KSTLE International Journal, Vol. 1, No. 1, June 2000, pp. 29-33

A Study of Contact Detection and Position Sensitivity of AE Sensor

Haesung Kwon and Sung-Hoon Choa*

Samsung HDD Division

Abstract : In this study, a methodology is developed and confirmed to find the physical contact between the slider and disc due to the defects of disk during head seeking operation using acoustic emission (AE) signal. The head/disk contact was detected during random and standard seeks, whereas no contact was detected during track following. During standard and random seeks, the torsion mode of slider excitation was observed at 680 kHz. Therefore, it is thought that AE technique can be used as an alternative method of the glide test by monitoring existence of the torsional mode of the slider during seek operation or can be used to detect the spacing loss during seeking operation. By appropriately choosing the location of the sensor, an order of magnitude increase in the sensitivity for RMS AE signal is observed. Therefore we can find take-off velocity clearly with high signal to noise ratio of AE signal.

Key words : hard disk drive, acoustic emission, seeking operation, position sensitivity

Introduction

Acoustic emission (AE) is high-frequency elastic wave generated by the deformation or destruction of solids, and has been used to study various interactions and contact phenomena. Since Kita *et al.* [1] first used this technique to study head/disk interaction in the disk drive, acoustic emission has been widely used in hard disk industry for head/disk contact detection. In particular, AE became a very useful tool to study the take-off behavior of the slider since AE sensor is much more sensitive to head/disk contact compared to strain gage sensor. Several studies have been discussed about interpreting skills and filtering techniques of AE signal [2,3]. Since slider/disk contacts excite the resonant frequencies of the slider, AE can also be used to determine contact mechanism such as contact occurrence, contact location, and contact force on the slider [4,5]. O'Brien *et al.* [6] observed resonance modes of slider vibration during head/disk contact at fixed RPM. Jeong *et al.* [7] demonstrated that AE sensor was an appropriate sensor to measure slider ringing mode, which was generated from contact with disk. Kwon *et al.* [8] observed bending mode at low RPM and torsional mode at high RPM by contact force simulation between the slider and the disk. Sharma *et al.* [9] found that bending and torsion modes were dominant vibration mode of the slider during take-off.

Along with the study of vibration mode and take-off behavior of the slider, AE sensor was also used to find out the evidence of spacing loss between the slider and the disk during seek motion qualitatively [10]. Spacing loss during seek operation is associated with the changes of the flying height, which are attributed to the design of head air bearing surface and seek velocity. Recently, the demand for high areal recording density in disk drive requires a continuous decrease of the head/disk spacing, i.e., a lower flying height. In this case, the slider's flying stability, especially the stability during track seeking operation, becomes of great importance to the reliability of disk drives. It is the intent of this study to develop a methodology to detect contacts between the slider and the disk during seeking operation using AE signal. Furthermore, AE sensor also can be used to detect the defects on the disk surface during head flying such as a glide test, which is commonly used to screen the disks for the presence of defects that are taller than a specific flying height. This paper investigates the contact behaviors between head and disk during seeking motion of the slider using AE sensor. Subsequently, the implications of use of AE signals in glide height testing are explained. In addition, the sensitivity of AE signal is studied with respect to AE sensor's mounting locations on the fixture arm.

*Corresponding author; Tel: 82-31-200-4749; Fax: 82-31-200-3144
E-mail: shchoa@sisa.smsung.com

Experimentals

A commercially available CSS tester (TTI T4000 Spin Stand) was used to study contact detection between the head and the disk as well as position sensitivity of AE sensor. Also Lotus CSS tester, which is another type of commercial CSS tester, was used for comparison. 50 percent (nano) negative pressure slider was used, which was made from Al_2O_3-TiC material. It has the nominal flying height of 40 nm (1.6 μin) at the operation speed of 5400 rpm, measured with a commercially available dynamic flying height tester (Phase Metrics). Fig. 1 is a schematic drawing of a side profile for the tested head when it is flying over a disk at the operating speed. The steep slope at the front end represents the leading edge taper, through which air gets into the air bearing surface. The leading edge

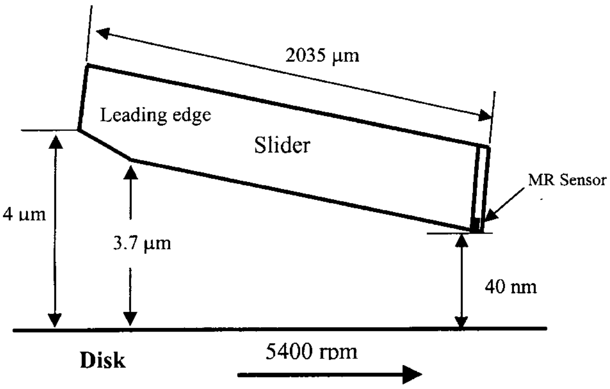

Fig. 1. Interface profile when a slider flies over a disk.

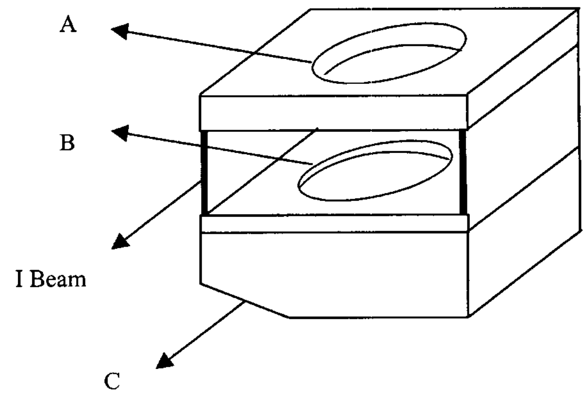

Fig. 2. Schematic diagram of the strain arm used to study the position sensitivity of the AE sensor.

taper is the largest opening between a slider and a disk. The front and back end of the taper is 4 μm and 3.7 μm from the disk surface. The gentle slope after the leading edge taper is part of the air bearing surface (ABS) which is made of two rails. The disks used in the test were produced on 95 mm diameter AlMg/NiP substrate with laser zone texture (LZT) on the landing zone. The laser bump shape for all disks is a crater type (or V shape type). The laser bump height is 18 nm. The disk is overcoated with nitrogenated carbon, about 100 Å thick, and lubricated with 14 Å of perfluoropolyether (PFPE) type lubricant. The surface roughness of the data zone is 5.5 Å Ra. The glide height of the disk is 22.9 nm (0.9 μinch) in the data zone and 36 nm (1.4 μinch) in the laser texture zone (landing zone), respectively.

AE signal was measured for three cases of typical slider operation modes: (a) during on-track following (or one track flying), (b) during seeking, and (c) during take-off. For take-off, the ramp up time from 0 rpm to 5400 rpm was 3 second. For seek operation, a slider sweeps at acceleration of 500 radian/s^2 and velocity of 20 radian/s between two specific radii of 27.9 mm and 38.1 mm. On-track following operation was done at radius of 25.4 mm with 5400 rpm. The AE data from AE sensor was amplified and was input to the data analyzer. AE signal was triggered and captured only when it exceeded a certain threshold. By using digital oscilloscope, the captured transient AE signal was converted into frequency domain to look into slider ringing mode which indicates the contact between slider and disk. Each spectrum was averaged when AE event occurred above threshold. The rms (root-mean-square) AE signals were recorded with a sampling rate of 2.5 MHz. Also in some cases, a high band pass filter (400-1000 kHz) was used to cut off lower frequencies which are not related to the natural frequencies of the slider body.

In order to generate the contact during head flying, several disks were prepared, which the scratches and the defects. In addition, in order to make more severe contact condition, particles were introduced on the disk surface, then the acoustic emission was measured to identify the contact behavior of the slider. Hundreds of alumina (Al_2O_3) powder particles, which has a normal distribution with a mean diameter of 1 μm, were dropped at the fresh disk using cotton swab. Alumina particle was chosen because it was commonly found in the inside of the drive as one of the contaminants.

The position sensitivity of the AE sensor was studied by mounting the sensor at two different locations on the strain arm. Fig. 2 is a schematic diagram of the strain arm. Location A of the sensor is after the thin section (I beam) of the strain arm, whereas location B of the sensor is before the thin section of the strain arm. The suspension was mounted at location C and the cantilever arm was mounted above location A. The AE waves, after being generated at the head/disk interface, travel through AE sensor at location B. These waves then go through the thin I beam section before reaching AE sensor located at A.

Results and Discussion

In order to generate the contacts during head flying, the disk was prepared by making small scratches intentionally on the disk surface, which were less than 2 or 3 μm. The scratches were made on the seeking (or sweep) operating area of the disk surface, which was between radius of 27.9 mm and radius of 38.1 mm. In the most cases, the height of the scratches was found to be higher than the flying height of the head through AFM measurements. In addition, some glide-failed disks, which have the pre-existed defects on the disk surface, were also used for testing. However, it was found that both of the scratch disk and glide-failed disk generated the same effects of contacts during head flying and the AE signal is not different. The flying height variation in the inner diameter (ID) to outer diameter (OD) seeking (OD seeking) and OD to ID seeking (ID seeking) are presented in Fig. 3. For the ID to OD seek, the flying height decreases by nearly 10 nm, on the other hand, for the OD to ID seek, the flying height increases substantially. The loss of flying height for the ID to OD seek is due to the loss of lifting pressure through side leakage, which is mainly attributed to the skew angle effect. If we do not have large enough flying height budget to absorb this decrease in flying height, the head-disk contact will possibly be occurred during seeking operation.

AE signal was measured in time domain and frequency domain respectively at each different operation modes as shown in Fig. 4, which are (a) on-track following, (b) seeking, and (c) take-off operation. Each figure in Fig. 4 consists of 4

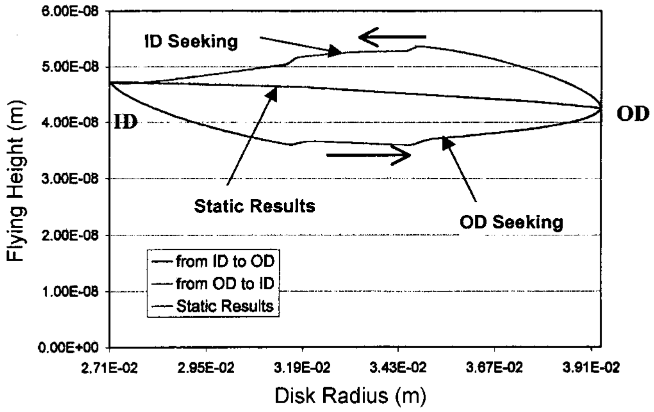

Fig. 3. Flying height variation in inner diameter to outer diameter (OD seeking), and OD to ID seeking (ID seeking).

rows. The 1st row shows AE signal in time domain captured with the specific threshold, the 2nd row is the magnified image of the first row, the 3rd row is the averaged spectrum of captured signal only, and the 4th row is the instantaneous spectrum of the 1st AE signal. The horizontal scale for the first row is 0.1 ms per division and for the 3rd and 4th row it is 0.1 MHz per division. Vertical axis represents the rms AE signal (mV). During track following operation shown in Fig. 4 (a), no resonance frequency peak was observed, indicating that there were hardly any contacts between the head and the disk during head flying. Note that track following operation was done at the data track of 25.4 mm, where no defect was present. On the other hand, during seeking and take-off operation, the resonant frequency of 680 kHz was found as shown in Fig. 4 (b) and (c). It indicates that there was contact between head/disk during seeking and take-off operation. Furthermore, a single prominent frequency of 680 kHz was observed during seeking operation. This frequency is close to the natural frequency of the torsional mode of the slider [11]. Therefore, it is thought that this mode comes from torsional vibration of slider. Only torsional mode is excited when slider hits defect or asperity in a fully stabilized state of slider air bearing. On the other hand, during take-off of the slider, bending and torsional modes were detected because the slider air bearing was not fully developed as shown in Fig. 4 (c). Consequently, it is apparent that each operating mode generates different contact behaviors. Therefore, AE technique can be used as an alternative method of the glide test by monitoring existence of the torsional mode of the slider during seeking operation.

In order to investigate the contact behaviors in the severe contact condition, particles were introduced on the disk surface, Hundreds of 1 μm alumina (Al_2O_3) powder particles were dropped at the fresh disk using cotton swab. The acoustic emission data was collected for two conditions: (a) on-track following operation (b) seeking operation. Take-off operation was not performed since particles are dropped only in the data track zone. In this case, testing was done at a different CSS tester, which is Lotus CSS tester, to see the effects of tester differences on AE signal. The acoustic emission (AE) signal was observed in time and frequency domain with 400~1000

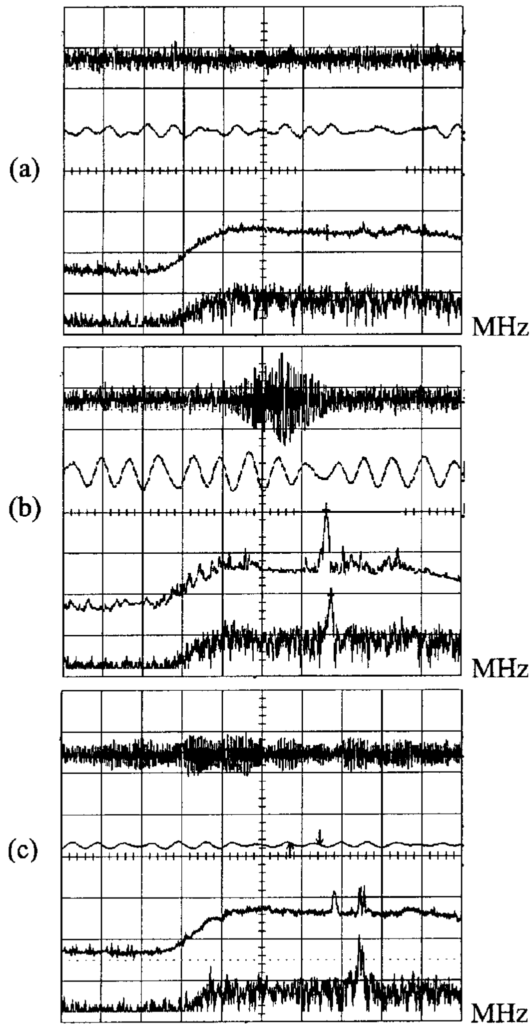

Fig. 4. Time and frequency dependent AE responses of the head during (a) on-track flying, (b) seek at 20 radians/sec, and (c) take-off operation.

kHz filter, and the averaged AE spectrum was monitored. It was the typical method frequently used in AE testing. Fig. 5 (a) shows the averaged AE spectrum for track following operation. Two peaks at 720 and 890 kHz were observed. These peaks are associated to the torsional and bending modes of the nano slider body vibration respectively, indicating that slider hits the particles during flying. For seeking operation in the data zone, these peaks remained unchanged as shown in Fig. 5 (b), implying that contact behaviors were identical for both cases. Note that this is the conflicting result observed in Fig. 4.

The fundamental reason for monitoring AE signal during asperity impact studies or glide height testing is that asperity or defect impact causes the slider to vibrate. Thus a vibration signal is an indication that a contact has occurred. However, as discussed in the several references [4,5], an impact at certain locations can cause the slider not to vibrate in certain modes. Furthermore, the placement of the sensor at location near nodal lines can make it nearly impossible to measure certain vibrational modes. Therefore, the sensor and impact location

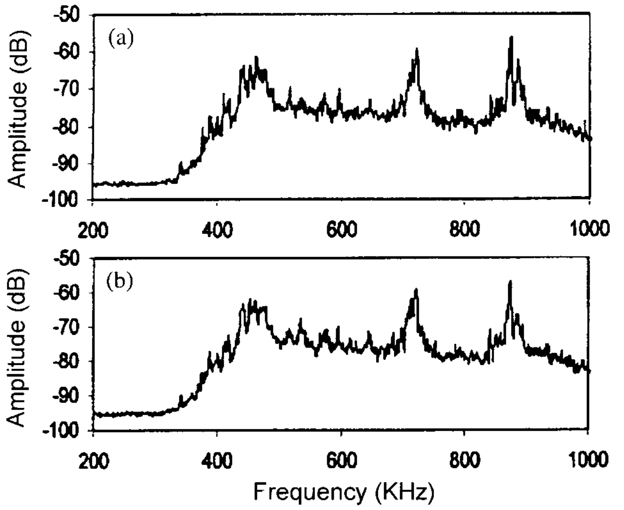

Fig. 5. Averaged AE frequency spectrum for (a) track following operation (b) seeking operation when the particles are introduced on the disk surface.

must be carefully considered if these vibration signals are to be properly interpreted. When the head flies over the particles, particles can enter the tapered leading area of the slider. Once particles go beyond the taper area, particles start contacting with whole surface area of the slider ABS rails including the slider nodal lines of the torsional and bending mode, which were seen in two peak of AE signal. Then contacts will create the excitation of the slider. This contact phenomenon is likely to be similar to that of the take-off operation of the slider on the laser texture zone, in which slider keeps contacting with several laser bumps on the disk until the slider reaches fully developed hydrodynamic flying, which is known as the take-off velocity or take-off point. However, the contact phenomenon caused by introduction of many particles in this study is not the normal contact condition, which is not generally encountered in the drive operation and glide testing. Therefore, monitoring single frequency, which corresponds to torsional vibration mode of the slider, will provide sufficient information for detecting the contact between the head and the asperity or defect on the disk surface during head flying. Also this methodology can be used as an alternative method of the glide testing. This methodology has one clear advantage over the conventional glide testing. Use of real head in this method can eliminate use of glide head, thereby save cost and testing time. However, the detailed correlation between this method and glide testing was not done in this study. It will be performed near future.

Another interesting observation was the shift of the resonance frequency from 680 kHz in Fig. 4 (b) to 720 kHz in Fig. 5 (b) for seeking operation, which was measured with different CSS testers. AE sensor itself is not a flat gain sensor, therefore frequency shift was commonly experienced during AE measurements depending on the types of the sensors and testers. Therefore, it is thought that the slight difference of the frequency is attributed to the difference of sensors used in each tester. Several experimental and numerical calculation works

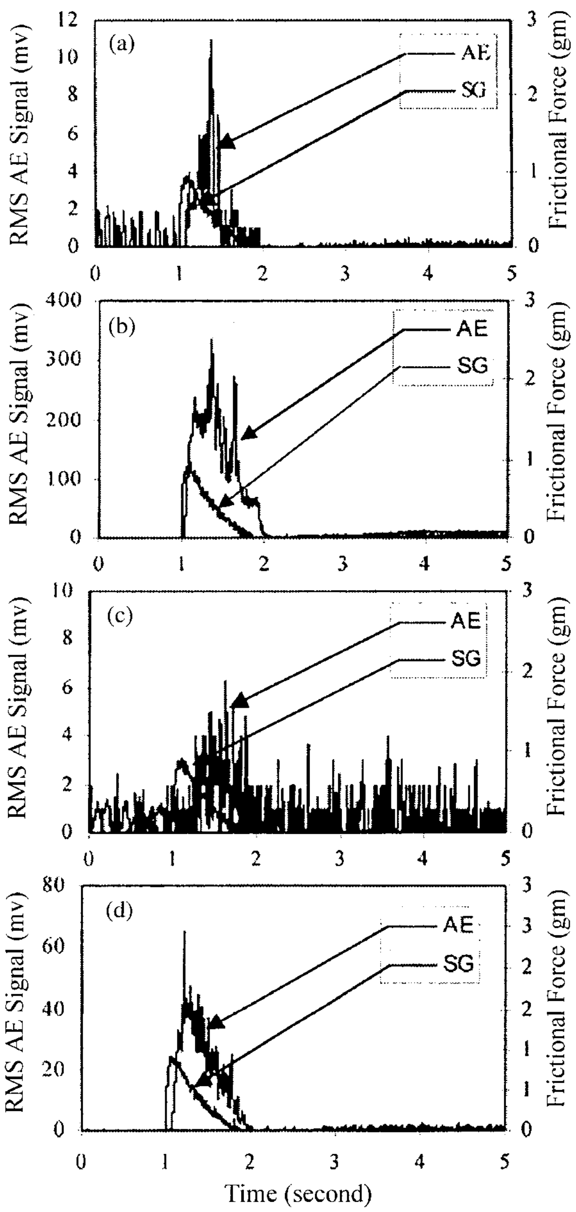

Fig. 6. Typical AE and strain gage (SG) frictional signals obtained from (a) AE sensor location A, unfiltered signal, (b) AE sensor location B, unfiltered signal, (c) AE sensor location A, 400~1000 kHz filtered signal, and (d) AE sensor location B, 400~1000 kHz filtered signal.

[5,9,11] confirmed that torsional and bending mode vibration of the nano slider occurred in the broad range of 650~900 kHz. The sensitivity of AE signal was substantially affected by the mounting location of piezoelectric (PZT) sensor, that is, AE sensor. Here the position sensitivity of the AE sensor was studied by mounting the sensor at two different locations on the strain arm. A typical result for the variation of the RMS value of the AE signal and the frictional force during take-off is shown in Fig. 6. Fig. 6 (a) and (b) show unfiltered AE signal for the sensor location A and B, respectively. From these two figures, nearly 30 times improvement in the peak RMS signal was observed between locations A and B. Fig. 6(c) and 6(d)

show 400~1000 kHz filtered AE signal for locations A and B, respectively. Again, an order of magnitude increase in the AE signal can be achieved between locations A and B of the sensor.

The increase in the sensitivity at location B compared to location A is likely due to attenuation of AE waves as it passes through I beam section of AE sensors fixture. Based on the dimensions of the strain arm, it is very difficult to estimate the attenuation of AE signal quantitatively as it is not well understood yet if the piezoelectric device measures solely displacement, stress amplitude or particle velocity associated with the AE wave or a combination of these parameters.

Conclusions

A methodology is developed and confirmed to find the physical contact between the slider and disc due to the defects of disk as well as the spacing loss during head seeking motion using AE signal. Resonant frequency during seeking operation is observed to be 680 kHz with 50% nano slider, which corresponds to the torsional vibration mode of the slider. AE technique can be used as an alternative method of the glide test by monitoring existence of the torsional mode of the slider during seek operation. By appropriately choosing the location of the sensor, an order of magnitude increase in the sensitivity for RMS AE signal is observed. Therefore we can find take-off velocity clearly with high signal to noise ratio of AE signal.

References

1. Kita, T., Kogure, K., Mitsuya, Y., and Nakanishi, T., 1980, New Method of Detecting Contact Between Floating-Head and Disk, IEEE Trans. on Magnetics, Vol. 16, No. 5, pp. 873-875
2. Benson, R. C., Sundaram, R., and Talke, F. E., 1988, A Study of Acoustic Emission from the Slider/disk Interface in a 51/4 inch Hard Drive, Tribology and Mechanics of Magnetics Storage System, ASLE special publications, Vol. 5, pp. 87-93.
3. Yeack-Scranton, C. E., 1986, Novel Piezoelectric Transducers to Monitor Head-Disk Interactions, IEEE Trans. on Magnetics, Vol. 22, No. 5, pp. 1011-1016.
4. Briggs, J. C., Chang, M. K., and Tse, M. K., 1992, High Frequency Slider Vibration during Asperity Impacts in Rigid Magnetic Disk System, Advanced Information Storage System, Vol. 4, pp. 181-194.
5. McMillan, T. C. and Talke, F. E., 1998, Identification of Slider/Disk Contacts Using the Energy of the Acoustic Emission Signal, IEEE Trans. on Magnetics, Vol. 34, No. 4, pp. 1819-1821.
6. O'Brien, K. and Harris, D., 1996, Head/Disk Interface Contact Detection Using a Refined Acoustic Emission Technique, Journal of Tribology, pp. 539-542.
7. Jeong, T. G. and Bogy, D. B., 1989, Natural Frequencies of Sliders and Transducers Used to Detect Slider-Disk Contacts, IEEE Trans. on Magnetics, Vol. 25, No. 5, pp. 3725-3727.
8. Kwon, H., Wahl, M. H., and Talke, F. E., 1996, Simulation of Asperity Contacts at the Rear Pad of Tri-Pad Sliders During Steady-State Flying, IEEE InterMag Conference at Seattle, EQ-23, 1996.
9. Sharma, V. and Talke, F. E., 1996, Tribological Investigations of Tri-pad Slider, IEEE Trans. on Magnetics, Vol. 32, No. 5, pp. 3651-3653.
10. Cha, E., Chiang, C., and J.K.Lee, J., 1995, Flying Height Change during Seek Operation for TPC Sliders, IEEE Trans. on Magnetics, Vol. 31, No. 6, pp. 2967-2969.
11. Harris, D., Venkatesan, S., and OBrien, K., 1998, Take Off Measurement of Pico Sliders on Laser Zone Textured Media, IEEE Trans. on Magnetics.Vol. 34, No. 4, pp.1693-1695.