Influence of Switching Field Distribution on the Transition Jitter in Grain-Position Controlled Granular Media

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Jitter noise reduction can be achieved by controlling the position of magnetic grains. We have shown that position controlled granular media can suppress jitter noise. In this paper, the influence of grain alignment on square and triangular lattices and the switching field distribution on the jitter noise was calculated with a Voronoi cell model. The switching field distribution was found to have a significant effect and depended on the down-track distance between grains.

Key words : magnetic recording, jitter noise, grain structure, switching field distribution, Voronoi cell

1. Introduction
Granular magnetic recording media have been used for hard disk drives (HDDs), which consist of magnetically-separated fine grains. In the case of granular media, the attainable areal recording density has been increased by reducing the grain size and its size distribution, providing low medium noise and high resolution. Recently, however, grain size reduction is becoming difficult as the super-paramagnetic limit of the grains is reached. Therefore, an alternative way to suppress the medium noise without shrinking the grain size is required for granular recording media.

In bit-patterned media (BPM), a precise lithographic process is used to form regularly aligned dots, reducing the medium noise and improving the thermal stability of the magnetic dots. We have reported that transition jitter noise could be reduced by using granular media similar to BPM\(^1\), in which the grain positions are controlled or correlated, but the recorded bits are composed of multiple grains as in usual granular media. It is expected that such position correlated media have potential as future high density recording media. Recent progress in media fabrication techniques, such as template media\(^2\) and self-organized grain structures suggests the feasibility of grain position control in granular media.

We have investigated the influence of grain alignment and switching field distribution (SFD) on transition jitter. In BPM, grain alignment on a triangular lattice has been used for the highest dot packing density\(^3\). We have already shown the influence on the jitter for the case of a square lattice alignment\(^1\), but the type of grain alignment is considered to affect the recording characteristics. Besides, though already known in BPM, the SFD may also have a similar effect. The influence of SFD on the transition jitter was investigated using square and triangular lattices for the grain alignment.

2. Modeling
Voronoi cells were used as a medium model of position-correlated magnetic grains. The grain position correlation was introduced by locating the seed points at regular intervals, i.e. on square or triangular lattices. As shown in Fig.1, regular square or hexagonal cells were formed from square lattice or triangular lattices, respectively. In addition, there are two orientations of the hexagon cells with different grain pitches in the down track direction. One is referred to as “Hex (horizontal)”, that seed points were located on lines along the cross track direction. The other is “Hex (vertical)”, with a smaller grain pitch in the down track direction. Three cell alignments (Square, Hex (horizontal) and Hex (vertical)) were considered in this paper. There were gaps between the cells to represent the non-magnetic boundary around grains. The average grain diameter was assumed to be 7 nm: thus, the grain pitches were about 7 nm in Square, 6.6 nm in Hex (horizontal) and 3.8 nm in Hex (vertical), respectively. Voronoi cells were generated by randomly displacing the seed points from their ordered positions according to a Gaussian distribution. The grain size was defined as the diameter of a circle with the same area as the Voronoi cell. The position distribution of the grains \(\sigma_{\text{pos}}\) is defined as the standard deviation of the grain centroid positions. The grain size distribution \(\sigma_{\text{D}}\) is defined as the standard deviation of the grain sizes. The procedure of Voronoi cell generation was as follows. First, seed points were located on square or triangular lattices. The grain pitch corresponds to the distance between neighboring cells in the down track direction. Then the seed points were randomly displaced from their ordered positions, with the displacement obeying a Gaussian distribution. Next, Voronoi cells were created and expanded or shrunk randomly, but without overlapping\(^4\). Finally, the position and grain size distributions were calculated. The position of the Voronoi cell seed points
controlled the grain position correlation. The grain size distribution was controlled by the seed point locations and also the grain size expansion/shrinking. Usual Voronoi cell modeling cannot realize random location of grains, and the maximum grain size distribution is limited to approximately 30%. In order to model realistic media structures with random seed positions, the Lloyd algorithm was used. Conventional granular media usually have no grain-position correlation. To model such random media the Lloyd algorithm was used. Fig. 1 shows examples of the grains with “Square”, “Hex (horizontal)”, “Hex (vertical)”, and “random” alignments. In this modeling, the standard deviations of grain position location, $\sigma_{\text{pos}}$, and grain size, $\sigma_D$, were adjusted to be 0.55 nm and 5%, respectively. The grain shapes without any size deviation are also shown as insets in fig. 1. There was no position correlation in the “random” cells, but peaks in the histograms of centroid positions are seen for the other alignments.

The average coercivity ($H_c$) was assumed to be 10 kOe. Its distribution obeyed a Gaussian distribution characterized by an average and a standard deviation. The switching field distribution (SFD) was defined as the standard deviation of the normalized switching field distribution. The head field gradient was 500 Oe/nm. Magnetization reversal of each grain was determined according to whether the head field at the grain centroid was larger than the coercivity of the grain, or not. Dipole interactions during writing should be taken into account. We assumed that the demagnetizing field deteriorated the head field gradient, which resulted in the 500 Oe/nm volume.

3. Influence of cell alignment on jitter noise

The relationship between transition jitter and the read-back waveform was calculated using the magnetization distribution and the reciprocity theorem with a read head with a 60 nm track width. A two-dimensional sensitivity function was used assuming a magnetic spacing of 5 nm, a medium thickness of 10 nm, and a shield-to-shield spacing of 20 nm. Transition jitter was defined as the standard deviation of the difference between the zero-crossing point of the waveform and the intended write position from the waveforms of 1000 Voronoi media. The relationship between transition jitter and write position is shown in Fig. 2. The zero of the write position corresponds to the head field being reversed at the grain boundary. The SFD was 0% in this calculation. In “random” media, the transition jitter did not depend on the write position. In contrast, for the position correlated media the transition jitter strongly depended on the write position. The write timing should be just in between grains in order to minimize transition jitter. In the “Hex (vertical)” media, very strict write synchronization is required because the minimum jitter was confined to a narrow range. This is

![Fig. 2 Relationship between transition jitter and write position when SFD is 0%](image-url)
a reflection of the small grain pitch (3.8 nm). The tolerable write synchronization range does not depend on the grain alignment, square lattice or triangle lattice, but on the grain pitch.

4. Influence of switching field distribution on jitter noise

In granular media, a finite switching field distribution should be taken into account in most cases. In addition, the head field gradient should be also finite. Because of this, irregular magnetization reversal is liable to occur. If a grain has a large switching field, the head field may be insufficient to switch it. On the other hand, grains with a small switching field may accidentally be re-switched after recording. Such irregular magnetization reversal caused by the wide SFD and insufficient head field gradient results in bit boundary fluctuations and, therefore, increases the transition jitter. The influence of the SFD on transition jitter noise for grain position correlated media was investigated.

Fig. 3 Schematic diagram of grain structure

Fig. 4 Examples of grain reversal in three media with, \( \sigma_{\text{pos}} \), \( \sigma_{D} \) and SFD of 0.55 nm, 5%, and 10%, respectively.

Fig. 5(a) Transition jitter as a function of the write position of a writer for a SFD of 5 %

Fig. 5(b) Transition jitter as a function of the write position of a writer for a SFD of 10 %

Fig. 5(c) Transition jitter as a function of the write position of a writer for a SFD of 15 %

Fig. 5(d) Transition jitter as a function of the write position of a writer for a SFD of 20 %
and grain pitch. The blue broken lines show the write position, with the left side of the line magnetized upward and the right side magnetized downward. It was confirmed that some grains were accidentally switched. The number of erroneously switched grains was a maximum in the “Hex (vertical)” medium. Transition jitter as a function of the write position of a writer for SFDs of 5%, 10%, 15%, and 20% is shown in Figs. 5(a), (b), (c), and (d) respectively. A large SFD generally increases the transition jitter, and flattens the optimum writing position in the grain-position correlated media. When the SFD was 10%, the narrow grain pitch medium, “Hex (vertical)”, had almost no advantage over a “random”, or regular granular medium. When the SFD was 20%, both the “Square” and “Hex (horizontal)” media were almost indistinguishable from the “random” medium and there was no advantage from grain-position correlation. Accurate write synchronization to control the write position at the grain boundary minimizes the transition jitter under certain conditions. Under the optimum writing conditions, the relationship between transition jitter and SFD is shown in Fig. 6. A moderate grain position correlation, such as a deviation of 0.55 nm, improves the transition jitter. However the high accuracy write timing such as 2 nm requires careful design of the skew angle and PLL accuracy. In the “Hex (vertical)” medium, in which the neighboring grain pitch is the smallest, the influence of the SFD on the transition jitter is the largest; even a 2% SFD is enough to increase the jitter. In contrast, the larger grain pitches of the “Hex (horizontal)” and “Square” media are more tolerant to increased SFD and no visible influence was observed when the SFD was less than 5%. The difference due to the grain pitch being about twice as big as “Hex (vertical)” medium. The bit length of the Hex (vertical) medium is shorter than the others, and the jitter is larger. Therefore the Hex (vertical) pattern is not advantageous for write clock synchronization. Overall, the influence of SFD on transition jitter was significant. For the grain position correlated media, the SFD is required to be smaller than 5% in order to effectively improve the transition jitter. If the SFD is larger than 15% grain-position correlation has no benefit.

5. Conclusion

For the new grain-position correlated media, the influence of SFD on transition jitter was investigated for three different media: square lattice, horizontal hexagonal lattice and vertical hexagonal lattice. Transition jitter was calculated by reciprocity from Voronoi cell models. The tolerable write synchronization timing for the grain-position correlated media became broader for media with a larger grain pitch in the down track direction, i.e., square lattice and horizontal hexagonal lattices were better than the vertical hexagonal lattice. The calculated results suggest that the influence of the SFD is significant. In order to realize low transition jitter the SFD must be below 5%, even for the wider grain pitch square or horizontal hexagonal media.

References

1) A. Hara, H. Muraoka, J. Appl. Phys. 115, 17B730.
2) D. Bedau, H. Aroa, J. M. Beaujour, A. Bodganov, et al. INTERMAG CB-1 (2014).
3) X. Yang, Y. Xu, K. Lee, S. Xiao, D. Kuo, D. weller, IEEE Trans. Magn. 45, 883 (2009).
4) S. Iwasaki, K. Nakamura, IEEE Trans. Magn. 11,1272 (1977).
5) H. Muraoka, Y. Sugita, Y. Nakamura, IEEE Trans. Magn. 35, 2235 (1999).

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