

สำนักหอสมุดกลาง พระจอมเกล้าลาดกระบัง

HDI DETECTION USING AN AE TECHNIQUE



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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF ENGINEERING IN DATA STORAGE TECHNOLOGY AND
INNOVATIONS (INTERNATIONAL PROGRAM)
INTERNATIONAL COLLEGE
KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
2013
KMITL-2013-IC-M-005-018



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หัวข้อวิทยานิพนธ์	การตรวจจับหัวอ่านสัมผัสกับแผ่นเก็บข้อมูลในฮาร์ดดิสก์ไดร์ โดยใช้อะคูสติกอิมิชันเทคนิค
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บทคัดย่อ

อะคูสติกอิมิชัน(AE) ใช้หลักการตรวจจับพลังงานที่อยู่ในรูปของคลื่นยืดหยุ่นที่เกิดจากความเค้นของวัสดุหนึ่ง อะคูสติกอิมิชันเซ็นเซอร์ถูกใช้อย่างแพร่หลายในการตรวจสอบที่ชิ้นงานที่ไม่ทำให้ชิ้นงานนั้นเกิดความเสียหาย ซึ่งได้แก่การตรวจความสอบการสัมผัส, การบิด, การงอ และรอยแตกของวัสดุ ซึ่งรวมถึงการสัมผัสกันระหว่างหัวอ่านและแผ่นเก็บข้อมูลของฮาร์ดดิสก์ไดร์(HDI) ในกระบวนการผลิตมีของเสียบางอย่างที่ต้องถูกจัดการโดยการการทำลายตัวฮาร์ดไดร์ทั้งตัวเพราะกลัวเรื่องของความสะอาดในฮาร์ดดิสก์ไดร์ ซึ่งก็รวมถึงอาการเสียที่เกิดจากการสัมผัสกันระหว่างหัวอ่านและแผ่นเก็บข้อมูล ซึ่งอาการเสียแบบนี้บางครั้งก็จะปะปนไปกับของเสียที่สามารถซ่อมแซมได้ โดยสาเหตุหลักที่เกิดปัญหาแบบนี้คือข้อมูลที่ได้จากทดสอบไม่เพียงพอที่จะบอกอาการเสียนั้นได้ทั้งหมด ดังนั้นวิทยานิพนธ์เล่มนี้ จึงนำเสนอการตรวจจับ การสัมผัสกันระหว่างหัวอ่านและแผ่นเก็บข้อมูลในฮาร์ดดิสก์ไดร์ โดยใช้อะคูสติกอิมิชันเซ็นเซอร์ ซึ่งใช้หลักการของการบิด, การงอ, การเสียรูปของวัสดุ ซึ่งในการทดสอบนั้นจะวางอะคูสติกอิมิชันเซ็นเซอร์ไว้ที่ด้านนอกของตัวฮาร์ดดิสก์ไดร์ หลังจากนั้นเซ็นเซอร์จะทำการวัดแรงดันไฟฟ้า เริ่มตั้งแต่ฮาร์ดดิสก์ไดร์เริ่มทำงานจนกระทั่งหัวอ่านโผล่ลงไปในแผ่นเก็บข้อมูล ซึ่งสัญญาณของเซ็นเซอร์ที่วัดได้ ต้องถูกทำให้อยู่ในรูปของแรงดันอาร์เอ็มเอส หลังจากนั้นก็ทำการเปรียบเทียบแรงดันอาร์เอ็มเอสที่วัดได้ ระหว่างก่อนและหลังโผล่หัวอ่านลงสู่แผ่นเก็บข้อมูล ถ้าแรงดันอาร์เอ็มเอสที่วัดได้มากกว่าค่าแรงดันเรสโซล ฮาร์ดดิสก์ไดร์ก็จะถูกจัดให้เป็นของเสียที่เกิดจากหัวอ่านและแผ่นเก็บข้อมูลเกิดการสัมผัสกันแล้ว

ผลจากการทดลองกับฮาร์ดดิสก์ไดร์ขนาด 2.5 นิ้ว ที่ความเร็ว 7000 และ 10000 รอบต่อนาที อะคูสติกอิมิชันเทคนิคสามารถที่ตรวจจับได้ถูกต้องแม่นยำประมาณ 93-94%

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Major program	Data Storage Technology
Academic year	2013
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ABSTRACT

Acoustic Emission (AE) sensors are commonly used in non-destructive testing to monitor the generation and propagation of contact, bending, torsion, and crack in material; including magnetic head-disk interaction (HDI). In Hard Disk Drive (HDD) manufacturing process, HDI is the one of mechanical failures that leads to the scrapping of finished drives. However, the segregating process between true and false HDI failures is mainly thesis presents the HDI detection using AE sensor based on the availability of stress wave technique occurs in Bending and Torsional modes. The AE sensor is placed outside the HDD to measure AE voltage signal once the drive starts up. The AE voltage will be converted to rms value or AE_{rms} . The threshold voltage which is the difference of AE_{rms} between spin up and loading head to disk can be used as a criterion to identify the appearance of HDI.

The experiment has been conduct on 2.5 inches drives with 7200 and 10000 rpm. With this technique the detection accuracy of 93-94% can be achieved.

ACKNOWLEDGEMENT

First of all, I would like to be grateful to Assoc.Prof.Dr. Somsak Choomchuay (my thesis advisor), for his helpful guidance, advice, idea and support during this research at KMITL.

Next, I thanked thesis committee members who are in College of Data Storage Innovation and faculty of engineering for their constructive comments and helpful discussions which gave me a better perspective on my own results.

Then, I also would like to thank my boss; Dr. Patiwat Kamonpet and Dr. Suwaree Suraprapich. They are prompt to support, suggest and innovate for this work.

After that, I should also mention to my graduation which is supported by National Electronics and Computer Technology Center (NECTEC) Thailand and Seagate Technology (Thailand) Co., Ltd. Furthermore would like to say thank you to international college and college of data storage, King Mongkut's Institute of Technology Ladkrabang

Finally, but it is not the least; I would like to thank my family, friends and subordinate for all of their help in anything of this work.

For any erroneousness or insufficiency which might be remained in this work, I am entirely responsible for all of them absolutely.

Chuchat Sodsri

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Acronyms, Definitions and Symbols

This thesis document uses the following set of Acronyms, Definitions and Symbols

AE	Acoustic Emission
C/R	Clean Room
CSS	Contact Start Stop
HDA	Head Disc Assembly
HDC	Head Disk Contacts
HDD	Head Disk Drive
HDI	Head Disk Interaction
HSA	Head Stack Assembly
LDV	Laser Doppler Vibrometer
LUL	Load/Unload
MBA	Motor Base Assembly
NRRO	Non Repeatable Run-Out
PCBA	Printed Circuit Board Assembly
PES	Position Error Signals
R/W Head	Read or Write Head
RPM	Round Per Minute
RRO	Repeatable Run-Out
SNR	Signal to Noise Ratio
VCM	Voice Coil Motor

CHAPTER 1

Introduction

Hard Disk Drive (HDD) is a magnetic device that utilizes magnetism to store data on media. The basic HDD operation consists of spinning media with head flying over the media and Write/Read data in tracks and sectors. In currently HDD manufacturing process has two main parts which are assembly HDA and drive testing. Normal manufacturing process has failure, the HDD has many failure modes such as Media related, drive PCBA related, mechanical related etc. Head Disk Interaction (HDI) is the one of mechanical failure and generates many issues in case of wrong disposition such as cross contamination, downtime ... etc.

1.1 Motivation

During drive test process has failure and current HDD industrial utilizes the auto system to manage the failed drives. HDI is the one of mechanical failure which needs to scrap all components due to cleanliness concerns. However, the segregating processes between true and false HDI failures are mainly difficult to detect due to inadequate information. So the challenge is how to discriminate actual from false HDI in the drive level. This thesis is to detect the HDI by AE sensor which used stress wave technique with Bending and Torsional mode during spinning up and loading head state. Figure 1 shows example of HDI failure

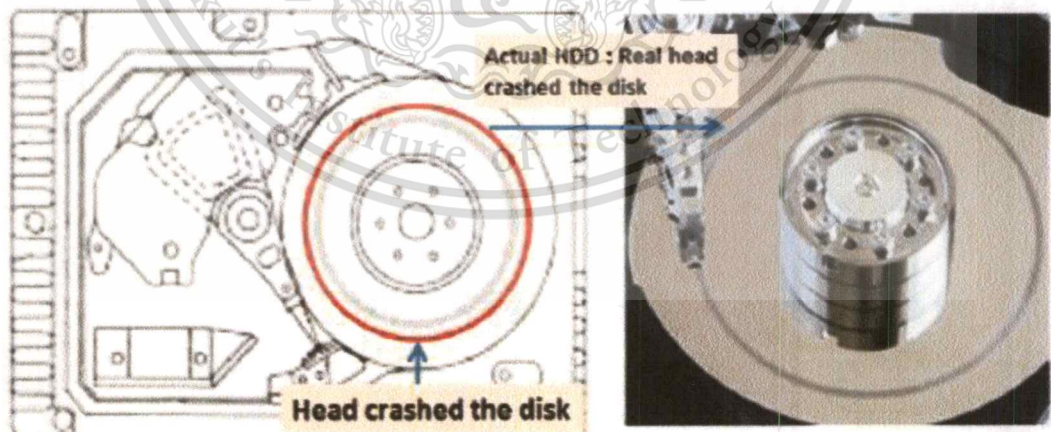


Figure 1.1 : Circumferential scratch (Head crashed the disk) after HDI [13].

1.2 Thesis Objective

In currently to classify the HDD is true or fault HDI by visual inspection. That meaning the HDD has already turned down before knowing the HDD is real or false HDI. For this work will develop a new system to detect HDI failure in the drive level. And the new HDI detector system is applied to HDD factory. This thesis is proposed to apply AE sensor to be captured HDI failure.

1.3 Scope of research

In this research applies AE sensors to detect HDI in drive level. Placed AE sensors outside the drives and then finding the location where AE_{rms} voltage is that is the best response. The AE sensor will be detected HDI failure which depends on AE_{rms} voltage. When the AE_{rms} voltage is over the AE_{rms} threshold, the drive is classified to HDI failure, unless the drive is disposed to normal flow. This AE sensor will be improved accuracy to detect real HDI drive.

1.4 Research Methodology

- 1.4.1 Get the HDI candidate drives.
- 1.4.2 The AE sensor is attached outside the HDD. Then the location of attached AE was selected by the best response of AE signal. After that
- 1.4.3 Adjust amplify gain to match with ADC range because AE signal is small and may need appropriate amplification to improve signal to noise ratio(SNR).
- 1.4.4 Select HDD operation states which are used to classify true or fault HDI drives.
- 1.4.5 Optimized the AE_{rms} threshold for studied HDD model.
- 1.4.6 Compare AE_{rms} signal to AE_{rms} threshold. If it is over AE_{rms} threshold, the drive will classify to real HDI drives.
- 1.4.7 Check accuracy for each AE_{rms} threshold with studied HDD model

1.5 Contribution

- 1.5.1 The system gives more information to classify true or fault HDI drives.

- 1.5.2 More accuracy to identify true or fault HDI.
- 1.5.3 Prevent escape HDI drives to mix other failure modes
- 1.5.4 Reduce the contamination in cleanroom process.

1.6 Literature Review

In 1998, Thomas C. McMillan and Frank E. Talke had been investigated the mechanical energy during head-disk contact with different slider types by using the AE sensor [1]. They used AE sensor to determine a velocity function for relative energy of the torsional and bending mode frequencies.

They used tri-pad and sub-ambient pressure tri-pad sliders that shown Figure 1.2 to investigate the energy during head disk contacted.

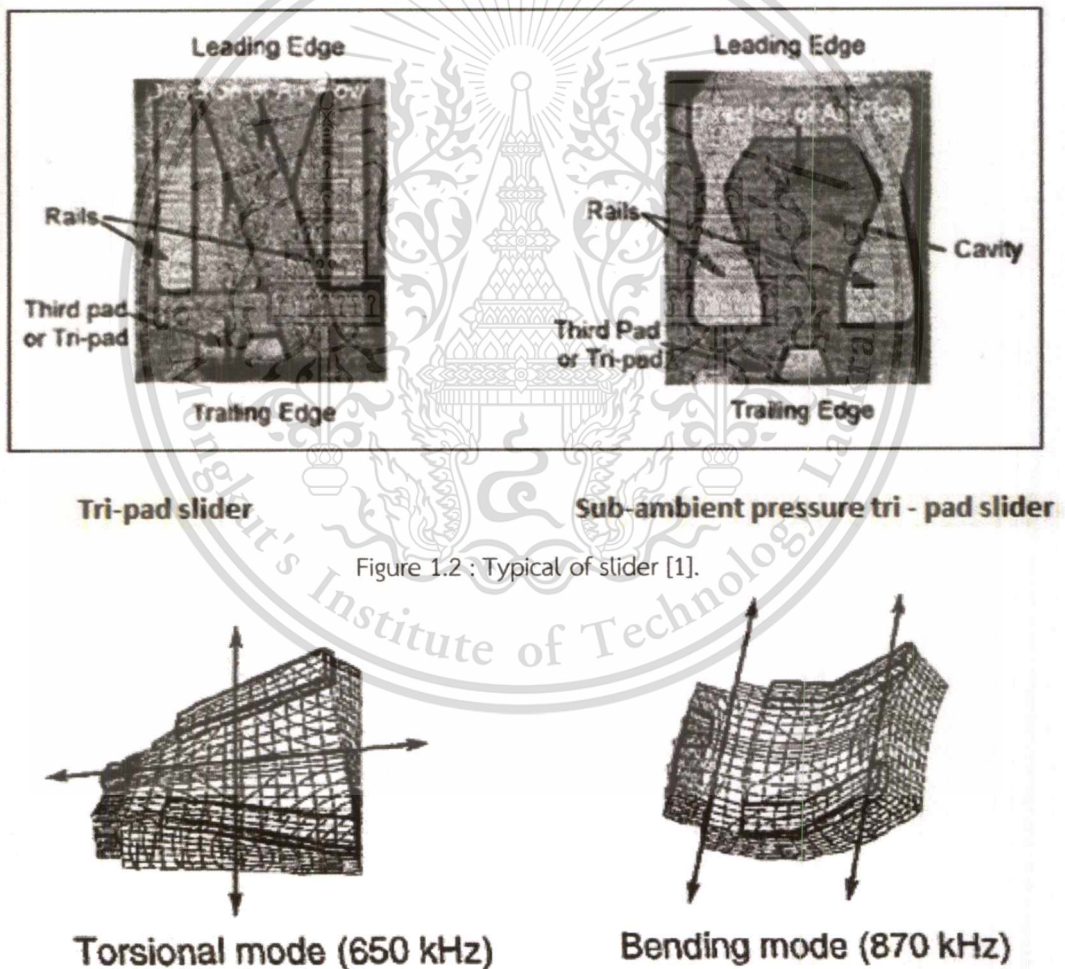


Figure 1.2 : Typical of slider [1].

Figure 1.3 : Finite element analysis for tri-pad slider during head-disk contact [1].

Figure 1.3 shows the result of finite element modal analysis for tri-pad slider during head-disk contact, they found torsional and bending energy are released when head disk contacted. The finite element modal analysis showed nodal lines of torsional mode intersect at geometric center of slider. But the bending mode had two nodal lines intersect near the leading edge and trailing edge of slider. So this was clearly if the tri-pad section of slider made contact to the disk, the most of energy was bending mode.

Figure 1.4 shows AE energy normalized by slider type. During head – disk contact concurrence, the tri –pad slider showed higher bending energy than torsion energy. That indicated the head disk contacts happened mainly at the Tri-pad region. For the sub-ambient pressure tri-pad sliders, the torsional energy was higher than the bending energy at low velocities. This trend was reversed, however, at high velocities. So far they have found the velocity function of torsional and bending energy depended on slider types.

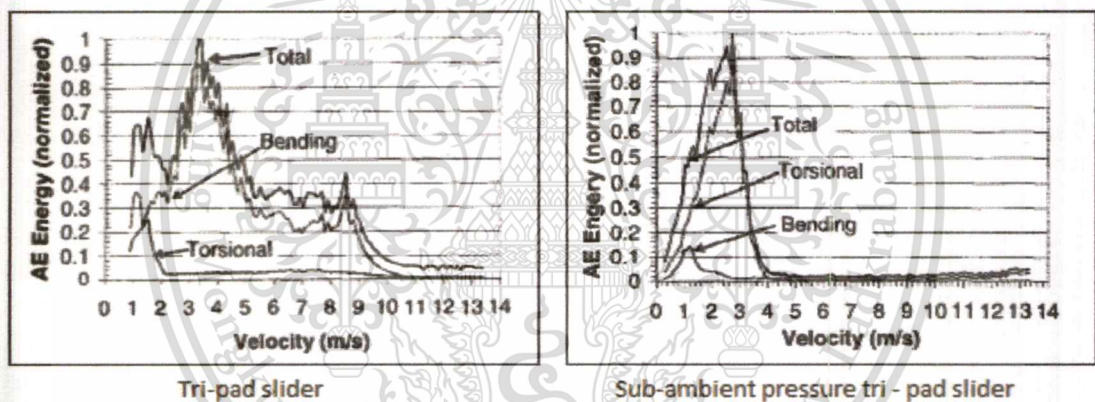


Figure 1.4 : AE energy normalized by slider type [1].

In 2001, Bernhard Knigge and Frank E. Talke studied nonlinear Dynamic Effects at the Head Disk Interface. They investigated the contact dynamics of pico slider with varies lubricant thickness by using Laser Doppler Vibrometer (LDV) and AE [17]. Figure 1.5 showed the experiment diagram of the AE and LDV systems. In this work, the LDV was bandwidth ranging around 10 KHz to 10 MHz and AE was bandwidth ranging around 20 kHz to 2.5 MHz respectively.

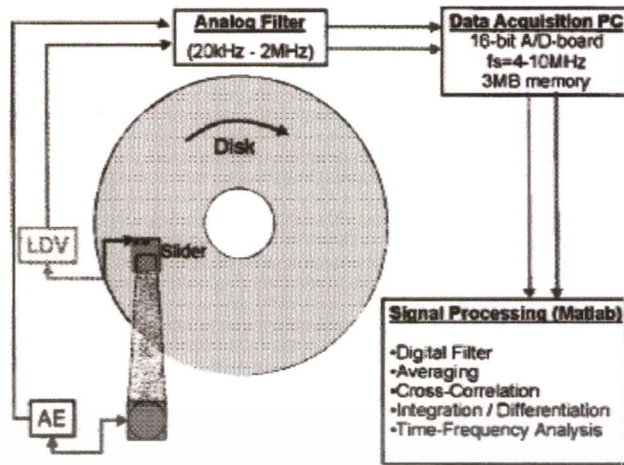


Figure 1.5 : Schematic of experiment setting for the AE and LDV system [17].

Figure 1.6 was LDV spectrum of outer trailing Edge (OTE) and Center Trailing Edge (CTE). At the OTE of slider, the LDV spectrum showed four vibration frequencies; Roll frequency at 123 KHz, Pitch frequency at 232 KHz, Torsion frequency at 1.28 MHz and Bending frequency at 1.68 MHz. When LDV placed at the CTE of slider, the torsion frequency (1.28 MHz) was disappeared and amplitude of Roll and Pitch were reduced.

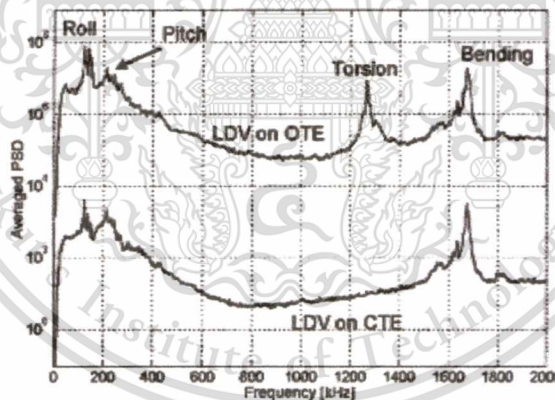


Figure 1.6 : Power spectrum of LDV signal with lubricant thickness [17].

Figure 1.7 shows AE spectrum with lubricant thickness 3.5 nm. The AE spectrum exhibited increasing amplitude when increasing the velocity and lubricant thickness. When varied the velocity, the amplitude ratio between S2 and bending mode were link a constant amplitude. This amplitude ratio was function of lubricant thickness which could possibly be used after optimization to determine lubricant thickness.

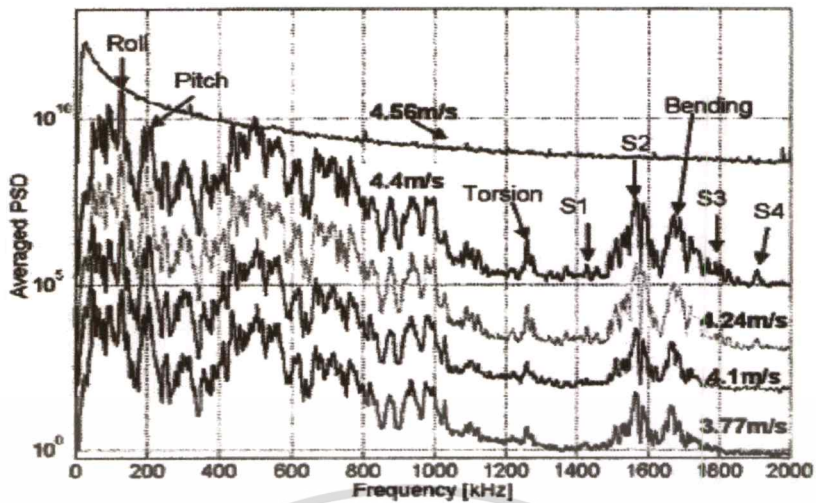


Figure 1.7 : AE spectrums with lubricant thickness 3.5 nm [17].

In Table 1.1 was comparison of data between AE and LDV signal with different Lubricant disks. The LDV and AE signal showed similar trend. When the amplitude signal and standard deviation were increasing, the lubricant thickness was also increasing

Table 1.1 : Compare between AE and LDV signal with different Lubricant disks [17]

Condition	3.5 nm lube	2.5nm lube	1.5 nm lube
LDV velocity on OTE[mm/s]	+/-265	+/-210	+/-50
LDV Standard Dev on OTE[mm/s]	21.8	9.8	6
AE[V]	+/-1.79	+/-1.29	+/-0.69
LDV Standard Dev[V]	0.29	0.15	0.08
Slider Take-Off Velcocity[m/s]	4.5	3.8	3.3

Base on the experiment results, they observed the increased torsion and bending mode vibration when the lubricant thickness increased. The LDV and AE signal standard deviations increased with increased lubricant thickness. So it meant that the vertical stick-slip behavior was leading to the major vibration.

In 2003, Bharat Bhushan and team studied what was key factor for changing the AE electrical energy to mechanical energy which occurred during mechanical contacts

(head disk contact)[2]. The AE output signal can be analyzed waveform characteristic both time and frequency domain.

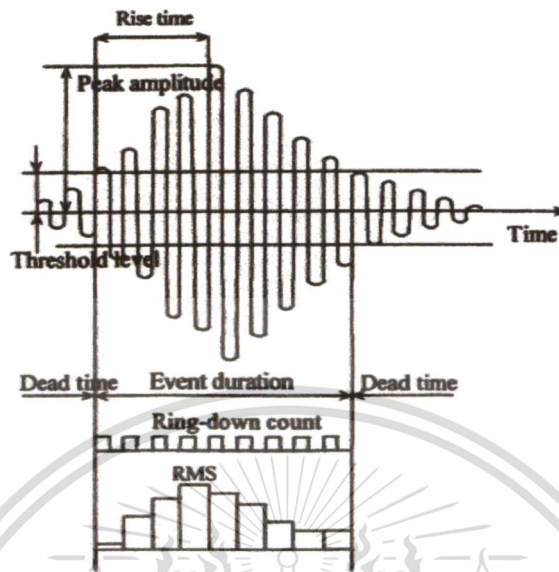


Figure 1.8 : Definitions of the AE signal characteristics in time domain [2].

The analytical models which computed the energy released as a result of material contacts arising from head disk interaction (HDI), Particulate contamination at the HDI and dynamic LUL during HDI [2].

Before running the experiment, the calibration of AE signal was necessary because it had to know the absolute value of the mechanical energy during head disk contact. Figure 1.9 shows calibration of AE signal using ball dropping experiment.

After completing AE signal calibration, the setting model Figure 1.9 was used to measure the AE signal for LUL model of HDD. Figure 1.10 was experiment result of LUL model during HDI occurrence. Figure 1.10 (a); to run the experiment with different LUL velocity, the experiment result showed electrical energy that was direct proportion to the voltage square was computed. After that from the calibration steady the mechanical energy was released due to contacts were computed. Figure 1.10 (b) exhibits the mechanical energy released during HDI occurrence varies approximately as the square of the LUL velocity as predicted by the analytical model. So far for HDD with LUL model, they found energy released during mechanical contacts depended on slider normal loads, radius of disk hit and composite Young's modulus. For the case of a particle trapped at the HDI, the released energy was a function of coefficients of friction at the

slider –particle and particle-disk interface apart from slider normal load. In case of L/UL, major of energy was depending on vertical loading speed

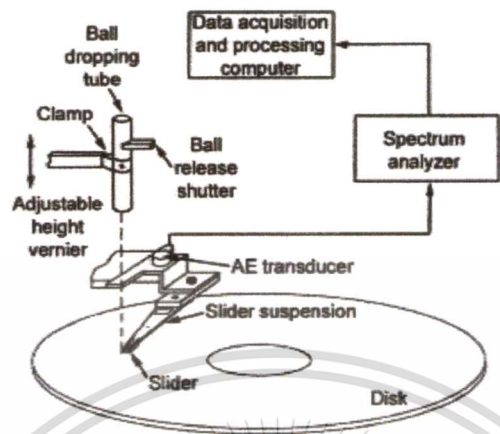
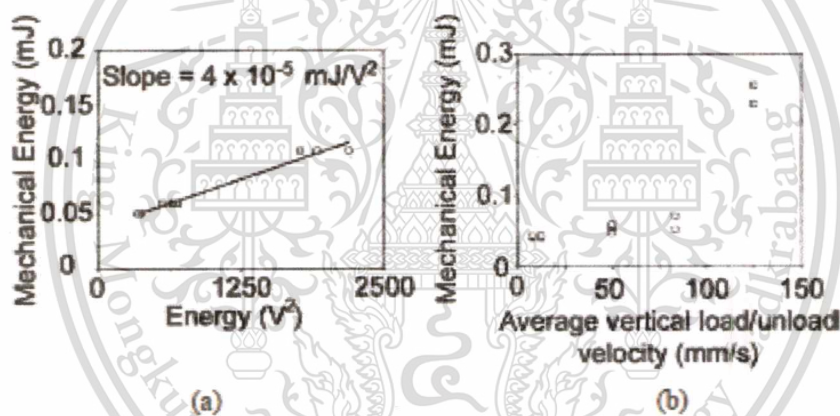


Figure 1.9 : Schematic setup of the ball dropping experiment [2].



- a) Calibration using ball dropping experiments for determination of the electrical to mechanical energy conversion factor
- (b) Mechanical energy released due to mechanical contacts during loading of slider for four different L/UL speeds for a Pico slider with lift-tab

Figure 1.10 : Experiment result of LUL model during HDI occurrence [2]

Base on the previous work for applied AE to detect HDI in drive level, they studied AE for the phenomenon during HDI occurrence, what kind of mechanical energy released during HDI, etc... They didn't apply the AE system to Hard Disk Drive factory to

detect the HDI in drive level. This work was applied AE sensor to detect the HDI in drive level.

1.7 Thesis Organization

This thesis was organized in the following manner. Chapter 2 provides an overview of HDD and manufacturing process in currently. Chapter 3 presented relation of theory of Acoustic Emission, which referred in this thesis. Chapter 4 shows research methodology and Optimization AE_{rms} threshold. And Chapter 5 concludes this research work by providing the conclusion and some importance issues for future work.



CHAPTER 2

Hard Disk Drive Introduction and Manufacturing process

2.1 Hard Disk Drive Introduction

Hard disk drive (HDD) is data storage device that are used as the primary storage device for a wide range of applications, including desktop, mobile, and server systems. Hard disk drives sit in the middle of the storage pyramid, between the semiconductor memories (Flash memory) and removable drives (CD-ROM, DVD, floppy disks) [5]. HDD is better than other storages in term of capacity, cost, and performance. HDD components bale to classify into 4 categories - magnetic components, electromechanical components, mechanical components, electronics component including PCBA (Print Circuit Board Assembly). Figure 2.1 is shown standards of HDD components.

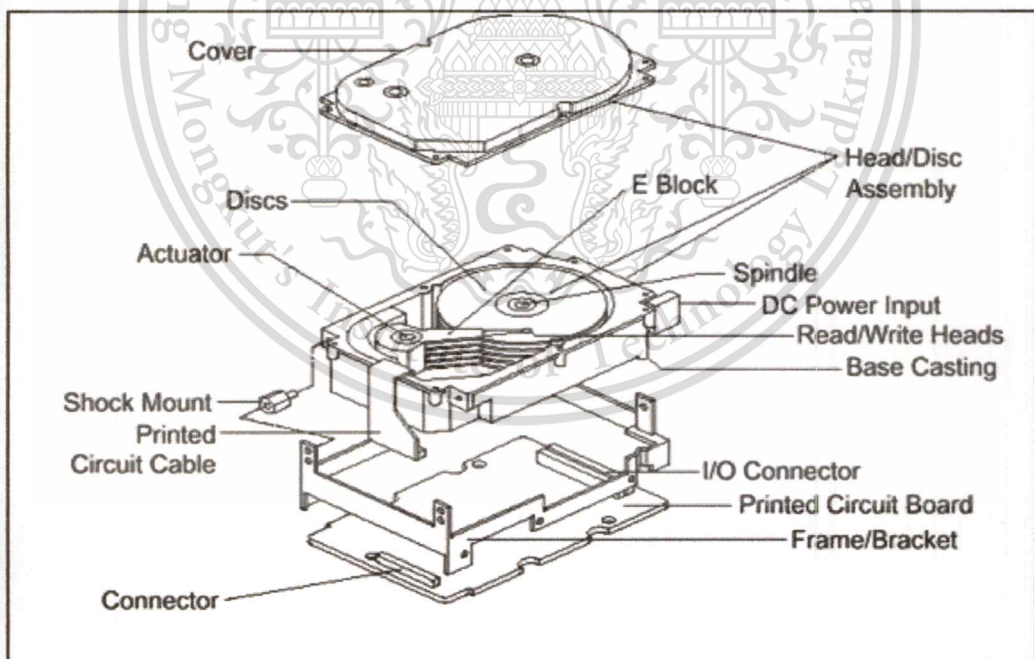


Figure 2.1 : Hard disk drives component [6].

2.1.1 Magnetic components in HDD

Magnetic components in HDD are media (patter) and head that enable storage and retrieval of binary information. In HDD, information bits are in concentric data tracks on a rotating platter coated with magnetic media [5]. Each platter side has one Slider (Write and Read heads) to read and write data. Each head is attached to a single actuator shaft.

2.1.2 Electromechanical Components

Electromechanical Components are a spindle motor and an actuator arm [5]. The spindle motor is mounted on Base deck that calls Motor Base Assembly (MBA). The Spindle motor is used to rotate the stacked platters during drive operation and normally platters have installed in their center and stacked on a spindle motor by clamp screw. An actuator arm in HDD is calling Voice Coil Motor (VCM). VCM actuator is used to moving HSA (hold the Read/Writes heads) to fly over the target data track of platter during read or written. The HSA has consisted Read Write heads, flexible circuit and voice coil. Figure 2.2 shows HSA.



Figure 2.2 : Head Stack Assembly (HSA)[16].

2.1.3 Mechanical component

Mechanical component is crash stop. These are small mechanical protrusions from the base plate and top cover used to restrict the movement of the actuator to fly over the platter [5].

2.1.4 Electronic components

In HDD Electronic components can be divided following functions as below.

1. Electronics for reading/writing is called the Read/Write channel. The Read-channel function has designed to improve signal-to-noise ratio (SNR). Data recovery, etc...
2. Electronics for control spindle motor and positioning of the read/write head which is called Servo channel.
3. Electronics Controller is the controlling various functions in HDD such as Read/Write data, data transfer rate between HDD to host, etc....
4. Electronics for interface controller which is used to interface the host system. In current interface has ATA/DE, SATA, SATA-2, SCSI, SAS and FC.
5. RAM, ROM etc.

Several of these functional components are often combined in a single chip that is called grand chip. As a result, we do not see many ICs on the PCB (printed circuit board) of an HDD. One IC that is not placed on the PCB but is kept inside HDA is the pre-amplifier. It is put as close to the read/write heads as possible to avoid amplification of noise, and is mounted on the flex-cable that carries signal between heads and PCB. The

output of the preamplifier is sufficiently large ensuring good signal-to-noise ratio at the input of the PCBA [5].

2.2 HDD Manufacturing Process

A HDD manufacturing process has separated into two main parts; clean room and backend process. Clean room(C/R) assembly process under the controlled particle environment starts from Basedeck(MBA) loading until top cover mounting yielding so called a Head Disk Assembly (HDA). After that, the HDA is passed to backend process for PCBA installation and functional test. The functional test is to calibrate and optimize functional systems such as servo mechanical tuning, read/write channel optimization and media defect mapping. Figure 2.3 shows HDD manufacturing process flows.

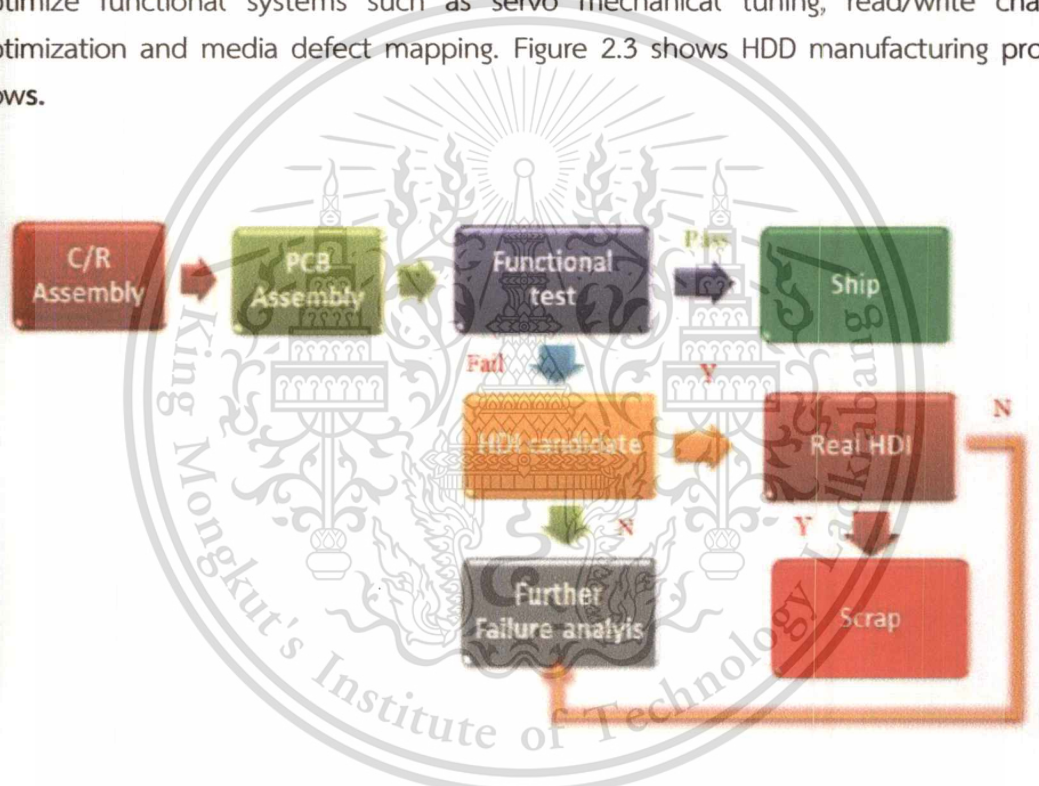


Figure 2.3 : Brief HDD manufacturing process

CHAPTER 3

Related theory of research

3.1 Principle of acoustic Emission

Acoustic emission sensors are commonly used in non-destructive testing to monitor generation and propagation of contact, bending, torsion and crack in material. AE is the sound that emitted an elastic wave when the material is undergoing stress. Normally AE is used stress wave technique to monitor the intensity of mechanical contacts. AE is stress waves which are produced during mechanical deformation of material. Figure 3.1 shows a simplified diagram of Acoustic Emission (AE) method. It is a process for generation and detection during material is undergoing. At that time the elastic waves are produced and represented to intensity of mechanical contact.

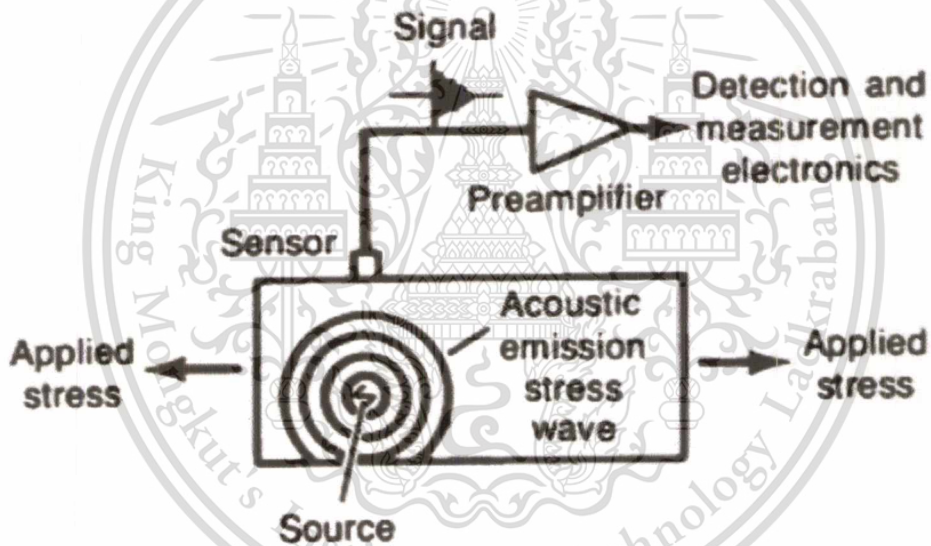


Figure 3.1 : Simplified diagram of acoustic emission method [7].

3.2 Acoustic Emission Sources

3.2.1 Stress

The AE process can be measured since beginning with stress. The stress likes an internal force field in material which transmits and balances to the external force. The description of stress is bending, torsion, tensile, compressive or shears. Figure 3.2 shows example types of stress. Normal stress is the average force per unit area. The

force of stress which acts through of as a three dimensional bodies. After material is under stress, the structure of material is also changed in shape that is called “Strain”. The physical of material can deform if the stress is high enough. Figure 3.3 shows characteristic of stress and strain. So the source of Acoustic emission is material come from material under stress.

When material is cracked, the kind of acoustic emission source is different. This is the key for nondestructive testing because the occurrence of a crack suddenly creates a new surface. This is a major effect to a structure’s integrity and the recognized source of high amplitude AE so application of AE technology is sued to defect of emission from growing crack in material. The amount of AE energy release is depending on size, severity, speed etc...

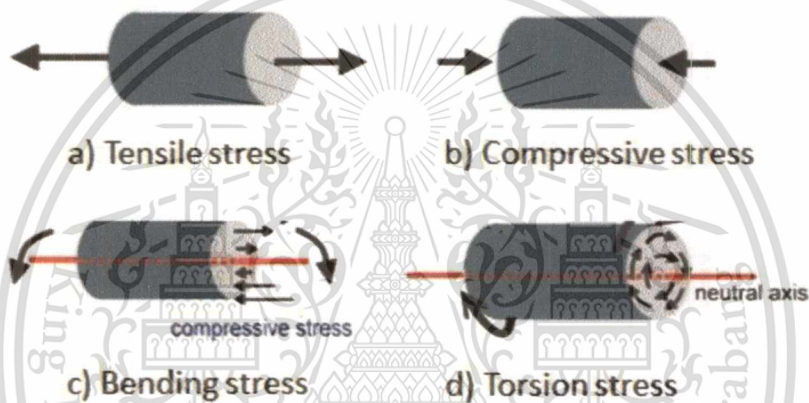


Figure 3.2 : Example type of stress [8].

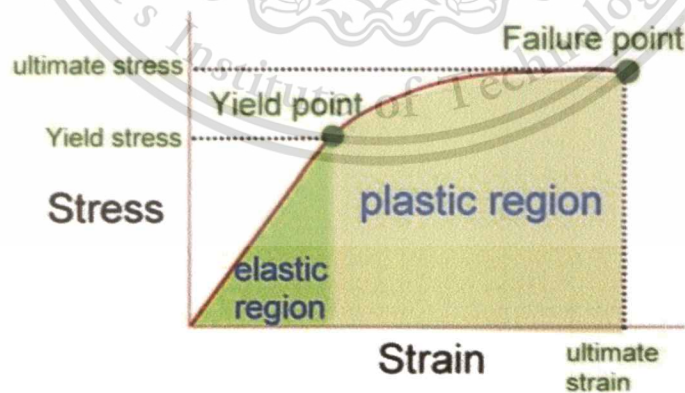


Figure 3.3 : Relationship between stress and strain [8].

3.3 Structural Stress and AE source

The locations of Acoustic emissions occur where the local stress is high enough for material permanent deformation. This usually occurs at stress concentrations, regions where the stress is increased by local geometry. The stress concentrations can tell location where is fatigue cracks initiation. During material deformation the emitted energy is released so the deformation tends to be relieved the high local stresses. The stress is transferred to some other parts of the material structure. This is called “Stabilizing effect”. In case of the material structure is unstressed and re-stressed again to the same level. The deformed regions tend between first time and second time is same level so the emission sources will not tend to remit the second time around, unless the stress exceeds the previous maximum.

When material is undergoing stress it changes the shape that calls “Strain”. The Strain has an elastic, reversible component and also a plastic, permanent component [9]. The elastic component of the strain occurs suddenly after the stress happened. The stress and strain field that inside the material is quickly distributed. Actually, the distribution takes place at the speed of sound, through the propagation of elastic wave [9].

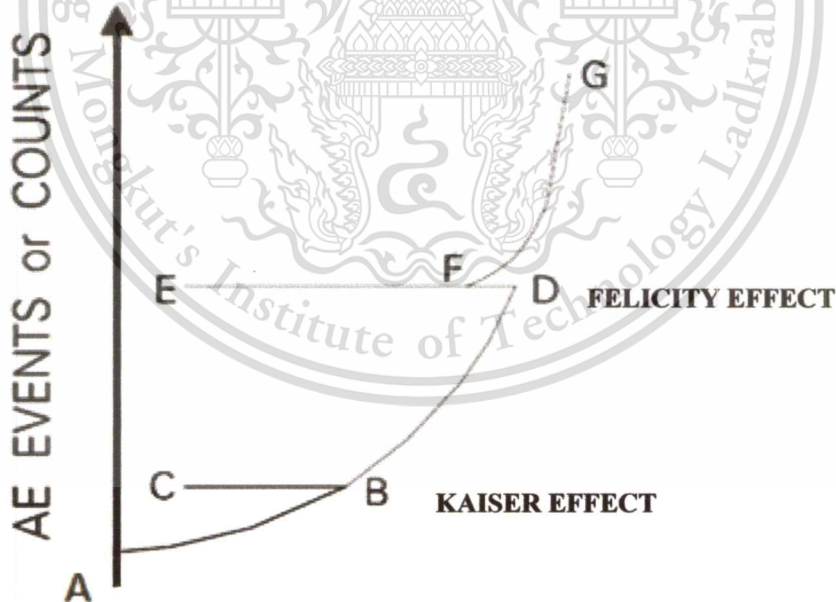


Figure 3.4 : Emission on repeated loading [9]

Figure 3.4 shows Emission on repeated loading, the emission is plotted directly against to the stress (load). The stress is increased, lowered, increased again to a higher level, lowered and finally increased to a higher level still (like a threshold). The acoustic emission is produced during the first stress increase (AB), the stress is lowered (BC) and increased again (CB) these is no more acoustic emission until before load maximum is exceeded. Acoustic emission continues as the stress is increased (BD), and then stop as the stress is lowered for 2nd time (DE). For the increasing the stress for the last time, observed the different emission pattern is occurrence, the acoustic emission starts up before the previous maximum stress is reached (F). The stress is increased (FG) that meaning the emission is continuation. The behavior observed at point B which no emission released until the previous maximum stress is exceeded, this is called “Kaiser Effect”. The behavior observed at point F which emission released below the previous maximum, this is called “Felicity Effect”

3.4 The Signal Shaping Chain

The signal shaping chain has four factors: source, wave propagation, sensor and signal –conditioning electronic. Figure 3.5 shows the signal shaping chain. The measured signal was controlled size and shape by each factor. After passed signal processing, the final signal shape is different from the source, this is a key for signal shaping chain in frequency domain. The concept all signals were analyzed to “Sine Wave” due to “Fourier transform”. Normal the emission source consists of broadband and radiating a varied frequency so this is the reason why selecting the sensor and electronic filtering for acoustic emission.

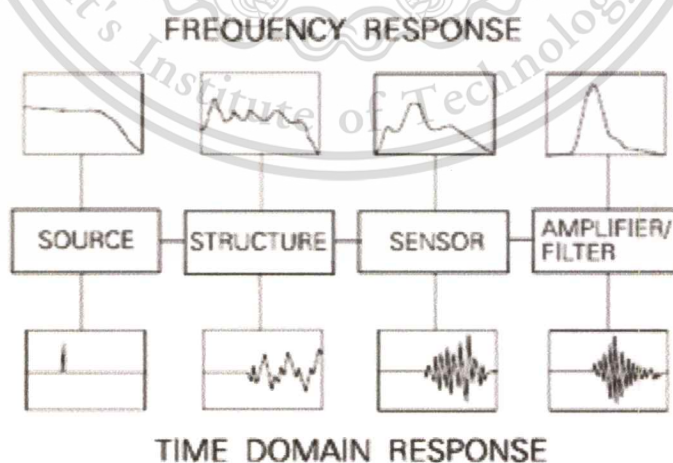


Figure 3.5: Signal shaping chain. [9]

3.5 Elastic Waves Propagation

3.5.1 Wave Types

The stress wave propagation has three modes. It has through isotropic, elastic media (Longitudinal and Shear) and Rayleigh waves. The motion of Longitudinal (compressional, dilatational or irrotational) wave is P-wave ((primary waves) which is parallel to the direction of the wave propagation. When the compressional and dilatational forces make active in these waves, they are also called pressure waves. P-wave is some kind like a normal stress. For the motion of Shear (Distortional or S-wave) wave is perpendicular to the direction of wave propagation, so S-wave is the participated to the shearing stress. Figure 3.7 shows wave types. The P-waves can propagate in all types of material but the S-waves can propagate only in material with shearing stress such as solids. A Rayleigh (surfaces) or R – wave is the elliptically polarized in the wave which is determined by propagation along the surface of a solid, and particle motion is a retrograde vertical ellipse [10]

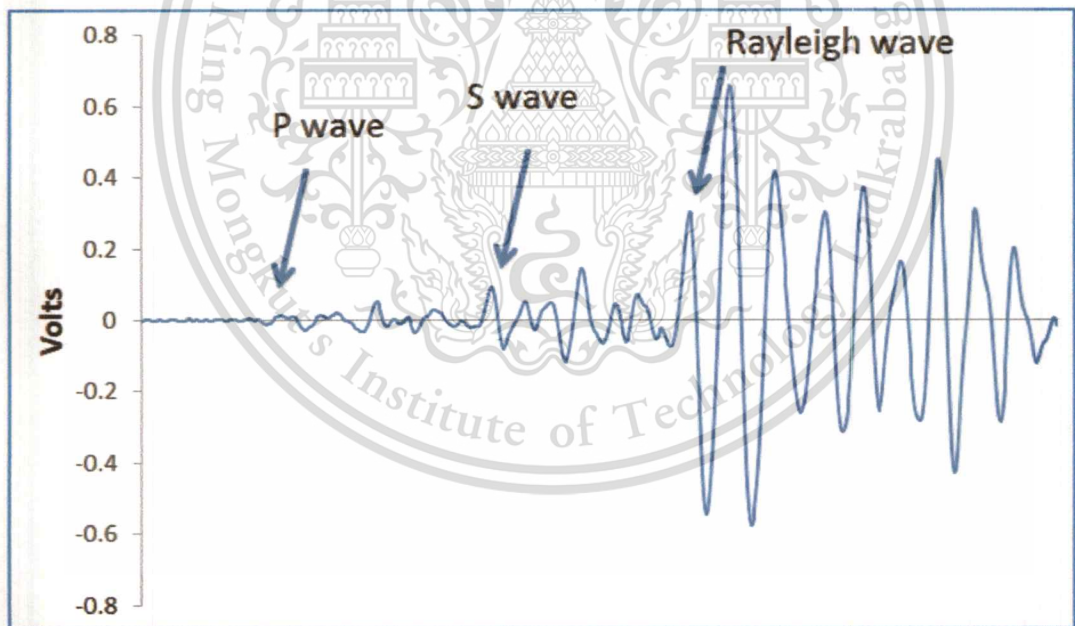


Figure 3.6 : Shows Wave types [11].

3.5.2 Wave Speed

The relationship between the material property and wave speed are from wave propagation in infinite, isotropic or elastic media [10]. In infinite media have only two type of waves; dilatational (P) and distortional(S) so an equation of the infinite elastic solids (C_p) shows as below.

$$C_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} \quad (3.1)$$

$$C_p = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \quad (3.2)$$

where E is a Young's modulus of elasticity, ρ is material density, ν is Poisson's ratio.

In bounded solids (thin plates or long rods), the P- wave speed varies on the lateral dimension of the solid relative to component wavelength [10]. For the Rod structures (such as Piles), The P- wave speed depends on Poisson's ratio, in this case the Rod diameter is less than the wavelength. Then the P- wave speed is also called the "Bar -wave speed (C_b)". The C_b equation shows as below.

$$C_b = \sqrt{\frac{E}{\rho}} \quad (3.3)$$

Normal concrete material the Poisson's ratio = 0.2, then the P-wave speed of infinite solid material is 5% higher than the Bar-wave speed of the long thin rod. The S-wave speed (C_s) of the infinite solid shown as below.

$$C_s = \sqrt{\frac{G}{\rho}} \quad (3.4)$$

where G is shear modules of elasticity; $G = E/2(1-\nu)$

α is ratio between S-wave and P- wave speed, so α equation as below.

$$\alpha = \frac{C_s}{C_p} \sqrt{\frac{(1-2\nu)}{2(1-\nu)}} \quad (3.5)$$

Finding the R –waves speeds (C_R), the question of C_R shows as below.

$$C_R = \frac{0.87+1.12\nu}{1+\nu} C_s \quad (3.6)$$

3.5.3 Reflection and Refraction

When the P- or S- wave front is event on the boundary between different materials, at that time the specular reflection is occurrences. Figure 3.7 A, shows the stress wave can be through the propagating along ray paths. The Ray reflection is similar the light Rays. Normal the angle of refraction of any ray is depended on the angle of event for that Ray.

The stress wave is reflected only at the boundary between two different materials. The rest infiltrates into the underplayed material. The wave speed ratio (C_2/C_1) in the different material shows as below.

$$\sin\beta = \frac{C_2}{C_1} \sin\theta \quad (3.7)$$

where β is angle of refraction, θ is a funtional of the angle incidence.

Stress wave is able to change propagated mode after striking the boundary material at the oblique angle. Referring for the angle of incidence, the P-wave can partial reflection as both P - and S - wave. If S –wave propagation is lower speed than the P-wave, this is reflect and refract at the angles θ_s and β_s . Figure 3.7 B shows the reflected and refracted angle of P-wave are less than reflection and refraction.

For the amplitude of reflected waves depend on the specific acoustic impedances at the interaction area, the distance from source, the angle of event and the attenuation along the wave path [10]. So The P- wave which is reflected at the interaction between two materials depends on the specific acoustic impedances of each material. The equation of specific acoustic impedances (Z) is following as below.

$$Z = pC_p \quad (3.8)$$

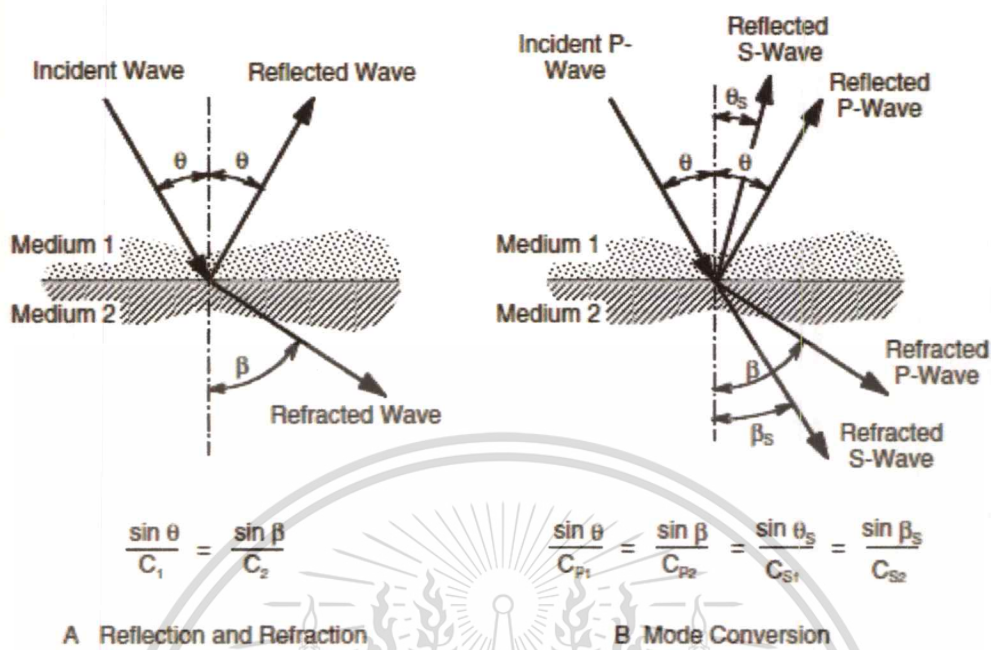


Figure 3.7 : P-wave event on an interaction between different martial [10].

In Table 3.1 shows P wave of specific acoustic impedance values for each material.

Table 3.1 : Example for acoustic impedance [10].

Material	Density(kg/m ³)	P-Wave Speed(m/s)	Specific Acoustic Impredance(kg/m ² -s)
Air	1.205	343	0.413
Concrete	2300	3000-4500	6.9 - 10.4 x 10 ⁶
Granite	2750	5500-6100	15.1 - 16.8 x 10 ⁶
Limestone	2690	2800-7000	7.5 - 18.8 x 10 ⁶
Marble	2650	3700-6900	9.8 - 18.3 x 10 ⁶
Quartzite	2620	5600-6100	14.7 - 16 x 10 ⁶
Soil	1400-2150	200-2000	0.28 - 0.43 x 10 ⁶
Steel	7850	5490	46.6 x 10 ⁶
Water	1000	1480	1.48 x 10 ⁶

3.6 Applied AE to capture head disk interaction in Hard Disk Drive

3.6.1 AE Parameters

AE is the sound that emitted an elastic wave when material is undergoing stress. Normally AE is used stress wave technique to monitor the intensity of mechanical contacts. AE is stress waves produced during mechanical deformation of material which used as the measurements tool to monitor Head Disk Contacts (HDC) in HDD. The elastic stress wave is generated during HDC. The waveform can be analyzed on both time and frequency domains. Figure 3.8 shows AE waveform characteristics in time domain. This is description each AE parameter in time domain.

1. Amplitude is an importance parametric for Acoustic emission because this parameter is used to determine the detecting ability of the signal. If the amplitude is over the minimum threshold, the events will be counted in AE.

$$\text{Amplitude (dB)} = 20 \log_{10} \left(\frac{V_{\max}}{1\mu V} \right) - \text{Gain} \quad (3.8)$$

2. Rise Time is the time of the first amplitude which is over first threshold crossing to the peak amplitude. The rise time is related to the proportional wave between source (stress) and AE sensor. Then this parameter is used to check the signal property and set the criteria of noise filter.
3. Duration is the delta time between the first threshold crossings to the last of threshold crossing. Normally this parameter is used to investigate category of sources and screen out the noisy signals.
4. Counts are the number of the AE signals which is over the threshold setting.
5. Energy is integral signal over the duration time during AE signal is over threshold.

6. Average Frequency [KHz] is calculated from the AE count which is divided by Duration time.

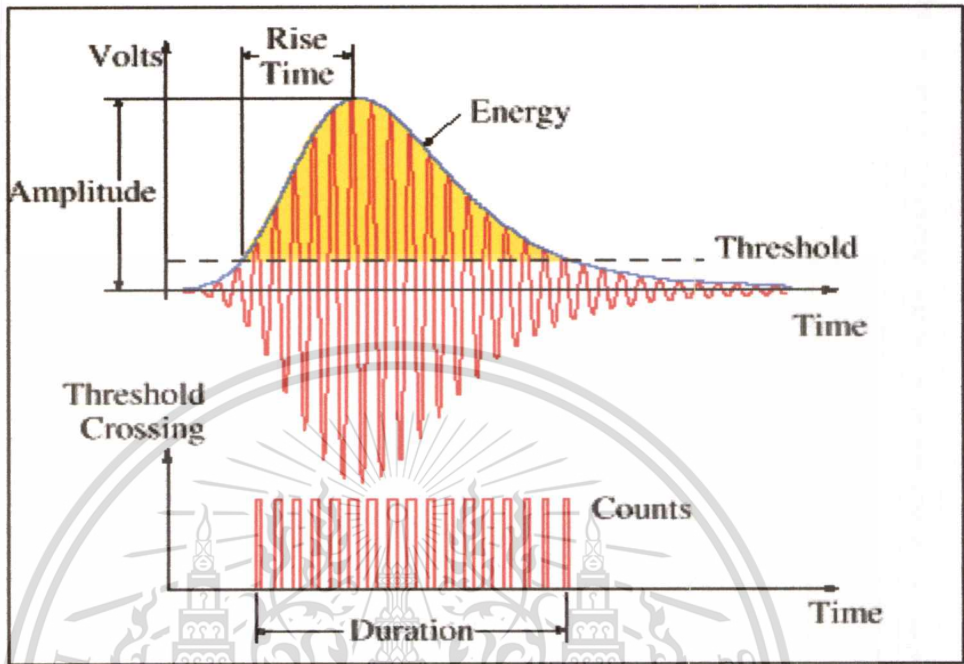


Figure 3.8 : AE waveform characteristics in time domain [3].

In time domain, commonly AE waveform characteristics are interesting in term of AE counts, peak amplitude, rise time, energies and voltage rms. Then the AErms voltage signal in time domain can be calculated follow formula as below.

$$AE_{rms} \text{ voltage} = \sqrt{\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} v^2(t) dt} \quad (3.9)$$

where $v(t)$ is AE voltage signal at time t , $[t_1 \ t_2]$ is interested time range. If $[t_1 \ t_2]$ is suiTable section, the AE rms voltage is refer the power at that time.

In frequency domain, using Fourier transform method to convert the signal waveform from time domain to frequency domain. Usually frequency domain mostly refers to Power spectrum, Nyquist frequency and dominant frequency. AE signal

processing uses frequency domain to get electrical energy. During AE sensing operation, the signal consists of two parts, lower and higher frequencies. The lower frequency represents mechanical contact frequency and the higher frequency represents AE frequency itself so signal output of AE is shown equation as

$$v(t) = f(t) * \sin \omega t \quad (3.10)$$

Where $f(t)$ is the low frequency component and $\sin \omega t$ is the high frequency component that generated by AE itself. The mechanical energy is the low frequency components generated from contacts which is directly proportional to the electrical energy of measured signal [2] that shown as

Mechanical energy $\propto$ Electrical energy

$$\alpha \int_{-\infty}^{\infty} f^2(t) dt = \int_{-\infty}^{\infty} \frac{v^2(t)}{\sin^2 \omega t} dt \quad (3.11)$$

During AE measurement, $\sin \omega t$ is electrical energy that generated by AE itself, so this parameter is removed because this energy is not mechanical energy. From (3.11) electrical energy of the measured signal is related to head disk contact (mechanical energy) which can be obtained using $v(t)$ [2].

$$\text{Mechanical energy} = \int_{-\infty}^{\infty} v^2(t) dt \quad (3.12)$$

3.6.2 Head Disk Interaction (HDI) during Load UnLoad (LUL)

Currently HDD has two typical modes of head parking area Contact Start Stop (CSS) and Load Unload (LUL). CSS is an old technology that head is parking on landing zone (parking on media) when not operating. The landing zone is on the media which is made a bump by laser process. As knowing the head is parking on the media when the system has vibration. The Head and disk contact occurs so this is weak point of CCS HDD which concerns for reliability. Figure 3.9 and 3.10 show CCS HDD system.

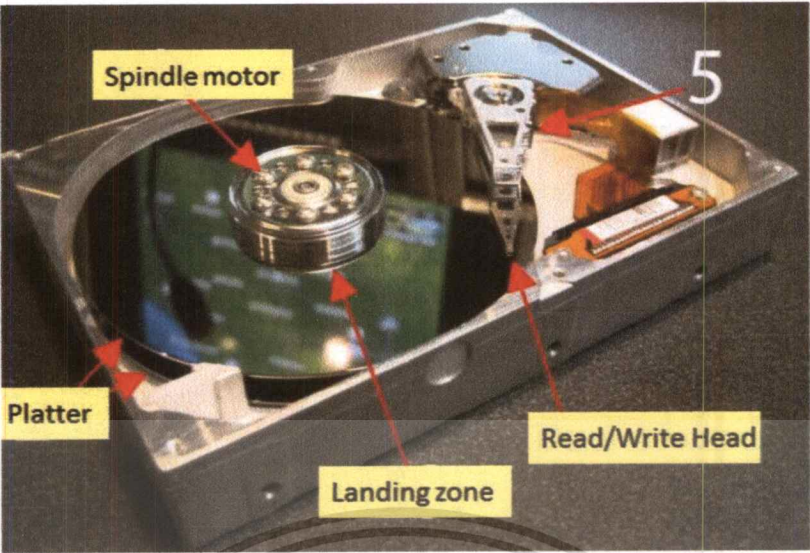


Figure 3.9 : Landing zone location of CSS system [15].

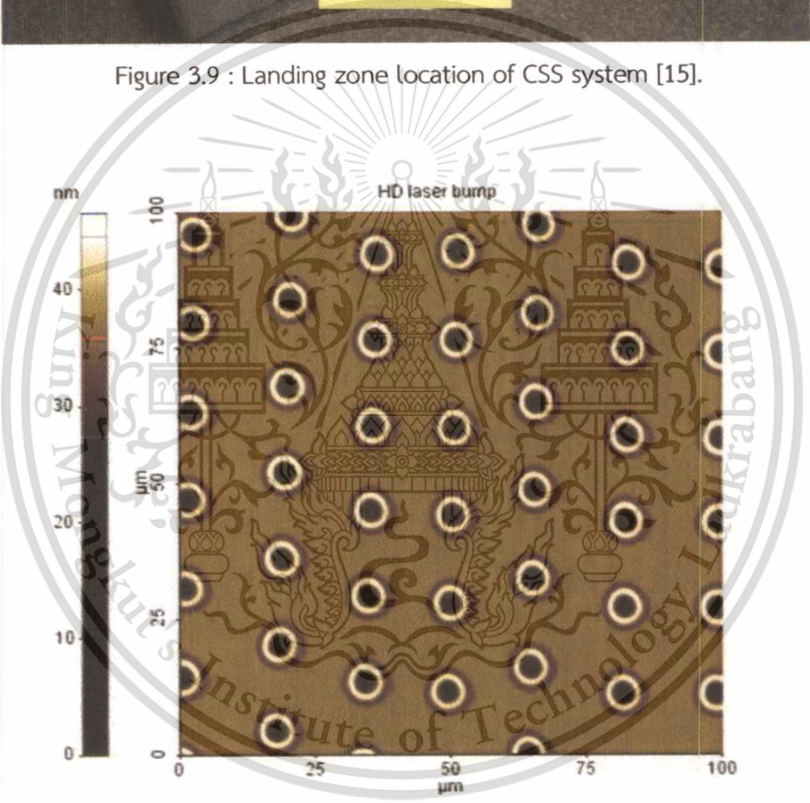
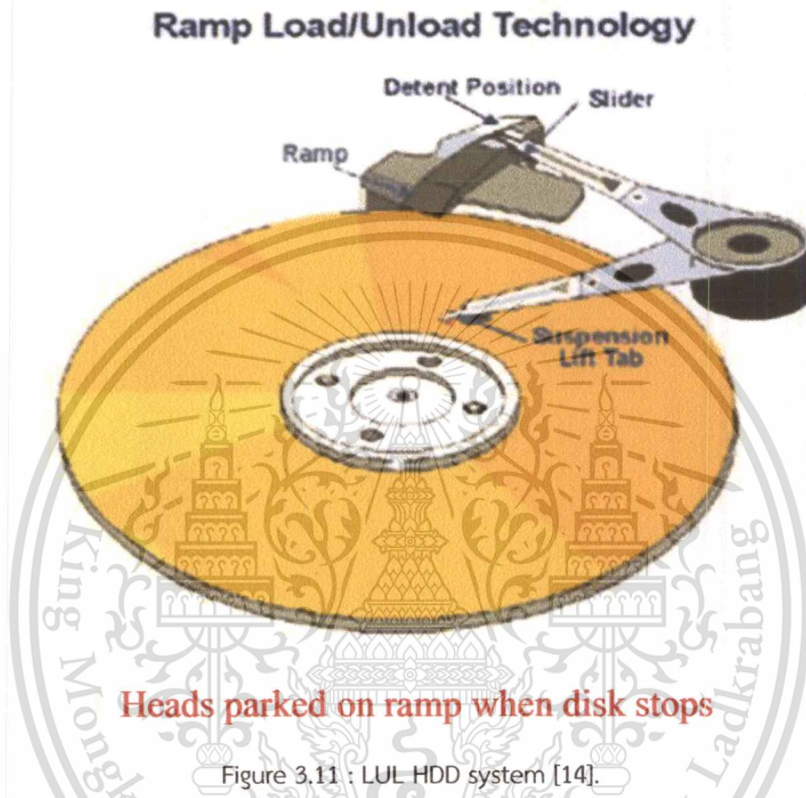


Figure 3.10 : Laser zone texture on platter of CSS system [12].

The LUL is a new technology that head is parking on ramp (outside of media). The concept of LUL is moving the Read/Write head (Slider head) from platter to Ramp when the drive does not operate. The purposed LUL technology is improved HDD reliability due to Head disk contact issue. Figure 3.11 shows LUL HDD system. This work

is focusing solely on LUL technology. In case HDI happens during head loading state (LUL), the read/write head is showing sign of flying ability issue and generating elastic stress waves due to mechanical contacts.



Figures 3.12 and 3.13 show a diagram of head disk contact model during LUL. Vertical head LUL mechanism has two parts; fly height on target when fly over the platter and at certain velocity during head loading. If HDI occurred, the velocity will be suddenly dropped. At that time the slider is deformed and then the kinetic energy is produced as a stress wave with Bending and Torsion energy [2]. The AE sensor is used to measure this energy.

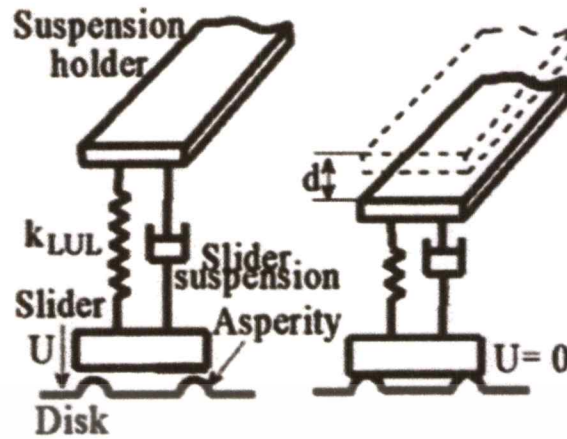


Figure 3.12 : Parametric slider suspension model during vertical load/unload head [2].

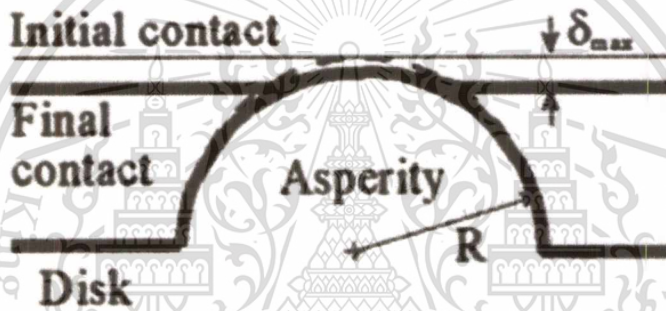


Figure 3.13 : The deformation of disk asperity as a result of HDI during head loading [2].

During HDI occurrence in Hard Disk Drive, the elastic wave is produced so this is formula to calculate the slider energy during HDD occurrence.

$$\text{Slider Energy} = \text{Energy deformation} + \text{Energy detected by AE} \quad (3.13)$$

$$\text{The slider kinetic energy} = \frac{1}{2} MU^2 \quad (3.14)$$

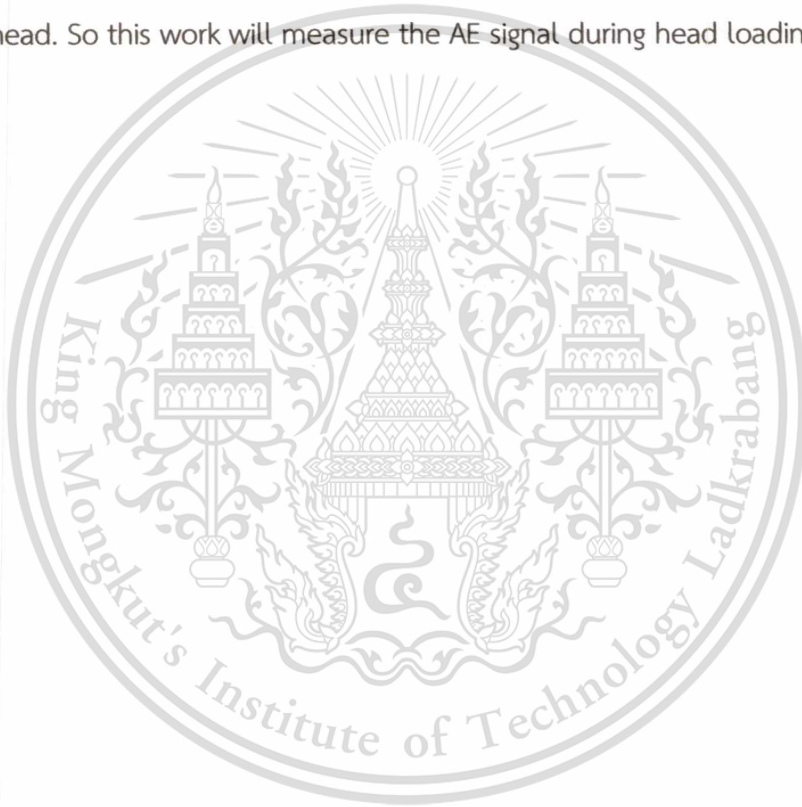
Where M is slider mass, U is the vertical velocity of head loading before HDI. $k_{LUL}d$ is spring force of normal case head loading and thus the maximum deformation of the asperity is[2]

$$\text{Max Asperity deformation energy} = \left(\frac{9(K_{lul}d)^2}{16RE^2} \right)^{1/3} \quad (3.15)$$

E is Young's Modulus for the slider and bump and R is radius. From (3.13) and (3.14), the energy happened during HDI at head loading state is shown in formula [2].

$$\text{Energy detection by AE} = \frac{1}{2}MU^2 - \left(\frac{9(K_{lul}d)^2}{16RE^2} \right)^{1/3} \quad (3.16)$$

From (3.16), almost all of the energy is depending on loading velocity of read/write head. So this work will measure the AE signal during head loading to platter.



CHAPTER 4

Research Methodology

4.1 System development

Designed system considers off line process to detect true Head Disk Interaction (HDI) in Hard Disk Drive (HDD). Figure 4.1 is a schematic diagram for detecting HDI. The designed system can be separated to four steps.

1. The number one represents AE sensor which is attached outside the HDD to measure the AE signal during HDI occurrence. This work is used PICO HF – 1.2 for AE sensor. The Sensor has frequency response range around 500 – 1850 KHz[18].
2. The number two is adjusting amplify gain to match with ADC range because AE signal is small and may need appropriate amplification to improve signal to noise ratio(SNR).

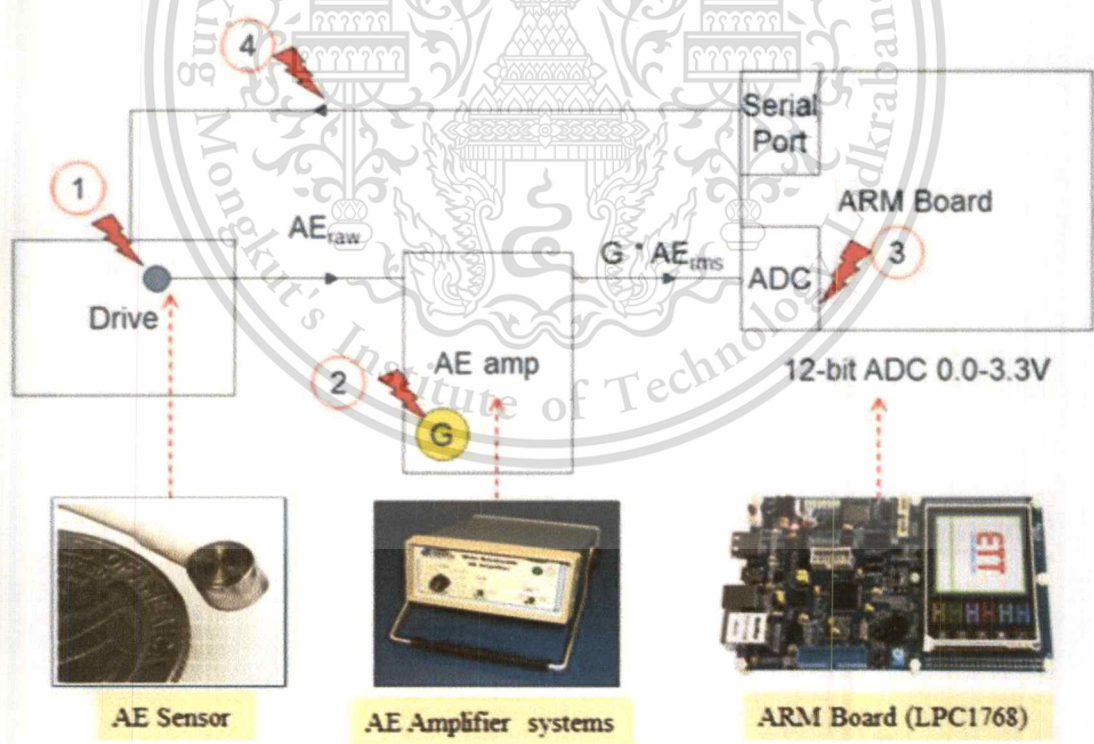


Figure 4. 1 : A schematic diagram for detecting HDI.

3. After that adjust starting points and spans of time to sample AE signal during motor spin and head loading. Normal the AE_{rms} signal is analog signal, in this state the AE_{rms} was converted to digital due to use to be identified true or fault HDI.
4. The last is programing to classify real or fault HDI as flow chart in Figure 4.2.

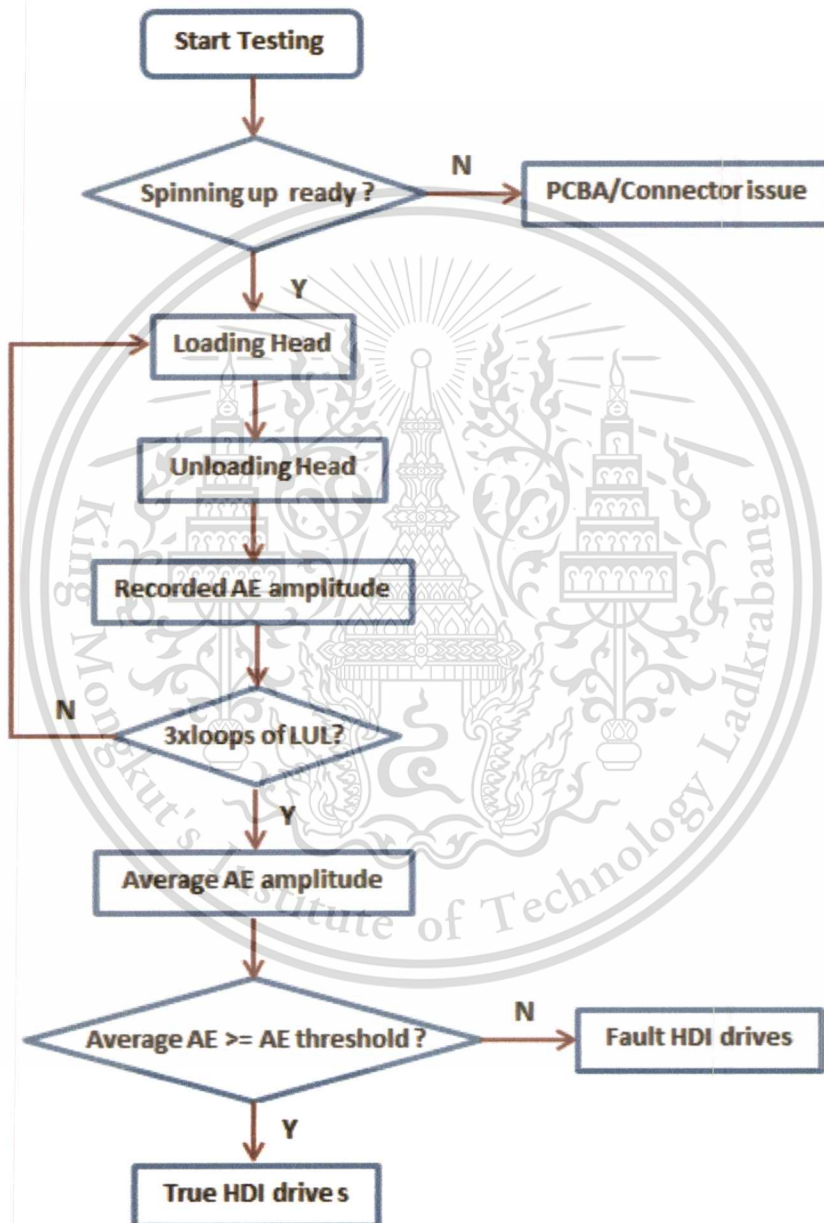


Figure 4.2 : Flow chart program for AE systems.

Figure 4.3 shows AE experimental setup for this work. The AE experiment setting consists of; 1.) Personal computer/Laptop sends command via comport to the testing drive. 2.) The testing drive which is attached to AE sensor at the desired position, receives command from PC for spin-up and load/unload head. 3.) AE sensor sends the analog vibrating signal and amplifies the signal by the configured amplifier. 4) Oscilloscope displays the input signal. This experiment setting is not included Arm board LPC 1768 due to turning the AE system only. The board LPC 1768 is applied the AE system to mass production because the Arm board will be displayed the test drive which is real or fault HDI.

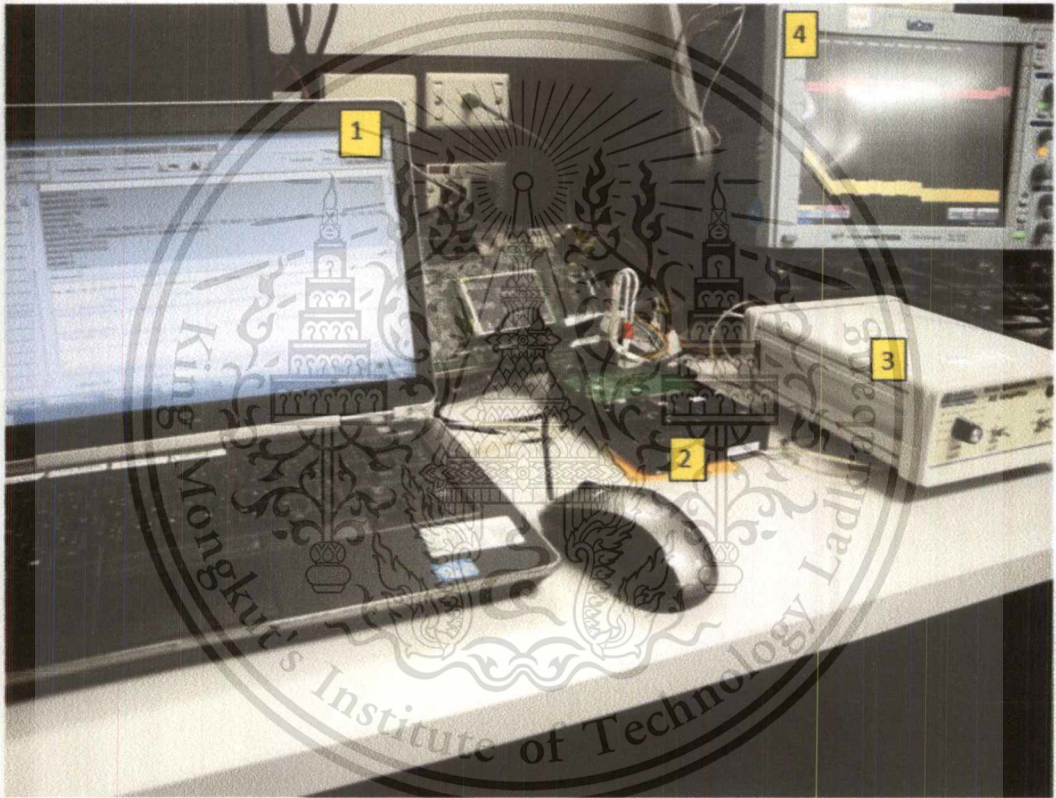


Figure 4.3 : AE experimental setup.

The concept of this work is to detect HDI during head loading, Figure 4.4 shows normalize head loading profile that can explain the loading process after spindling motor has already met Round per Minute (RPM) target. The number one represents head start moving, next head breaks away from detention (RAMP), then head slow down

to constant speed, while head fall off Ramp, after that head start flying out at constant speed and finally head brake at mid stroke.

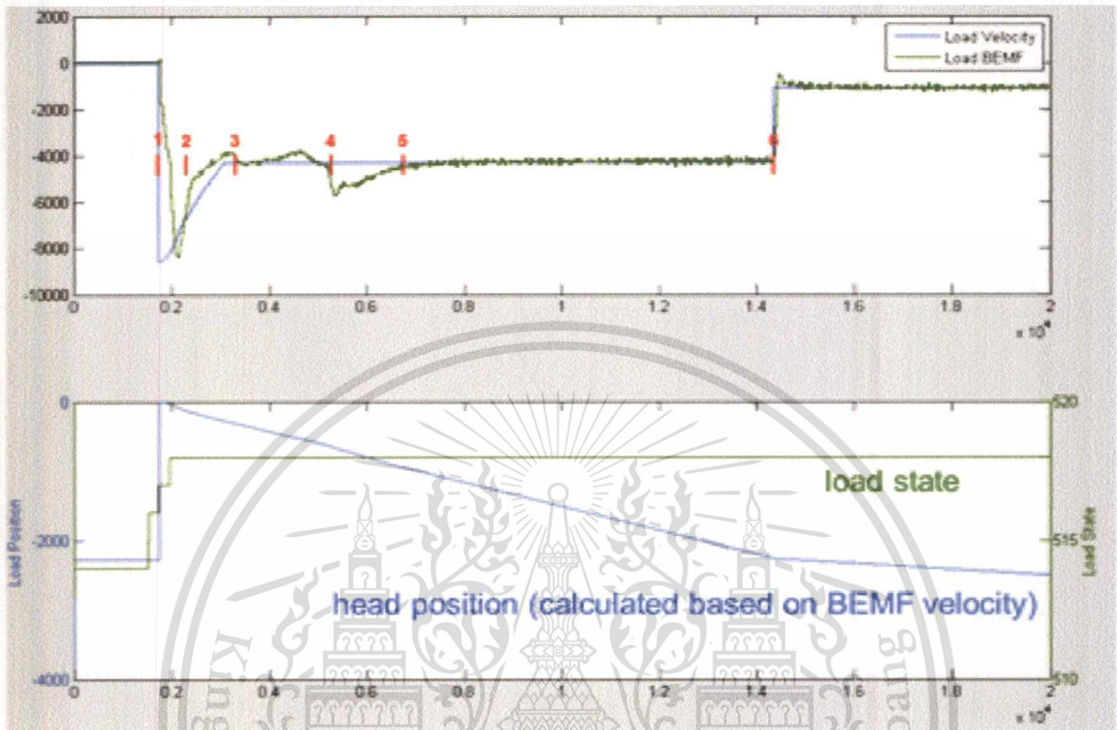


Figure 4.4 : Normalize head loading profile.

4.2 Finding source location of elastic wave during HDI occurrence

As knowing AE sensor can measure the signal after the elastic wave occurs. For this work need to detect HDI in HDD level. Then the AE is placed outside on the HDD. To find where the location for getting the best response for AE signal; the first is finding the location which gives the best response for AE sensor. For the HDD model, the top cover area is thinner and should be better than other areas to get elastic wave. Figure 4.5 shows each area on top cover which is attached AE sensor.

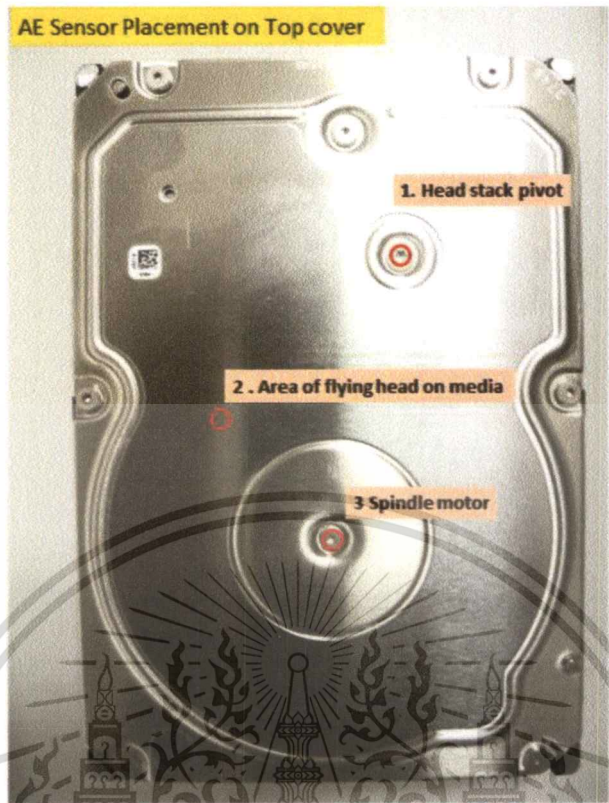


Figure 4.5 : AE sensor placement on each location on HDD top cover.

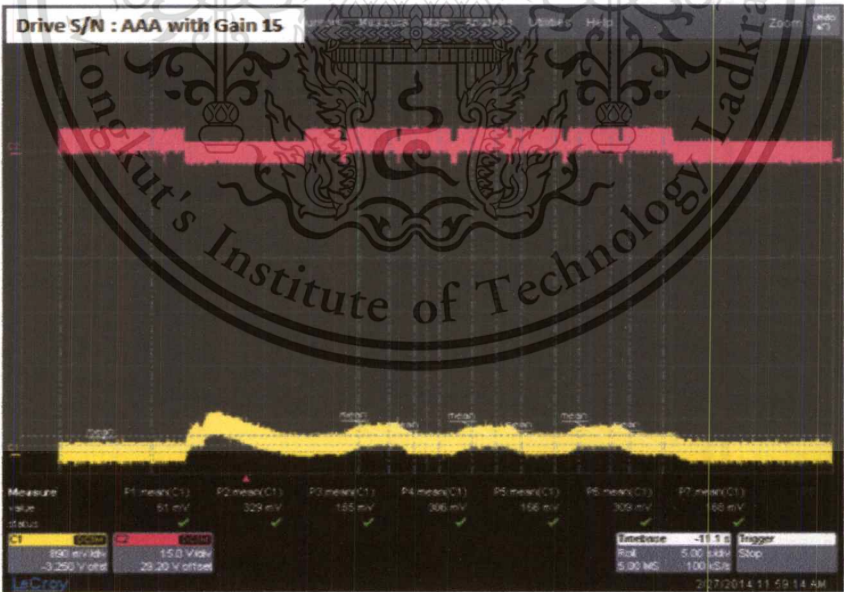


Figure 4.6 : AE signal which placed AE sensor on the flying head area.

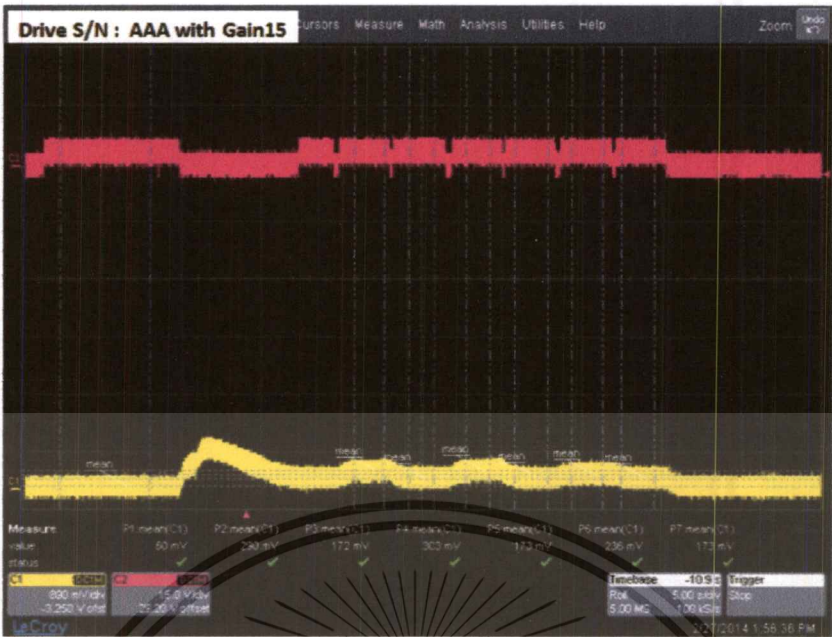


Figure 4.7 : AE signal which placed on spindle motor.

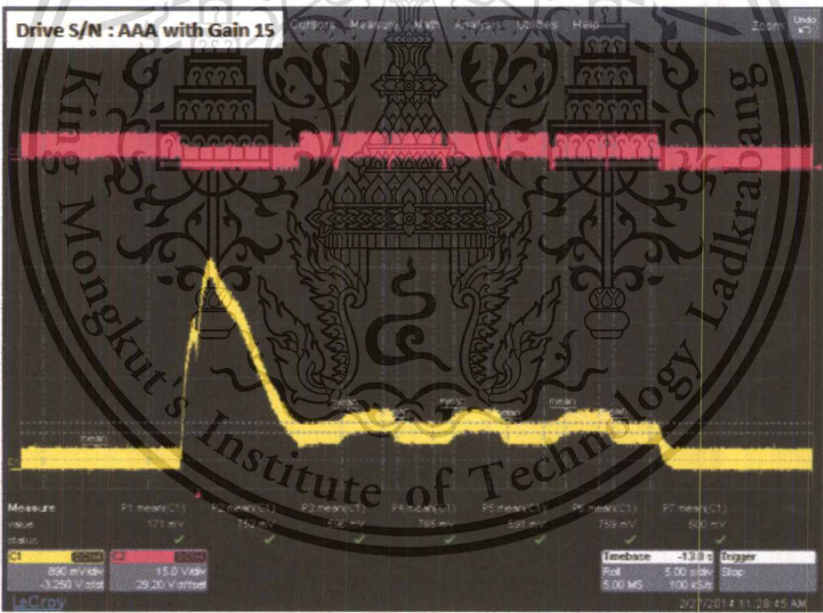


Figure 4.8 : AE signal which placed on the actuator pivot of HSA.

Figures 4.6-4.8 show AE response in each location on top cover. The scope signal of attached AE sensor is on the flying head area which is the lowest response for the AE

signal. For the spindling motor area, the responding AE signal is a bit better than the flying head area.

Base on AE signal was measured each location on HDD top cover area; the attached AE sensor on the actuator pivot of head stack assembly (HSA) is the best response. Then this work use this location to be attached the AE sensor for measured the AE signal.

4.3 Optimized AE Amplifier Gain

The AE_{rms} signal is small signal and may need appropriate amplification to improve Signal to Noise Ratio (SNR). Then the optimized AE amplifies gain to match with ADC range is necessary. This system is used AE5A amplifier because the Amplifier is small, high performance and filter an incoming AE signal (direct from AE sensor or from an external preamplifier). The AE5A amplifier has two types of output signal; AE_{rms} voltage and AE peak detection output. Then the AE5A amplifier modules are switch selectable. This work is used AE_{rms} output which is useful to assess the stability of ABS (Air Bearing) during HDI occurs. In this case when the acoustic energy is maintained long enough to make RMS measurements.

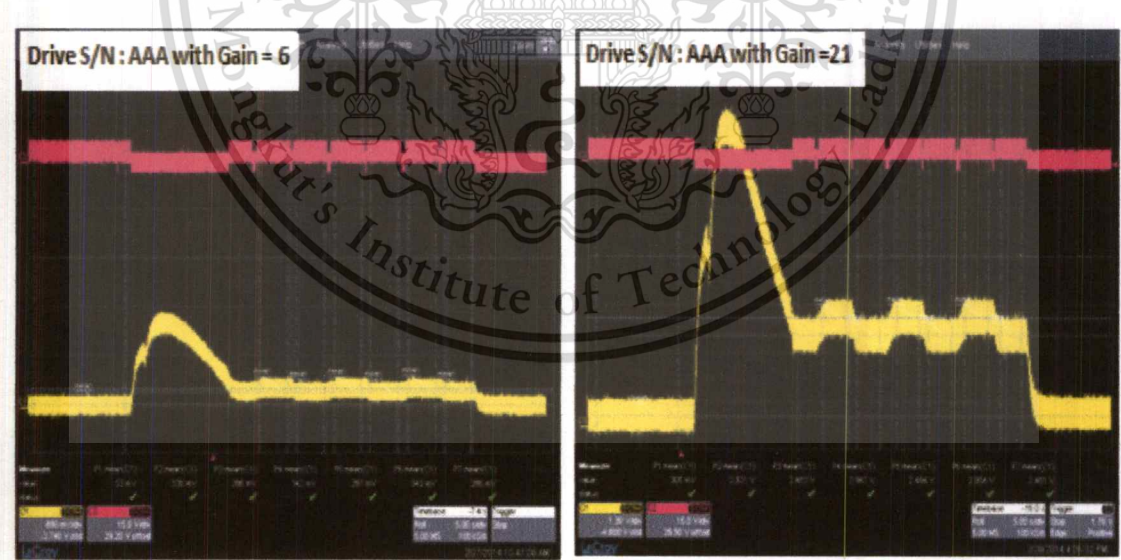


Figure 4.9 : AE signal with different Gain adjustment.

Figure 4.9 shows the AE signal with different Gain. As seeing on the AE signal with gain 15 shows the good SNR, good shape...etc. However the optimized Gain depend on the HDD design. Therefore before using the AE to detect HDI must be optimized the gain.

4.4 Identified HDD is true or fault HDI

The AE_{rms} signal of the AE5A amplifier is analog signal. This analog signal is converted to Digital signal by Arm Board (ET-NXP ARM KIT (LPC1768)). After that the ADC signal is used to identify the HDD whether true or fault HDI. As knowing each HDD model is different design such as HDD size(3.5" or 2.5 inch), HDD capacity, Head design, RPM(round per minutes), HDD mechanical design etc... So before the Arm board is using to be identified HDI for each HDD model, the Arm Board is also optimized or taught follow up the HDD design.

4.5 Experiment to detect HDI

This experiment is studying to be detected HDI of HDD model and what is the key for contributed AE signal. Normally HDD operation has many states, so this work will be used AE_{rms} signal between spin up and loading head to disk, can be used as a criterion to differentiate actual from false HDI.

4.5.1 Scope signal during HDI occurrence

Scope signal Figure 4.10 is AE_{RMS} during Load (HDI). The AE_{rms} signals measure since motor spin-up until completion of head loading. AE signal can be split into four states: the first step is spinning up motor; next BEMF Closed Loop Spin; then spinning complete and waiting for two seconds; and finally starting head loading to platter. Observation AE sensor gives out high AE_{rms} signal in all states, but the system is interested only in state four because this is started head loading. At head loading state, the AE sensor can measure AE_{rms} signal so it means that the head disk interaction occurs and then generates stress wave (Bending and Torsion Energy).

Generally the Spectrogram represents the spectrum of frequencies in a sound, elastic wave ...etc. The spectrogram is energy graph which consists of frequency (y axis) and time function(x axis) [4]. The AE signal is converted to Spectrogram which represents energy spectrum in frequency domain over time. When the spectrum frequency shows high value at particular frequency at certain point in time, it means sound amplitude at that particular frequency is emitted around that given time. Fig 4.11 is Spectrogram of AE_{rms} signal during HDI occurrence. This Spectrogram is represented since spin-up until head flying over media during HDI occurs. It can be observed that the Spectrogram is high spectrum at head loading state and after that the spectrums still maintain the high spectrum value which means head has continuous contact with media.

Figure 4.12 is Spectrogram of AE_{rms} signal for Non-HDI drive. This Spectrogram is represented since spin-up until head fly over media. Seeing on the normalized AE_{rms} almost show no difference signal level before and after head loading. So that means this drive doesn't have any elastic waves. Then this drive is none HDI.

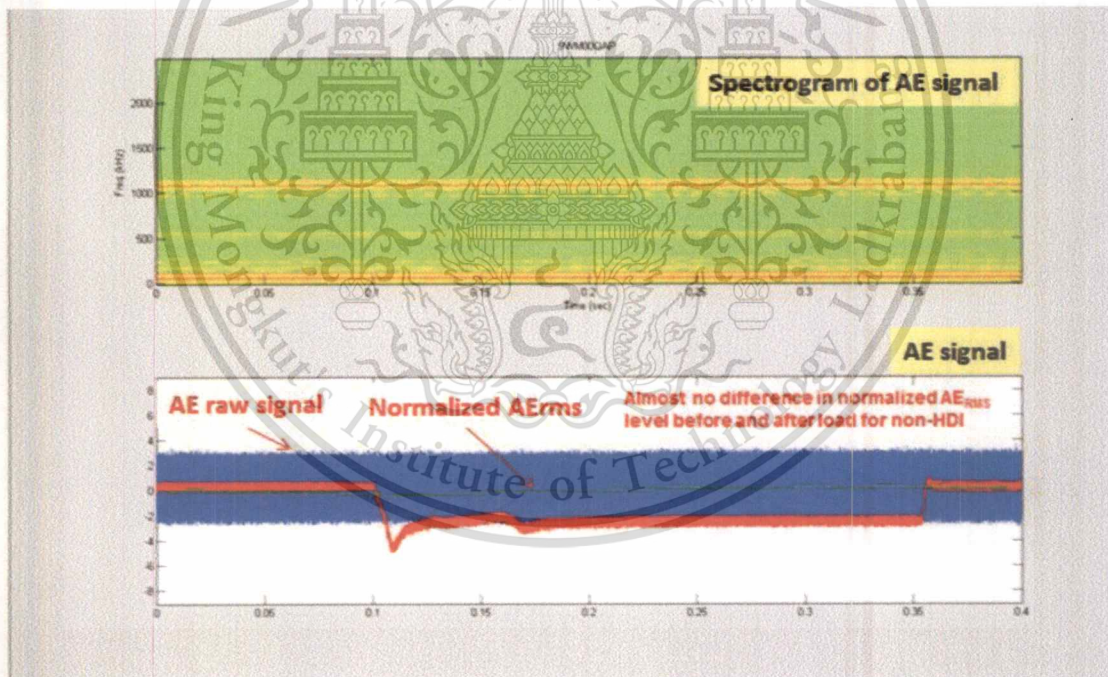


Figure 4.12 : Spectrogram of AE_{rms} signal for non-HDI HDD.

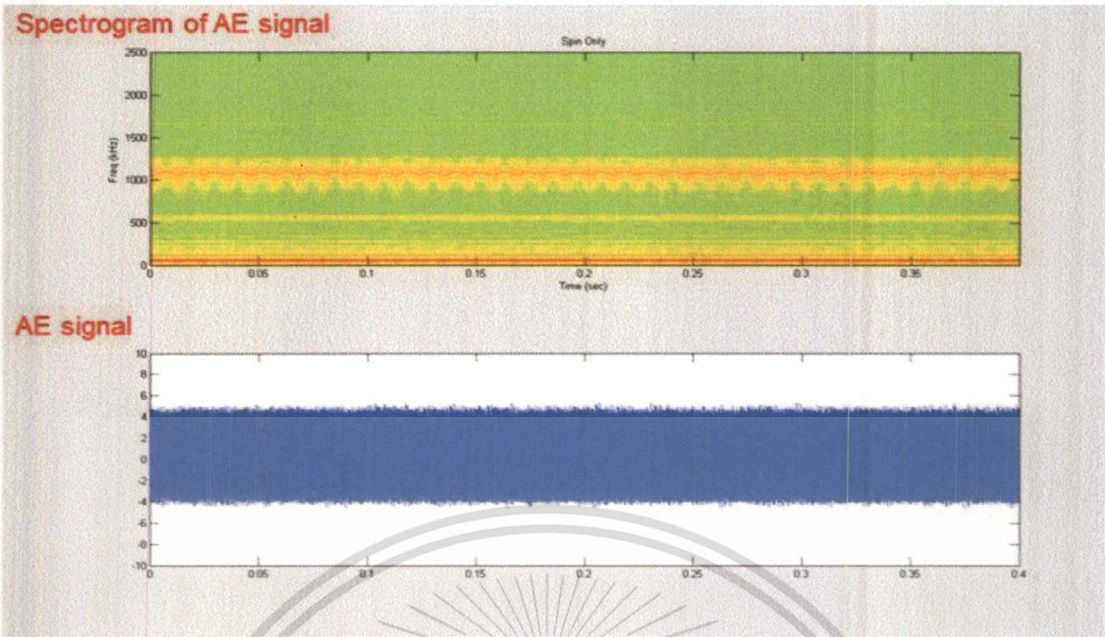


Figure 4.13 : Spectrogram for the HDI drives during spin only.

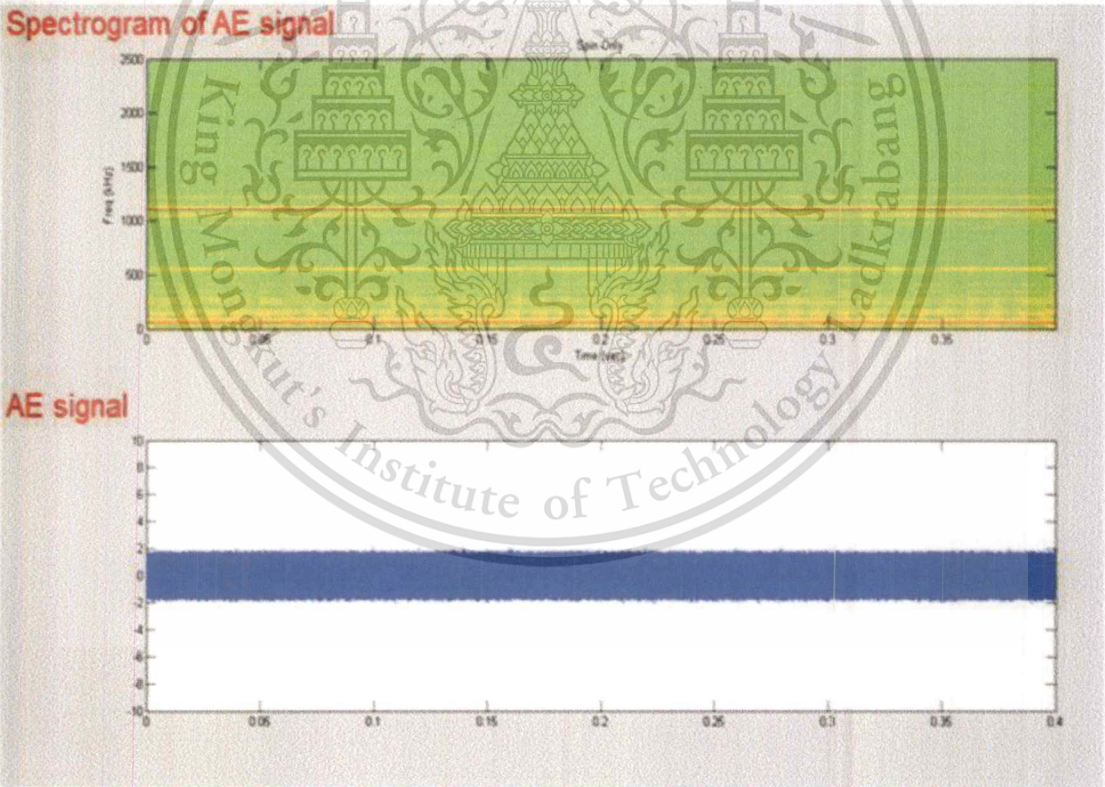


Figure 4.14 : Spectrogram for the non- HDI drive during spin only

Figure 4.13 and Figure 4.14 show the Spectrogram of the HDI and non-HDI drive during spin mode only. Observed both HDI and non-HDI drives are similar AE signal's response. The Spectrogram exhibits a bit elastic wave occurrence.

4.5.3 HDD Model 2.5 inch Experiment

The HDI candidates of 2.5" HDD have been collected on both 4xHeader and 8-Header configurations of a certain drive model to determine AE_{rms} threshold. The experiment is selected the HDI candidate from servo mechanical failure around 100xdrives per groups to optimized the AE_{rms} threshold for each model. The sequence of the experiment will bring the HDI candidate to be optimized Gain and measured the AE signal between spin up and loading head to disk for each drives. After that the drives were confirmed by visual inspection to be turning the AE threshold for each HDD model.

This is step to optimized the AE_{rms} threshold which is follow; the first step is measured spin noise of AE_{rms} during steady state motor spin; and the final state is measured AE_{rms} during head loading to platter. So this is formula to finding the AE_{rms} threshold.

$$AE_{rms} \text{ threshold} = AE_{rms} \text{ signal of head loading to platter} - AE_{rms} \text{ Motor spin (4.1)}$$

4.5.3.1 8-Header with 7200 RPM experiment result

For 8-Header configuration after optimized the amplified gain is around 21. After that the 100x drives were measure the AE_{rms} to finding the AE_{rms} threshold. In Table 4.1 and 4.2 are individual delta AE_{rms} (Head load – Motor spin) between HDI drives and non-HDI drives respectively. Base on Table 4.1and 4.2, observe that the most HDI drives have delta AE_{rms} is higher than 78 mV. But the most non- HDI drives have delta AE_{rms} is less than 78 mV. Then the 8-Header configuration is setting AE_{rms} threshold = 78 mV. However Table 4.1 and Table 4.2 have some drives misclassification between the true and fault HDI. The root cause of misclassification has many factors such as Resonance in HDD, light HDI, Modulation, etc...

Table 4.1 : Individual delta AErms for 8-Header (7200 RPM drive) HDI drives.

Drive S/N	AErms Motor spin (mV)	AErms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
A01	938	1244	306	HDI
A02	1006	1278	272	HDI
A03	962	1219	257	HDI
A04	1004	1246	242	HDI
A05	1029	1255	226	HDI
A06	983	1204	221	HDI
A07	1015	1235	220	HDI
A08	975	1192	217	HDI
A09	945	1159	214	HDI
A10	923	1137	214	HDI
A11	948	1161	213	HDI
A12	982	1195	213	HDI
A13	963	1176	213	HDI
A14	932	1133	201	HDI
A15	977	1175	198	HDI
A16	969	1165	196	HDI
A17	988	1180	192	HDI
A18	975	1166	191	HDI
A19	934	1123	189	HDI
A20	1030	1210	180	HDI
A21	1010	1186	176	HDI
A22	991	1165	174	HDI
A23	943	1112	169	HDI
A24	976	1145	169	HDI
A25	1008	1174	166	HDI
A26	1010	1168	158	HDI
A27	983	1141	158	HDI
A28	946	1104	158	HDI
A29	989	1144	155	HDI
A30	988	1138	150	HDI
A31	950	1097	147	HDI
A32	927	1069	142	HDI
A33	983	1112	129	HDI
A34	986	1107	121	HDI
A35	963	1075	112	HDI
A36	978	1084	106	HDI
A37	950	1054	104	HDI
A38	993	1071	78	HDI
A39	994	1060	66	HDI
A40	956	1020	64	HDI
A41	959	1013	54	HDI
A42	55	74	19	HDI
A43	42	43	1	HDI

Table 4.2 : Individual delta AERms for 8-Header (7200 RPM drive) non-HDI drives.

Drive S/N	AERms Motor spin (mV)	AERms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
A44	953	954	1	Non HDI
A45	1066	1067	1	Non HDI
A46	1059	1060	1	Non HDI
A47	955	957	2	Non HDI
A48	1070	1081	11	Non HDI
A49	1002	1032	30	Non HDI
A50	987	1018	31	Non HDI
A51	962	997	35	Non HDI
A52	999	1035	36	Non HDI
A53	978	1015	37	Non HDI
A54	1000	1037	37	Non HDI
A55	1015	1052	37	Non HDI
A56	1007	1046	39	Non HDI
A57	1021	1061	40	Non HDI
A58	971	1012	41	Non HDI
A59	986	1028	42	Non HDI
A60	982	1025	43	Non HDI
A61	1019	1063	44	Non HDI
A62	975	1019	44	Non HDI
A63	1008	1052	44	Non HDI
A64	964	1008	44	Non HDI
A65	981	1025	44	Non HDI
A66	1001	1045	44	Non HDI
A67	940	984	44	Non HDI
A68	1002	1047	45	Non HDI
A69	965	1011	46	Non HDI
A70	996	1042	46	Non HDI
A71	956	1002	46	Non HDI
A72	980	1026	46	Non HDI
A73	1026	1074	48	Non HDI
A74	1037	1085	48	Non HDI
A75	1028	1076	48	Non HDI
A76	915	963	48	Non HDI
A77	957	1006	49	Non HDI
A78	1008	1057	49	Non HDI
A79	1023	1072	49	Non HDI
A80	900	950	50	Non HDI
A81	980	1032	52	Non HDI
A82	1008	1061	53	Non HDI
A83	978	1031	53	Non HDI
A84	941	996	55	Non HDI
A85	940	997	57	Non HDI
A86	973	1030	57	Non HDI
A87	1036	1095	59	Non HDI
A88	954	1013	59	Non HDI
A89	930	989	59	Non HDI
A90	1013	1074	61	Non HDI
A91	970	1032	62	Non HDI
A92	959	1023	64	Non HDI
A93	995	1060	65	Non HDI
A94	975	1041	66	Non HDI
A95	954	1021	67	Non HDI
A96	1055	1126	71	Non HDI
A97	925	997	72	Non HDI
A98	1021	1094	73	Non HDI
A99	967	1045	78	Non HDI
A100	962	1068	106	Non HDI

Table 4.3 is calculated AE accuracy to detect HDI of 8Hd configuration. So far AE_{rms} threshold = 78 mV has had accuracy around 93% with over reject around 2 % and escape around 5% respectively.

Table 4.3 : AE accuracy to detect HDI of 8-Header with 7200 RPM configuration.

Confirmed by VMI	AE Classification	Drive quantity
HDI Drives	HDI Drives	38
	Non-HDI Drives	5
Non-HDI Drives	HDI Drives	2
	Non-HDI Drives	55
Total quantity		100
AE Accuracy		93.0%

Figure 4.15 is based on experiment results AE_{rms} threshold of 8Hd = 78mV are determined. After confirmation by visual inspection, the detection accuracy of actual HDI is calculated to be around 93%.

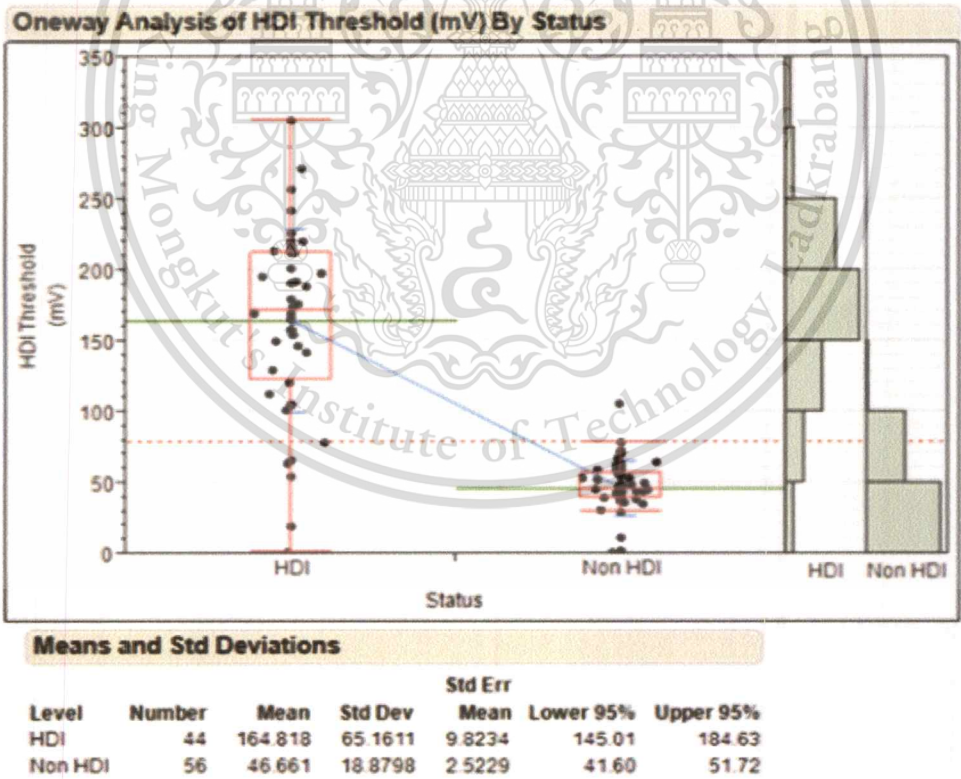


Figure 4.15 : Experiment result for 8xHeader (7200 RPM) with threshold = 78mV.

4.5.3.2 4-Header with 7200 RPM experiment result

For 4-Header configuration after optimized the amplified gain is around 21. After that the 100x drives were measured the AE_{rms} to finding the AE_{rms} threshold. In Table 4.4 and 4.5 are individual delta AE_{rms} (Head load – Motor spin). Between HDI drives and non-HDI drives respectively. Base on Table 4.4and 4.5, observe that the most HDI drives have delta AE_{rms} is higher than 64 mV. But the most non- HDI drives have delta AE_{rms} is around 33-50 mV. Then the 4-Header configuration is setting AE_{rms} threshold = 64 mV. However Table 4.4 and Table 4.5 have some drive mis-classification between the true and fault HDI. The root cause of mis-classification has many factors such as Resonance in HDD, light HDI, etc...

Table 4.4 : Individual delta AE_{rms} for 4-Header (7200 RPM drive) HDI drives.

Drive S/N	AErms Motor spin (mV)	AErms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
B01	908	1043	135	HDI
B02	954	1071	117	HDI
B03	916	1021	105	HDI
B04	947	1048	101	HDI
B05	936	1066	130	HDI
B06	896	971	75	HDI
B07	970	1165	195	HDI
B08	908	1042	134	HDI
B09	929	1048	119	HDI
B10	784	903	119	HDI
B11	823	971	148	HDI
B12	875	991	116	HDI
B13	909	1050	141	HDI
B14	993	1090	97	HDI
B15	904	1116	212	HDI
B16	860	1027	167	HDI
B17	841	1033	192	HDI
B18	890	1012	122	HDI
B19	923	1129	206	HDI
B20	917	1073	156	HDI
B21	945	1047	102	HDI
B22	949	1086	137	HDI
B23	872	973	101	HDI
B24	955	1178	223	HDI
B25	912	1026	114	HDI
B26	889	999	110	HDI
B27	934	1104	170	HDI
B28	940	1022	82	HDI
B29	922	1059	137	HDI
B30	912	1090	178	HDI
B31	973	1035	62	HDI
B32	905	1054	149	HDI
B33	966	1114	148	HDI
B34	895	1019	124	HDI
B35	888	1103	215	HDI
B36	884	1054	170	HDI
B37	896	1082	186	HDI
B38	37	43	6	HDI
B39	1042	1045	3	HDI
B40	924	1074	150	HDI
B41	881	992	111	HDI
B42	869	1024	155	HDI
B43	934	1054	120	HDI

Table 4.5 : Individual delta AE_{rms} for 4-Header (7200 RPM drive) non-HDI drives.

Drive S/N	AErms Motor spin (mV)	AErms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
B44	923	967	44	NON HDI
B45	896	971	75	NON HDI
B46	921	1014	93	NON HDI
B47	940	980	40	NON HDI
B48	934	970	36	NON HDI
B49	951	989	38	NON HDI
B50	954	992	38	NON HDI
B51	949	1000	51	NON HDI
B52	972	1011	39	NON HDI
B53	947	982	35	NON HDI
B54	970	1011	41	NON HDI
B55	938	976	38	NON HDI
B56	909	942	33	NON HDI
B57	934	972	38	NON HDI
B58	892	940	48	NON HDI
B59	958	997	39	NON HDI
B60	929	983	54	NON HDI
B61	943	985	42	NON HDI
B62	916	961	45	NON HDI
B63	940	999	59	NON HDI
B64	875	916	41	NON HDI
B65	952	998	46	NON HDI
B66	895	932	37	NON HDI
B67	932	976	44	NON HDI
B68	916	964	48	NON HDI
B69	934	974	40	NON HDI
B70	891	947	56	NON HDI
B71	885	917	32	NON HDI
B72	925	964	39	NON HDI
B73	930	970	40	NON HDI
B74	976	1024	48	NON HDI
B75	969	1023	54	NON HDI
B76	965	1008	43	NON HDI
B77	948	992	44	NON HDI
B78	958	1004	46	NON HDI
B79	915	961	46	NON HDI
B80	922	965	43	NON HDI
B81	921	960	39	NON HDI
B82	957	1004	47	NON HDI
B83	874	929	55	NON HDI
B84	935	969	34	NON HDI
B85	939	977	38	NON HDI
B86	907	962	55	NON HDI
B87	876	934	58	NON HDI
B88	895	944	49	NON HDI
B89	900	954	54	NON HDI
B90	901	953	52	NON HDI
B91	935	971	36	NON HDI
B92	902	955	53	NON HDI
B93	896	949	53	NON HDI
B94	930	994	64	NON HDI
B95	882	934	52	NON HDI
B96	927	963	36	NON HDI
B97	907	968	61	NON HDI
B98	924	969	45	NON HDI
B99	939	980	41	NON HDI
B100	923	977	54	NON HDI

In Table 4.6 is calculated AE accuracy to detect HDI of 4-Header configuration. So far AE_{rms} threshold = 64 mV has had accuracy around 94% with over reject around 3% and over escape around 3% respectively.

Table 4.6 : AE accuracy to detect HDI of 4-header configuration.

Confirmed by VMI	AE Classification	Drive quantity
HDI Drives	HDI Drives	40
	Non-HDI Drives	3
Non-HDI Drives	HDI Drives	3
	Non-HDI Drives	54
Total quantity		100
AE Accuracy		94.0%

For fig 4.16 is based on experiment results AE_{rms} threshold of 4-Header = 64mV are determined. After confirmation by visual inspection, the detection accuracy of actual HDI is calculated to be around 94%.

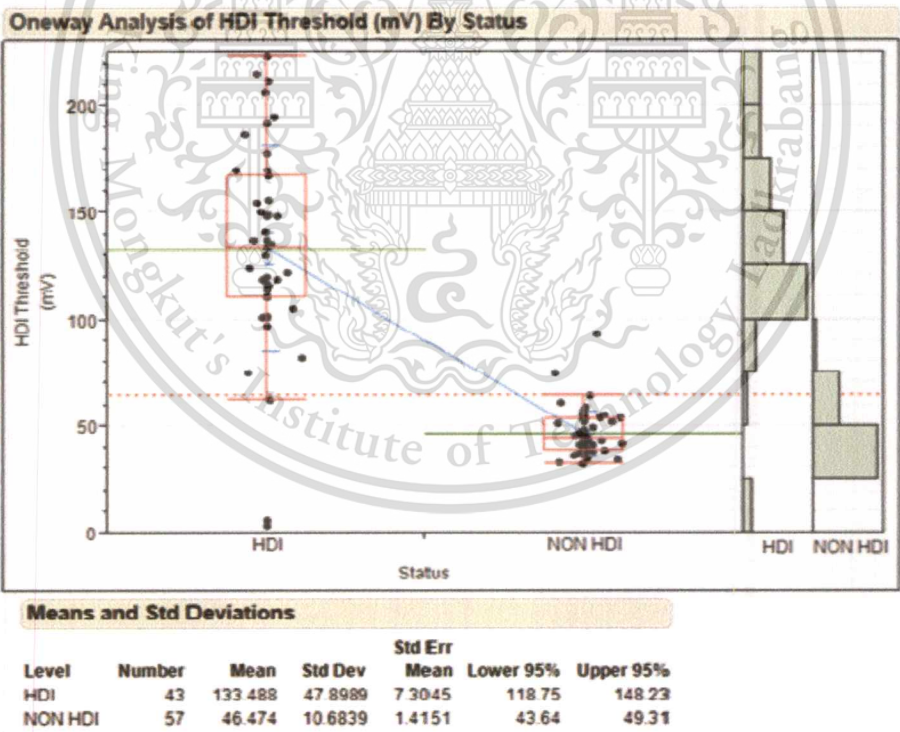


Figure 4.16 : Experiment result for 4xHeader(7200 RPM) with threshold = 64mV.

4.5.3.3 8-Header with 10000 RPM experiment result

For 8-Header configuration after optimized the amplified gain is around 21. After that the 100x drives were measure the AE_{rms} to finding the AE_{rms} threshold. In Tables 4.7 and 4.8 are individual delta AE_{rms} (Head load – Motor spin) between HDI drives and non-HDI drives respectively. Base on Table 4.7 and 4.8, observe that the most HDI drives have delta AE_{rms} is higher than 85 mV. Then the 8-Header with RPM 10000 is setting AE_{rms} threshold = 85 mV. However, some drives have mis-classification between the true and fault HDI. The root causes of mis-classification the same as the 8-Header and 4-Header with 7200 RPM configuration

Table 4.7 : Individual delta AE_{rms} for 8-Header (10000 RPM drive) HDI drives

Drive S/N	AE_{rms} Motor spin (mV)	AE_{rms} signal head loading (mV)	Delta AE_{rms} (Head loading - Motor spin) (mV)	Confirmed by VMI
C01	2659	3043	384	HDI
C02	3543	3924	381	HDI
C03	2682	3011	329	HDI
C04	3210	3496	286	HDI
C05	2949	3225	276	HDI
C06	2321	2582	261	HDI
C07	3279	3535	256	HDI
C08	2554	2804	250	HDI
C09	2891	3141	250	HDI
C10	3034	3283	249	HDI
C11	2622	2865	243	HDI
C12	3330	3570	240	HDI
C13	2919	3154	235	HDI
C14	2425	2657	232	HDI
C15	2354	2586	232	HDI
C16	3504	3735	231	HDI
C17	3281	3501	220	HDI
C18	3288	3506	218	HDI
C19	2303	2509	206	HDI
C20	3276	3465	189	HDI
C21	3321	3510	189	HDI
C22	2835	3004	169	HDI
C23	3039	3169	130	HDI
C24	3050	3178	128	HDI
C25	2780	2898	118	HDI
C26	3260	3360	100	HDI
C27	3268	3359	91	HDI
C28	2876	2961	85	HDI
C29	3396	3475	79	HDI
C30	2990	3062	72	HDI
C31	2251	2255	4	HDI
C32	2389	2390	1	HDI

Table 4.8 : Individual delta AE_{rms} for 8-Header (10000 RPM drive) non-HDI drives.

Drive S/N	AErms Motor spin (mV)	AErms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
C33	2964	3102	138	NON-HDI
C34	3243	3376	133	NON-HDI
C35	3304	3402	98	NON-HDI
C36	3505	3598	93	NON-HDI
C37	3267	3350	83	NON-HDI
C38	3254	3336	82	NON-HDI
C39	3174	3255	81	NON-HDI
C40	2305	2384	79	NON-HDI
C41	2980	3058	78	NON-HDI
C42	3167	3243	76	NON-HDI
C43	3304	3378	74	NON-HDI
C44	2940	3011	71	NON-HDI
C45	2854	2923	69	NON-HDI
C46	2741	2809	68	NON-HDI
C47	3014	3080	66	NON-HDI
C48	2887	2952	65	NON-HDI
C49	3110	3175	65	NON-HDI
C50	2749	2812	63	NON-HDI
C51	3363	3425	62	NON-HDI
C52	2433	2495	62	NON-HDI
C53	2999	3056	57	NON-HDI
C54	2769	2825	56	NON-HDI
C55	2822	2878	56	NON-HDI
C56	3325	3380	55	NON-HDI
C57	3147	3201	54	NON-HDI
C58	2736	2790	54	NON-HDI
C59	2796	2847	51	NON-HDI
C60	3125	3173	48	NON-HDI
C61	3328	3375	47	NON-HDI
C62	3089	3136	47	NON-HDI
C63	2846	2892	46	NON-HDI
C64	2535	2581	46	NON-HDI
C65	3447	3490	43	NON-HDI
C66	2893	2934	41	NON-HDI
C67	2889	2927	38	NON-HDI
C68	2196	2232	36	NON-HDI
C69	2856	2892	36	NON-HDI
C70	2965	2998	33	NON-HDI
C71	2794	2824	30	NON-HDI
C72	3014	3044	30	NON-HDI
C73	3146	3176	30	NON-HDI
C74	2692	2721	29	NON-HDI
C75	3215	3244	29	NON-HDI
C76	2947	2975	28	NON-HDI
C77	2426	2451	25	NON-HDI
C78	3011	3036	25	NON-HDI
C79	3129	3154	25	NON-HDI
C80	2731	2755	24	NON-HDI
C81	3034	3058	24	NON-HDI
C82	3266	3289	23	NON-HDI
C83	3454	3476	22	NON-HDI
C84	2880	2900	20	NON-HDI
C85	2017	2035	18	NON-HDI
C86	2541	2558	17	NON-HDI
C87	3094	3108	14	NON-HDI
C88	2487	2500	13	NON-HDI
C89	3327	3340	13	NON-HDI
C90	2624	2636	12	NON-HDI
C91	2643	2655	12	NON-HDI
C92	2954	2965	11	NON-HDI
C93	2689	2699	10	NON-HDI
C94	3167	3177	10	NON-HDI
C95	2673	2681	8	NON-HDI
C96	2626	2633	7	NON-HDI
C97	3258	3265	7	NON-HDI
C98	3119	3124	5	NON-HDI
C99	2440	2444	4	NON-HDI
C100	3122	3122	0	NON-HDI

In Table 4.9 is calculated AE accuracy to detect HDI of 8-Header with 10000 RPM. So far AE_{rms} threshold = 85 mV has had accuracy around 92% with over reject around 4 % and escape around 4% respectively.

Table 4.9 : AE accuracy to detect HDI of 8-header with 10000 RPM configuration.

Confirmed by VMI	AE Classification	Drive quantity
HDI Drives	HDI Drives	28
	Non-HDI Drives	4
Non-HDI Drives	HDI Drives	4
	Non-HDI Drives	64
Total quantity		100
AE Accuracy		92.0%

For figure 4.17 is based on experiment results, AE_{rms} threshold of 8-Header = 85 mV are determined. After confirmation by visual inspection, the detection accuracy of actual HDI is calculated to be around 92%.

For 8 Head with 10000 RPM, the HDI drives have mean of AE signal around 200 mv. But Non-HDI drives have mean of AE signal around 40 mV.

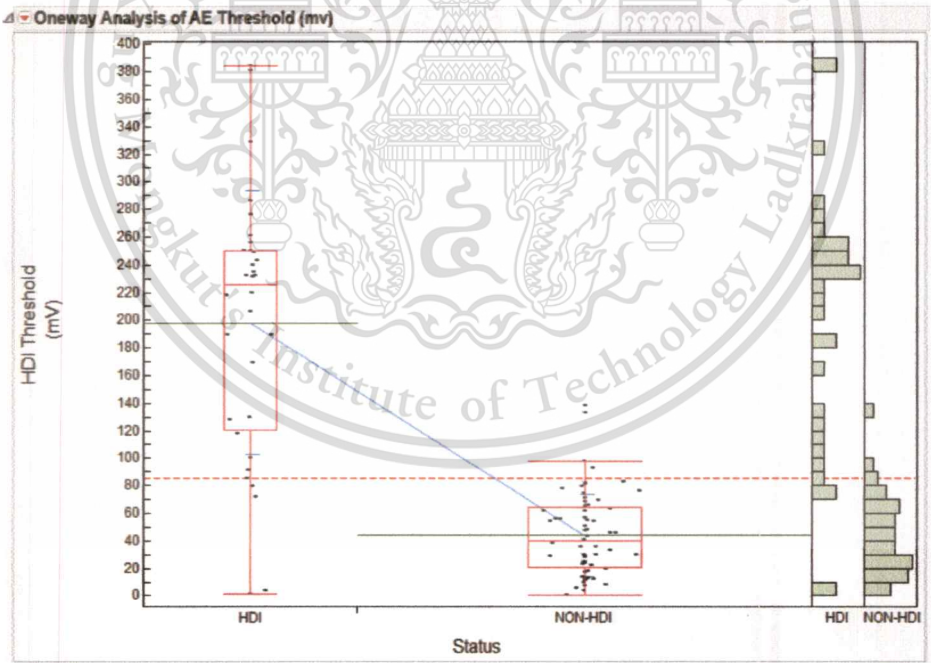


Figure 4.17 : Experiment result for 8xHeader (1000 RPM) with threshold = 85mV.

4.5.3.4 4-Header with 10000 RPM experiment result

For 4-Header configuration after optimized the amplified gain is around 21. After that the 100x drives were measured the AE_{rms} to finding the AE_{rms} threshold. In Table 4.10 and 4.11 are individual delta AE_{rms} (Head load – Motor spin). Between HDI drives and non-HDI drives respectively. Base on Table 4.10 and 4.11, observe that the most HDI drives have delta AE_{rms} is higher than 74 mV. So the AE_{rms} threshold of 4xheader with 10000 RPM is greater than or equal to 74 mV.

Table 4.10 : Individual delta AE_{rms} for 4-Header (10000 RPM drive) HDI drives.

Drive S/N	AERms Motor spin (mV)	AERms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
D27	2906	3201	295	HDI
D18	2545	2786	241	HDI
D16	2740	2977	237	HDI
D19	3067	3295	228	HDI
D26	2685	2911	226	HDI
D14	2337	2550	213	HDI
D24	2391	2600	209	HDI
D25	3249	3456	207	HDI
D07	3345	3551	206	HDI
D21	3474	3679	205	HDI
D34	3409	3611	202	HDI
D28	2800	3000	200	HDI
D33	3139	3337	198	HDI
D32	3413	3609	196	HDI
D20	3374	3569	195	HDI
D02	2500	2693	193	HDI
D10	3248	3433	185	HDI
D13	3207	3375	168	HDI
D04	2400	2565	165	HDI
D01	2200	2358	158	HDI
D12	2625	2780	155	HDI
D09	2516	2670	154	HDI
D08	3449	3602	153	HDI
D17	3419	3572	153	HDI
D11	2369	2520	151	HDI
D05	2302	2451	149	HDI
D03	2234	2381	147	HDI
D22	3257	3373	116	HDI
D15	2388	2503	115	HDI
D29	3078	3190	112	HDI
D06	3110	3212	102	HDI
D23	2115	2209	94	HDI
D30	3685	3759	74	HDI
D31	3279	3350	71	HDI
D35	2942	3005	63	HDI
D37	2450	2460	10	HDI
D36	2470	2477	7	HDI
D38	2880	2880	0	HDI

Table 4.11 : Individual delta AE_{rms} for 4-Header 10000 RPM drive) non-HDI drives.

Drive S/N	AErms Motor spin (mV)	AErms signal head loading (mV)	Delta AE rms (Head loading -Motor spin) (mV)	Confirmed by VMI
D39	3297	3420	123	NON- HDI
D40	3025	3135	110	NON- HDI
D41	2730	2819	89	NON- HDI
D42	2643	2716	73	NON- HDI
D43	2846	2917	71	NON- HDI
D44	3510	3576	66	NON- HDI
D45	3378	3442	64	NON- HDI
D46	3265	3327	62	NON- HDI
D47	2749	2811	62	NON- HDI
D48	2749	2806	57	NON- HDI
D49	2805	2861	56	NON- HDI
D50	2502	2557	55	NON- HDI
D51	3210	3261	51	NON- HDI
D52	2502	2553	51	NON- HDI
D53	3030	3076	46	NON- HDI
D54	2630	2676	46	NON- HDI
D55	2954	3000	46	NON- HDI
D56	3158	3203	45	NON- HDI
D57	3010	3054	44	NON- HDI
D58	2977	3021	44	NON- HDI
D59	2842	2885	43	NON- HDI
D60	2570	2612	42	NON- HDI
D61	2801	2843	42	NON- HDI
D62	2564	2604	40	NON- HDI
D63	3252	3291	39	NON- HDI
D64	2720	2759	39	NON- HDI
D65	2973	3011	38	NON- HDI
D66	2598	2635	37	NON- HDI
D67	3022	3057	35	NON- HDI
D68	3034	3069	35	NON- HDI
D69	2910	2944	34	NON- HDI
D70	2835	2869	34	NON- HDI
D71	2983	3016	33	NON- HDI
D72	3359	3392	33	NON- HDI
D73	2900	2931	31	NON- HDI
D74	2972	3002	30	NON- HDI
D75	2676	2704	28	NON- HDI
D76	2508	2536	28	NON- HDI
D77	2950	2978	28	NON- HDI
D78	2922	2950	28	NON- HDI
D79	2650	2677	27	NON- HDI
D80	3062	3086	24	NON- HDI
D81	3258	3282	24	NON- HDI
D82	2890	2913	23	NON- HDI
D83	2920	2943	23	NON- HDI
D84	2626	2644	18	NON- HDI
D85	2833	2850	17	NON- HDI
D86	2909	2921	12	NON- HDI
D87	3159	3171	12	NON- HDI
D88	2497	2508	11	NON- HDI
D89	2746	2756	10	NON- HDI
D90	2839	2847	8	NON- HDI
D91	2598	2606	8	NON- HDI
D92	2708	2716	8	NON- HDI
D93	2984	2991	7	NON- HDI
D94	2465	2469	4	NON- HDI
D95	3235	3238	3	NON- HDI
D96	2797	2800	3	NON- HDI
D97	2732	2733	1	NON- HDI
D98	2477	2477	0	NON- HDI
D99	2481	2481	0	NON- HDI
D100	2476	2476	0	NON- HDI

In Table 4.12 is calculated AE accuracy to detect HDI of 4-Header configuration. So far AE_{rms} threshold = 74 mV has had accuracy around 92% with over reject around 3 % and escape around 5% respectively.

Table 4.12 : Calculated AE accuracy to detect HDI of 4-header configuration.

Confirmed by VMI	AE Classification	Drive quantity
HDI Drives	HDI Drives	33
	Non-HDI Drives	5
Non-HDI Drives	HDI Drives	3
	Non-HDI Drives	59
Total quantity		100
AE Accuracy		92.0%

For figure 4.18 is based on experiment results AE_{rms} threshold of 4-Header = 74 mV are determined. After confirmation by visual inspection, the detection accuracy of actual HDI is calculated around 92%.

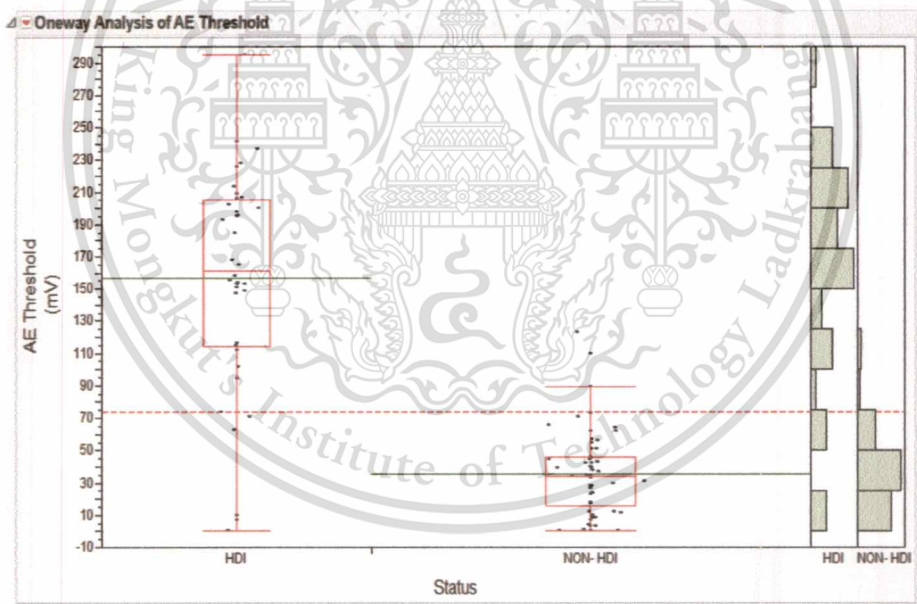


Figure 4.18 : Experiment result for 4xHeader(10000 RPM) with threshold =74mV.

CHAPTER 5

Conclusion and Future work

5.1 Result and conclusion

The data in this work shows the AE_{rms} threshold during head loading state which can be used to classify true or fault HDI failure. The AE_{rms} thresholds of different HDD models are different due to load velocity, number of heads, speed of spindle motor and the composite Yong's modulus. This work is concentrated on the determination of AE_{rms} thresholds of 4-Header and 8-Header with different speed of spindle motor (RPM). The experiment result shows the threshold of 8-Header is higher than 4-Header; both 7200 and 10000 RPM model because more heads are also higher amplitude stress wave. So more heads which are also more area and mass of slider to contact on the disk, this is caused why more head numbers are higher AE_{rms} threshold than a less head numbers. Comparing for the speed of spindle motor, the result shows the higher speed is also higher amplitude stress wave because during HDI occurrence the higher speed is also very fast to contact between head and disk. This is the reason why the higher speed of spindle motor is higher AE_{rms} threshold than a lower speed of spindle motor. So the number of heads and spindle speed are the key for optimized threshold for studied HDD model which base on the experiment result.

In Table 5.1 shows the experiment result of 2.5 inches HDD model compares with number of header and speed of spindle motor. The detection accuracies of actual HDI for the studied model around 92% - 94%. There is some HDI classification error around 6-8% due to light HDI issue, Modulation issue Mechanical Resonance. The HDI classification error can be separated into two groups; escaped and over reject case. The root cause of escaped case is related light HDI or light scratch. And the root cause of over reject case is related mechanical resonance, modulation issue and etc.

Table 5. 1 : Comparing experiment result by different HDD model.

Product	Header	AE rms Theshold	Over reject	Escape	Accuracy to detect HDI drive
2.5 " with 7200 RPM	8	78 mV	2%	5%	93%
2.5 " with 7200 RPM	4	64 mV	3%	3%	94%
2.5 " with 10000RPM	8	85 mV	4%	4%	92%
2.5 " with 10000RPM	4	74 mV	3%	5%	92%

5.2 Discussion HDI classification error by AE

5.2.1 Escaped Case

The light HDI is lightly contact between heads and media that means the elastic energy is a little release. Then the measured AE_{rms} signal is less than AE_{rms} threshold. This is the reason why these drives are escaped. Figure 5.1 shows the light HDI failure.

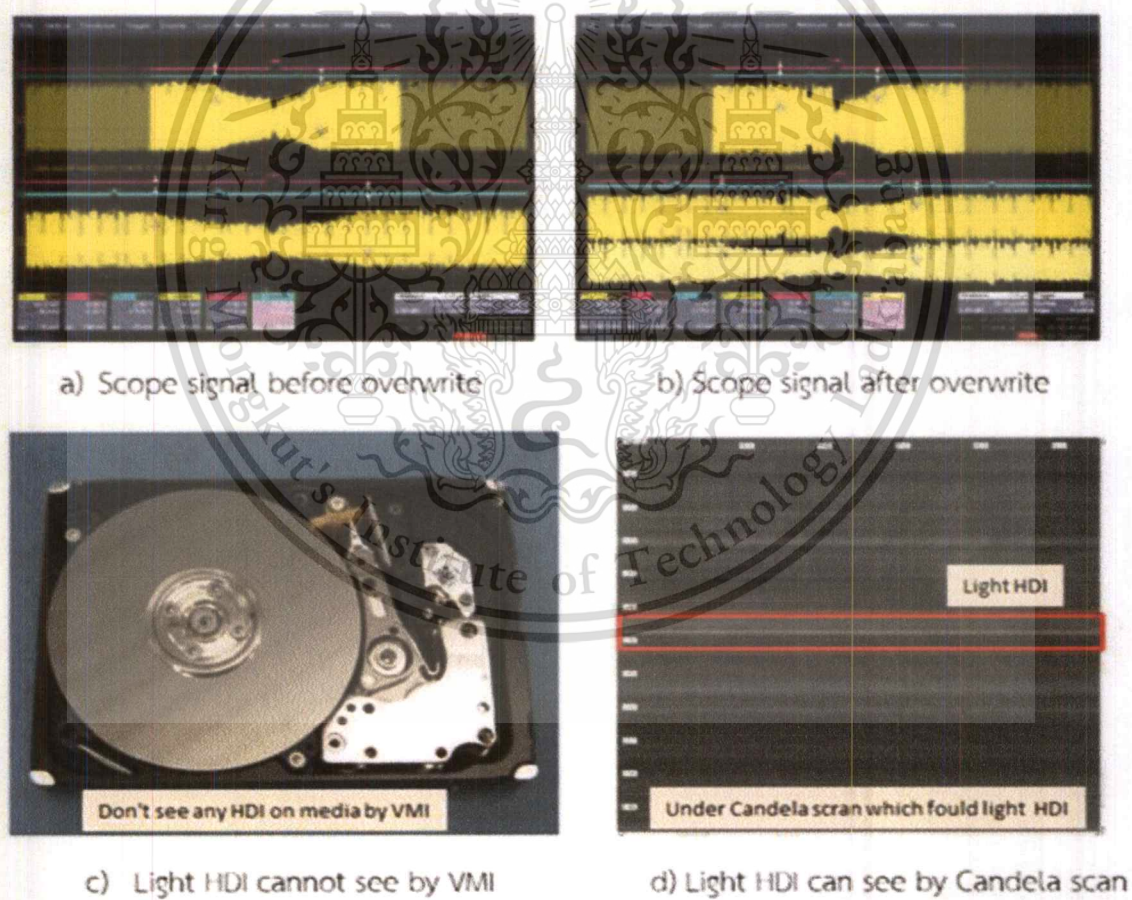
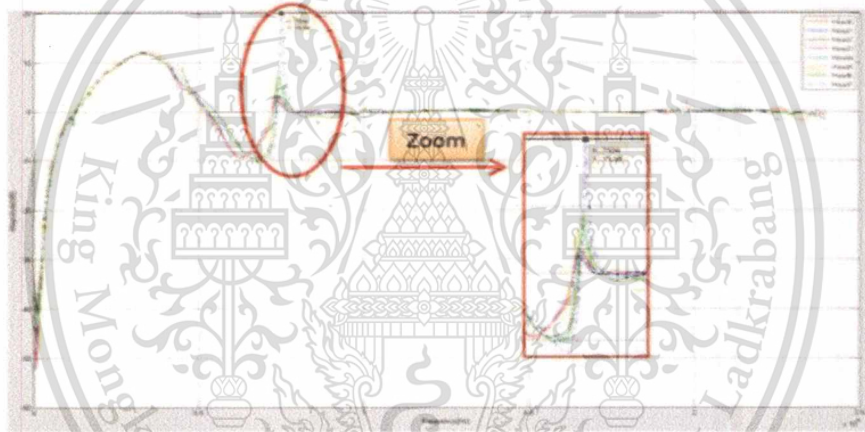


Figure 5.1 : The light HDI on HDD.

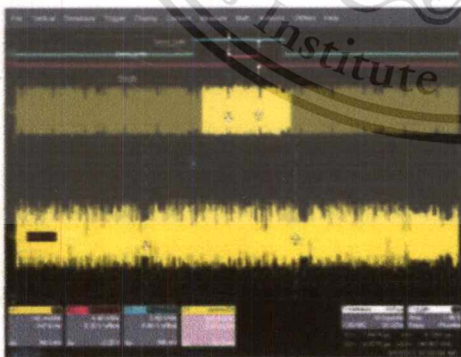
Figure 5.1 a) shows scope signal on the light HDI location, the scope signal shows amplitude dropped on the failing location. Figure 5.2 b) shows scope signal after overwriting at the failing location, observed the failing location cannot be recovered by overwriting that meaning the media has permanence damage. Normally HDI failure can be seen by eyes but the light HDI cannot be seen by eyes. Seeing Figure 5.1 c) the media look clean, no any sign damage. However the light HDI can be seen by Candela scan. Under the candela scan, light HDI or light scratch were found. The candela scan on media shows Figure 5.1 d).

5.2.2 Over Reject Case

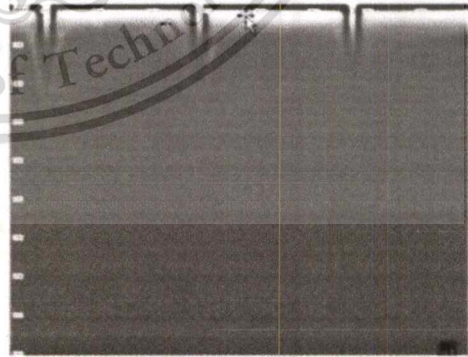
5.2.2.1 Mechanical issue



a) Bode plot shows sign resonance around 7KHz



b) Scope signal shows normal



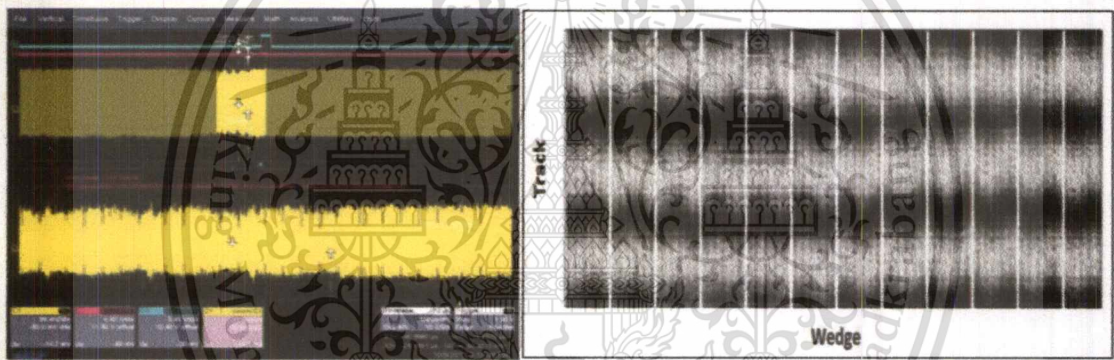
c) Don't see any HDI by Candela scan

Figure 5.2 : Mechanical resonance from VCM.

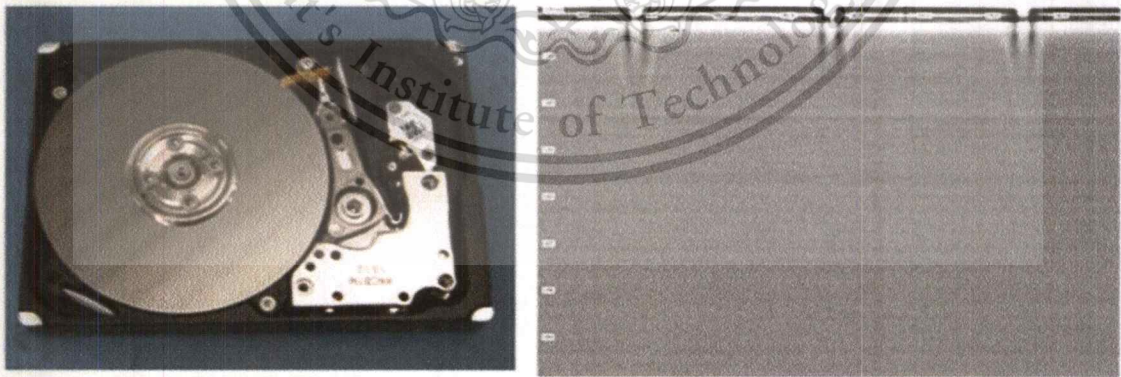
In HDD has many mechanical issues such as mechanical resonance, high PES (Positioning Error), High NRRO/RRO (Non-Repeatable Run-Out/Repeatable Run-Out) etc... During the mechanical issue is occurrence which effected to drive performance such as head flying ability, head Off-track, and seek error, poor write/Read head. Figure 5.2 shows mechanical resonance from VCM (Voice Coil Magnet). For this case the AE_{rms} signal is over AE_{rms} threshold, so this drive is classified to HDI failure but actually the drive is non-HDI after VMI. This is example case for over reject by AE classification because the resonance of VMC is affected to flying ability and off-track.

5.2.2.2 Modulation issue

Figure 5.3 shows the modulation failure in HDD . Modulation issue is one case of over reject by AE clarification. Seeing more detail of modulation Figure 5.3 a) and b) on scope signal and magnetic mapping respectively.



a) Scope signal show sign Modulation b) Magnetic mapping shows sign Modulation



c) Don't see any HDI on media by VMI d) Don't see any HDI by Candela scan

Figure 5.3 : Modulation issue.

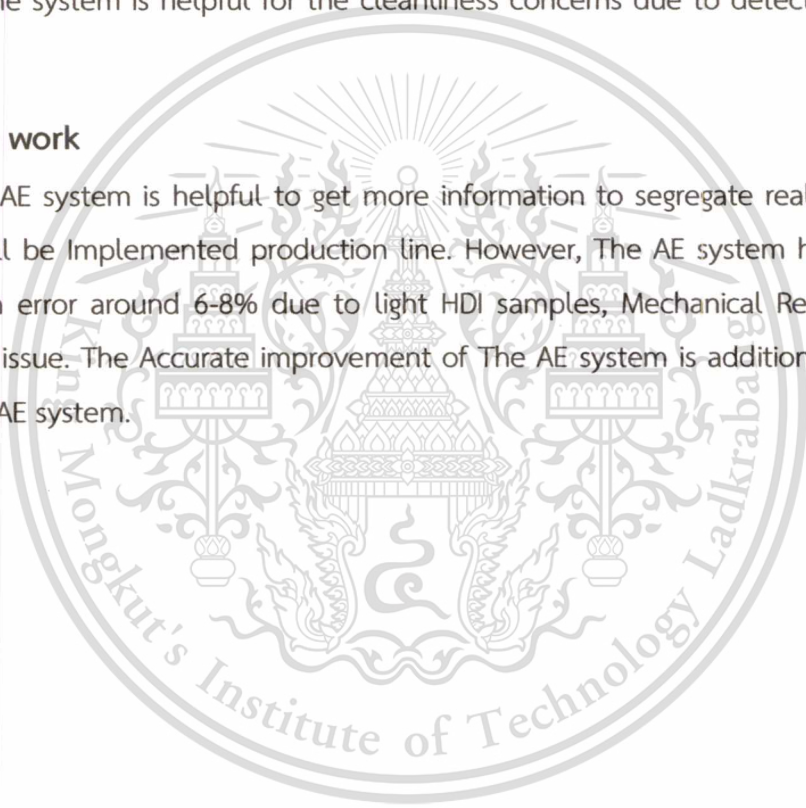
When the modulation is occurrence, the Read/Write head have shown sign unstable during on-track. In case of high severity of modulation, the read/write head shows sign flying ability during on track. At that time the vibration of flying ability can be captured by AE because the measured AE_{rms} signal is higher than AE_{rms} threshold, so this is the reason why the AE classification is incorrect.

5.3 Research advantage

1. The AE sensor can be segregated process between real and false HDI failures.
2. Accuracy to classify HDI and Non-HDI is good around 93-94%.
3. The system is helpful for the cleanliness concerns due to detect HDI in drive level.

5.4 Future work

The AE system is helpful to get more information to segregate real or fault HDI drives. It will be Implemented production line. However, The AE system has some HDI classification error around 6-8% due to light HDI samples, Mechanical Resonance and Modulation issue. The Accurate improvement of The AE system is additional Band pass filter in the AE system.



REFERENCES

- [1] Thomas C. McMillan and Frank E. Talke, "Identification of Slider/Disk Contacts Using the Energy of the Acoustic Emission Signal", IEEE TRANSACTIONS ON MAGNETICS, Vol.34, .NO. 4, pp 1819-1821, JULY 1998.
- [2] Bharat Bhushan, Fellow, IEEE, Yuanjie Wu, and Nikhil S. Tambe, "Sliding Contact Energy Measurement Using a Calibrated Acoustic Emission Transducer", IEEE TRANSACTIONS ON MAGNETICS, VOL. 39, NO. 2, pp. 881-887, MARCH 2003.
- [3] Miinshiou Huang and team, "Using Acoustic Emission in Fatigue and Fracture Material Research", no.11, vol. 50, November 1998,
- [4] UCL (2013, Oct) Acoustics of Speech and Hearing
[Online]. <http://www.phon.ucl.ac.uk/courses/spsci/acoustics/week1-10.pdf>
- [5] Abdullah Al Maxmun, GuoXian Guo and Chao Bi, "Hard Disk Drive Mechatronics and Control", CRC press, 2006
- [6] StorageReview(2013, Apr). Hard Disk Operational Overview
[Online] http://www.storagereview.com/Guide/over_op.html
- [7] Adrian A. Pollock(2013, May) "Acoustic Emission Inspection"
[Online] : <http://www.scribd.com/doc/31628749/Acoustic-Emission-Inspection>
- [8] National Taiwan University in 2002(2013, May), Force and Strength
[Online] : <http://www.pt.ntu.edu.tw/hmchai/bm02/bm02method/ForceMeasure.htm>
- [9] Charles J Hellier "Nondestructive Evaluation", McGRAW-HILL, 14 Mar 2001
- [10] V.M. Malhotra and N.J. Cario "Nondestructive testing of concrete", 2nd ed, CRC press
- [11] Muravin (2013, Aug) , Acoustic Emission
[Online] : <http://www.muravin.com/ae/index.html>
- [12] Parkafm (2013, Aug). Park Systems – AFM machine
[Online] : http://www.parkafm.com/jp/gallery_list.php?code=&page=8&word=ST
- [13] Wikipedia(2013, Aug). Head_crash.
[Online] : http://en.wikipedia.org/wiki/Head_crash
- [14] StorageReview(2013, Apr), Head Load/Unload Technology
[Online] : <http://www.storagereview.com/Guide/featuresHead.html>
- [15] David Hartsock(2013, Nov) , What is a hard drive
[Online] : <http://www.davescomputertips.com/what-is-a-hard-drive/>
- [16] Artem Rubtsov (2013,Dec), HDD from inside: Main parts
[Online] : http://hddscan.com/doc/HDD_from_inside.html

- [17] Bernhard Knigge and Frank E. Talke “Nonlinear Dynamic Effects at the Head Disk Interface”, IEEE TRANSACTIONS ON MAGNETICS ,Vol. 37, .NO. 2, pp 900-905, MARCH 2001
- [18] Mistrasgroup (Jan’13), ACOUSTIC EMISSION (AE) SENSORS
[Online] : http://www.mistrasgroup.com/products/solutions/acousticemission/sensors/PICO_HF-1.2.aspx



APPENDIX

Publication List

1. Chuchat Sodsri, Assoc.Prof.Dr. Somsak Choomchuay2, “HDI Detection by Using an AE Technique”, In proceeding of ISCIT 2013, ppNoraburi hotel ,Samui, Thailand 4-6 September ,2013.

ISCIT2013

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HDI Detection using an AE Technique

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Abstract – Acoustic Emission(AE) sensors are commonly used in non-destructive testing to monitor generation and propagation of contact, bending, torsion and crack in material; including magnetic head-disk interaction (HDI). In Hard Disk Drive (HDD) manufacturing process, HDI is the one of mechanical failure which need to scrap all components due to cleanliness concerns. However, the segregating process between true and false HDI failures are mainly difficult to detect due to inadequate information. This paper presents the detection of the HDI using AE sensor - stress wave technique with Bending and Torsional modes during spin up and loading head state. The AE sensor is placed outside the HDD to measure AE voltage signal since the drive start up. The AE voltage will be converted to be AE rms. The AE rms threshold, which is used the delta of AE rms between spin up and loading head to disk, can be used as a criterion to differentiate actual from false HDI.

Keywords—Hard disk drive; Acoustic Emission; Head-Disk Interaction; Head Disk Assembly; Print Circuit Board Assembly

I. INTRODUCTION

Hard Disk Drive is a magnetic device that utilizes magnetism to store data on media or disk. The main parts of HDD comprise disks, read/write head, spindle motor and Print Circuit Board Assembly (PCBA). In typical HDD operation, drive starts by spinning up motor, next head loading to fly over the media maintaining a non-contact position [4], seeking to particular cylinder to write/read data in particular sectors. Nowadays, HDD manufacturing process has separated into two main parts; clean room and backend process. Clean room(C/R) assembly process under the controlled particle environment starts from basedeck loading until top cover mounting yielding so called a Head Disk Assembly (HDA). After that, the HDA is passed to backend process for PCBA installation and functional test. The functional test is to calibrate and optimize functional systems such as servo mechanical tuning, read/write channel optimization and media defect mapping. Fig. 1 shows HDD manufacturing process flow.

Servo mechanical tuning required in the functional testing phase is found to be a major cause of HDI. In Fig. 2 is an HDI failure which shows sign of circumferential scratches on media, also head bent and observed contamination or particle over all drives. The possible causes of HDI are drive assembly process mechanical design, contamination, etc. The challenge

is how to discriminate actual from false HDI at drive level. The AE sensor has become a popular nondestructive test, the method commonly used to detect mechanical contact between two or more components [6]. During mechanical contacts, elastic waves are produced corresponding to intensity of mechanical contact[5]. The advantage of AE technique is simplicity for measurement and ability to detect contact between head and disk [7]. The critical factor to yield a strong AE signal is the mounting location of AE over the HDD during spin and load cycle of drive.

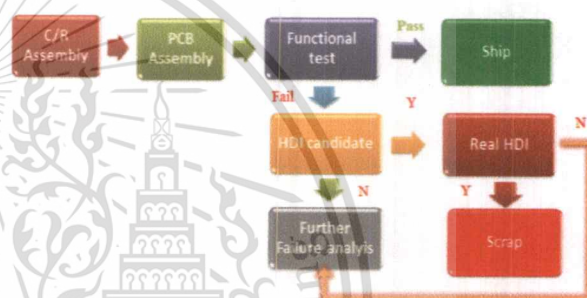


Fig.1 HDD manufacturing assembled process

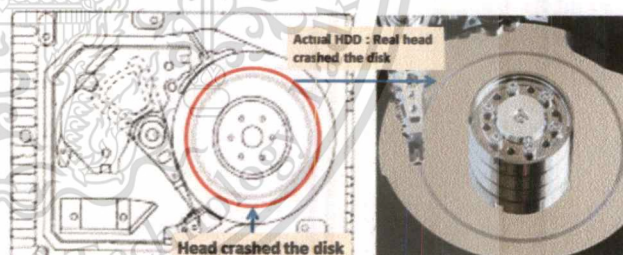


Fig. 2 shows circumferential scratch (Head crashed the disk) after HDI [8]

II. ACOUSTIC EMISSION BASIC AND HDI DURING LUL

A. AE basic

AE is the sound that emitted an elastic wave when a material is undergoing stress. Normally AE is used stress wave technic to monitor the intensity of mechanical contacts. AE is stress waves produced during mechanical deformation of material. Which used as the measurements tool to monitor

Head Disk Contacts (HDC) in HDD. The elastic stress wave is generated during HDC. The waveform can be analyzed on both time and frequency domains. If the signal is over the AE threshold, the events will be counted, as shown in figure 3.

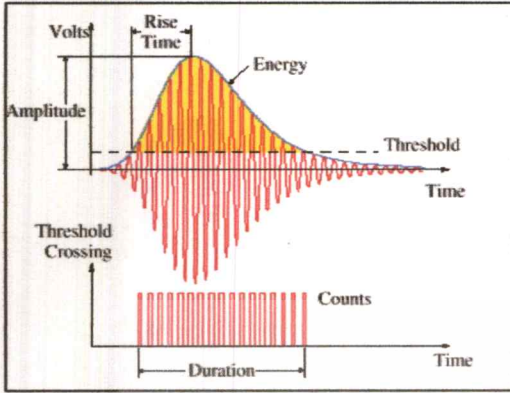


Fig. 3. AE waveform characteristics in time domain [2]

In time domain, commonly AE waveform characteristics are interesting in term of AE counts, peak amplitude, rise time, energies and voltage rms. Then the AE rms-voltage signal in time domain can be calculated follow formula as below.

$$\text{AE rms voltage} = \sqrt{\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} v^2(t) dt} \quad (1)$$

Where $v(t)$ is AE voltage signal at time t , $[t_1 t_2]$ is interested time range. If $[t_1 t_2]$ is suitable section, the AE rms voltage is refer the power at that time.

In frequency domain, using Fourier transform method to convert the signal waveform from time domain to frequency domain. Usually frequency domain mostly refers to Power spectrum, Nyquist frequency and dominant frequency. AE signal processing uses frequency domain to get electrical energy. During AE sensing operation, the signal consists of two parts, lower and higher frequencies. The lower frequency represents mechanical contact frequency, and the higher frequency represents AE frequency itself. So signal output of AE is shown equation as

$$v(t) = f(t) * \sin \omega t \quad (2)$$

Where $f(t)$ is the low frequency component and $\sin \omega t$ is the high frequency component that generated by AE itself. The mechanical energy is the low frequency components generated from contacts which is directly proportional to the electrical energy of measured signal [1] that shown as

$$\text{Mechanical energy} \propto \text{Electrical energy} \\ \alpha \int_{-\infty}^{\infty} f^2(t) dt = \int_{-\infty}^{\infty} \frac{v^2(t)}{\sin^2 \omega t} dt \quad (3)$$

During AE measurement, $\sin \omega t$ is electrical energy that generated by AE itself, so this parameter is removed due to not mechanical energy. From (3) electrical energy of the measured signal is related to head disk contact (mechanical energy) which can be obtained using $v(t)$ [1].

$$\text{Mechanical energy} = \int_{-\infty}^{\infty} v^2(t) dt \quad (4)$$

B. HDI during LUL

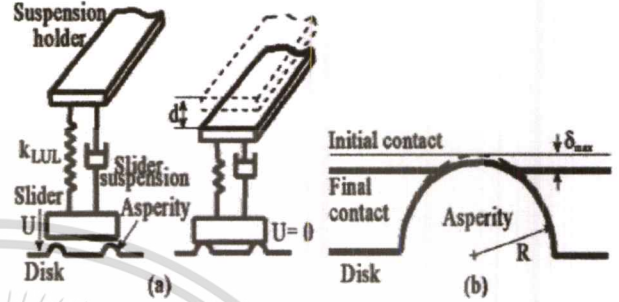


Fig.4. (a) Schematic shown parametric slider suspension model during vertical load/unload head. (b) Expanded view of the deformation of disk asperity as a result of slider-disk contact during loading of slider [1]

Currently HDD has two typical modes of head parking area Contact Start Stop(CSS) and Load Unload(LUL). CSS is an old technology that head is parking on landing zone (parking on media). LUL is a new technology that head is parking on ramp (outside of media). This work is focusing solely on LUL technology. In case HDI happen during head loading state (LUL), the read/write head is showing sign of fly ability issue and generating elastic stress waves due to mechanical contacts. Fig 4 shows a diagram of head disk contact model during LUL. Vertical head LUL mechanism has two parts; fly height on target when fly over the media and at certain velocity during head loading. If HDI does occur, the velocity will be suddenly dropped. At that time the slider is deformed and then the kinetic energy is produced as a stress wave with Bending and Torsion energy [3]. The AE sensor is used to measure this energy.

$$\text{Slider Energy} = \text{Energy deformation} + \text{Energy detected by AE} \quad (5)$$

$$\text{The slider kinetic energy} = \frac{1}{2} MU^2 \quad (6)$$

Where M is slider mass, U is the vertical velocity of head loading before HDI. k_{LUL} is spring force of normal case head loading and thus the maximum deformation of the asperity is [1]

$$\text{Max Asperity deformation energy} = \left(\frac{9(K_{LUL}d)^2}{16RE^2} \right)^{1/3} \quad (7)$$

E is Young's Modulus for the slider and bump and R is radius. From (5) and (6), the energy happened during HDI at head loading state is shown in formula [1].

$$\text{Energy detection by AE} = \frac{1}{2} MU^2 - \left(\frac{9(K_{tut}d)^2}{16RE^2} \right)^{1/3} \quad (8)$$

From (8), almost all of the energy is depending on loading velocity of read/write head.

The purpose of this work is to detect HDI during head loading. Fig. 5 shows normalize head loading profile that can explain the loading process after spindle motor is already met Round Per Minute(RPM) target. The number one represents head start moving, next head break away from detention (RAMP), then head slow down to constant speed, While head fall off Ramp, after that head start flying out at constant speed and finally head brake at mid stroke.

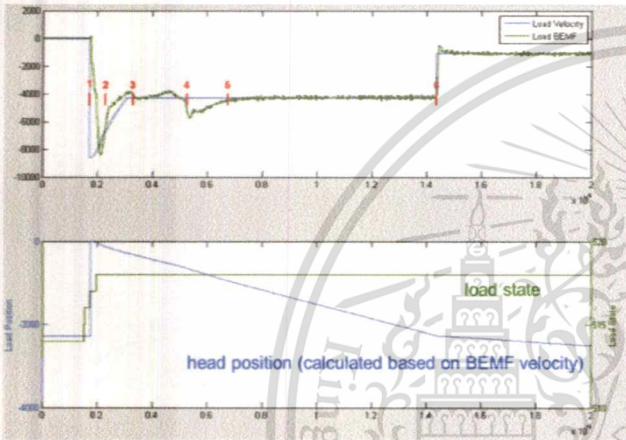


Fig. 5 shows normalize head loading profile

III. EXPERIMENTS AND RESULTS

The experiment is set to detect the HDI drives during head loading by AE sensor. Fig.6 shows a schematic diagram for a setup to detect HDI. The number one represents AE sensor which is attached outside the HDD on actuator pivot of head stack assembly (HSA) that holding the read/write head, next adjusting amplify gain to match with ADC range because AE signal is small and may need appropriate amplification to improve signal to noise ratio(SNR). After that adjust starting points and spans of time to sampling AE signal during motor spin and head loading, and lastly get command status back for more info to make decision.

Scope signal in Fig. 7 is AE rms signals which measure since motor spin-up until completion of head loading. AE signal can be split into four states: the first step is spin up motor; next BEMF Closed Loop Spin; then spin complete and wait for two seconds; and finally start head loading to platter. Observation AE sensor gives out high AE rms signal in all states, but the system is interested only in state four because this is start head loading. At head loading state, the AE sensor

can measure AE rms signal so meaning that the head disk interaction does occur and then generates stress wave (Bending and Torsion Energy). If AE rms signal exceeds a certain threshold then the drive is classified HDI.

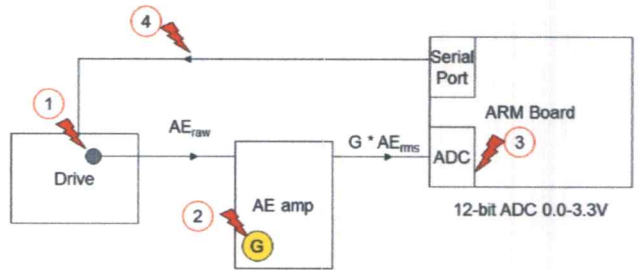


Fig.6 is a schematic diagram for detecting HDI

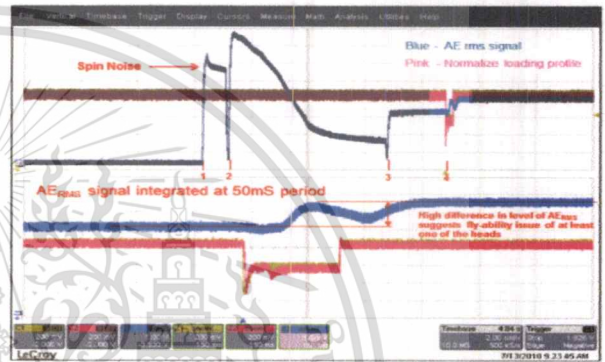


Fig.7 Scope signal of AE rms since motor spin-up until completed head loading

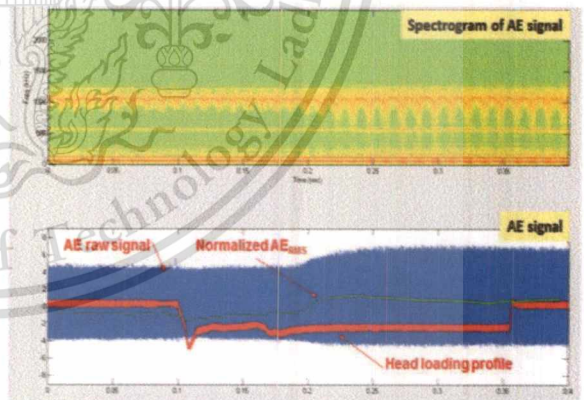


Fig.8 Spectrogram of AE rms signal

AE signal is converted to Spectrogram which represents energy spectrum in frequency domain over time. When the spectrum frequency shows high value at particular frequency

at certain point in time, it means sound amplitude at that particular frequency is emitted around that given time. Fig. 8 shows Spectrogram since spin-up until head fly over media. Observe that the Spectrogram is high spectrum at head loading state and after that the spectrums still maintain the high spectrum value which means head has continuous contact with media.

HDI candidates of 2.5" HDD have been collected on both 4xHeader and 8-Header configurations of a certain drive model to determine AE rms threshold. In Fig. 9 and 10 show experiment result of the 4-Header and the 8-Header drives respectively. Base on experiment results AE rms threshold of 4Hd = 64 mV and 8Hd = 78mV are determined. After confirmation by visual inspection, the detection accuracy of actual HDI is calculated to be around 94% for 4-Header and 93% for 8-Header.

The experiment in this work shows the clear cut AE rms threshold during head loading state that can be used to detect HDI failure. The threshold of each HDD model is different according to load velocity, number of heads, the radius of the head-disk contact and the composite Yong's modulation. The AE rms threshold of the 4xHeader model is lower than that of the 8xHeader model. With such setting the detection of real HDI for 4xHeader and 8xHeader are around 94% and 93% respectively. Around 6-7% mis-classification still needs more investigation. However most of them are light HDI. More efforts are to be made to improve the accuracy.

ACKNOWLEDGMENT

This work is funded by the National Electronics and Computer Technology Center (NECTEC) Thailand and the Seagate Technology (Thailand) Co., Ltd. The author would also like to thank the international college and the college of data storage, King Mongkut's Institute of Technology Ladkrabang for their supports.

REFERENCES

- [1] Bharat Bhushan, Fellow, IEEE, Yuanjie Wu, and Nikhil S. Tambe, "Sliding Contact Energy Measurement Using a Calibrated Acoustic Emission Transducer", IEEE TRANSACTIONS ON MAGNETICS, VOL. 39, NO. 2, MARCH 2003, pp. 881-887.
- [2] Mianhui Huang and team , "Using Acoustic Emission in Fatigue and Fracture Materials Research", JOM, November 1998, vol. 50, no. 11
- [3] Thomas C. McMillan, Frank E. Talke and Joshua C. Harrison, "Identification of Slider/Disk Contacts Using the Energy of the Acoustic Emission Signal", IEEE TRANSACTIONS ON MAGNETICS, Vol. 34, NO. 4, JULY 1998, pp 1819-1821.
- [4] Kaoru Matsuoka, Koji Taniguchi and Masaru Nakakita, "In-Situ Wear Monitoring of Slider and Disk Using Acoustic Emission", ASME JANUARY 2001, Vol. 123, pp. 175-180
- [5] H. A. Duncan, "Energy processing techniques for stresswave emission," J. Acoust. Soc. Amer., vol. 65, pp. 1556-1561, 1979.
- [6] R. V. Williams, Acoustic Emission. Bristol, U.K.: Adam Hilger, 1980.
- [7] T. Kita, K. Kogure, Y. Mitsuya and T. Nakanishi, "New method of detecting contact between floating - head and disk", IEEE TRANSACTIONS ON MAGNETICS, VOL. MAG-16, NO. 5, SEPTEMBER 1980
- [8] Wikipedia, Inc 2013. Head_crash. [online] Availabel : http://en.wikipedia.org/wiki/Head_crash

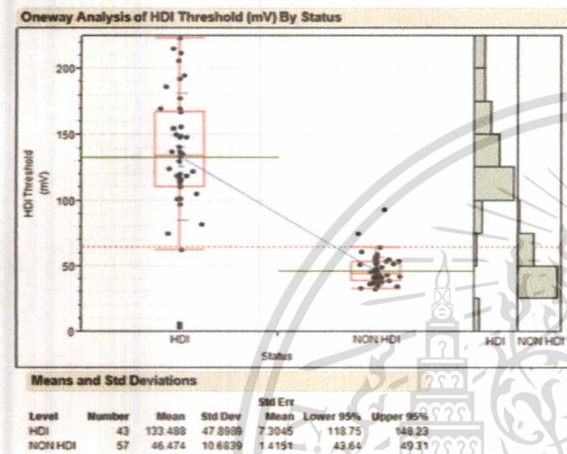


Fig. 9 shows experiment result for 4xHeader with AE rms threshold =64mV

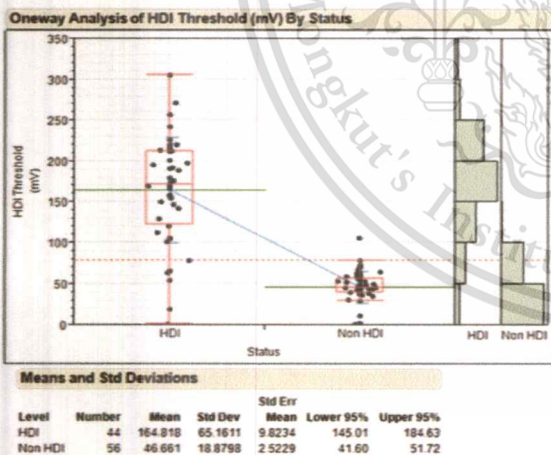


Fig. 10 shows experiment result for 8xHeader with AE rms threshold =78mV

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