Design concepts and verified performances in automotive HDD

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Abstract: Automotive HDD is required to have exceptionally higher reliability than mobile PC-use HDD. The design concepts and performance verifications of the third generation automotive HDDs with the last set of the LMR (Longitudinal Magnetic Recording) technologies and the fourth generation automotive HDDs with the first set of the PMR (Perpendicular Magnetic Recording) technologies are reported in detail. Both generations of automotive HDDs are already being applied to the automotive market at wider range of environmental temperature (-30 to 85 degree Celsius). Moreover it demonstrated that these products were able to function in the range of -43 to 107 degree Celsius without any bit-error-rate degradation. This paper should be the first to demonstrate the basic read/write performances of both LMR and PMR technology HDDs in this wide range of environmental temperature.

Key words: automotive HDD, LMR, PMR, TFC, TMR, navigation system, telematics

1. Introduction

The Market size opportunity of automotive HDD is expected to be extremely larger in near future [1] [2] [3]. The HDD industry can expect a new market for automotive application aside from PC, enterprise -system, and consumer electronics-use such as TV, game, and music applications.

Figure 1 shows customer requirements and market needs for automotive HDD. The capacity needs for automotive HDD are not so strong compared to PC-use HDD, however, temperature range, altitude, reliability and supply term needs are much more severe. Other needs are almost as the same as PC-use HDD.

Figure 1 Market needs for automotive HDD compared to PC-use HDD

The historical data capacity and general purpose trend of automotive HDD are shown in Figure 2. Each content capacity budget target for system, telematics, audio/visual and map can be estimated. The first and second generation automotive HDDs have been applied

for navigation devices in 2003. The all generations of automotive HDD have one disk and two heads. The HDDs were, however, required to have wider temperature ranges, higher altitude specifications, higher reliabilities, and longer term supplies than PC-use HDDs. The third generation has been added the use for digital contents of audio and/or visual program in 2005. The fourth generation has been required more capacity of 40 or 50 GB mainly because of high definition and detailed map information in 2007 and 2008. The fifth generation automotive HDD is required 80 to 100 GB capacity for telematics as a new function. In the coming 2010 and 2012 brand new car models, as vehicle related management will become more important as well as AV and telematics applications. The management will use the sensor data inside vehicles and drive recorder data of vehicles. Higher reliable and larger capacity automotive HDD with matured technologies are strongly required compared to PC-use HDD.

Figure 2 Data capacity and general purpose trend for automotive HDD

2. Discussion

2.1 HDD design concept corresponded to specifications

The three main specifications for automotive HDDs, data capacity, temperature range and altitude are shown in Figure 3. The HDD use environment is much more severe compared to PC-use HDD. Especially the operation temperature range is required -30 to 85 degree Celsius compared to 5 to 55 degree Celsius in PC-use. The first generation automotive HDDs couldn't achieve this requirement because HDD design was basically for PC application. Therefore the limited temperature range between 0 and 60 degree Celsius was used. From the second generation mechanical parts and LMR (Longitudinal Magnetic Recording) head/disk combinations were improved and applied for the automotive application. Although PMR technologies had been applied in PC-use HDDs from around 2005, the technologies were not mature yet enough to be applied in automotive HDDs.

For 16 to 50 GB (1 disk / 2 heads model) HDD, we have been shipping the products with LMR matured technologies. The latest product applying PMR (Perpendicular Magnetic Recording) technologies for over 80GB (1 disk / 2 heads model) has been introduced into 2009 and 2010 brand new car market. This paper describes the design and verified performance data of the last LMR HDD and the first PMR HDD under a wide temperature range.

As the temperature dependence of the magnetic properties in a disk is the key design factor. K_uV/kT and dH_c/dT were designed as the higher priority between HDD design team and disk team. Although TFC (Thermal Flying-height Control) was not mature technology in the beginning development project, TFC was introduced positively and put in practical use first for automotive HDD after the long reliability examinations. Protrusions (PTR) of heads have three kinds; thermal PTR, Write PTR and TFC. These were adjusted and the ABS of slider surfacing design was carried out to consider no contact between heads and disks.

Figure 3 The main specification of automotive

2.2 Design keys in the 50 GB/disk generation automotive HDD with LMR

(1) Magnetic spacing

Brand new car models from 2007 required temperature range of -30 to 85 degree Celsius and altitude limit up to 5,500m. The last LMR HDD with 50 GB/disk (about 90 Gb/sqin) was introduced using TMR (Tunneling Magneto Resistive) head and TFC technologies because the matured LMR HDD technologies should be used. The Read/Write performances, especially OW (Overwrite performance) and S/N (Signal to Noise ratio) depend strongly on magnetic spacing. As can be seen from above arguments, the magnetic spacing is one of the most important key design points in automotive HDD. The magnetic spacing should be designed to balance R/W and HDI (mechanical Head Disk Interface) performances.

As for wide temperature range and altitude capability, TFC function and the new-designed ABS (air bearing surface) shape head were applied. The temperature dependence of the fly-height (FH) with -0.04 nm /deg C and the atmospheric pressure dependence of the FH with less than 3 nm at the 5,500 m altitude were designed and approved. The magnetic spacing was decreased under 40 degree Celsius compare to the former generation automotive HDD in the range of the lower temperature limit as shown in Figure 4. Under about 40 degree Celsius a heater in a head element is on. As the lowest FH happens in the condition of the highest temperature and the highest altitude, the minimum FH and the magnetic spacing are designed with optimizing the slider-ABS and the TFC management. The reader and writer element position is approaching to a disk surface to obtain satisfied OW and S/N. Moreover TMR reader technology was fully applied to the 50GB/disk and 100GB/disk automotive HDDs to obtain higher S/N. The TMR reader instability and noise performances were reported in other papers [4, 5].

Figure 4 Magnetic spacing design concept

(2) Design and verification of R/W performance

The relation between SER (Soft Error Rate; same meaning as Bit Error Rate) and OW is shown in Figure 5. SER under $10E-8.8$ was not measured due to the

limited testing time. The OW was defined by the 2T-signal difference after 17T-signal writing on first 17T-signal. No SER dependence on OW was observed under -25 dB, and OW value of -25dB was designed as the reasonable target to obtain an optimum SER in the read/write system.

Figure 5 SER vs. O/W performance in the 50 GB automotive HDD with LMR

Figure 6 shows the comparison of S/N vs. temperature with TFC-on or TFC-off. The S/N examples were measured at ID and OD in -30, 0, 30 and 60 degree Celsius in the four head & disk combinations. S/N with TFC on at -30degree Celsius was improved over 1dB. The average SER dependence on the spacing with TFC function was -0.66 order / nm. The heater power of TFC function is optimized for each temperature range and user data zone.

(3) Temperature dependence of 50 GB/disk automotive HDD with LMR

The interface specifications with disk supply was $KuV/kT > 100$ and $dHc/dT = -16$ Oe/deg C. The interface specification with head supply was $d(FH)/dT = -0.04$ nm. Figure 7 shows the SER performance in the -43 to 100 degree Celsius temperature range. SER under $10E-7.4$ was not measured because of the testing time limitation. As can be seen although the SER average with $10E-7.5$ and no degradations were observed, this wider temperature range read/write performance for LMR has been demonstrated first. Sufficient margin of

temperature performances between -30 and 85 degree Celsius were verified for 50 GB automotive HDD products with LMR. TFC was adjusted at each temperature as shown in Figure.4.

Figure 7 Temperature dependence of SER in 50 GB automotive HDD with LMR

2.3 Design keys in the 100 GB/disk automotive HDD with PMR

(1) Design and verification of R/W performance

The 100GB/disk automotive HDD was designed with PMR technologies because the PMR technologies for PC-use HDD had been in operation in the field and the failure mode could be managed in 2006. The head and disk combination for 160 GB/disk for PC-use HDD was based. The dHc/dT and KuV/kT of PMR disks were designed as the same values as 50GB/disk HDD and applied to the first PMR automotive HDDs. The disks were newly developed based on disk samples for 160GB/disk PC-use HDD. The TMR reader with an advanced barrier layer was designed and applied to gain the designed S/N and SER in the twice higher density. The new TMR reader sensitivity was 1.6 or more times than for 50GB/disk HDD. To satisfy the customer's requirement for the more severe condition of 85 deg C and 5,500 m, the improved ABS slider and TFC management technologies were applied. The temperature dependence of the fly-height (FH) with -0.04 nm /deg C and the atmospheric pressure dependence of the FH with less than 1 nm at the 5,500 m altitude were designed and approved.

Figure 6 The comparison of S/N vs. Temperature with TFC-adj or TFC-off

Figure 8 shows SER vs. O/W performance in the 100 GB/disk automotive HDD with PMR. SER under $10E-8.1$ was not measured due to the limited testing time. The OW was defined by the 2T-signal difference after 17T-signal writing on first 2T-signal. No SER dependence on OW was observed under -20 dB, and OW value of -25 dB was designed as the reasonable target to obtain an optimum SER in the read/write system.

Figure 8 SER vs. O/W performance in the 100 GB automotive HDD with PMR

Figure 9 shows an example of the relation between SER and protrusion values. The protrusion means to reduce the spacing between head reader/writer and disk in reading or writing as shown in Figure. 4. SER under $10E-8.1$ was not measured due to the limited testing time. The average SER dependence on the spacing with TFC function was -0.70 order / nm. The heater power of TFC function for each head in a HDD was designed and set at the temperature and zone area.

Figure 9 SER vs. protrusion in the 100 GB automotive HDD with PMR

An example of the relations between OW and write-protrusion at each -30, +30 and +85 degree Celsius under the condition of a constant read-protrusion was shown in Figure 10. The OW dependence on the write protrusion showed different performance results in those three temperatures. Those performances were not so strongly depending on the

Write-protrusion, which was the spacing between head writer and disk in the area under -25dB. This tendency may be attributed to the magnetic interaction between head writer and SUL (Soft Under Layer), of which magnetic flux penetrates easily into PMR disks. Therefore, comparing to LMR, the PMR OW saturation was more easily happened in the condition with strengthening the head writer magnetic field by reducing the spacing.

(1) -30 deg-C

(2) +30 deg-C

(3) +85 deg-C

Figure 10 O/W performance vs. protrusion in the 100 GB HDD with PMR

Figure 11 shows the comparison of SER vs. temperature with TFC-on or TFC-off. The SER examples were measured at ID and OD in LT (-30 degree Celsius), NT (30 degree Celsius) and HT (85 degree Celsius) in the four head/disk combinations. SER with TFC on at -30 degree Celsius was improved over 2 orders. The optimum heater power of TFC function for each head in a HDD was designed followed by a target SER and set at the temperature and zone area.

Figure 11 The comparison of SER vs. Temperature with TFC-adj or TFC-off

(2) Temperature dependence of 100 GB automotive HDD with PMR

Figure 12 shows the SER performance depending on temperatures of four head and disk combinations in 100 GB automotive-HDD with PMR. The SER average between -43 and 107 degree Celsius with $10E^{-7.5}$ and no degradations were verified. Sufficient margin of temperature performances between -30 and 85 degree Celsius were verified for 100 GB automotive HDD products with PMR.

Figure 12 Temperature dependence of SER in 100 GB automotive HDD with PMR

3. Conclusion

The design concepts and performances in automotive HDD have been demonstrated with LMR and with PMR technology sets as well. In the automotive application, the HDD use environment is much more severe compared to PC-use HDD. Especially the operation temperature range is required -30 to 85 degree Celsius compared to 5 to 55 degree Celsius in PC-use. This is the first time to demonstrate no SER degradations in wider temperature range with PMR HDD and LMR HDD products.

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