD. With an evaluation based on the write width, however, the border area between a region of magnetization reversal and a region that maintains the original recording, i.e., the erase band is not evaluated. As a result, when media having been evaluated as having a narrow write width is evaluated in an actual HDD, no improvement in track density may be found in some cases. Also, in the evaluation of magnetic recording media, in addition to the evaluation of write width, track pitch is also evaluated in conformance with the method for determining track pitch in an actual HDD, and then development is carried out based on those results.

Fig. 3 shows an example of track pitch evaluation performed in consideration of both the write width and the erase band in experimental magnetic recording media. Media C shows a group in which only the coercivity was changed by adjusting the magnetic layer thickness. Media A and B were evaluated as requiring a track pitch larger than the write width, but media C was evaluated as being capable of realizing a track width that is the same as the write width. The track pitch obtained in a track pitch evaluation performed in consideration of the erase band also corresponds well to the track pitch actually established in an HDD. At present, the evaluation of track pitch, together with the aforementioned signal evaluation, is regarded as important evaluation that correspond to actual HDDs parameters.

In addition to reducing the write width, increasing the tracking precision has also contributed greatly to improving the track density in actual HDDs. Also, the evaluation of magnetic recording media has come to require high tracking precision that is difficult to realize

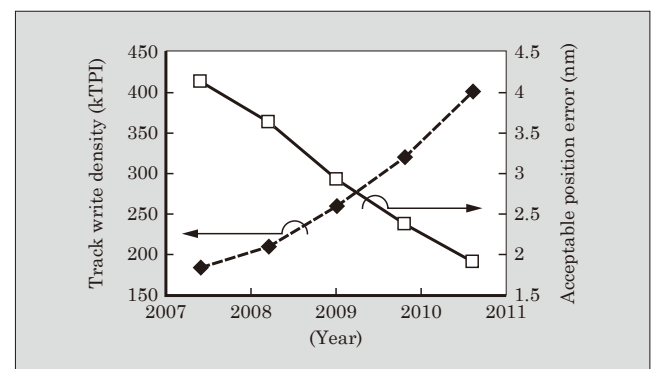


Fig.4 Change in track density and change in required tracking precision

with conventional evaluation equipment. By utilizing a driving mechanism based on piezoelectric actuators capable of highly-reproducible fine adjustments of the head position and by adopting statistically measures, Fuji Electric has increased the evaluation precision to 1.3 nm, realizing tracking precision comparable to that of an actual HDD. Fig. 4 shows the changes in track density and the required tracking precision in recent years. As the track density increases significantly in the future, tracking precision on the order of several nanometers, which is much smaller than the present granular size (of the approximately 4 to 6 nm size crystalline grains in the magnetic layer), will be required, and tracking precision of 1 nm is expected to be required by 2013. This indicates that the granular size is an impediment to not only increasing the linear recording density, but also to increasing the track density, and further refinement of the grain size has become increasingly more important.

2.3 Evaluation and Analysis Techniques for Other Electromagnetic Conversion Characteristics

One type of evaluation relating to electromagnetic conversion characteristics is evaluation involving a side-shielded head, which has become the mainstream in today's magnetic heads. With a side-shielded head, spreading of the write width due to a magnetic field from a main magnetic pole is controlled. As shown in Fig. 5, however, a return magnetic field drawn toward a side shield located a distance several tracks away

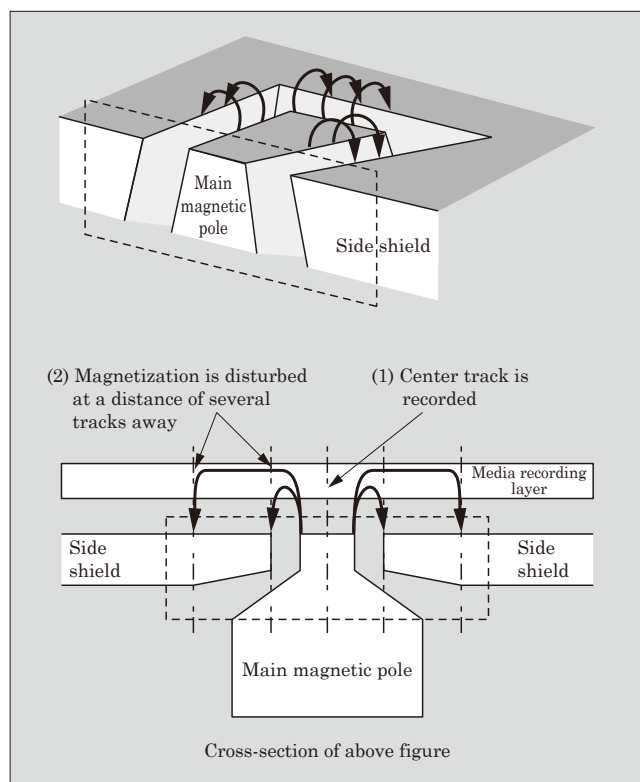


Fig.5 Magnetic flux and side track erasure (STE) in side-shielded head

disturbs the magnetization in that vicinity, and causes the phenomenon known as side track erasure (STE) and this must be evaluated accurately.

Fig. 6 shows a visualization of the STE phenomenon that occurs when a square-wave signal for one track is recorded onto a magnetic recording media that has been completely DC-erased, and the head is moved between adjacent tracks to acquire the playback signal waveform. At a location away from the center track, magnetization in the opposite direction can be seen. Since an actual perpendicular magnetic recording HDD is never completely DC-erased before use, this evaluation has strict conditions. Nevertheless, evaluation of this characteristic is necessary in order to improve the reliability of magnetic recording media. This type of STE phenomenon is affected not only by the magnetic characteristics of the magnetic layer, but also by the magnetic path, which is determined by the layer design of the entire magnetic recording media, including the soft under layer (SUL) and the non-magnetic interlayer disposed on the SUL. Additionally, evaluation of the STE phenomenon often shows a different trend than the evaluation of side erasure in an adja-

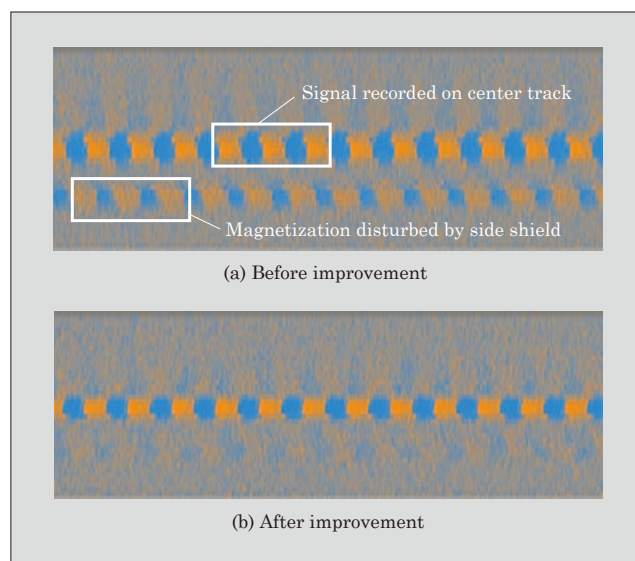


Fig.6 Visualized STE (side-track erasure)

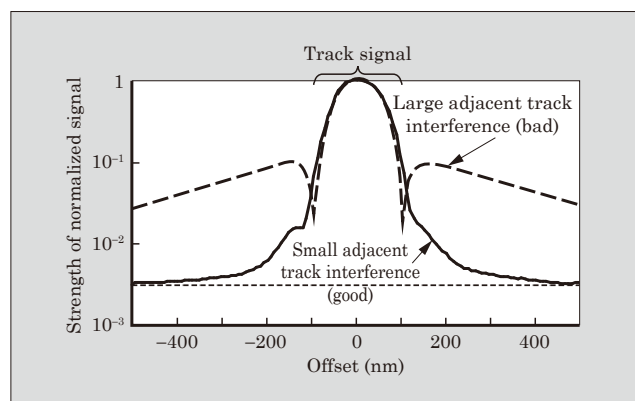


Fig.7 Evaluation of adjacent track interference

cent track, and efforts to improve this phenomenon are being advanced as one of the main focal points for optimization of the layer structure of magnetic recording media.

To achieve high-density recording, in addition to measures for preventing STE, the overlapping of magnetic fields emanating from magnetization recorded in side tracks must be suppressed to the extent possible. This also is closely related to the SUL properties.

Fig. 7 shows, for a signal recorded on a center track, the change in playback signal strength as the head is moved between adjacent tracks, and the arrows in the figure point to levels of interference between tracks. Signals remaining at a distance from the center indicate that signals from different tracks overlapped during playback, and as a result, recording density is difficult to increase. Signals remain between adjacent tracks because the magnetic fields emanating from magnetism recorded on the media spread between adjacent tracks. This spreading of magnetic fields is affected by the magnetic characteristics (particularly the magnetic anisotropy) of the SUL. In the figure, the solid line shows good characteristics, while the broken line shows a phenomenon observed in magnetic recording media when a problem in the SUL characteristics causes the interference between tracks to worsen. In the case of media having an anomalous SUL, particularly when performing low density recording, signals at a distance from the track center are found to be less likely to have been attenuated, and this characteristic is used to detect SUL anomalies.

3. Future Efforts

In future HDD development, progress in increasing

the track density is expected to be realized at a faster rate than improvements in linear recording density. Additionally, the shingled-write recording method, presently in its research stage, will likely be realized in the not so distant future. Increasing the tracking precision is the key for these techniques. With evaluation based on the shingled-write recording method, after improving the tracking precision, signals overwritten in one direction must be evaluated, and evaluation of adjacent track interference would be difficult to apply as an extension of conventional thinking. While investigating error-rate evaluations of simulated shingle-write recording and the elemental technology required for two-dimensional recording and playback, which is advocated as a future technology, evaluation methods that can support those technologies and permit faster measurements are being studied.

4. Postscript

With advances in magnetic recording media and magnetic heads that enable higher density recording, coupled with advances in signal processing techniques, tracking techniques and drive technology, the capacities of HDDs are increasing. In order to provide media for realizing even larger capacity HDDs, Fuji Electric intends to incorporate the latest drive technology, promote more sophisticated evaluation and analysis techniques, and develop higher density recording media to contribute to the development and stable production of larger capacity storage devices.

References

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