A Study of Low Touchdown Improvement in Perpendicular Disk Drives

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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-005-010

Thesis Title	A Study of Low Touchdown Improvement in Perpendicular Disk Drives
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Degree	Master of Engineering
Program	Data Storage Technology (International Program)
Year	2013
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ABSTRACT

A common approach for read/write heads to increase the areal density in disk drives is to reduce the fly height. The objective of such reduction is to improve the signal quality. Since a lower fly height is prone to damage the media due to particle contamination, in this work, we investigate the effects of head contamination on the unreliable test results. Additional test sequences are proposed to remedy such events. We perform the experiments on the additional test commands before making the touchdown calibration at the backend test process. Finally, we monitor further on the drive yield and quality to ensure that no side effect occurs. The experimental results show that touchdown (TD) profiles are significantly improved by using the proposed methods.

ACKNOWLEDGEMENTS

I would like to express my deepest and sincerest gratitude to my advisor Assoc. Prof. Dr. Pornchai Supnithi, and my assist, Mr. Pramook Toworachot in advising me for this research work. I appreciate the thesis committee for their precious time and advice to make this thesis completely. Completion of my thesis may not have been achieved without their support and advice.

Furthermore, I would like to thank Western Digital (Thailand) Co., Ltd. which has provided the company scholarship and opportunity for studying in the master program, and supported me throughout the study period. At the same time, I would like to thank all my colleagues who encouraged me and supported to identify the tools for my research, the development team of Western Digital Thailand in helping me to allow for the experiment. It would not have been possible to juggle between the work and the study at the same time without the support of my colleagues and the WD family.

Finally, I am very grateful to my family for all love, caring, understanding and motivation throughout my life, especially my parents.

Suphadech Thanuthsutikhun

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CHAPTER 1

INTRODUCTION

1.1 Significance and background

For the past 10 years, the areal densities of the magnetic disk drives have been advancing at a pace of about 35% per year. The maximum areal densities in HDDs are expected to more than double during the ten-year period, therefore, hard disk drive technology with areal density of 10 Tbit/in^2 should be available by 2015. [1].

The HDD industry is expected to manufacture 2Tbit/in^2 technology products sometime between 2012 and 2016 as shown in Figure 1.1. In 2015, the HAMR (Heat Assisted Magnetic Recording) or the BPMR (Bit Patterned Media Recording) will be the candidates to achieve the areal density 2Tbit/in^2 or above. The pattern media is the next generation after HAMR to get more areal density, however, BPMR requires a number of technical changes, such as head design, signal processing, and write timing [2].

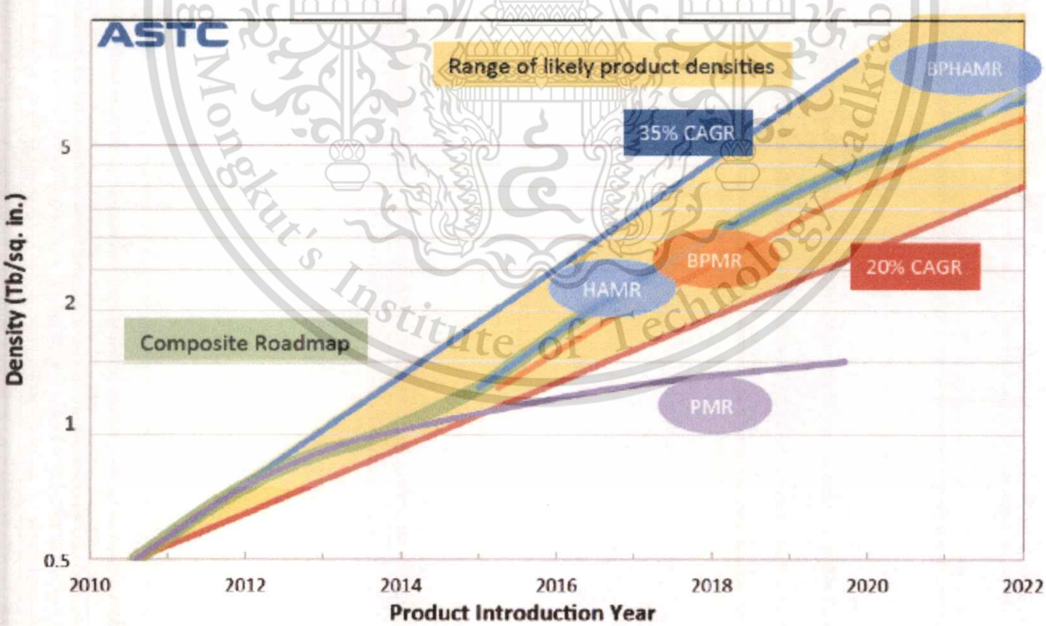


Fig. 1.1 Areal density timeline [2].

To achieve a high recording areal density, many designs have to be employed from areal density above 2Tbit/in^2. The read and write head technology and the new read channel are required to approaching higher recording densities. Significantly, the higher areal densities require that the recording transducer (head) be held ever closer to the moving magnetic storage medium. The Head Media Spacing (HMS) which is too large results in loss of resolution and magnetic transition density. The spacing which is too small may endanger the durability of the Head-Medium Interface (HDI) on perpendicular magnetic recording (PMR).

The particle contamination problem of hard disk drives is a growing concern in today's drive industry as the gap between the slider and disk continues to be decreased to improve the bit error rate performance and help for signal-to-noise ratio (SNR) reduction. It causes not only the mechanical damage to the head-disk interface, but also the thermal effects on the data reading and writing of MR heads. The effects of various operating parameters via load and unload speed, disk speed, ramp height, and disk dynamics on load/unload performance, friction and stiction and durability of a head-disk interface (HDI) need to be studied. The slider, the read/write heads, and magnetic recording media are the key components of the HDD and all together form the HDI, as illustrated in Figure 1.2. These heads are integrated into the ceramic slider, which includes an Air-Bearing Surface (ABS) formed in relief on its surface facing the disk, Figure 1.2 (a) shows the air entrained between the ABS and disk generating a lift by virtue of the viscous properties of air being squeezed through the gap. The flow of air is guided by the ABS to control the head–media spacing within close tolerance (0.1 nm). The separation distance between read and write elements and the disk directly affects both signal strength and resolution, and it is therefore critical to the recording density of the HDD.

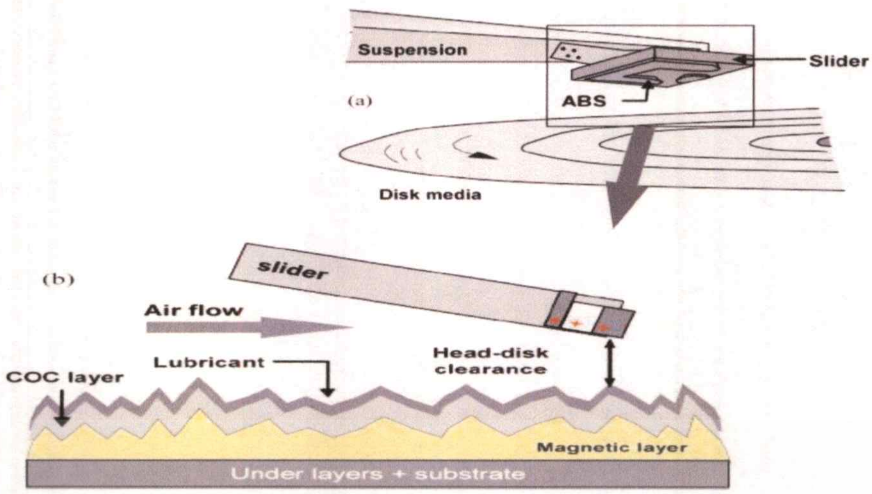


Fig. 1.2 Schematic diagram of the head–disk interface [1].

As magnetic recording densities increase, hence the magnetic spacing and the head flying height must be decreased correspondingly. Today, only a few nanometers separate the slider from the disk surface moving at 30 m/s. Figure 1.2 (b) shows the side view of slider flying over a cross section of the disk surface (roughness exaggerated). Recording transducers write to and read from the disc's magnetic layer, while the carbon overcoat (COC), lubricant layers, and surface roughness limit how close to the disk the recording elements can fly.

1.2 Hypothesis

The particle contamination in hard disk drives is an important issue because the particles can significantly affect the reliability of the drive. The contamination can come from the incoming material issue, or the cleanroom Hard Disk Assembly (HDA) processes can also generate the contamination. Figure 1.3 shows the example cleanroom HDA process. The touchdown failures are mostly caused the contamination issue. The contamination can cause the touchdown power (TDP) change. The amplitude can be positive or negative. The difference the interpolated touchdown (TD) between pre-test and post-test is called delta TD. The TDDVT exceeded Limit failure will occur when the interpolated touchdown power between pre-test and post test exceeds the test limit. For a good HDD, the difference in TDP must be within ±15 mW. The experimental results show that most of failed drives cannot replicate the results after re-processing.

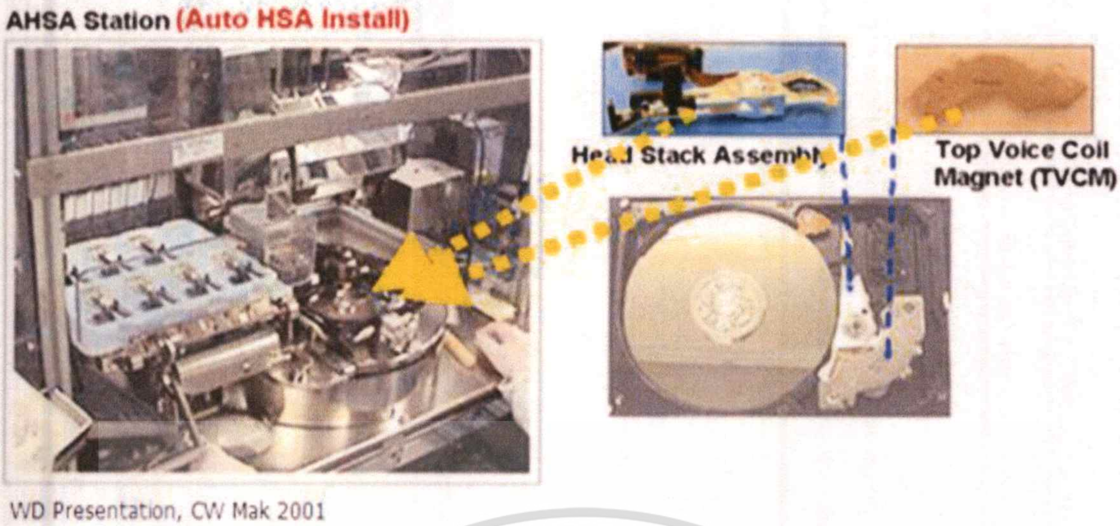


Fig. 1.3 Auto HSA installations (in cleanroom HDA process).

1.3 Proposed method

This thesis proposed new test methods to improve the touchdown failure rates in the perpendicular disk drives. The proposed methods incorporate an additional test module initiated prior to the primary test. The test command will first sweep the heads toward ID and OD back and forth with a number of specified cycles. Furthermore, we add an additional servo step to vibrate the heads to eliminate head contamination. Then comparison and analysis of the two different methods are made to obtain the best optimization results. The varying aspect ratio (AR) will suggest what number can be achieved using a proper value to set for the iterative loop of the head. The key parameters such as, average zone EM, touchdown parameters, and head media spacing (HMS) are in this study.

1.4 Goal and objectives

The Key Performance Index (KPI) target keeps changing each quarter (Q/Q) and the goal is to bring up the product yield close to 92%. The preliminary Failure Analysis (FA) report shows touchdown (TD) profile change between pre-test and post-test due to the contamination. In this research, we enhance the tester software to improve TD failure. The objectives of this research are

1.4.1 To determine the root causes of touchdown (TD) failure.

1.4.2 To provide the methods to improve the root causes to meet the goal.

1.4.3 To study the performance and stability of the proposed methods.

1.4.4 To reduce the TD failure below 0.5%.

1.5 Scopes

We focus on the characteristics and reliability of the touchdown failure rates of both currently employed and the proposed method. The measurement of the proposed method is product yield.

1.5.1 This study is based on current available Perpendicular Magnetic Recording (PMR) system.

1.5.2 To demonstrate the proposed methods and choose the best optimal one to improve the HDD test process.

a) The first proposed method, seek the heads toward ID and OD back and forth with a number of specify cycles.

b) The second proposed method is the first method with an additional head vibration process together with sweeping the head across the stroke between Inner Disc (ID), Middle Disc (MD), and Outer Disc (OD).

c) The experiment is done on 500 sample drives with various specified number of cycles. The drive contains the same head media type.

1.5.3 Finally, we perform a partial experiment on 30% of drives produced before fully releasing the code to the production.

1.6 Expected benefits

1.6.1 To reduce the TDDVT delta exceeded limit failure rate (FR).

1.6.2 The proposed method is less complex and requires less processing time to eliminate the contamination during the DFH optimization process.

1.6.3 Capability in developing and improving the backend test processes to improve the touchdown failure.

CHAPTER 2
Background and Theory

2.1 Introduction

Chapter 2 describes the fundamentals of Hard Disk Drives (HDD) and introduces the HDD test failure, HDD test operations, and fundamental of Head-Disc Interface (HDI). Moreover, the characteristics and reliability are also explained.

Data storage technology has advanced to increase the capacity responding to the customer demand. One major factor to be carefully managed is "fly-height" (in the range of nanometers) in order to optimize the design in magnetic recording for the highest areal density. The high reliability requirements dictate more stringent test conditions and design rules. In addressing areal density challenges, Perpendicular Magnetic Recording (PMR) has come into existence. It is considered superior to the existing Longitudinal Magnetic Recording (LMR) method that has been in existence since the beginning of the HDD, some fifty years ago.

As the areal density increases, HDD design has lesser margins for errors. Reference [1] outlines tribological issues brought about by PMR technology. In addressing areal density challenges, PMR has come into existence. The technology invented to address current challenges brought about issues the existing technology took decades to resolve. In particular, the magnetic media structure, which relies on well-segregated grains of 6–10 nm diameters, can exhibit a rough structure, with peak-to-mean amplitude of 3–6 nm. This topography could affect the overall reliability of the head–disk interface. Figure 2.1 introduces this fundamental with PMR technology. The higher protrusions in the lately media coupled with a lower flying height in the implementation of the latter technology posed yet another risk to HDD. The Giant Magnetoresistive (GMR) & Tunneling Magneto-Resistance (TuMR) heads are employed in particular HDD designed. A minor head crash from contamination still results in the head temporarily overheating due to friction with the disk surface. It could render the unreadable data for a short period until the head temperature stabilized (so called "thermal asperity", a problem which could partially be dealt with by proper electronic filtering of the read signal). However, it has been noted that filtering alters the electronic behavior of the signal but nothing physical. The highest point contacts the transducer resulting is in degradation at the head-disk interface.

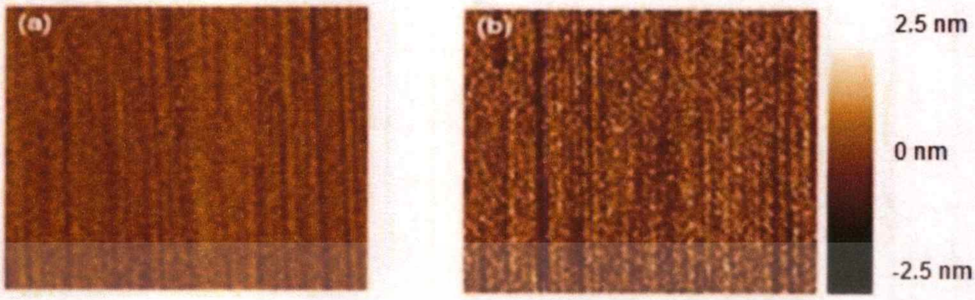


Fig. 2.1 AFM (Atomic Force Microscopy) picture of (a) LMR media compared to (b) PMR media [3].

This is complicated to link and sync up with the touchdown failure that was fully analyzed from the failed drives in the HDD test process. It has been noticed that the touchdown failure research in HDD has not been published in public because it has never been studied due to the company confidentially. Therefore, the study and literature review concentrated on the relevant products which have touchdown problem.

2.2 Fundamentals of hard disk drives

A typical HDD consists of a spindle that holds circular disks, also called platters, which hold the recorded data. The platters are made from non-magnetic materials, usually aluminum alloy or glass and are coated with a shallow layer of magnetic materials typically 10–20 nm and outer layer will coat with the carbon for protection.

The information is written to and read from the platter as it rotates past devices called read-and-write heads that operate very closely (often tens of nanometers) over the magnetic surface. The read-and-write head is used to detect and modify the magnetization of the material immediately under it. In each drive, there is one head for each magnetic platter surface on the spindle, mounted on a common arm. An actuator arm (or access arm) moves the heads on an arc (roughly radially) across the platters as they spin, allowing each head to access almost the entire surface of the platter as it spins. The arm is moved using a voice coil actuator or in some older designs a stepper motor.

The HDD electronics control the movement of the actuator and the rotation of the disk, and perform reads and writes on demand from the disk controller. The feedback of the drive electronics is accomplished by means of special segments of the disk dedicated to servo feedback. The servo feedback optimizes the signal-to-noise ratio of the GMR sensors by adjusting the voice-coil of the actuated arm. The spinning of the disk also uses a servo motor.

2.2.1 Components

Figure 2.2 shows the components of the HDD and the descriptions of each one.

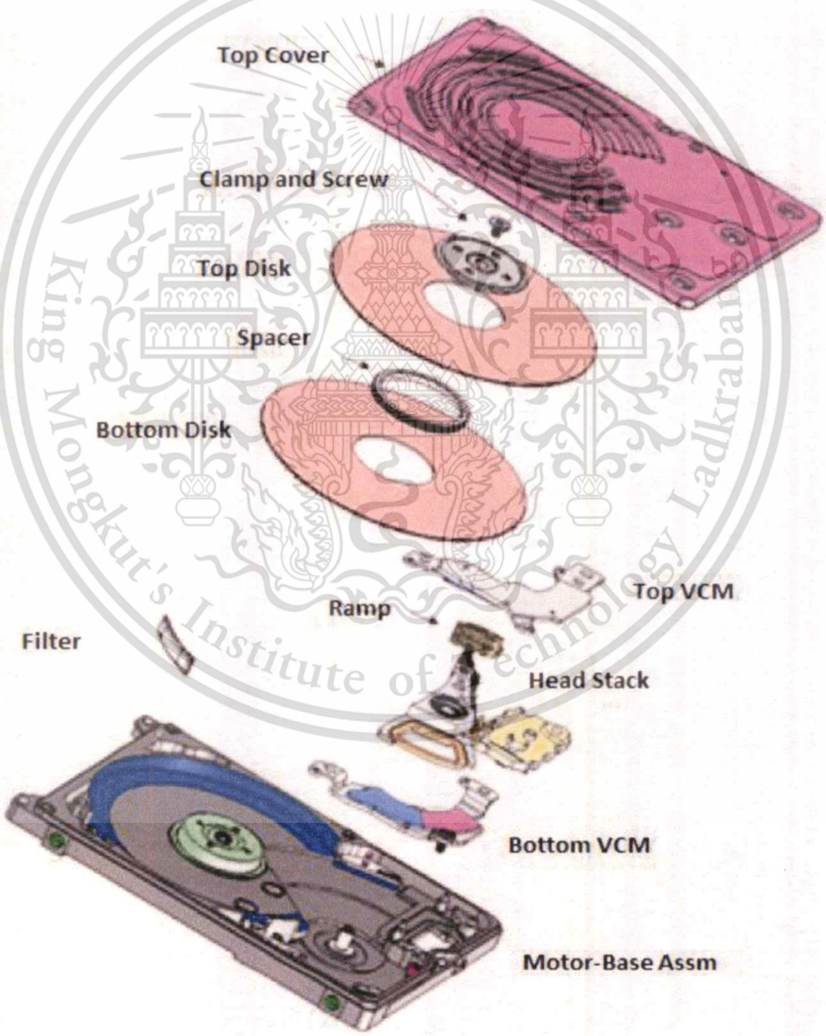


Fig. 2.2 HDD component [9].

The *"Disk media"* is composed of magnetic bits used to record and retrieve data in binary format. The Capacity of a hard disk drive depends on the total amount of disk media available and areal density. It is attached to motors by a disk clamp. The *"Head Stack Assembly (HSA)"* is a combination of slider (writer and reader), head arm, pivot, voice coil motor, It reads and writes while fly height 9-12 nm above disk media around, when converting electrical pulses to magnetic transitions. The *"Dual magnetic voice coil motor"* is installed on the top and bottom of the voice coil and is used to move the head stack assembly to the proper place. It works by Faraday's law. Current is induced when the voice coil motor movement between top and bottom magnets. The *"Filter"* is placed in the hard disk drive two places. The first filter is called an air recirculation filter, used to entrap contamination. A second filter (a breather filter) allows air to pass or leave as air pressure. The *"Disk clamp"* is installed on the top of the disk media to hold the media and helps balance the disk media. The *"Base and top cover"* cover all interior components to weak closed environment and to protect particular contamination from outside. Some base types will have a motor built into the base. The *"Ramp"* is the landing zone for the actuator when the hard disk drive is powered off. It helps the head not to land on the media when the hard disk drive is shutdown. The *"Latch"* prevents the head stack from crashing to the motor and control movement when head stack stops working.

2.3 Assembly process

Figure 2.3 describes the hard disk assembly process. The first process cleans the HDD parts with chemical, and the second process assembles bottom voice coil magnet in the base then performs the ramp installation. The next process is the media installation followed by clamp bias installation for holding the media while the hard disk is turned on. After this process, the operator must test the balancing and acceleration to check the balance and imbalance of the media during spin up. Ramp installation is the next process, and needs the operator to inspect the gap between disk and ramp. The head stack assembly is installed before the top voice coil motor magnet is installed to complete the circuit. This part has current flow in the voice coil when the hard disk drive is working and force of a magnetic field. The latch is the lastly, part which is installed in the hard disk drive. It prevents the head stack flying off the disk. To completely close the environment, a top cover is installed and sealed before going to a leak test.

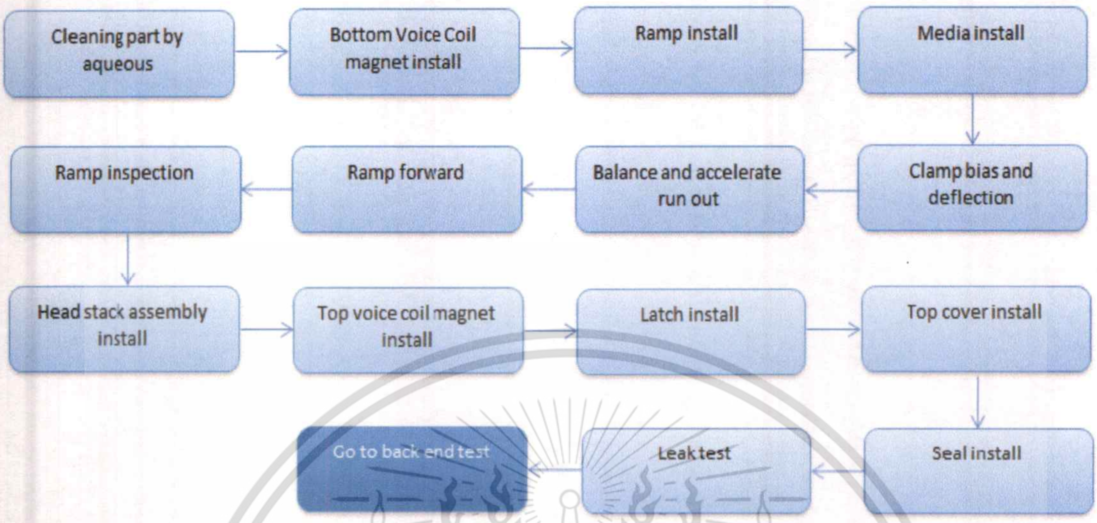


Fig. 2.3 Hard disk drives assembly process.

2.4 Hard disk drive failures

Most hard disk drive failures come from top five issues. They are firmware issues, mechanical failure, electronic failure, logical failure and physical failure. During all test processes, all machines and testers keep a history log to show each limit or step test in memory and send them to the main database (data warehouses). Normally, engineers can access these data to analyze where the hard disk drive failures come from. Figure 2.4, shows the concept of HDD during operation. As the HDD speed operates at 5400 RPM, therefore, the fly ability is considered how the head can fly over as close as on the media. This gives some guidance to find the related parameters needed. Based on this, three major issues related to HDI as follows: head media spacing, media roughness, and thermal asperity.

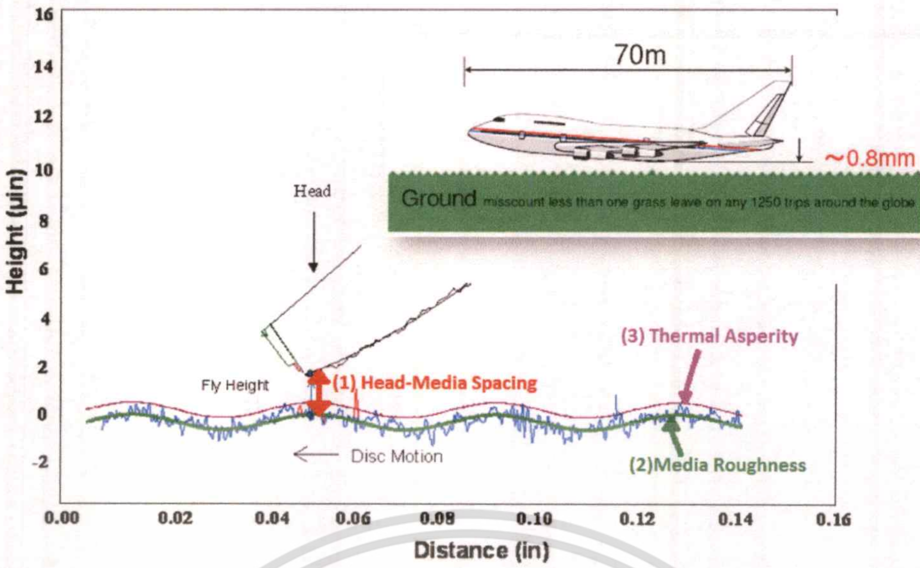


Fig. 2.4 The concept of HDD motions during operation [4].

2.5 Test process and assembly parameters

During step test process or assembly, all parameters are generated and uploaded to the database. The important parameters are followed.

The *"Touchdown"* is a test verification parameter for read and writes operation of the initial test station. It is a test sequence to collect the touchdown value to determine the maximum power that will be applied to the head (unit is MW). During this step, power is applied from the low level (until the head contacts the media) until it reaches the maximum allowable power.

The *"Touchdown Interpolate"* is a process for collecting touchdown data. This is the same thing the touchdown has performed, but this test is repeated multiple times and statistical analysis is performed.

The *"Head Qual OW (head qualification overwrite test)"* verifies the performance of the head and media during the final test station at the backend. The test writes data with the 1st frequency at 400 KHz and the 2nd frequency at 1.2 KHz and measures the residual amplitude coming from the 1st frequency. In an idle test, we should not find any residual amplitude from the 1st frequency because the writer should overwrite the previous data by 100 percent. A bad overwrite may come from a problem during the optimization process (optimization between head and media during the initial test to find optimum points for each head- media pairing) or thermal asperity due to temperature increase.

The *"VGA (Variable gain amplifier)"* performs for reading operation test at Initial test. This test can screen changeable head. The *VGA test starts* to let the VGA adapt to the reader signal for each drive and reads the newly adapted VGA setting, compares that with the setting that was captured earlier on from the test process.

The *"MRR (Magneto-Resistive Resistance)"* is MR resistance testing. When the preamp biases head to read and store data, we measure the head voltage and calculate by the ratio voltage and current. Low MRR is one of the root causes of head-disk interface issue.

The *"Bit Error Rate (BER)"* is read-write performance. It can be calculated by how reader can read after writer writes the data on the media and report as the percentage of bits that have errors.

The "Pbert (Partial Bit Error Rate Test)" is the test verification parameter that performs at the final test station at the backend site. This step measures the bit error rate of all user zones and collects the results by Pbert per head, per zone and per drive.

The *"DFH (Dynamic Fly height)"* is a test step to verify after writing servo signal on media. It can identify the distance between the head and disk media when the hard disk is working. This parameter is measured from current that apply to the resistance heater at the reader. A stable flying height is necessary to achieve low BER.

The *"Error Margining (EM)"* is a channel DVT (PTM) designed to find the SNR margin from the BER cliff of all heads and zones of a drive. This information is saved to the drive at the end of the test. In the enhanced multi track test, the program measures the EM for multiple tracks and presents the statistical performance results.

The *"SNR (Signal to Noise Ratio)"* is the ratio of the level of the information-bearing signal power to the level of the noise power.

The *"OTRC (Off Track Read Capability)"* is the capability for read-write offset data on the adjacent track. The sector resolution test is generally used for failure analysis, and the measurement is taken around a defective sector. The standard measurement is ±1 track and ±50 sectors. In sometimes, a measurement by wedge on a single track can be useful for failure analysis.

2.6 Fundamentals of head-disc interface

In a HDD, the spacing between a Magnetic Recording (MR) head and disk is a critical parameter to its capacity and performance. Reducing this spacing has long been the goal of designers. The fly height has been greatly reduced as a result of this effort. An alternative to lowering fly height is the reduction of head-to-media spacing based on the needed, in other words, reducing the spacing only during reading and writing. Figure 2.5 shows head-disc clearances, the space between the slider and disk which is the primary factor for HDI reliability.

2.6.1 Head media spacing (HMS)

High density drives of the future will require that mechanical spacing, or fly height, approach zero. Similar reductions will be required in disk and head protective overcoat layers, since these layers add to the magnetic spacing. In the quest for improving signal amplitude (thereby improving SNR, BER and leading to better margin at higher areal density), the effect of thicknesses of lubricant, carbon overcoat and even magnetic layers were being studied [5]. The magnetic spacing (between head and media) was immediately reduced if the lubricant or carbon overcoat thicknesses were reduced. This was an alternative to lowering the flying height.

As illustrated in Figure 2.5, any reduction in terms of h (flying height), or lubricant thickness, or carbon overcoat thickness immediately brought the magnetic spacing down and hence increased signal amplitude.

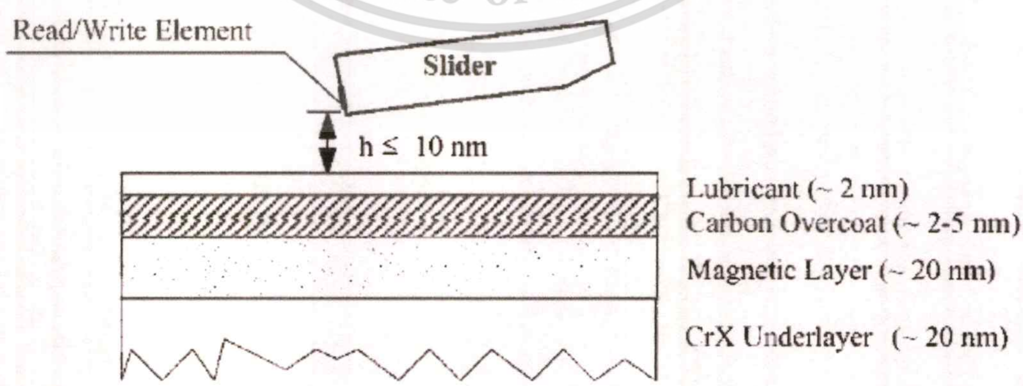


Fig. 2.5 Typical schematic illustrations of a head-disk system [5].

Since the hard disk supports a continually increasing areal density and provides a very durable interface necessary for low flying across the disk surface. In addition, this surface must be very smooth with essentially no defects to minimize contact with the slider, and exhibit minimal waviness which could also interfere with low flying. Disks are formed by the process of sputtering multiple metallic films and a protective overcoat layer onto a highly planar, low defect glass substrate. The glass has been chosen based on its smoothness as well as modulus which yield stable mechanical properties in the drive. The protective overcoat which is normally a carbon based material is covered with a thin lubricant layer to improve the durability of the head disk interface. To avoid head section, a ramp load/unload mechanism is used to prevent the head from resting on the disk when it is not rotating. This allows the use of very smooth disk surfaces and facilitates the continuing trend to lower flying.

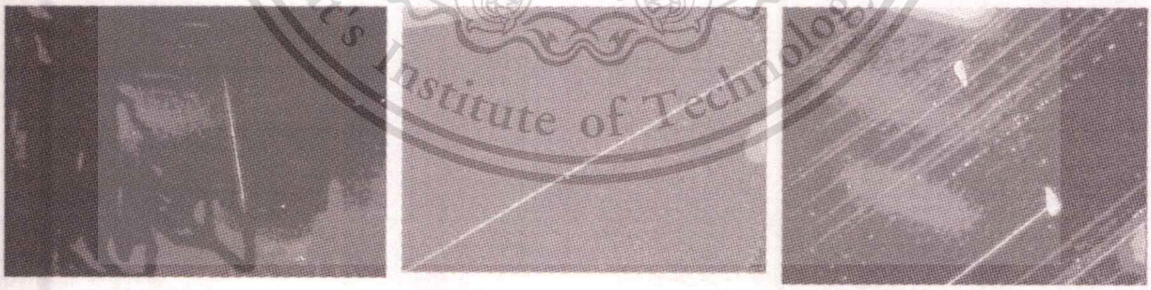
It is important to understand precisely what is happening within the drive, and which systems areas are failing under conditions of vibration. When mechanical components are vibrated, they bend and distort, and this is further compounded when vibrated at resonant frequencies. There are two major mechanical components that, when excited at resonance, can result in data transfer failure. Firstly, there is the suspension arm that pretension the head against the disk to counterbalance its aerodynamic up thrust. This is designed to control the flying height of the head during normal operating conditions. If the flying height of the head is such that it is outside of its normal operating range, then the signal degrades, and ultimately can lead to data transfer failure.

In severe cases, the head will crash down onto the disk and cause irrecoverable damage. Secondly, there is the hard disk (the data storage medium) itself. The disk can be driven such that it flutters up and down, causing tracking (or mis-registration) problems. The problem can be compounded by the fact that if the suspension arm is resonating, and therefore the head, the disk can be driven into oscillation due to the head pushing onto the disk and vice-versa.

2.6.2 Media roughness

As head-disk spacing gets inevitably smaller where the disk surface becomes rougher. The current technology deployed to address the areal density challenge, the impact due to media roughness pose another challenge.

Reference [5] presented a brief and concise report of material science studies performed on the defects of the recording media to characterize and understand their source. The study involved the characterization of sub-micron features and particles between hard disk interface. The media scratches, particles and defect areas on the heads were analyzed by SEM&EDX, FE-AES, and TOF-SIMS. The particle numbers were detected by Liquid Particle Count System (LPC). The results provided insight into the type and possible cause of the media scratch. It also showed direct evidence of media scratch caused by unstable load/unloading condition (serious crash to media). The study also showed that particles on head could contribute to media scratch, and when it happened, LPC result indicated that the number of particles on the failed head was higher than normal ones and it could scatter over the media (resulting in scratch trace). All these implied that it was essential to optimize the flying conditions of the slider, especially during the course of load/unload the slider on the moving disk. Figure 2.6, summarized some of the results presented in [6]. The classification of failure type was important to our work as there was associated probable source to each of the types of defects.



(a) (b) (c)

Fig. 2.6 Kind of media scratch pattern (a) short line scratch, (b) typical scratch trace, (c) abnormal marking [6].

Knowing probable causes of each type of defects were critical to our work as in the quest for a statistical model. It was often difficult if we did not properly segregate data from a "cause and effect" standpoint. In other words, it was essential to group data by "observable response" and its "related input" before data modeled and statistical methods applied.

2.6.3 Thermal asperity (TA)

As presented in Sections 2.6.1 and 2.6.2, with the reduction in head-disk spacing coupled with the rougher recording media for perpendicular magnetic recording, the chances of encountering a thermal event increased. The effects of the thermal events are summarized in [4], [7]. During the read process, the magnetoresistive (MR) head sensed the change in flux via the transitions of the magnetic pattern written on the disk surface, resulting in an induced voltage pulse called a transition pulse. When an asperity (or a surface roughness) came into contact with the slider, both the surfaces of the slider and the tip of the asperity were heated, which resulted in an additive voltage transient known as thermal asperity (TA) in the readback signal. Typically, a TA signal has shown in Figure 2.7, a short rise time (60–150 ns.) with a long decay time (1–5 ns), and its peak TA amplitude could be 2 to 3 times the peak of the readback signal. The TA effect could cause a burst of errors in data detection, which could easily exceed the correction capability of the error correction code (ECC), and thus resulted in a sector read failure.

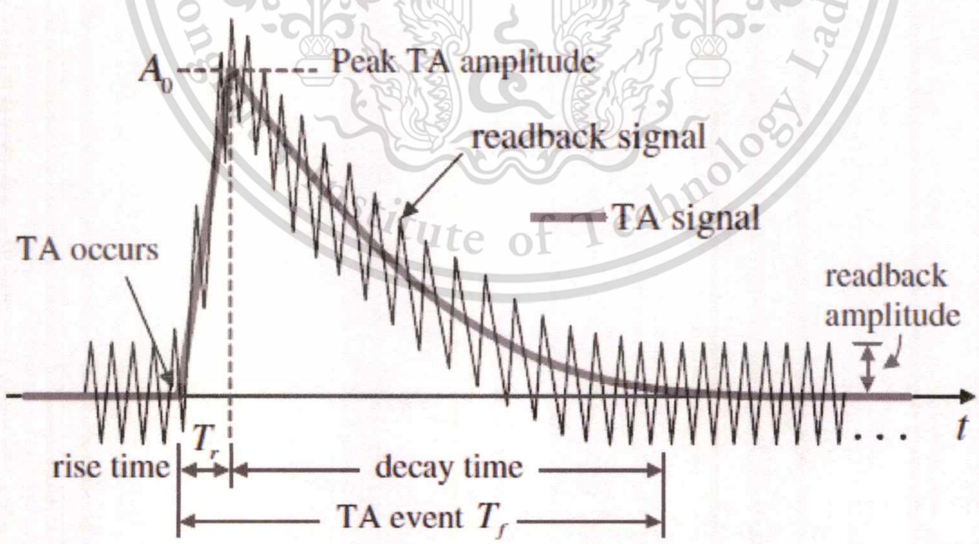


Fig. 2.7 TA model [7].

2.6.4 Fly height (FH)

The amount of space between the heads and the platters is called the flying height. Over the years the flying height has been lowered consistently, with the requirement that there should be no head media contact during operation that can result in damage. Some of the factors that determine flying height are the relative media velocity. This varies with the track radius. The weight of gram load (weight) and the flexure design and width of the Air Bearing Surface (ABS). As the head moves from the outermost track to in the innermost track, apart from the decrease in media velocity, the skew angle, which measure the alignment of the head to the track also changes, Figure 2.8 shows the variation in flying height due to these factors.

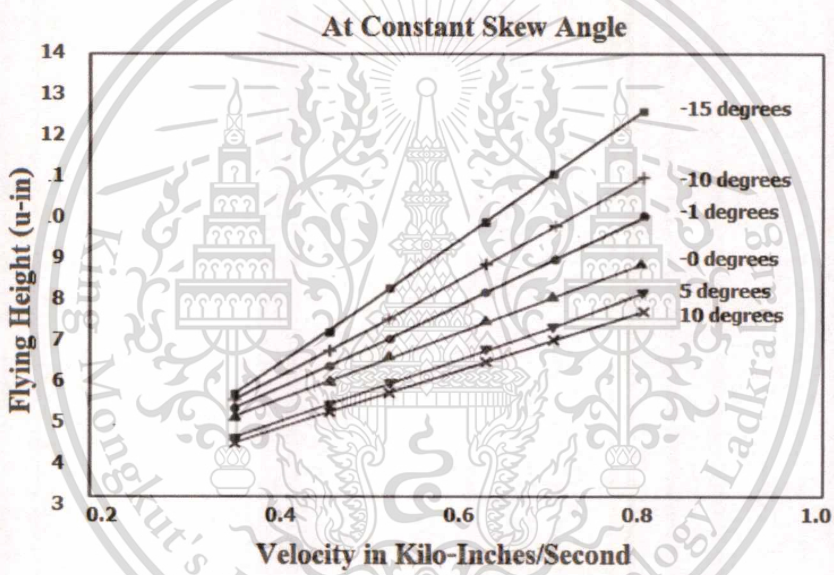


Fig. 2.8 Flying height versus velocity for different skew angles [4].

Based on a head media spacing, media roughness, and thermal asperity study, we conclude that the particle contamination can cause touchdown power change. The cleanliness is very important to aviod poor dynamic fly height (DFH) optimization process. This is also one of the key parameters affected to HDI issue. Figure 2.9 shows the the HDD parameters that the tester has generated and kept in HDD database. These are important parameters, such as touchdown (TD), Dynamic Fly Height (DFH), Over Write (OW), Error Margin (EM), Magneto-Resistive Resistance (MRR) use for failure analysis. For example, during the assembly, the roughness and number of Thermal Asperity (TA) are focused on. In particular, the number of defects and contamination are recorded.

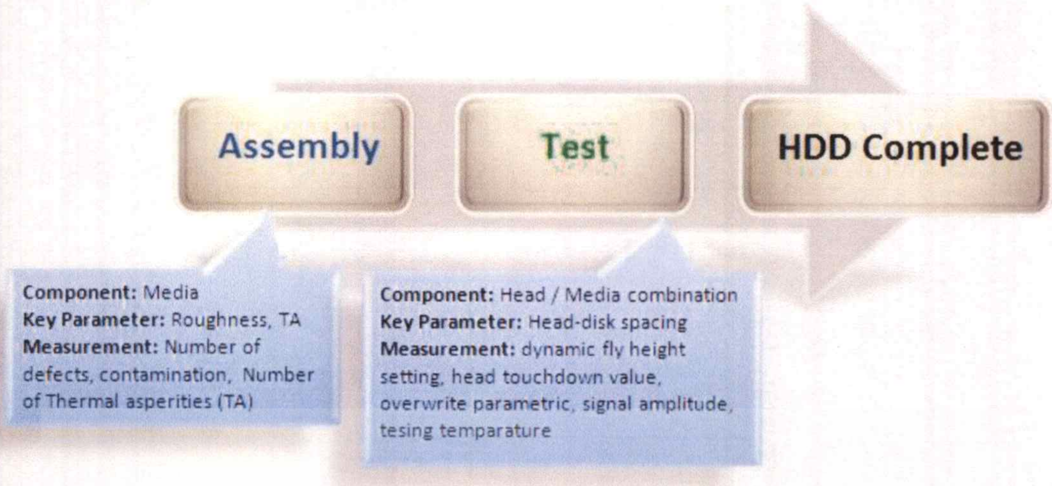


Fig. 2.9 Key parameters measurements taken during the manufacturing of HDD.

Figure 2.10 shows the top 3 pareto in HDD testing process. We review the top pareto in HDD report failures and interested in the touchdown drive verification test (TDDVT) delta exceeded limit failure. Based on FA experience in provious products, we suspect that the particle contamination can be the root cause of this failure. In this research, we study the fundamental of touchdown process to enhance the test method in order to avoid the particle contamination. Finally, the goal is to reduce the TDDVT delta exceeded limit failure below 0.5%.

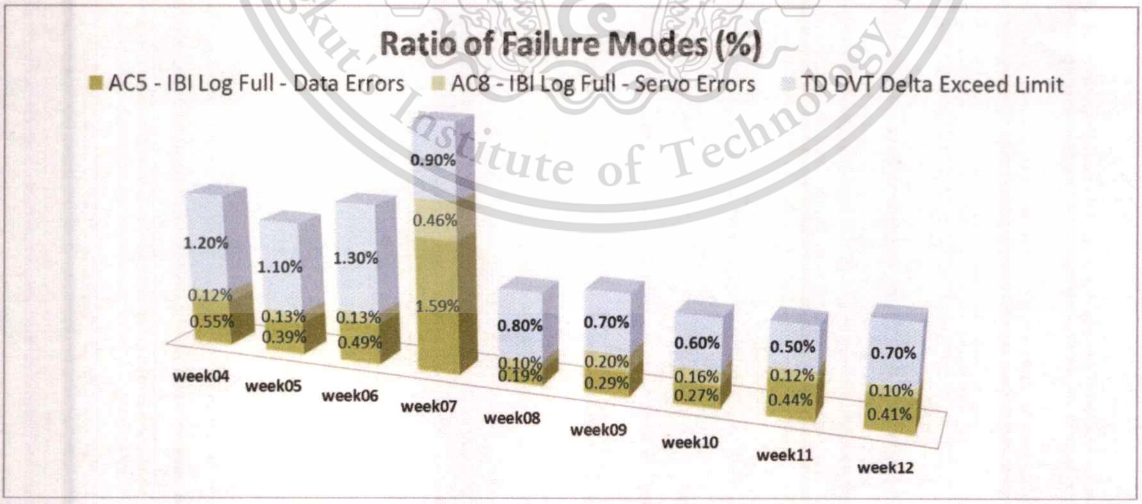


Fig. 2.10 Failure pareto in HDD test process.

CHAPTER 3

Touchdown Test Process

This chapter describes 3 areas. Section 3.1 overviews the issue of particle contamination in hard disk drives. Section 3.2 explains the procedures of the touchdown test process. Section 3.3 is related to the observation of touchdown failure and test parameters, and describes the symptom of the touchdown failures.

3.1 Particle contamination in hard disk drives

The drive level cleanliness measurements are more difficult to perform than component-level tests. Drive-level particle counting is used by nearly all manufacturers as an indication of start-up cleanliness. Conventionally, air from the interior of the disk drive is sucked out via a particle-count port, and a laser particle counter is used to count particles larger than 0.1 μm in diameters. The incorporation of a condensation nuclei counter (CNC) can extend the lower detection limit to 0.01 um [8].

In this test, the sensor is placed within the head/disk assembly (HDA) enclosure. The particle counts may be obtained during disk spin-up, full speed operation and spin-down. Air flow spinning off the disk is monitored during this test, which is therefore more representative of real-life operation. Tear-down and analysis of the head disk interface is frequently done on an audit basis to determine debris build-up with time. Stiction force measurements in a simulated drive environment are performed less frequently to assess drive susceptibility to slider/disk adhesion [8]. A test system that closely mimics the chemical environment of a disk drive has been presented by Koka [8]. This system is designed specifically to study the effect of organic contaminants in a well-controlled, chemically-stressed environment. In the tester, heads and disks are subject to several thousand contact start/stops, and friction/stiction forces at the head/disk interface are continuously monitored. The key elements of the tester are the spin-stand and controller, the data acquisition and control unit and the contaminant introduction system.

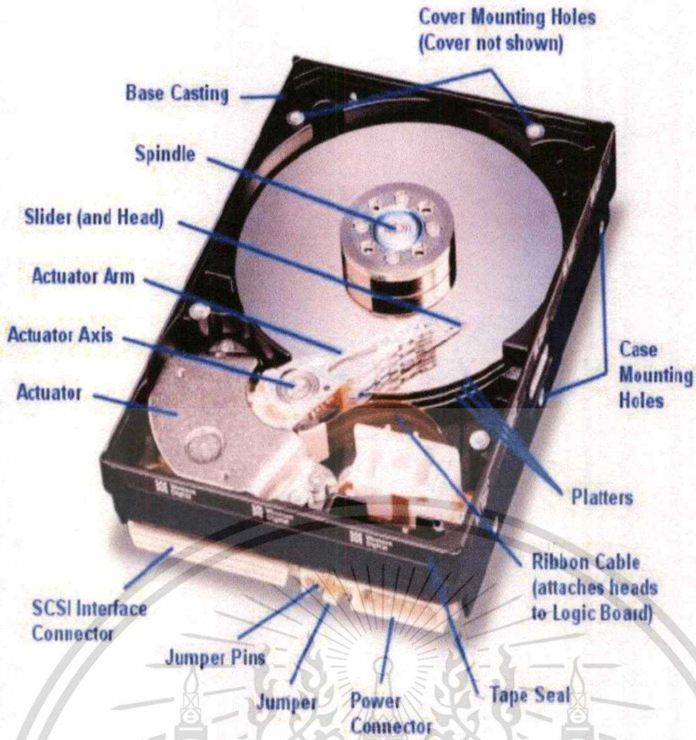


Fig. 3.1 Materials of the parts that are found in Hard disk drive [9].

In general, the particles are mobile and transferable and most are easy to clean but some are very sticky. The particles can be divided into 2 types, which are hard particles caused by scratches (complete damage) or hard errors (incoming material issue) and soft particles coming from smear on the media or soft error (re-writable). Figure 3.1 shows the materials of the parts in Hard Disk Drives (HDD) and describes the risk of contamination exposure on each part.

(A) Base Casting or Motor to Base (MBA)

This component part is made from pure aluminum or aluminum alloys. The risk of contamination exposures as follow the bare aluminum casting has quite a rough surface and can be difficult to clean as well as being a particle source. Typically, it has relatively complex shapes with matching areas and blind and through holes which compound cleaning and drying problems.

Crash Stops

This component part is made from injection molded plastic piece with an elastomeric bumper and sometimes a permanent magnet latch and it is used to restrain the Head Stack Assemble (HAS) from moving beyond the Inner Disc (ID) and Outer Disc (OD) boundaries of the prescribed travel zone, and also to latch the HSA into the landing zone or unload position for the drive shut down. The risk of contamination exposures as follows: the magnetic contamination of crash stops can occur during manufacturing and shipping or handling, and the elastomeric bumper can be difficult to clean, but due to the small size they are typically not a major contamination source.

(B) Filters

This component part is made from woven or matted synthetic fibers, glass fibers, and carbon fibers or granules. It's typically used to filler out particles which become airborne during the operation of the drive, to allow for pressure equalization within the drive and for organic vapor adsorption. The risk of contamination exposures as follows: the fibers on fillers as well as fibers shedding from the edges can be a manufacturing problem with HDD filers, but these are uncommon.

(C) Gaskets

This component part is made from synthetic rubber, synthetic foam elastomer, and gaskets can be used standard O-rings, custom elastomeric rings or others, as well as custom foam due cuttings. They are typically used to seal around and between components such as motors and base casting or covers to base casting and around the connectors. The risk of contamination exposures as follows: the material and manufacturing process selection are critical to getting clean gaskets. Under cured elastomers, especially silicones can outgas and cause product killing contamination, and the die-cut foam gaskets can be loaded with particles along the cut edges and are nearly impossible to clean.

(D) HGA (Heads Gimbal Assembly)

This component part is made from a combination of materials which may include ceramic or ferrite slider, stainless steel epoxy, copper or gold wires, plastic or teflon wire insulation and is used to provide the attachment point and suspension for this slider. The risk of contamination exposures as follows: the suspension components may be loaded with small particles which are difficult to remove, and the sliders may be contaminated with assembly debris including, abrasive particles from the lapping process and uncured adhesives.

(E) HSA (Head Stack Assembly)

The head is made up of a composite of different parts and moving them across the media during operation of the drive. The complete assembly for mounting the slider to the actuator are consist of Head Gimbal Assembly (HGA) plus, flex cables, cable connectors, amplifier modules, pivot nearing, actuator coils. Finally, we called it as HSA (Head Stack Assembly). The risk of contamination exposures as follows: the cleaning processes must be gentle to avoid damaging the fragile slider wire attachments. As many of the components are received in a ready to use condition, but they may not be clean enough for use as received, depending on the cleaning handling, storage and shipping which have previously occurred. The pivot or bearing pressing generated particles which cannot remove with aqueous cleaning due to potential bearing damage and grease cross contamination.

(F) Media

This component part is made from aluminum, glass or ceramic disks which are coated to provide the magnetic recording layer and a lubricated surface, the magnetic recording layer provides the usage of the small magnetic domain which store the zeros and ones which make up the binary data records. The risk of contamination exposures as follows: the media cannot be cleaned and is used as received from the disk manufacturing process. Some process result in the disk which is highly contaminated with particles and the lube components can collect on the sliders and form a “glue” which can collect more particles until a head crash occurs. The pre-sputter contamination on the media can result poor Glide yield, high thermal asperities or sputter layer delamination. Contaminated lube baths can result in disk surface contamination.

Based on the media roughness study, we can conclude that the lubricant or overcoat thicknesses and typical scratches on the media (which represented the medium roughness) could bring the magnetic spacing down (also to increase signal amplitude). It was important to keep this observation as one of the key parameters affected to Head-Disc Interface (HDI).

(G) Motor

This component part is made from machined aluminum hub, bearing, internal armature assembly and it provided the hub for attachment to the media, spacers and top clamp as well as the armature and bearing to spin the media under the slider at high rotational speeds. The risk of contamination exposures as follows: the motors are normally received ready to use cannot be aqueous cleaned after assembly. Therefore the cleanliness of the motor is dependent on the cleanliness of the motor manufactures process. The magnetic particle from within the motor is a known contamination problem.

(H) Spacer

This component part is made from aluminum, stainless steel or ceramic. It used to control the drive spacing of the media stack. The risk of contamination exposures as follows: the stamped stainless steel generally contains a large number of particles and is very difficult to clean. Machined spacers are generally much cleaner and more cleanable, and the ceramic spacers are also difficult to clean and can break during handling and under the stress of being torqued down in a disk stack.

(I) Top Cover

This component part is made from aluminum, stainless steel, plastic or a combination of these materials and is used to cover the drive to exclude external particles and atmospheric contamination. The risk of contamination exposures as follows: the sub-assembled covers cannot be cleaned in an aqueous cleaner if the parts are assembled with adhesive. Due to the large surface area, even reasonably clean cover assemblies still contain millions of particles which are exposed to the inside of the drive.

3.2 Procedures of the touchdown test process

The touchdown (TD) calibration is used to find the maximum power that can be applied to the heater element for each head on a drive. This is accomplished by continuing to apply power to lower the heads until they make contact with the media or until the maximum allowable power has been applied. This process (called TDCal) is finished at the pre-test called Initial Drive Test (IDT). Firstly, we have to know how to categorize failure analysis as touchdown power change (TPD). In HDD failure analysis, the TD failure can be classified into two cases as follow.

3.2.1. Case1: Repeatable touchdown power change failure

A. The failure due to head slap

In figure 3.2 shows the data track areas might be too close, so it creates too much overlapping to the margin between each data track. Consequently, it leads to touchdown power change which causes head slap. Regarding to the test process, head media defect is a sign of the head slap at the error location. As a result, if head slap is at the error location, touchdown power has changed on the same head. Thus, head slap is one of the failures, causing touchdown power changes.

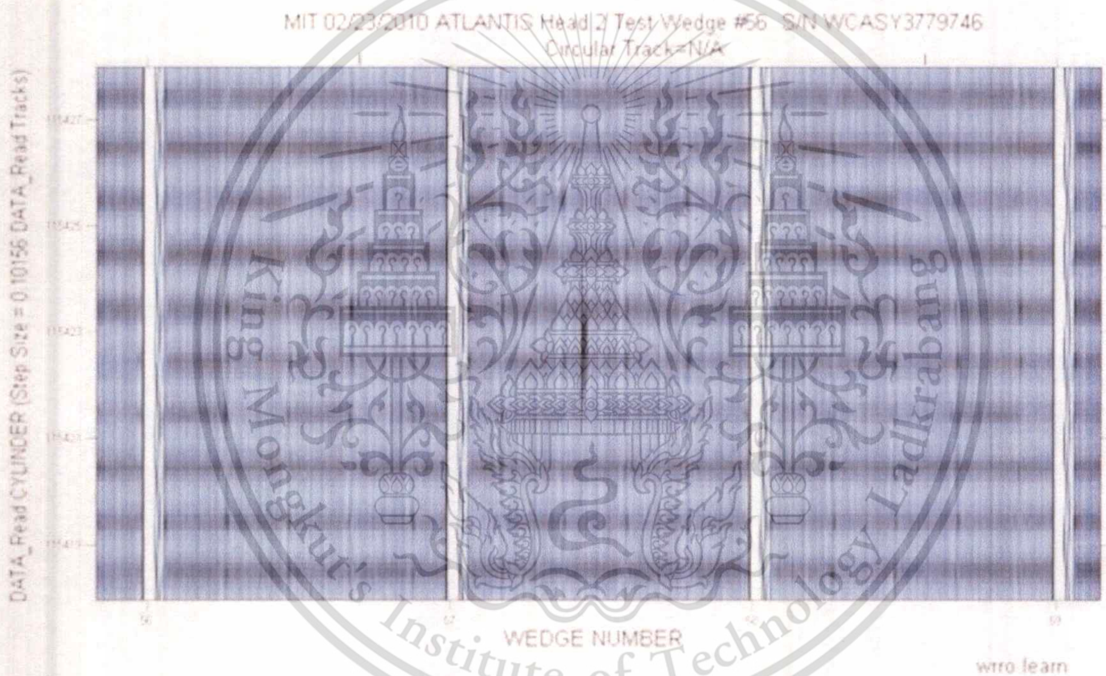


Fig. 3.2 MIT (Magnetic Imaging Tool) plot from HDD micro defect.

B. The failure due to head scoring

In Figure 3.3 shows a plot of the Bit Error Rate (BER) by head and zone. We can see that in the head3, the brown dashed line is located far below other dashed lines indicating the sign of overwrite (OW) degradation and touchdown power change on the same head. The media is known to have Thermal Asperity (TA) which causes head scoring.

As a consequence, the head scoring causes overwrite degradation. The touchdown power change is on the same head as detected from the graph. This failure can cause a sector with full amplitude to decrease amplitude after a write operation. This is considered the poor write and read error rate. The overwrite degradation or bad overwrite means that there is no error during the write process, but the error is found on reading process.

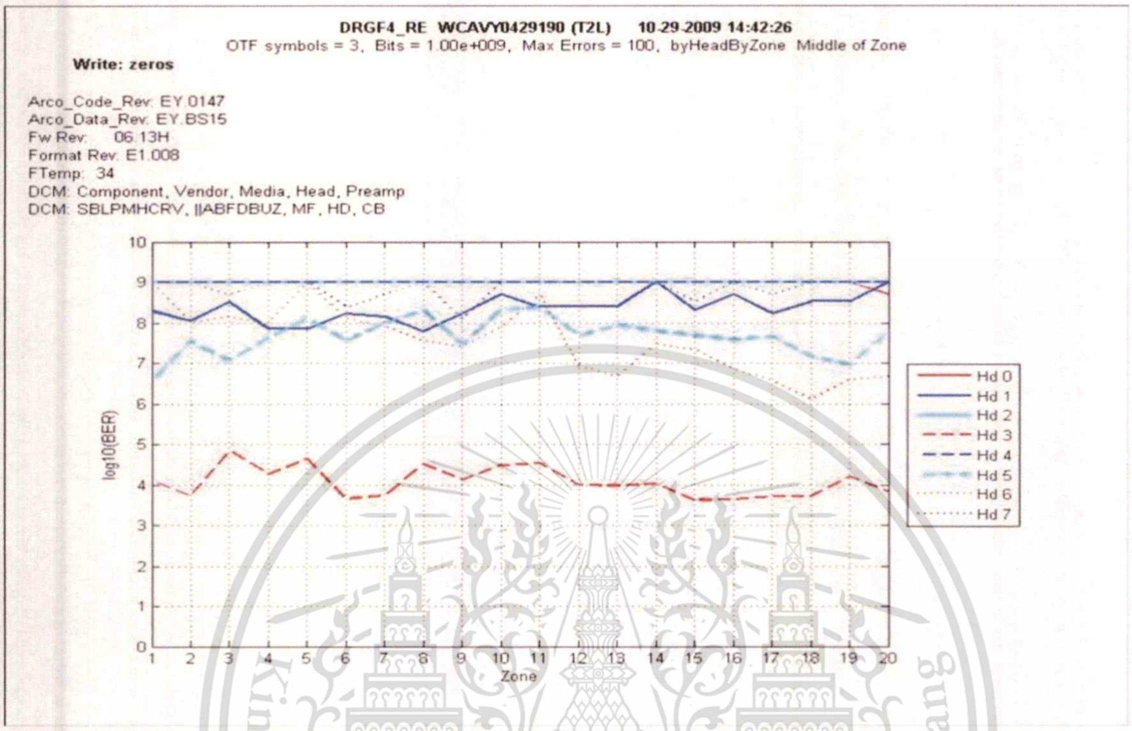


Fig. 3.3 The error rate of head scoring failure.

C. The failure due to pole scoring

The Pole Scoring comes from the write abortion due to low TAA (Total Average Amplitude). In Figure 3.4 shows sequential Glist entries on the head0 and seeks error reported in writing operation. The waveform on an oscilloscope shows the wedge (WG) signal drops and this is the cause of high DC offsets. The failure analysis result shows the sign of head sigop (BLP), Base Line Noise (BLN), Asymmetry, and others.

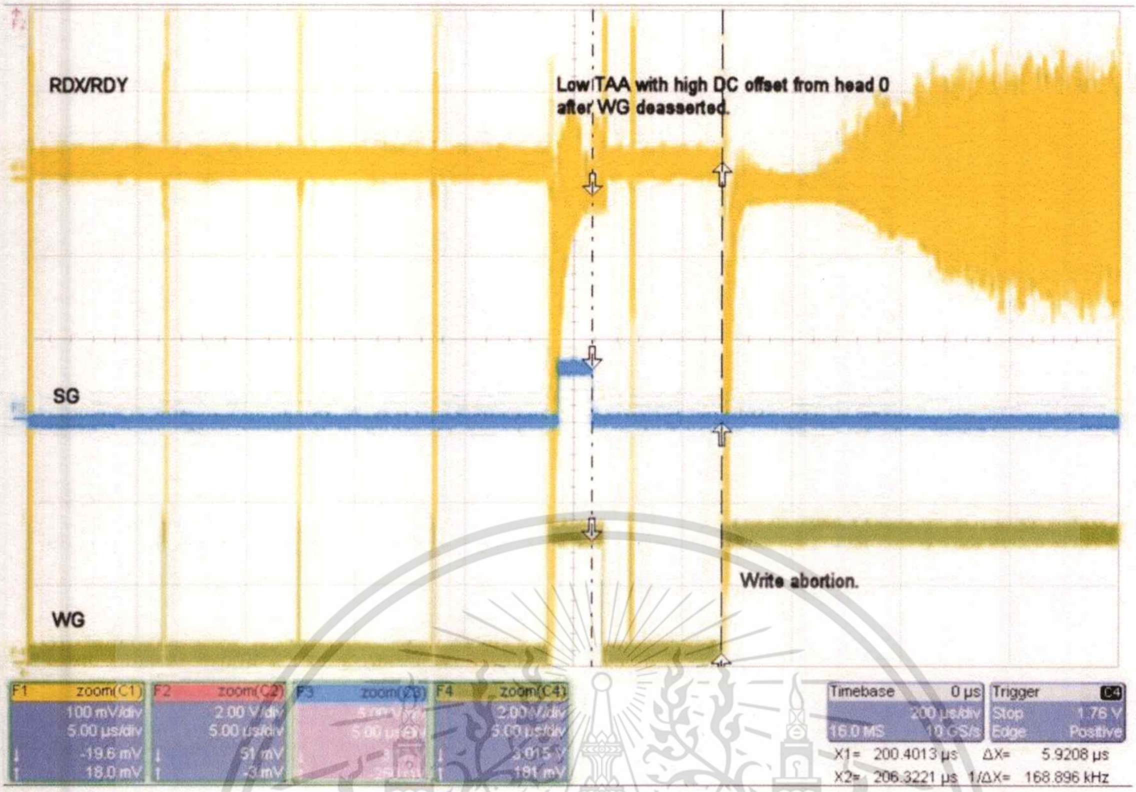


Fig. 3.4 The scope image of base line noise (BLN).

3.2.2. Case2: Non-repeatable touchdown power change failure

We conducted the test two times with the same drive. At the first time, the touchdown failure occurred during performing the test in temperature and altitude chamber so called Xcalibre tester. Then, we ran the touchdown drive verification test (TDDVT) with the original value of Track per Inch (TPI) and Kilo Flex change per Inch (KFCI) instead of overwriting with new TPI/KFCI.

There are two cases which can occur as follows:

A. The test can repeat low TD, i.e., the TD power repeats the original value when reprocessing the drives with the original TPI/KFCI. In this case, the failed heads will exhibit the poor bit error rate (BER) because the head is degraded during the test. As a result, we will send the defective head to supplier for investigating the cause of degradation.

B. The test cannot repeat low TD, i.e., the TD power does not repeat the original value after reprocessing the drives with the original TPI/KFCI. In this case, we suspect that the particle may move away for the re-test.

The case B is the case that we are interested in since the touchdown failure cannot be repeatabled at the second time. The contamination during the optimization process may cause poor DFH calibration and make the drive become intermittent of the touchdown failure. We will talk about this issue later in Section 3.2.5.

3.2.3. The method to categorize failure analysis as process touchdown power issues

The touchdown drive verification test (TDDVT) delta exceeded limit failure will occur when the interpolated touchdown power (TDP) between pre-test and post test exceeds the test limit (±15mW), or we can call touchdown power change (TDP) failure. Figure 3.5 shows how to get the TD power (in mW). Usually, the touchdown scenario can be found late or early TD detection. We will describe how to classify this whether is late or early TD in Section 3.3.

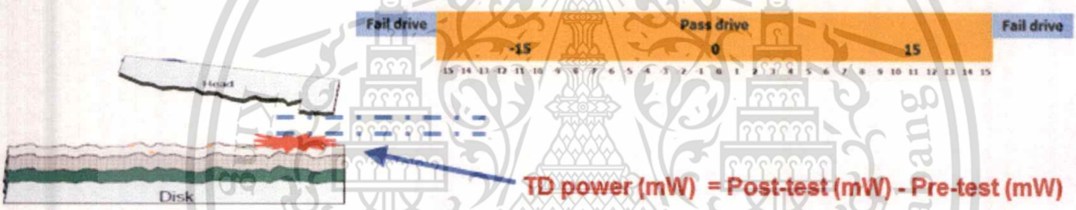


Fig. 3.5 Delta TD between post-test and pre-test.

3.2.4. Definition of TDCal and TDDVT

The calibrated touchdown (TDCal) process is run at the beginning of the test process in order to set a target of head media spacing. The target comes from the optimal value between DFH calibrations minus DFH back-off. The DFH back-off is a constant number and the number will be different, depending on the product. The number given for a DFH optimization process such as Overshoot Duration (OSD), Overshoot Amplitude (OSA), write current (Iw) is pulled from the test script (called cotools.trx, this is a special tool used for WD only) and kept as the text file for further test as follows: Firstly, running the calibrated touchdown TDCal uses command “getflexbias” and pulls the data from the file 0x96 and stores it in “flexbias.txt”. Secondly, running the Touchdown Drive Verification Test (TDDVT) uses command “gettdvt”, pulls data from the file 0x98 and stores it in “tddvt.txt”. The raw TD data has collected from each zone. The result shows the interpolated touchdown power (TDP) by zone data.

3.2.5. Touchdown scenarios

In the test process, there are two cases of touchdown failures that can happen during the HDD test process as follows,

(A) TD power decrease (early TD)

The TouchDown Drive Verification Test (TDDVT) power on the failed head location has ***Lower*** TD power than the TDCal power acquired at the initial test process. They indicate that the failed heads have ***"lower flying height"***. We suspected that the contamination on the head tip pole caused the touchdown power to decrease. These are potential causes of early touchdown as follows: the margins of some mechanical parts have changed such as either shift-up or down, but still within tolerance. The particle contamination can also be the cause of low or inconsistent TD behavior. Additionally, the helium charge process is not completed during the process of writing spiral signal onto the media, but it can cause TD behavior. Helium is the first process (in the sub-sequence of the filler process) before starting backend test.

(B) TD power increase (late TD)

The touchDown drive verification test (TDDVT) power on failed head location has ***Higher*** TD power than the TDCal power acquired at the initial test process. They indicate failed head has "***higher flying height***". The possible cause of the touchdown power increase can come from carbon wear. The potential cause of late TD as follows: head wears, the particle contamination, can cause low touchdown during test process, but now cleaned. In this case, the touchdown failure cannot duplicate when reprocessing. The difference in touchdown test conditions such as environment or vibration, or the margins of some mechanical parts have changed such as either shift-up or down, but they are still within tolerance. The TD value shows different results on repeated test runs. Accordingly, the TD power fluctuates. Moreover, due to the TD power fluctuation, it means that the failed drives cannot duplicate the failure on bench. However, the TD power fluctuation occurs only one time during the testing process.

This is the case we are interested in and it had been investigated. The first-level failure analysis result and second-level FA result show the same sign, which contaminates on the failed head location. We need to make the gap between head and media (in other word, head disc interface: HDI) closer as much as we can so that we can achieve a high areal density per platter. To make the gap closer, the head cleanliness has to be considered. The experiments had been performed to study the characteristics of touchdown behaviors with two different methods and use the existing method as the baseline for comparison. We hope that the experimental results will be useful for development of the future magnetic recording head media.

3.2.6 The relationship between ABS design and head disk interface (HDI)

The read-write element is suspended by a suspension. This is floating above a disk by an air bearing. The bearings are machine elements and thier function is to promote smooth relative motion at low friction between solid surfaces. The spindle, gears, and slider bearings are a few types of bearings which are available in the current head technology. The functions of an air bearing are to provide low friction sliding between the slider and the disk, maintain a constant separation between the disk and the read-write element (the fly height), and provide stiffness and damping the head/disk interface. Figure 3.6 shows an example of competitive Air Bearing Surface (ABS) from different HDD products. If not designed properly, a padded slider will tip, causing bimodal stiction.

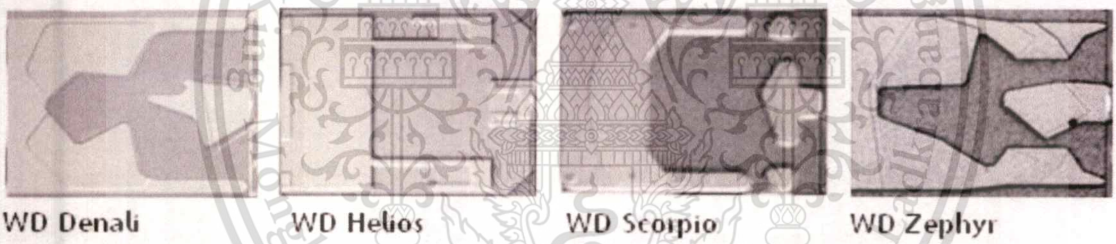


Fig. 3.6 Examples of competitive air bearing surface (ABS).

Figure 3.7 shows a simulation of the TD profile simulation at HGA level. This head uses in Denali product. Ideally, we want the TD profile to be flat across the stroke. But, according to the failure analysis report in section 3.3.6, we can see the TD power as a curve, highest at MD and lower at Inner Disc (ID) and Outer Disc (OD). This is because the TD profile is purely Air Bearing Surface (ABS) design dependent parameter. The TD profile depends on a combination of FH, pitch, roll, DFH efficiency, and DFH push back. The sensitivity will be different from OD to ID. However, we can see TD profile highest at ID zone and lower at Middle Disc (MD) to OD in some products that use the different head (different ABS design).

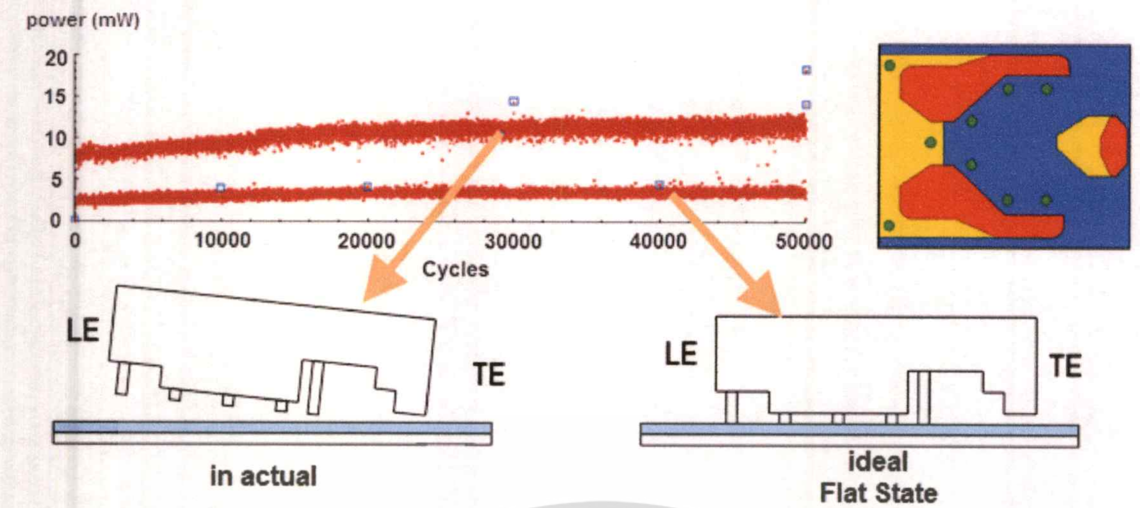


Fig. 3.7 The TD profile simulation (at HGA level).

3.2.7 HDD test operations

Figure 3.8 shows the overview of the HDD test process. After assembling, the drive is transferred from the cleanroom and goes through printed circuit board assembly before starting test drive performance in the tester.

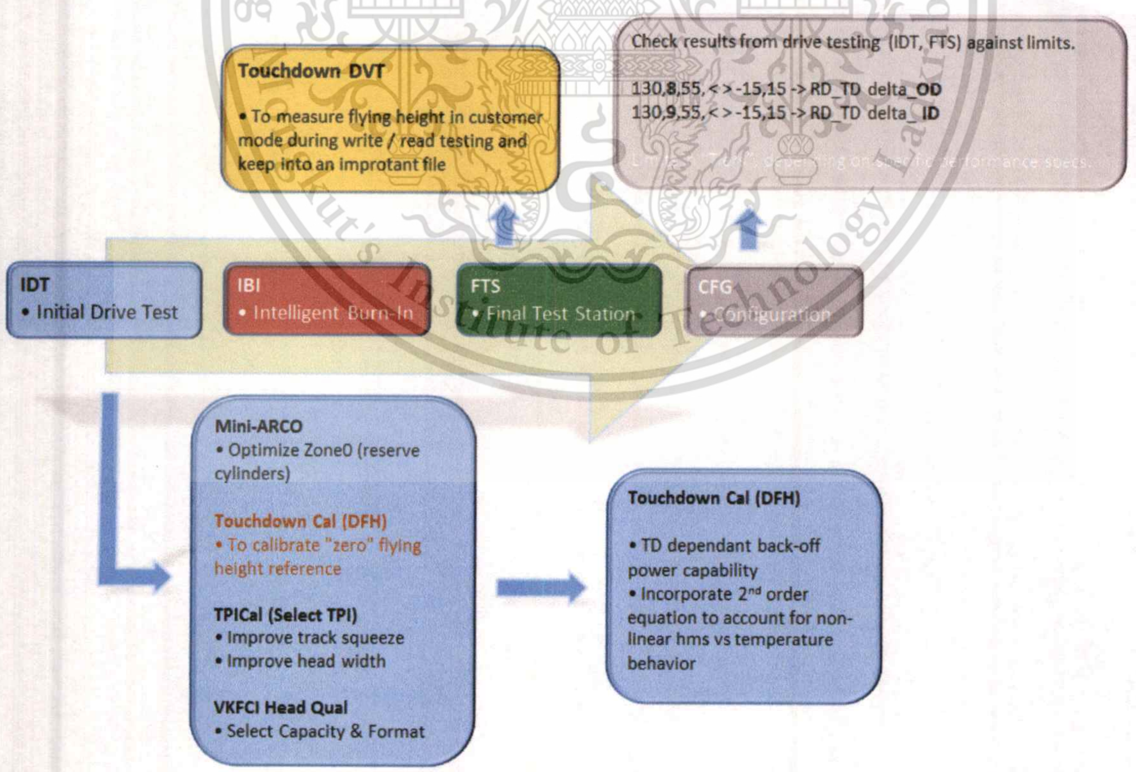


Fig. 3.8 HDD test operations.

The overall testing steps are as follows: *"Initial Drive test (IDT)"* to check mechanical, electrical, firmware, drive configuration, and start component optimization. This step determines whether the drive works properly. The next process follows by *"Intelligent Burn In (IBI)"*. This step starts to customize the firmware for each head and media pair and performs a defect scan to prepare the drive for user mode. The *"Final Test Station (FTS)"* performs read and write tests and sensitive temperature testing at ambient and hot temperatures. Finally, *"Customer Configuration (CFG)"* is the last step checking customer requirements. All limits and configurations must pass all specific customer requirements.

Every single drive may carry with different Firmware (FW) versions since FW keeps changing because we need to improve product yield, support new material, quality issue, and etc. Figure 3.9 shows the outlines of controller FW. The ROM code is the hard code kept in Print Circuit Board Assembly (PCBA). Normally, it is kepts in the OD zone (5-10 MB approximately). The overlays are reserved for HDD manufactory which the user cannot access into this area. The overlays consist of product image and process image. To spin the drive, product image has to work properly. To clarify, it must not have any corrupted files. Then, the drive will start loading firmware from PCBA and execute the series of the HDD tests.

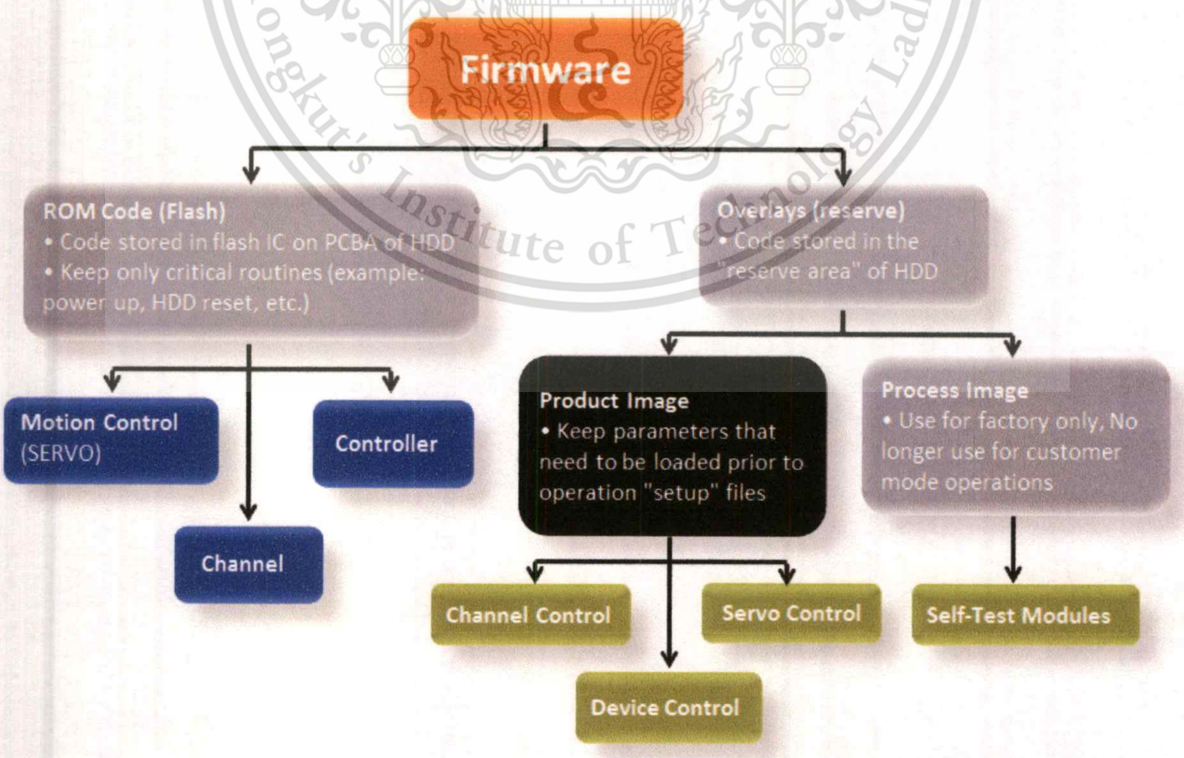


Fig. 3.9 Outlines of controller firmware.

3.3 Observation of touchdown failure and test parameters

The magnetic recording head will touch the media while calibrating process. Meanwhile, the head is not supposed to touch the media during the normal read-write operations. Due to the heads making contact with the media, the stress will be registered in the servo flexbias component which will be measured and saved into log file for analysis. As a result of this test, the maximum power corresponding to the reader & writer for each head and zone combination will be saved into the test log for reference of other test portions.

This research reviews the state of the touchdown (TD) delta exceeded limit failure. The interpolated touchdown power (TPD) comes from the calibration process between pre-test procedures, which give the calibrated TD, TDCal, and post-test procedures, which provide the touchdown drive verification test (DVT) TD, or TDDVT respectively. The TouchDown Power (TPD) will collect from 2 zones, i.e, Outer Disc (OD), and Inner Disc (ID). The TD power (mW) for both OD and ID will be kept in the test log files at the specific location called Global IDentification (GID). The difference between the pre-test and post-test TDs can be computed from

$$\Delta TD_{Outer\ Disc(OD)} = TDDVT_{OD} - TDCal_{OD} \tag{3.1}$$

and

$$\Delta TD_{InnerDisc(ID)} = TDDVT_{ID} - TD\ Cal_{ID} \tag{3.2}$$

The TD delta exceeded limit failure will occur if

$$|\Delta TD_i| >= 15 \text{ mW}, \tag{3.3}$$

where i stands for ID or OD. Once this failure is detected, the failure event will be reported in the database.

The touchdown calibration is necessary for HDD test process which aims to achieve the specific target of head media spacing. As mentioned in section 3.2.5, most of the touchdown failure scenarios come from the particle contamination. It is problematic that some particles hold onto the head tip pole during the touchdown calibration process. The ΔTD will be indicated pass or file drive and will be reported in the workbench yield reporting as the percentage of the touchdown exceeded limit failure. Figure 3.10 shows the specification of the touchdown power limitation of a sample product

Fig. 3.10 Touchdown limits specification.

Firstly, we will consider the Zephyr product. Figure 3.11 shows drive configuration of Zephyr 750GB. What the failure analyses have performed is based on 15 drives and the result shows in Table 3.1. We notice that there is no head trend on the failed head location. This is quite random. The touchdown power value is the difference between production and bench rerun. As shown in Section 3.3.1, there are 2 sample drives (SN#2, SN#6) which cannot be recovered after reprocessing. We have sent the drives to second-level FA for tear down analysis and the result shows the contamination related to the failed drive.

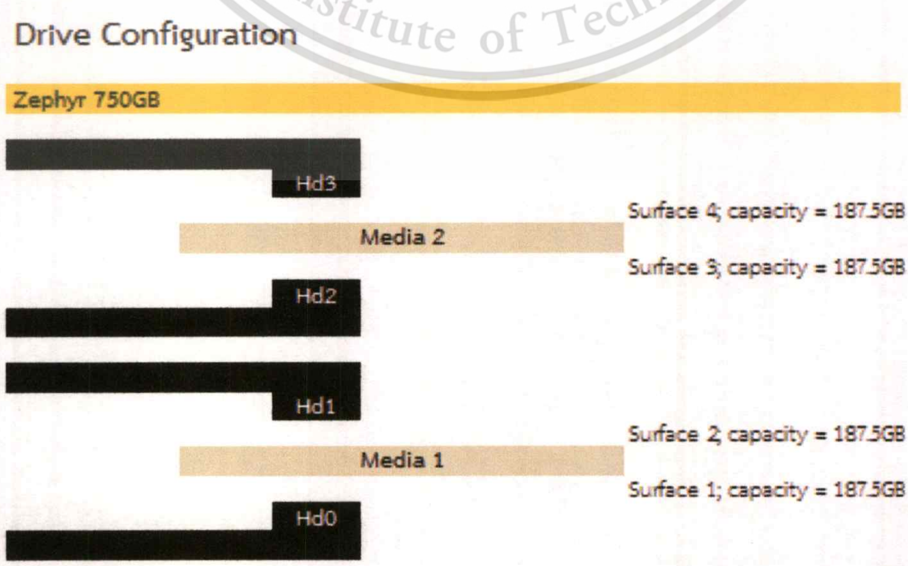


Fig. 3.11 Drive configuration of Zephyr 750GB.

Table 3.1 Failure analysis TD drive (Zephyr Product)

No	Capacity	Product	Head Failed Location	Category	Scope signal	FA Descirption	Conclusion
SN1	750GB	Zephyr	0	Re-process	Normal	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - TD profile on Hd0 is recovered after rerun	Fly Height issue
SN3	750GB	Zephyr	1		Normal	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - TD profile on Hd1 is recovered after rerun	Fly Height issue
SN5	750GB	Zephyr	1		Normal	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - TD profile on Hd1 is recovered after rerun	Fly Height issue
SN4	750GB	Zephyr	0		Asymmetry Head	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - can duplicate on bench	suspect head degraded
SN7	750GB	Zephyr	2		Instability Head	- Observed TD pow er decrease - TD profile show TDDVT (mW) < TDCal (mW) - can duplicate on bench	suspect head degraded
SN8	750GB	Zephyr	0		Instability Head	- Observed TD pow er decrease - TD profile show TDDVT (mW) < TDCal (mW) - can duplicate on bench	suspect head degraded
SN9	750GB	Zephyr	2		Instability Head	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - can duplicate on bench	suspect head degraded
SN10	750GB	Zephyr	0		Asymmetry Head	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - can duplicate on bench	suspect head degraded
SN13	750GB	Zephyr	2		Instability Head	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - can duplicate on bench	suspect head degraded
SN14	750GB	Zephyr	0		Asymmetry Head	- Observed TD pow er increase - TD profile show TDDVT (mW) > TDCal (mW) - can duplicate on bench	suspect head degraded
SN2	750GB	Zephyr	0	Send to AS Lab	Normal	- TD profile show TDDVT (mW) > TDCal (mW) - Found contamination on failed head	Contamination
SN6	750GB	Zephyr	1		Normal	- TD profile show TDDVT (mW) > TDCal (mW) - Found contamination on failed head	Contamination
SN11	750GB	Zephyr	0		Normal	- TD profile show TDDVT (mW) > TDCal (mW) - No contamination on failed head	-
SN12	750GB	Zephyr	2		Normal	- TD profile show TDDVT (mW) > TDCal (mW) - No contamination on failed head	-
SN15	750GB	Zephyr	1		Normal	- TD profile show TDDVT (mW) > TDCal (mW) - No contamination on failed head	-

3.3.6 Failure analysis observation on Zephyr 750GB

In the study, we selected 15 samples of TD failure drives for the experiment. We sent 5 drives to the contamination lab for tear down analysis. The result shows 2 out of 5 drives found abnormal on the head pole tip. The picture from Scanning Electron Microscope (SEM) shows contamination on the particular head.

The remaining 10 drives are sent to measure the TD power and rerun on the bench. The result shows that 3 out of 10 drives cannot duplicate the low TD. The TD profile looks normal. We suspected that the particles moved away. Table 3.1 shows the FA results. The 3 out of 10 drives can recover after reprocessing. The drive failed with delta TD exceeded the test limit, some drives had lower and some of them was higher. After rerunning TDCal on the bench, we found the TDCal power on the abnormal head recovered both ReadTD and WriteTD power. Figures 3.12 (a), 3.13 (a), 3.15 (a) show the interpolated touchdown between pre-test and post-test. The horizontal axis represents the touchdown value by heads across all the stroke (0-20zone). Figure 3.12 (a) shows the interpolated touchdown between pre-test and post-test which have TDP lower than the TD spec ±15 mW on the Hd0 (abnormal head). We can call TDDVT delta exceeded limit failure or Touchdown Power (TPD) change failure. Figure 3.12 shows TD profile of ReadTD and WriteTD recovers after reprocessing. The green line shows ReadTD after rerun. The blue one represents WriteTD after rerun. The result shows improvement. We suspected that the particles moved away.

Product: Zephyr (SN#1)

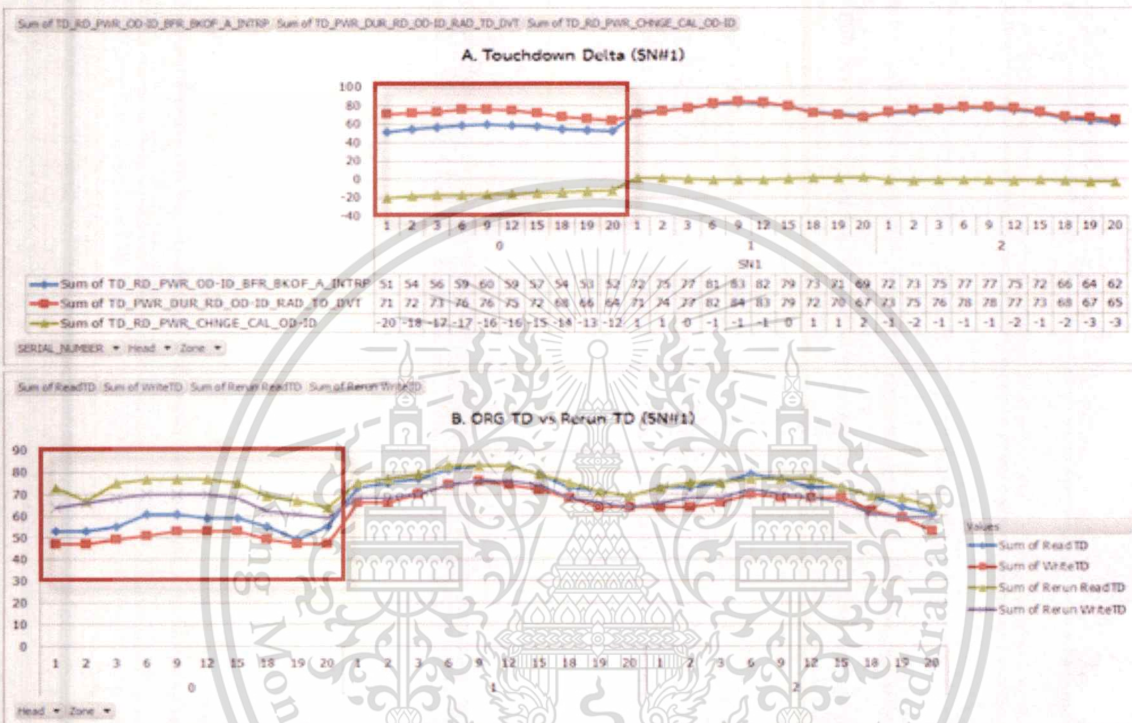


Fig. 3.12 Comparison of TD delta between the original TD and rerun TD of HDD SN#1.

In this case, we suspected the contamination was the cause of TD failure. We sent the non-repeatable TD failure to contamination lab for tear down analysis. The result shows 2 out of 5 drives found an abnormality. We inspected the defective drive by using the scanning electron microscope (SEM) with a 200,000x magnification rate. The result shows as follows, Figure 3.13 for SN#2 and 3.15 for SN#6 respectively. No abnormality remains on the remaining drives. Therefore, further analysis is necessary in order to understand the root cause of the TD drive.

Figure 3.13 (a) shows the interpolated touchdown power between pre-test and post-test. We can see that TD power >15 mW on head0. This is suspected that there would be some contamination hold on the head pole tip.

Product: Zephyr (SN#2)

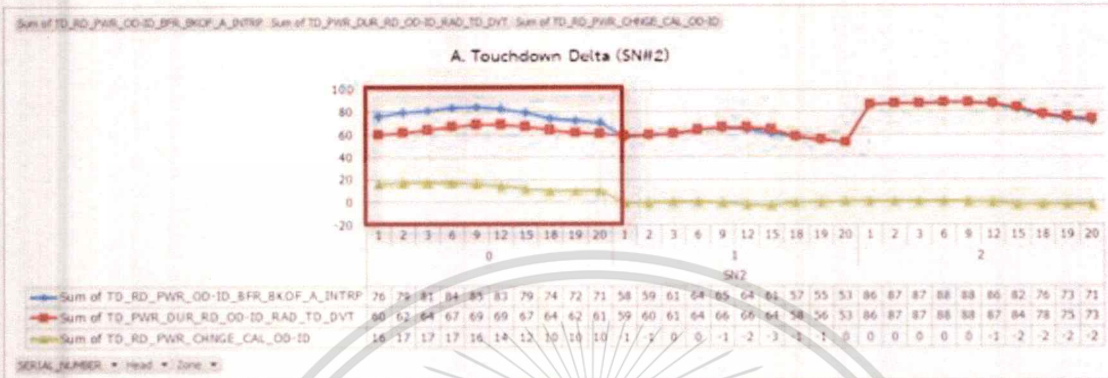


Fig. 3.13 Comparison of TD delta between the original TD and rerun TD of HDD SN#2.

Figure 3.14 shows tear down analysis result of the drives SN#2. According to figure 3.13, head0 is abnormal. The contamination lab shows contamination of moderate C-O flake found at the extreme OD of the media surface. The top surface looks normal and has no abnormality.

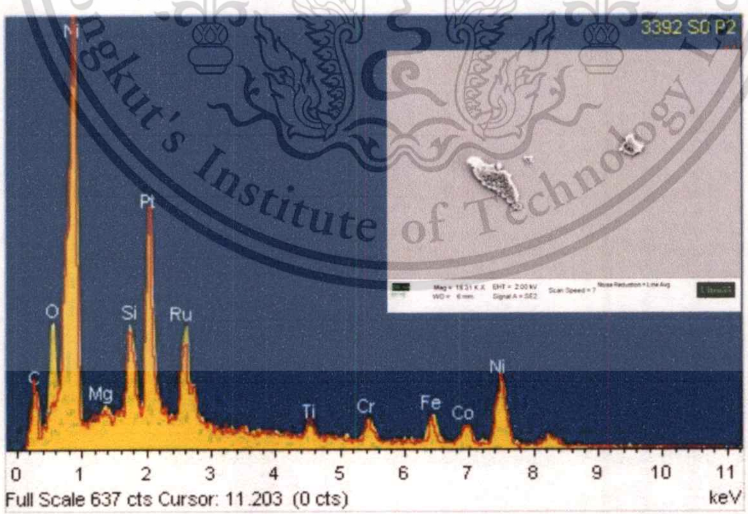


Fig. 3.14 The scanning electron microscope (SEM) image of drive SN#2.

Figures 3.15 shows the interpolated ΔTD power between pre-test and post-test exceeded the spec ±15 mW on Head1.

Product: Zephyr (SN#6)

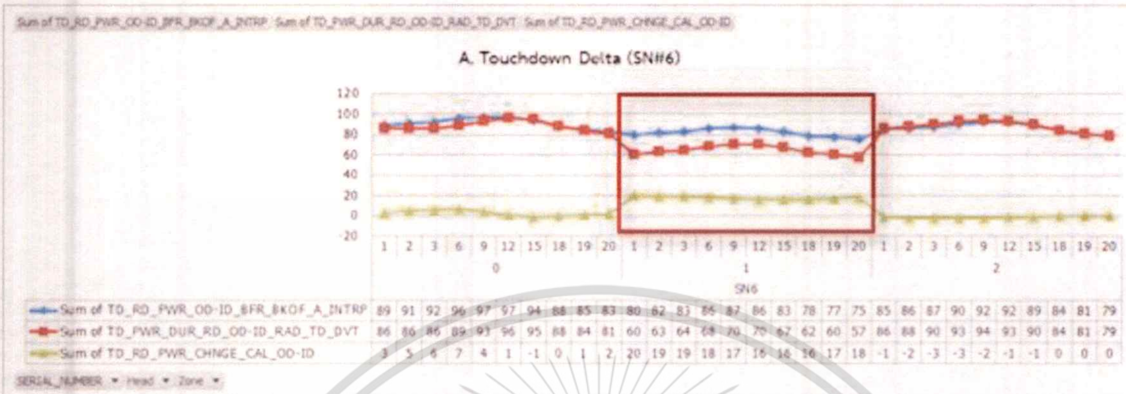


Fig. 3.15 Comparison of TD delta between the original TD and rerun TD of HDD SN#6.

Figure 3.16 shows the tear down analysis of the drive SN#6. From SEM picture, we can see the contamination Diamond-Like Carbon (DLC) wearing on the head pole tip. This is the root cause TD power decrease. The TD profile of the remaining heads looks normal.

Fig. 3.16 Picture from the scanning electron microscope (SEM).

The remaining 9 out of 15 drives which cannot recover after reprocessing. The TD profile shows that the read interpolated touchdown TDCal is lower than read TDDVT at PostBI. We take two sample drives SN#4, SN#8 to investigate the TD profile and the result is shown in Figure 3.17, 3.19. The interpolated touchdown between pre-test and post-test is higher than ±15 mW. This is considered as TD failure. Figure 3.17 (b), 3.19 (b) show results after rerun. The drive cannot recover TD failure.

Product: Zephyr (SN#4)

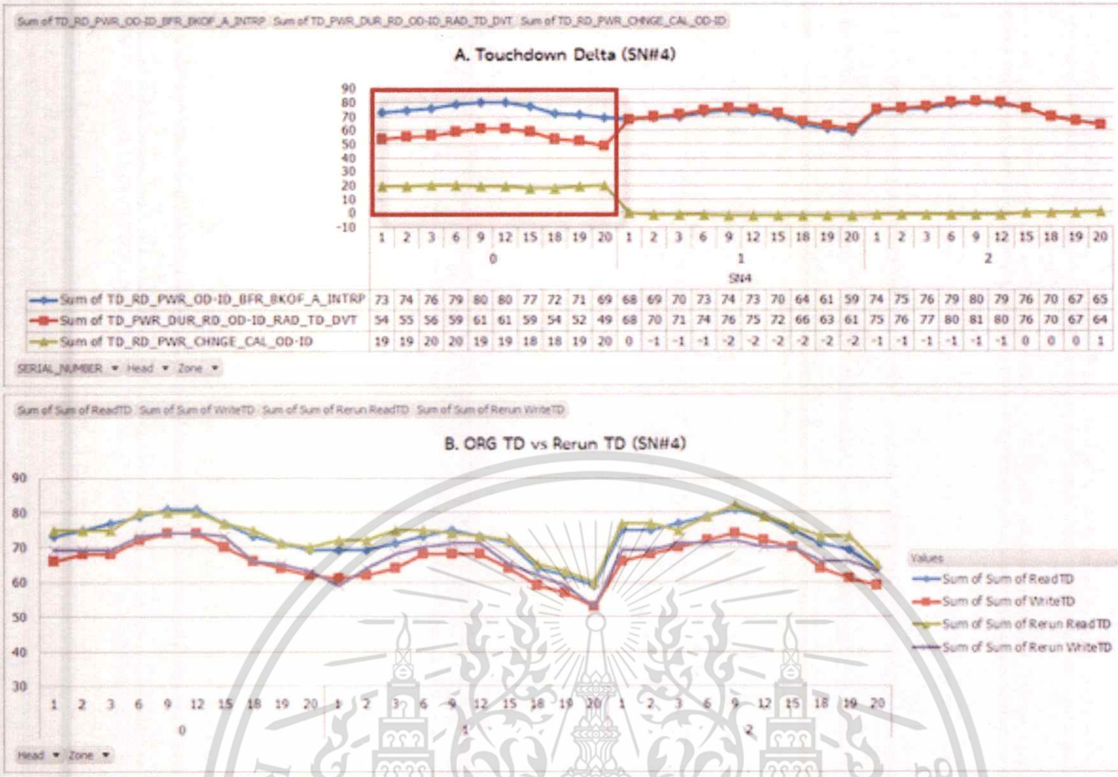


Fig. 3.17 Comparison of TD delta between the original TD and rerun TD of HDD SN#4.

Figure 3.17 shows the result after rerun. The drive can duplicate TD failure. We use the oscilloscope to measure the signal. Figure 3.18 shows the scope picture of drive SN#4. The waveform received from the abnormal head (head0). We can see that the waveform looks abnormal. We zoom-in on that location and observe asymmetry signal. Normally, it is supposed to be flat across all the waveform. Therefore, we suspect that the head may be degraded during the test process. The abnormal drive will be sent to the HSA supplier for investigating the root cause which can be either the head stack process or the drive process related.

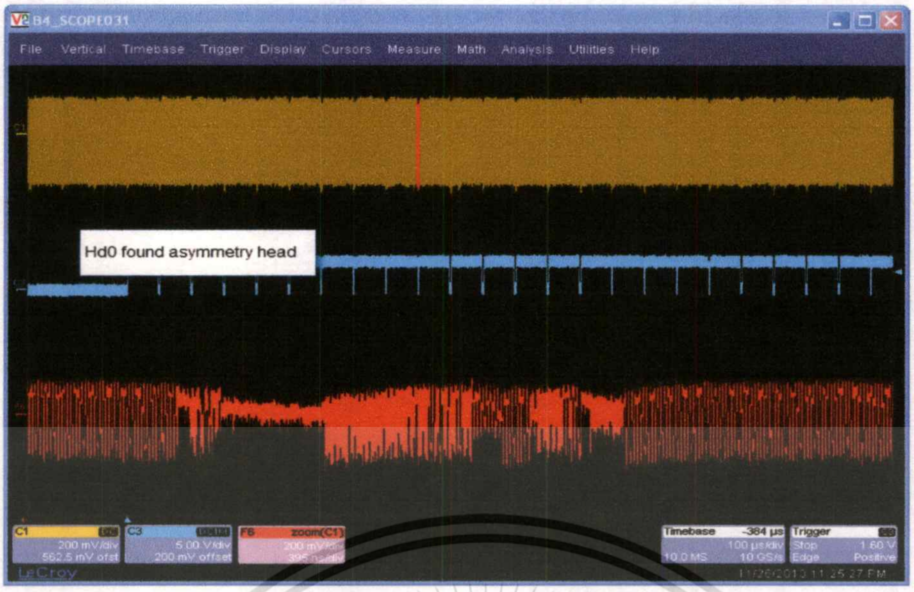


Fig. 3.18 Asymmetry signal on head0.

Figure 3.19 shows early touchdown on head#2. The interpolated touchdown power between pre-test and post-test lower than ±15 mW. Figure3.19 (b) shows the TD power after rerun. The drive cannot recovery after reprocessing.

Product: Zephyr (SN#8)

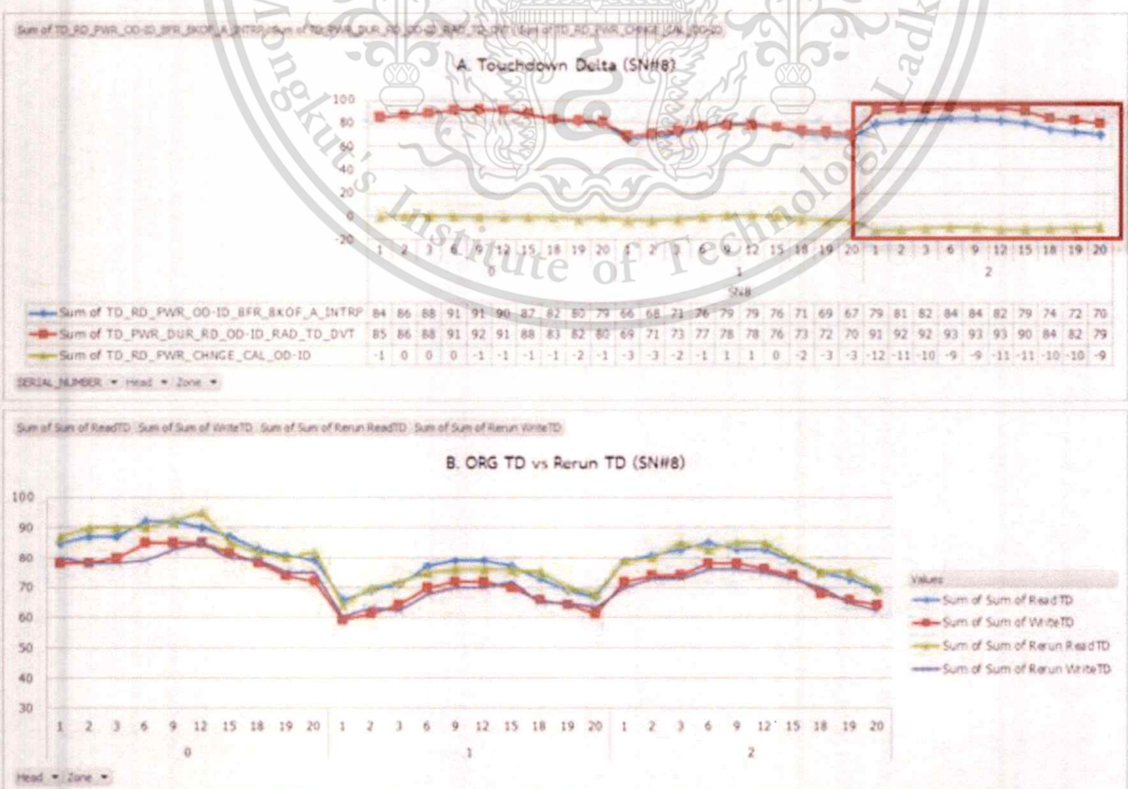


Fig. 3.19 Comparison of TD delta between the original TD and rerun TD of HDD SN#8.

Figure 3.20 shows instable signal on the abnormal head. We observe the popping signal on the failed head location (head2). In red color, we zoom-in from the yellow color. Normally, the waveform in yellow color must be flat. We suspected the head might be degraded during the HDD test process. We will ship the HDD to Head Stack Supplier for further investigation.

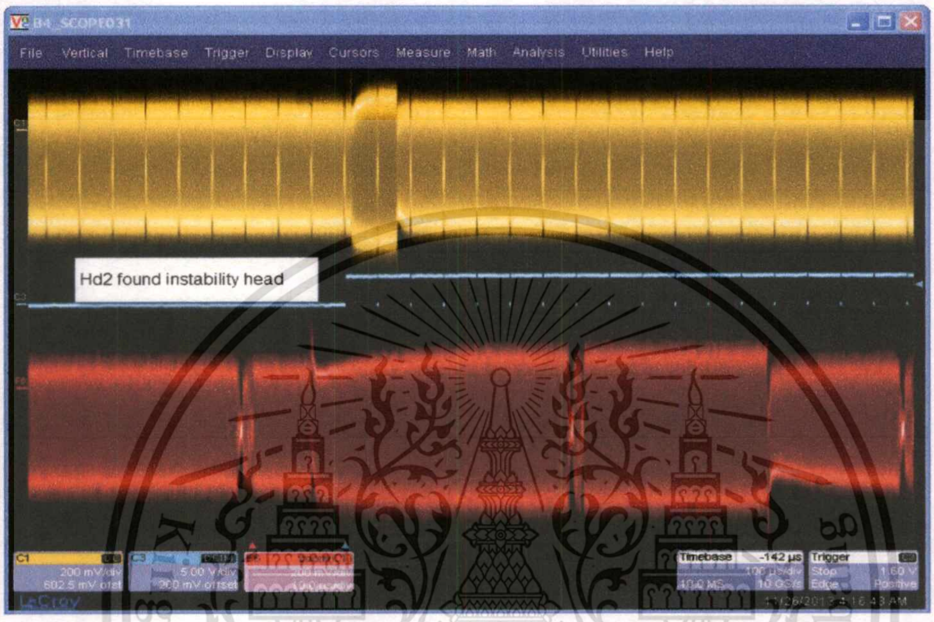


Fig. 3.20 Instability signal on head2.

Moreover, we choose one more product to investigate the TD failure. We found that the symptom of TD failure is the same Zephyr. The contamination is the root cause of TD failure. Figure 3.21 shows product platform of Jamaica 320GB. The failure analyses are performed and based on 5 drives. The result is shown in Table 3.2. There is no head trend observed on the abnormal drives (TD failure).

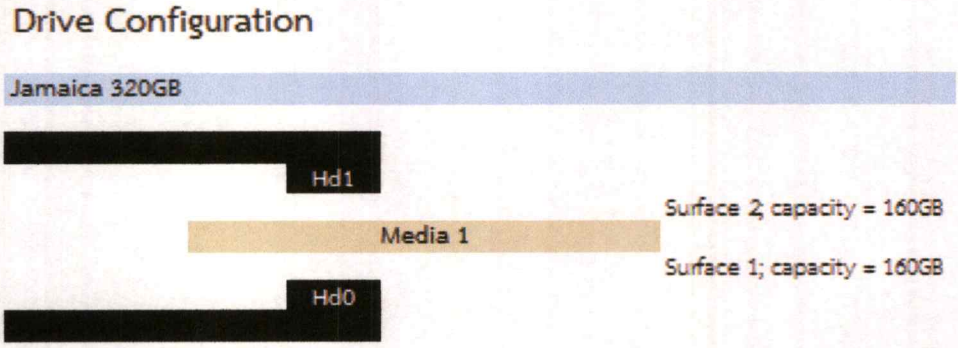


Fig. 3.21 Drive configuration of Jamaica 320GB.

Table 3.2 Failure analysis TD drive (Jamaica Product)

No	Capacity	Product	Failed Head	Category	Scope Signal	Description Failure Analysis	Conclusion
SN16	320 GB	Jamaica	0	Re-Process	Normal	- TD interpolate higher than TD DVT - Observe TD change after rerun touchdown Cal on bench	Fly Height issue
SN20	320 GB	Jamaica	1		Normal	- TD interpolate higher than TD DVT - Observe TD change after rerun touchdown Cal on bench	Fly Height issue
SN17	320 GB	Jamaica	1		Instability Head	- TD interpolate higher than TD DVT	Head Degradation
SN18	320 GB	Jamaica	1	Send to AS Lab	Instability Head	- TD interpolate higher than TD DVT - Observe TD change after rerun touchdown Cal on bench	–
SN19	320 GB	Jamaica	1		Normal	- TD interpolate higher than TD DVT - Observe TD change after rerun touchdown Cal on bench	–

3.3.7 Failure analysis observation on Jamaica320GB

In the study, we selected 5 samples of TD failure for the experiment. We sent 2 drives to the contamination lab for tear down analysis. The 3 remaining drives were sent to reprocess. The result shows non-repeatable low touchdown for 2 out of 3 drives. The TD profile looks normal. The contamination lab result for another 2 drives shows contamination issue on Head1. Table 3.2 shows FA reporting TD failure. Figure 3.22 (a) shows interpolated touchdown power between pre-test and post-test of sample TD failure SN#16. Figures 3.22 (b) shows interpolated touchdown both WriteTD and ReadTD. The TDP is recovered after reprocessing. The green line represents rerun of the ReadTD and the blue line is WriteTD.

Product: Jamaica (SN#16)

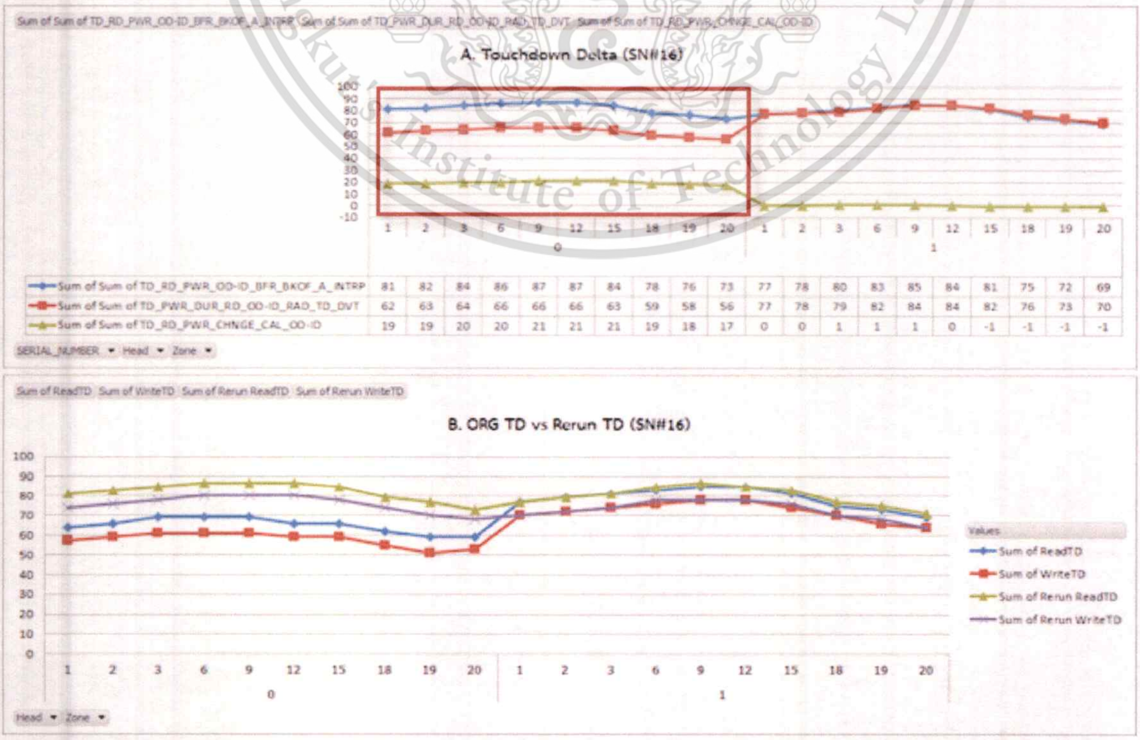


Fig. 3.22 Comparison of TD delta between the original TD and rerun TD of HDD SN#16.

Figure 3.23(a) shows interpolated touchdown power between pre-test and post-test of sample drive SN#20. The rerun result shown in Figure 3.23 (b), interpolated touchdown power WriteTD and ReadTD recover. Apparently, the interpolated TDP higher than TDDVT means early touchdown on head#1.

Product: Jamaica (SN#20)

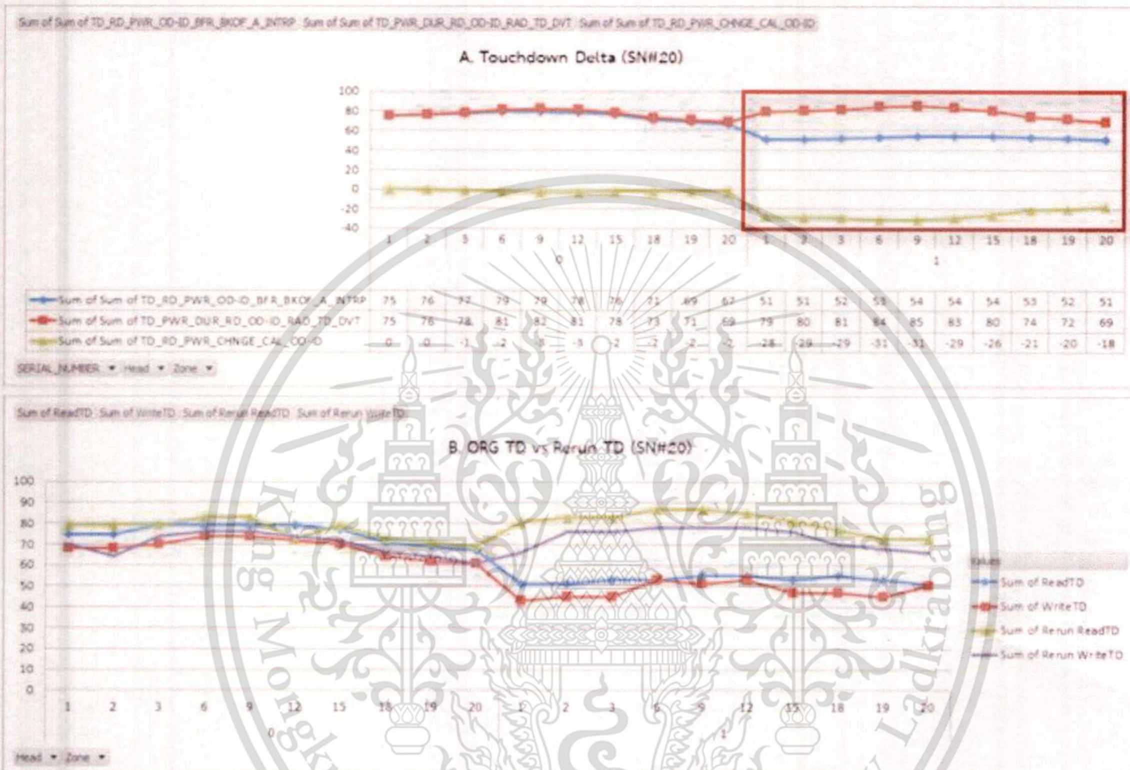


Fig. 3.23 Comparison of TD delta between the original TD and rerun TD of HDD SN#20.

Figure 3.24 (a) shows early touchdown. The touchdown power between pre-test and post-test >±15 mW on Head1. After reprocessing the abnormal drive (TD failure), we can see that the touchdown power cannot recover. Figure 3.24 (b) shows the result of rerun drive SN#17.

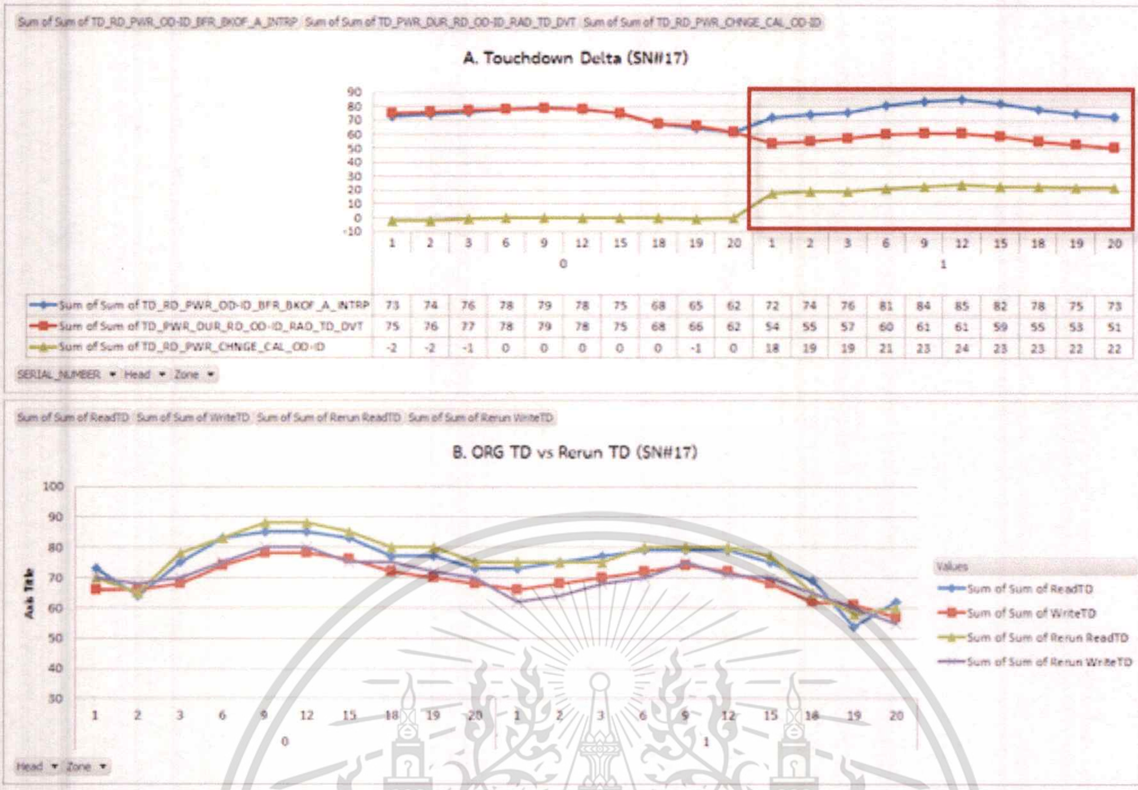


Fig. 3.24 Comparison of TD delta between the original TD and rerun TD of HDD SN#17.

Figure 3.25 shows the oscilloscope waveform the drive SN#17. We zoom-in on the abnormal wedge location. We can see the instable signal on the abnormal head (head1).

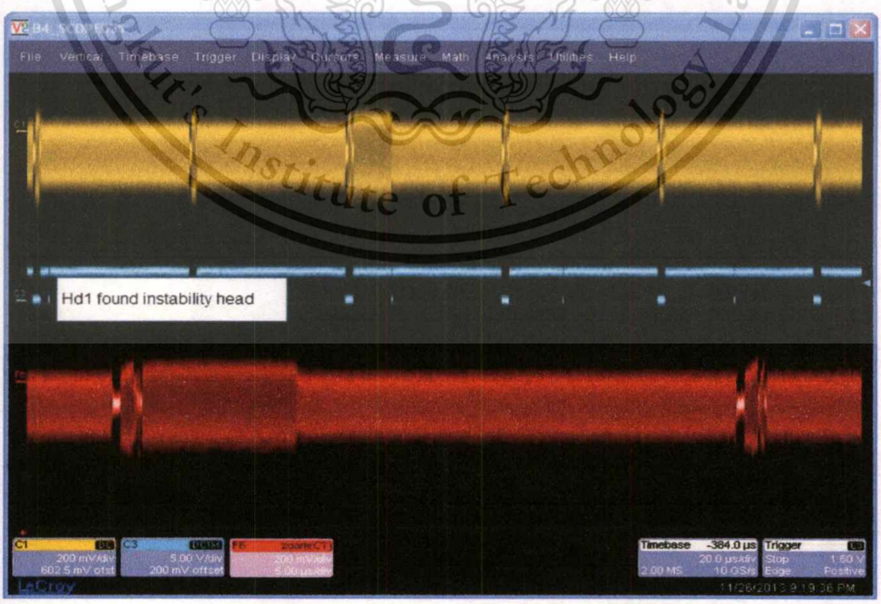
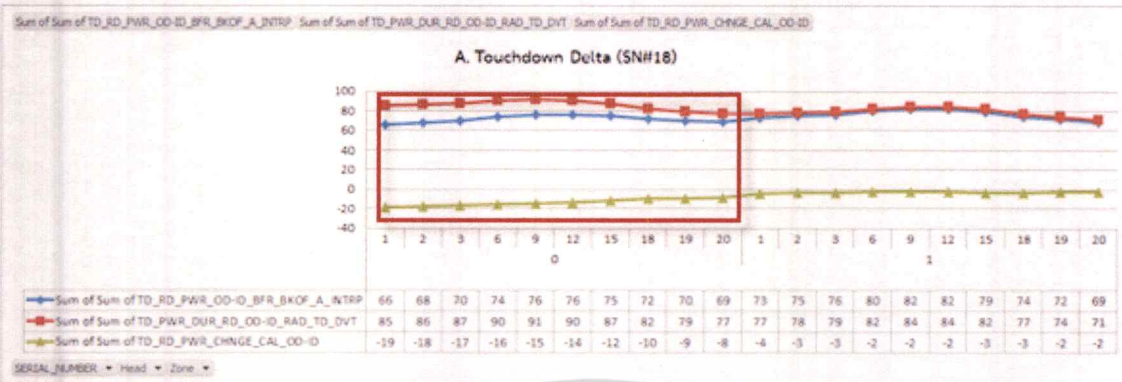


Fig. 3.25 Asymmetry signal on head1.

Figure 3.26 shows one more example of TD failure. The TDP between post-test and pre-test > ± 15mW on head0.



	0										1									
	1	2	3	6	9	12	15	18	19	20	1	2	3	6	9	12	15	18	19	20
Sum of Sum of TD_RD_PWR_OD-ID_BFR_BKOF_A_INTRP	66	68	70	74	76	76	75	72	70	69	73	75	76	80	82	82	79	74	72	69
Sum of Sum of TD_PWR_DUR_RD_OD-ID_RAD_TD_DVT	85	86	87	90	91	90	87	82	79	77	77	78	79	82	84	84	82	77	74	71
Sum of Sum of TD_RD_PWR_CHNGE_CAL_OD-ID	-19	-18	-17	-16	-15	-14	-12	-10	-9	-8	-4	-3	-3	-2	-2	-2	-3	-3	-2	-2

Fig. 3.26 Comparison of TD delta between the original TD and rerun TD of HDD SN#18.

The contamination lab result shows abnormality on head0. The tear down analysis report shows significanlly that there is some contamination on the abnormal head. Figure 3.27 shows the SEM) with a 200,000x magnification rate. The result of the inspected defective drive found moderate amount of smear across pole on head0. These smears are too thin to be detected. Figure 3.28 is a baseline for reference (good head, no contamination).

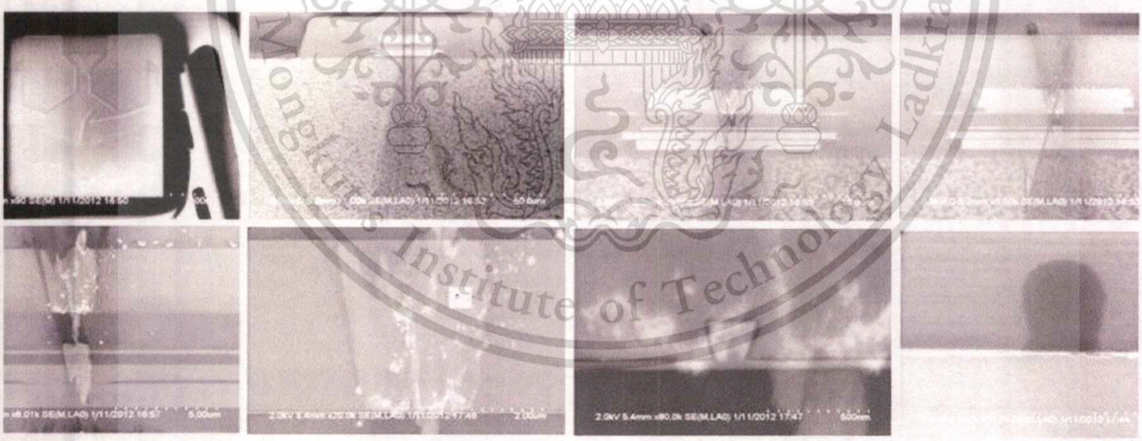


Fig. 3.27 The scanning electron microscope (SEM) on the failed head.

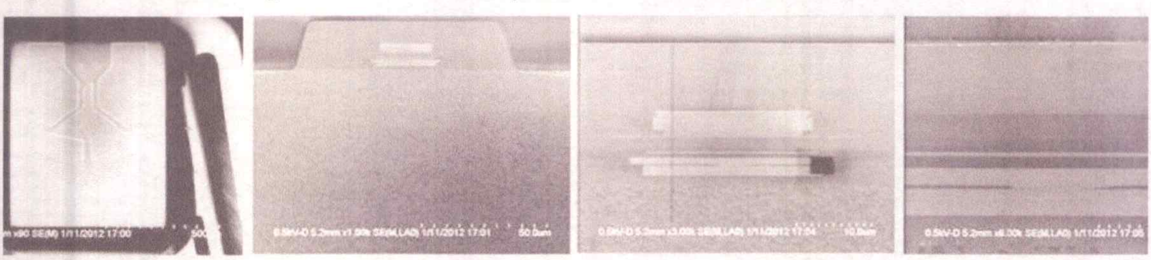


Fig. 3.28 The scanning electron microscope (SEM) on the good head.

CHAPTER 4
Proposed Methods

This chapter describes the concepts of the proposed methods to improve the touchdown failure. Regarding to failure analysis (FA) report of the Touchdown Drive Verification Test (TDDVT) delta exceeded limit failure, it shows the particle contamination that can cause the poor DFH optimization. We suspected that the contamination hold on the head tip pole contributed to TDDVT delta exceeded limit failure. The Failure Analysis (FA) shows that 40% of the TDDVT delta exceeded limit failure is non-repeatable in the Laboratory. In the experiment, we spun the drive and rerun the DFH calibration. The touchdown (TD) profile of both ReadTD and WriteTD both is recovered. Since, contamination lab analysis results often show that the particle is a main reason of TD failure. In this research, we proposed the method to reduce contamination.

The method we propose is to exercise the head before starting series of the test modules. The proposed methods incorporate additional test modules prior to primary test. The first method will sweep the heads from Inner Disc (ID) toward Outer Disc (OD) region back and forth with a specific number of cycles. The second method is similar to the first one with additional head vibrate process.

4.1 The first method: full stroke seek (FSSK)

The first method will perform sweeping the heads from the OD toward ID regions with a specified number of cycles before operating the backend test process. This step is an additional process between flash firmware and the read write gap (RDWRgap) calibration process as shown in Figure 4.1. The test module that performs sweeping the head is included in the subsequence of test package called “Random_avg_seek”. The test algorithm is performed on the series of functions in order to collect all the information and necessary data to determine Bit per Inch (BPI), Track per Inch (TPI), and to define the Logical Block Addressing (LBA). The LBA is a common scheme used for specifying the location of blocks of data stored on computer storage devices. Figure 4.1 shows the initial test process and description of each section as follows: *“Flash Firmware”* is a process to install the controller firmware (FW) into the drive. If the process is clear, then the drive will be able to spin up. The *"Mini-ARCO (Mini-Advanced Read Channel Optimization)"* performs an optimization process in the reserve cylinder zone (zone 0). This is an essential area that contains the factory test data setting. The user cannot access this area. The *"RDWRgap (Read Write Gap)"* to calibrate the track width to match the head reader and the writer of each head. This process is necessary for optimal narrow or wider head to maximize the areal density per surface. The *"touchdown calibration process"* is a process to calibrate a "zero" head media spacing (HMS), and the optimal dynamic fly height (DFH) powers for drive operation. The *"Track Per Inch calibration"* to assure the drive selects proper TPI, this process will need a total of logical block address (LBAs) from each zone to determine if capacity is met. The *"Variable Kilo Flex Change per Inch (VKFCI)"* adjustments will be made across individual zones and the heads to meet target capacity. The *"full ARCO"* will optimize data zone 1 to 20 at ambient and hot temperature. This process is the same as Mini-ARCO but will perform the test in the user area.

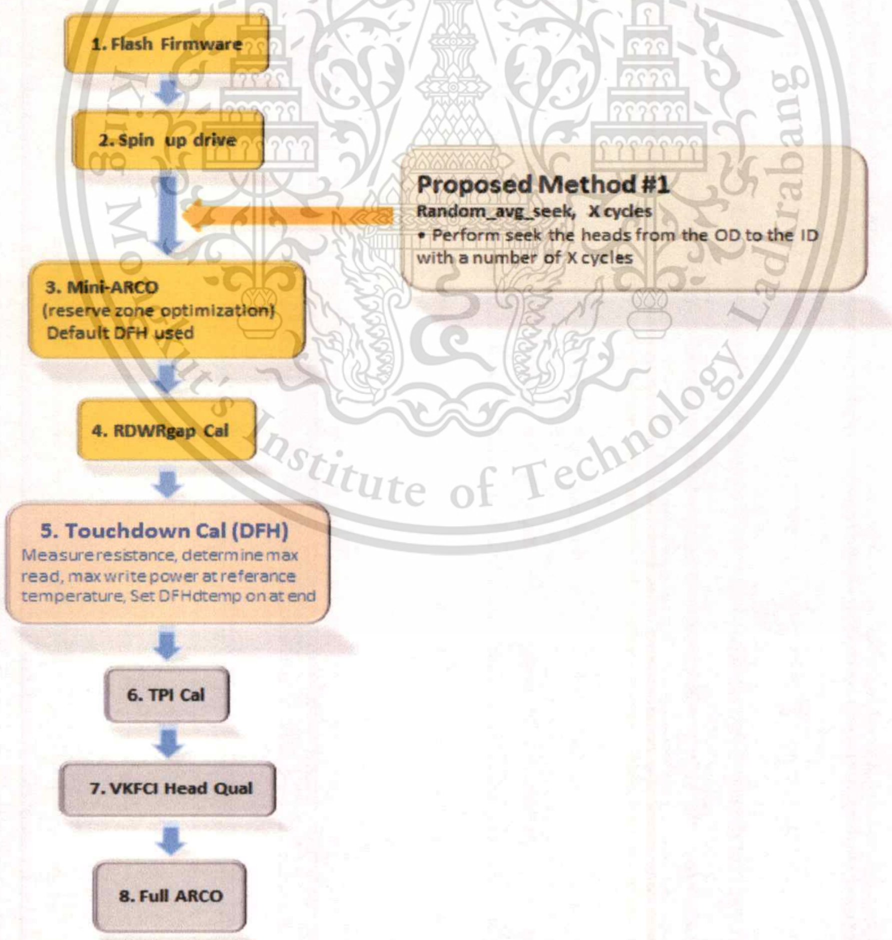


Fig. 4.1 The test sequence and additional stop of the first proposed method.

4.1.1 Touchdown data collection for FSSK

The touchdown test will perform a series of functions in order to collect all the information and data necessary to determine the maximum power that can be applied to the heads. The test will be executed as a stand-alone ARCO test. The testing processes are defined in the input data structure, which was discussed in Section 4.

4.1.2 Framework of touchdown data collection

To get test data from data buffer, the vendor specific command (VSC) has populated and included in the touchdown test process. We set write buffer to zero. We then run the preamp gain calibration and do a write cylinder head sector (CHS) to collect reference information from this operation. Afterwards, the process applies power to lower heads. The servo flexbias accumulates the stress counts. The head arm deviates from the track, so the servo flex bias circuit increases the amount of current to take the head arm back to the desired track. If stress count is above the limits, the touch down condition is met, and then the servo flexbias processes exit the loop. Then, this procedure is repeated for each selected zone. Finally, the test data will record into the Extreme Margin Monitoring System (XMMS) server with specific file ID. (ID -> 0x96) and exit and return control to Controller firmware. These are all in initial drive test (IDT) process. We have to collect touchdown power and do checking the number between post-test versus pre-test and then see whether the delta between this number is exceeded as per factory specific definement or not.

4.2 The second method: HSA resonance

The second method is common with the first method with an additional head vibration process using the vendor specific command (VSC). The step to vibrate the head is added to the servo code which applies the resonance frequency (F_R) to the head. This section describes the frequency range of actuator resonance. This proposal is to measure the primary resonance mode frequency for the actuators used in WD programs. This is to characterize the flex-circuit resonant frequency at the Inner Disc (ID), Middle Disc (MD) and Outer Disc (OD) of the HSA stroke. The flex-circuit is one of the HSA parts. To vibrate the head, the new servo is needed to make the F_R. The VSC is required to perform head vibration process. The VSC is the subsequence of functional areas in controller firmware. The concept of the write pole tip protrusion (WPTP) is copied to this method and put into the earlier of test sequence to protect the head touch on the media during vibrating the head. The WPTP is consisted of the flexbias deceleration and spin-touchdown command which will keep the coefficients of Write Current (Iw), Overshoot Amplitude (OSA), Overshoot Duration (OSD), and frequency. To adjust Iw, OSA, OSD and resonance frequency (F_R) cause the head to change its fly height. Usually, the WPTP is calculated by the firmware. The channel.trx has a WPTP calculator built-in. Regarding to the flexbias deceleration for the OD and ID, when the head touches the lubricated level, it interferes with the landscape and then will feedback to IBO block (Intelligent Back off) to lift the head up. For spin touchdown at the MD zone, we use servo detection. The drive is put into an idle state as the head touches the media, causing sudden change of rotational speed.

4.2.1 An actuator pivot flex assembly (APFA) resonance modeling and analysis

An APFA model is built on the basis of a simplified pivot assembly model as shown in Figure 4.2.

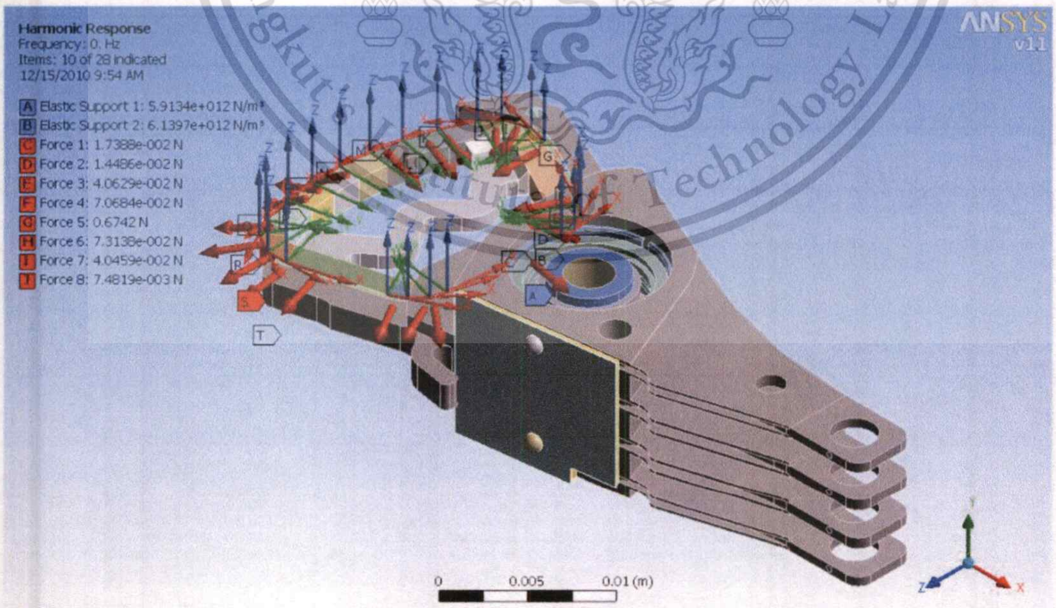


Fig. 4.2 Actuator pivot flex assembly (APFA) model.

The axis along the center of coil profile is the direction for the major stiffness constant of the material. The effects of the enclosure are simulated by using enclosure stiffness simulation and are modeled as distributed stiffness (elastic foundation) over the two ends of pivot shafts. A modal analysis is used to generate the modes including the resonance frequencies and the modal shapes, whereas the harmonic analysis is used to analyze the frequency response function of the system. In addition, the new servo code will use a different TD test zone map rather than the current flexbias based TD feature. The analysis of an APFA is supported by finite element analysis (FEA) on pivot assembly and on the coil (properties and the applied force). The relationship between the finite element analysis and the assembly is illustrated in Figure 4.3. The main features of HSA resonance are APFA resonance and HGA one.

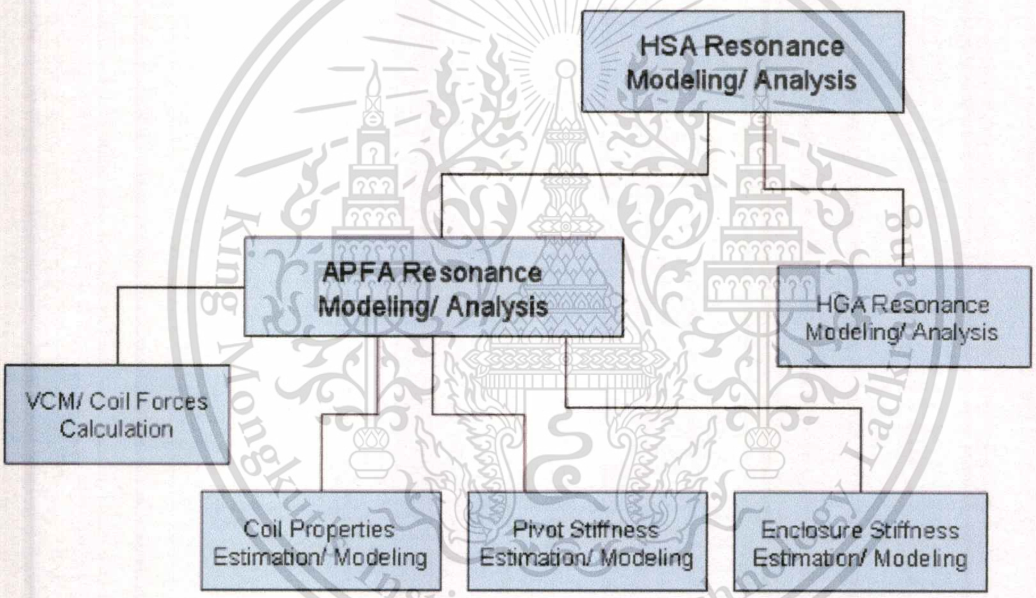


Fig. 4.3 The relationship between the finite element analyses and the assemblies.

The HSA resonance is intended to vibrate the head before starting the first proposed method. It works by applying the new servo code. The two independent TD detection metrics (flex bias and frequency resonance, F_R) are collected simultaneously. The DFH power step during a TDCal sweep will collect for one revolution and then analyze to see if either one has exceeded a touchdown detection threshold. If a touchdown is detected at a given DFH power step, two additional counters for confirmations are done to confirm the TD point. The two counters are “Flex Bias Detect” and “Frequency Detect Incremented” during this process.

Basically, the new servo code is applied to make a frequency resonance (F_R). The most convenient way to implement the resonance frequency is to add the hooks to the current "servo_scan_data" structure and make changes to servo scan state machine to collect the head media spacing HMS in order to avoid the head touch on the media. Figure 4.4 shows the initial test process and description of each step.

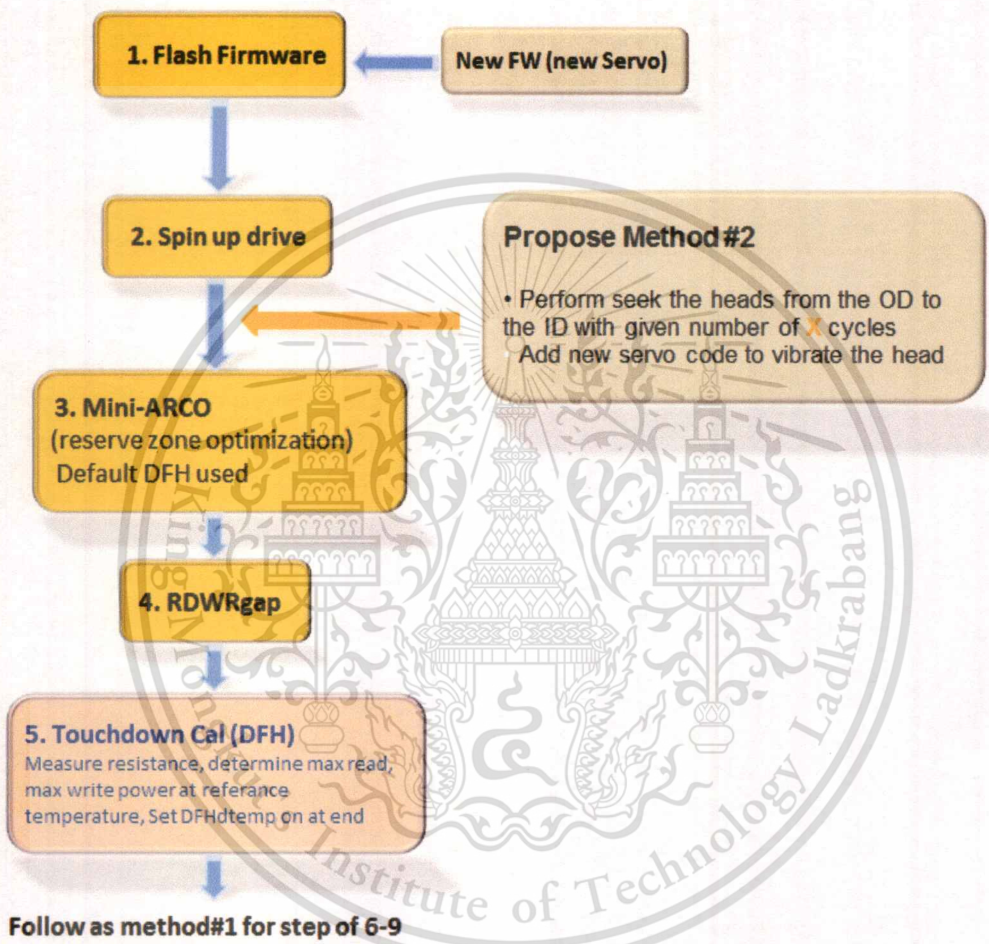


Fig 4.4 The optimal sequence and additional step of the second proposed method.

4.2.2 Touchdown data collection for HSA resonance

In order to make the head vibrate, we need to create another two specific GIDs (Global Identification) for detecting information of TDCal. The different variable name is needed to keep up the value of *"TDDetectModeRead"* and *"TDDetectModeWrite."* The data will be saved into file 0x96 in HDD in reserve cylinder area and WD database. To perform the frequency resonance for vibrating the head, we need to add the vendor specific command (VSC) to execute new servo. The VSC command includes the following steps, keeps the existing VSC servo scan data, and adds extra options to return the following items in the servo scan data. There are three kinds of data are DSW (Disk Synchronous read/Write), and SSM (Servo Sync Mark), and gray code (missed SSM and bad gray code will cause the count to be bad). However, the VSC may need an option for the host to adjust the DSW time predictor. Thus, the servo code does not abort a write operation in the middle of the detection. Then it takes a spin out of tri-state after a programmable number of servo wedges. The key parameters to determine the head media spacing are "TDDetectModeRead" and "TDDetectModeWrite. This is to guarantee that the head will not touch the media where the head vibration is still happening.

The additional TDCal test parameters will be saved for the analyses in this proposed method. The flex bias and frequency resonance metrics are collected for each touchdown sweep (per head, per tested zone, and read/write modes). Currently, flex bias reference values are saved to touchdown result file 0x96. The flex bias baseline reference variable name is MinMaxBase. This is currently saved into file 0x96 in BaseMinMaxRead and BaseMinMaxWrite. The frequency reference variable name is FR_Range. The new touchdown GID's will need to be created to support data collection, including TD_flexbias_baseline_for_read, TD_flexbias_baseline_for_write, FR_baseline_for_read, and FR_baseline_for_write.

CHAPTER 5

Experimental Results and Discussions

The experiments and the data analysis are performed at Western Digital Bangpa-in manufacturing plant and King Mongkut's Institute of Technology Ladkrabang. All the experiments related to the conventional Perpendicular Magnetic Recording (PMR) system have been performed on the commercially available XCalibre platform (Teradyne). The failure analysis made by using the test log and microsoft excel software to plot the touchdown delta value for analysis.

This chapter describes the experimental results and it consists of 3 sections. Section 5.1 explains the experimental result of 500 drives by using the first proposed method (Full Stroke Seek, FSSK) with various specified number of cycles and same Head Media combination. The second method is the first method with additional head vibrate process. Section 5.2 describers the test result with a bigger quantity (called Mass Production: MP). We do partial experiments on 30% of drives produced starting from week#5 to week#6 for data collection. The HDD parametric comparison between the current method and the proposed methods also included in this section. The key parametric and risk assessment of the proposed method is discussed in section 5.3, and finally the conclusion of the experiment is made.

5.1 Proposed method

This section describes the experimental results of the LVM (Low Volume Mode) with various specified number of cycles of the proposed methods.

5.1.1 The first proposed method (full stroke seek: FSSK)

Firstly, we demonstrate the first method by sweeping the heads to determine the suitable number of cycles. We divided the 500 sample drives into 5 groups with each group tested by the different experiment software. All drives are of the same product and each group has the same head and media type as well. The experiment started from package "A" by 500 cycles of head sweeping, and then followed by package "B" by 2,000 cycles, package "C" by 5,000 cycles, package "D" by 7,000 cycles, and package "E" by

10,000 cycles respectively. We can see that for the number of 5,000 cycles is provided the optimal result. More cycles did not reduce the wastage rate. Table 5.1 shows the TDDVT delta exceeded limit failure rate comparison between the current method and the first proposed method with various specified number of cycles. The productivity gain is estimated from 40,000pcs HDD builds per day. However, we noticed that the first method with 5,000 cycles has additional test time of 20 seconds.

Table. 5.1 Comparison of the first proposed method with specified number of X cycles.

Product	Zephyr						
Head	Type A						
Media	Type B						
Failure Rate (FR %) TDDVT Delta Exceeded Limit	Current method (control lots)		1.33%	1.12%	0.98%	1.20%	0.85%
	Sweeping head with specify number of X cycles						
	Test package	Name	A	B	C	D	E
		Cycles	500	2,000	5,000	7,000	10,000
Failure Rate (FR %) TDDVT Delta Exceeded Limit	Proposed method (the first method)		1.21%	1.27%	0.65%	0.82%	0.54%
Improvement (FR %)			0.12%	-0.15%	0.33%	0.38%	0.31%
Estimate 40K HDDs build per day			40,000	40,000	40,000	40,000	40,000
Improvement (FR %)			0.12%	-0.15%	0.33%	0.38%	0.31%
Additional Test Time (Seconds)			8	15	20	28	36

Moreover, we have demonstrated the first proposed method with different head and media types. Based on the preliminary data, we observe that the package "C" (5,000 cycles) is able to reduce the TDDVT exceeded limit failure. We can see that TDDVT exceeded limit failure is improved by 0.45%. Table 5.2 shows the experimental results of the proposed method of each head and media type. We can see that the failure rate is reduced significantly. The TDDVT delta exceeded limit failure rate is reduced from 1.1% to 0.6%. There is eventually 0.5% reduction. It means that the proposed method can help improve TD failure and even uses different Air Bearing Surface (ABS) design.

Table. 5.2 Comparison of TD failure between different head and media types.

Test software	package "C" (5,000 cycles)

Head - Media Type	%FR - TDDVT Delta Exceed Limit		Improvement (%FR)
	Current Method	Proposed Method	
A - B	1.1%	0.6%	0.5%
C - D	1.1%	0.7%	0.4%
E - F	1.1%	0.6%	0.5%
G - H	1.1%	1.1%	0.0%

5.1.2 The second proposed method (HSA resonance)

The second method is the first method with additional head vibration process. We divided the 500 sample drives into 5 groups with each group tested by the different experiment software. All drives are of the same product and each group has the same head and media type as well. The HDD test process will sweep the head from Outer Disc (OD) toward Inner Disc (ID) back and forth. The head vibration process will perform at the same time when the head sweeps between OD and ID. Table 5.3 shows the TDDVT delta exceeded limit failure rate comparison between the current method and the proposed methods with different test software. The result of the second method shows at the test of 5,000 cycles which is not significantly different in comparison with 7,000 and 10,000 cycles. For 5,000 cycles (test package "C"), the failure rate is reduced from 1.2% to 0.8%. We conclude that the proposed method can help reduce 0.4% of TD failure rate compared with the current method.

Tabel. 5.3 Comparison of the second proposed method with specified number of X cycles

Product	Zephyr						
Head	Type A						
Media	Type B						
Failure Rate (FR %) TDDVT Delta Exceeded Limit	Current method		1.1%	1.1%	1.1%	1.1%	1.1%
	Seek head with specified number of X cycles						
	Test package	Name	P	Q	R	S	T
		Cycles	500	2000	5000	7000	10000
TDDVT Delta Exceeded Limit	Proposed method		1.10%	1.20%	0.80%	0.70%	0.70%
Improvement (FR %)			0.00%	-0.10%	0.30%	0.40%	0.40%

Based on the experiment results of the second method, the head vibration process does not help improve the TDDVT delta exceeded limit failure. Based on preliminary data of 500 sample drives, the TDDVT delta exceeded limit failure rate of the second method and the first method yields the same experimental results. However, we will demonstrate with more sample HDDs later in section 5.2.

5.2 Test result in HDD manufacturing

At the beginning of the experiment, the 500 sample drives with the proposed methods had been evaluated. This is a WD test procedure to ensure that there is no code bug before starting to evaluate the new test software with more sample HDDs. In this section, we decide to conduct partial experiment on 30% of HDDs produced, starting from week5 to week6 for the further monitoring and comparing both of the first and the second proposed methods with the test of 5,000 cycles only. The experiment drives have been registered with EEN (Engineering Eval Notice) for tracking. The sample HDDs comes from the same head and media type.

5.2.1 Test result of the first method (full stroke seek)

To make the data more confident, we keep running 500 drives with 5 experiment codes (500, 2,000, 7,000 and 10,000 cycles) in weekly loading for 15 weeks for data collection, except the package "C" 5000 cycles that we had partially released on 30% of drives produced on week06 and fully implemented on week07. Figure 5.1 shows the comparison between the first proposed method versus the current method based on 15-

week data points. The X axis shows the time periods. The Y axis shows the TD failure rate with a different specified number of cycles. The different color the line graph represents of the cycle count. However, we focus on the yellow color as it is the TD failure rate from the first proposed method. The red one represents the baseline. The baseline is the TDDVT delta exceeded limit failure in normal HDD manufactory. The reason why we see up and down trend on 500, 2,000, 7,000, and 10,000 cycles because the sample size of HDD testing is too small, only 500 sample drives running along the way. Finally, we can see that the TDDVT delta exceeded limit failure is reduced from 1-1.5% to 0.5-0.8% approximately from the proposed methods.

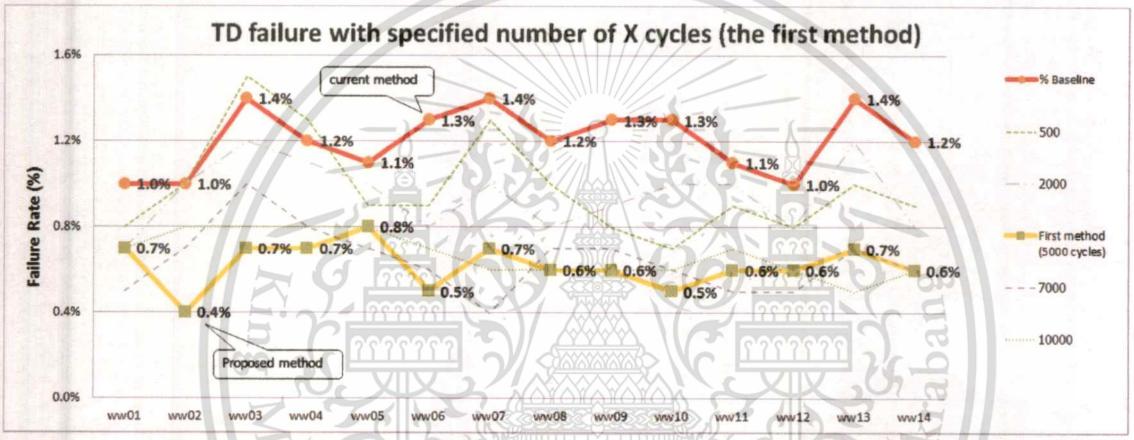


Fig. 5.1 Comparison of TD failure rate between the current method and the proposed methods with different experimental packages.

In figure 5.2 shows the TDDVT delta exceeded limit trend compare between the second proposed method and the current method. The X axis represents the time periods and Y axis is failure rate (%FR).

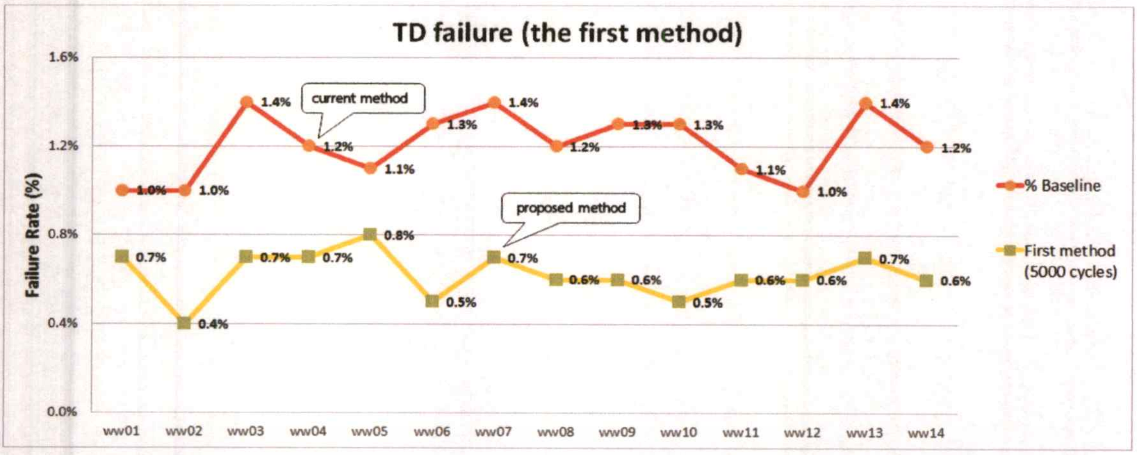


Fig. 5.2 Comparison of TDDVT delta exceeded limit between the current method and the first proposed method.

We pull the test log from HDD database with the current method and the experiment drive of the first proposed method for comparison. The current method uses test package AD.M.6J and the AD.M.7A is used in the experiment. There are 2 sample groups with different head and media type. Table 5.4 shows the key HDD parametric which is kept in WD server called XMMS (Extreme Margin Monitoring System). We can see that the Data Error, Plist, Servo Error are improved significantly. These key parameters can indicate that the proposed method is no risk to affect the HDD performance.

Table. 5.4 Comparison of XMMS parameter between the current test package (AD.M.6J) and the experimental package (AD.M.7A)

Site	WDTH	WDTH	WDTH	WDTH
Product	Zephyr	Zephyr	Zephyr	Zephyr
Data Source	Production	Eval	Production	Eval
Test package	AD.M.6J	AD.M.7A	AD.M.6J	AD.M.7A
Media	WDSG (9F7)	WDSG (9F7)	WDSG (9F7)	WDSG (9F7)
HSA	WDB K10N ABS	WDB K10N ABS	WDB M11N ABS	WDB M11N ABS
Capacity	750	750	750	750
Drive Parameter				
AVG_data_error	834.125	681	746.75	365.25
AVG_plist	831.25	584.5	719.25	368.25
AVG_servo_error	250.25	120	303.75	123.25

5.2.2 Test result of the second method (HSA resonance)

In this section, we discuss the result of the second proposed method. The experiment is fixed with 5000 cycles. We use the experiment package named "R" for experiment with 500pcs sample HDD for 5 weeks loading and partially release on 30% of drives produced starting from week06 onwards for data collection. In figure 5.3 shows the TDDVT delta exceeded limit trend. The X axis represents the time periods and Y axis is failure rate (%FR). The yellow line is the TD failure rate from the proposed method. The red one is TD failure rate in normal production used for comparison.

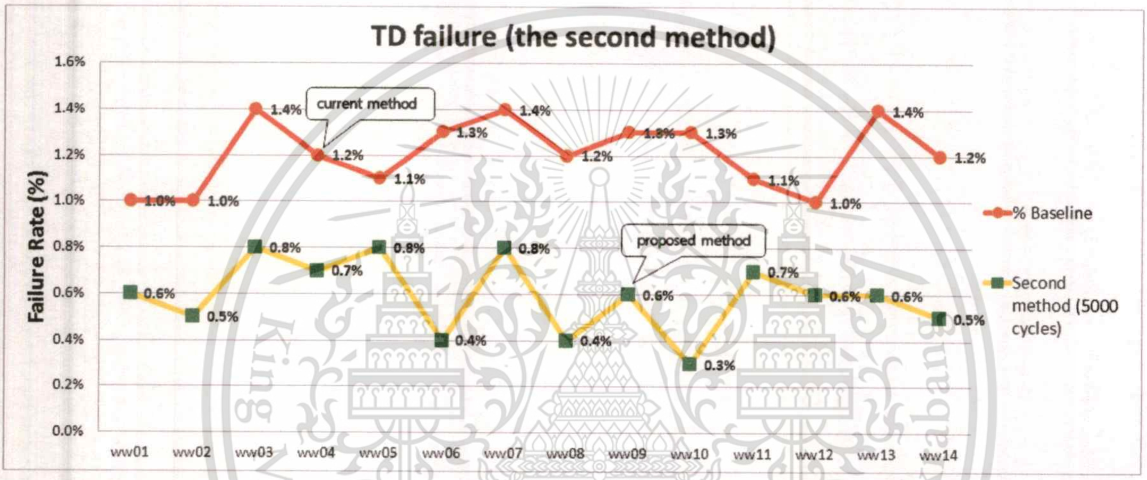


Fig. 5.3 Comparison of touchdown failure rate between current method and the second proposed method

Table 5.5 shows the comparison of the key parameter pulled from the test log XMMS (extreme margin monitoring system) between the current package AD.M.6J and the experiment package AD.M.70. There are 2 sample groups with different head and media type for comparison. Similarly, the Data Error, Plist, Servo Error are slightly improved.

Table. 5.5 Comparison of XMMS parameter between the current test package (AD.M.6J) and the experiment test package (AD.M.70)

Site	WDTH	WDTH	WDTH	WDTH
Product	Zephyr	Zephyr	Zephyr	Zephyr
Data Source	Production	Eval	Production	Eval
Test package	AD.M.6J	AD.M.70	AD.M.6J	AD.M.70
Media	WDSG (9F7)	WDSG (9F7)	WDSG (9F7)	WDSG (9F7)
HSA	WDB K10N ABS	WDB K10N ABS	WDB M11N ABS	WDB M11N ABS
Capacity	750	750	750	750
Drive Parameter				
AVG_data_error	834.125	354	746.75	490.438
AVG_plist	831.25	453.75	719.25	572.813
AVG_servo_error	250.25	199.75	303.75	253.813

Figure 5.4 shows 15-week data point of the TDDVT delta exceeded limit failure comparison between the first method and second method. The dot line represents the current method which comes from normal production. This data comes from the same head and media type. In conclusion, the first proposed method and the second method yield the same comparable results. It means that the second method does not help much improve the touchdown failure.

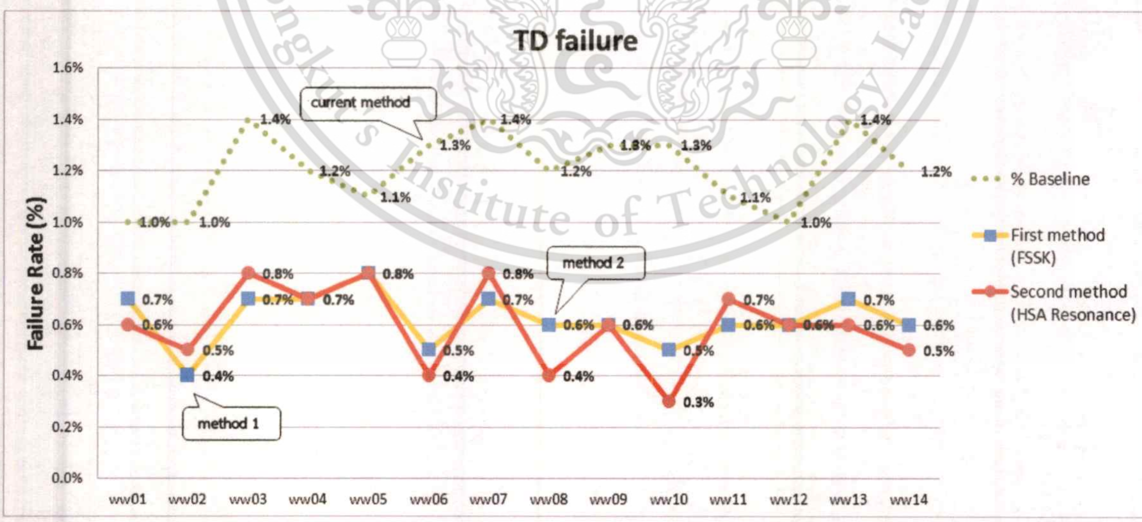


Fig. 5.4 Comparison of TD failure rate between the first proposed method and the second proposed method.

In summary, Fig 5.4 shows obviously that the head vibration process does not help improve the touchdown failure. Thus, the first proposed method (FSSK) is a promising candidate for HDD testing process. The TDDVT delta exceeded limit failure rate is reduced after week7 onwards. Moreover, we submit the passer from the first method to perform the channel characterization test. This is to ensure that HDD performance still maintains and guarantees that the proposed method is no risk. Based on channel characterization parametric shows the average zone EM, Touchdown parameters, and HMS, they look comparable to the current method. Therefore, the risk is low to deliver the proposed method to normal production. The channel characterization parametric and observation will be described later in Section 5.3.

In addition to this research, the statistical analysis is used to determine the suitable number of specified cycles. The mean and standard deviation equations are taken for calculation. Table 5.6 shows the mean value of TD failure based on 14-weeks data. The mean value is the sum of the N values divided by the number of values. We use statistical tool in excel to plot the correlation between the TD failure rate at different number of X cycles.

Table. 5.6 the mean and standard deviation of TDDVT delta exceeded limit failure.

	Current method
Failure Rate (FR %) TDDVT Delta Exceeded Limit	1.17%
Mean±STD	1.17% ± 0.16%
Standard Deviation (σ)	0.16%

	Experiment Packages				
Cycle	500	2000	5000	7000	10000
Failure Rate (FR %)	0.99%	0.95%	0.62%	0.64%	0.67%
Mean±STD	0.99%±0.23%	0.95%±0.16%	0.62%±0.11%	0.64%±0.15%	0.67%±0.1%
Standard Deviation (σ)	0.23%	0.16%	0.11%	0.15%	0.10%

Figure 5.5 shows the individual plot of TD failure versus the number of specified cycles. The data consist of the TD failure on 14-weeks data. There are five groups of the data which different specified number of cycles. Then, we use the tool in Minitab program called Stat, and then use Anova to analyse and obtain the correlation of the P

value and the R-sq. The coefficients of R-square indicates how well data points fit a statistical model. The p-value is the probability of obtaining a test statistic result. The results show that P value is 0.03 and the R-sq = 74.8%.

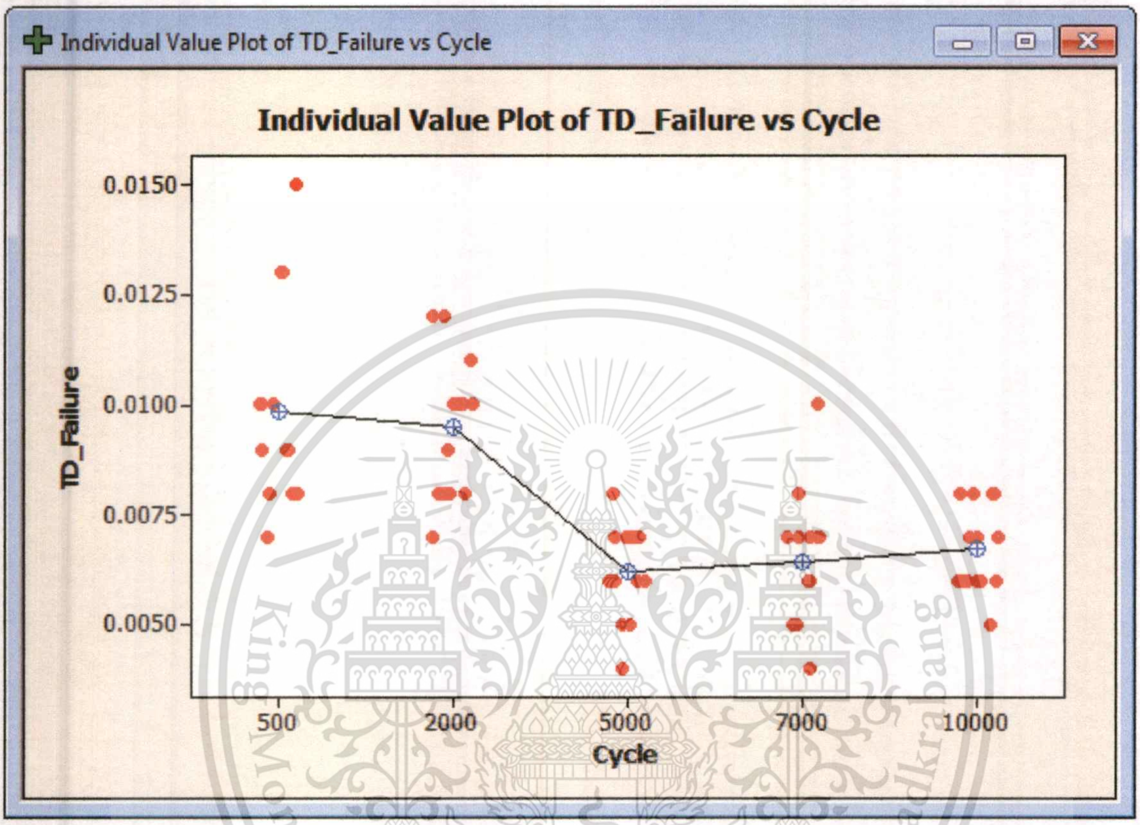


Fig. 5.5 The individual value plot of TD failure vs. cycle.

5.3 Key parameters and risk assessment

This section illustrates the HDD performance gathered from the test log. The picture shows the comparison between the current method and the proposed method. The key parameters used to demonstrate the risk assessment are EM (Error Margin), TD (TouchDown), and HMS (Head Media Spacing). Figure 5.6 shows the comparison of Average Zone EM between production data and the first proposed method (FSSK). The data is obtained from test log GIDs (Global Identification) which reports as contact_ID 53, 54, and 55. The contact_ID 53, 54, and 55 represent for OD, MD, and ID respectively from 0 to 20 zones. According to figure 5.4, the proposed method has 0.05dB lower than the current method. The definition of Error Margining (EM) is a channel DVT predictive technology model (PTM) designed to find the Signal to Noise (SNR) margin from Bit Error Rate (BER) cliff of all heads and zones of a drive.

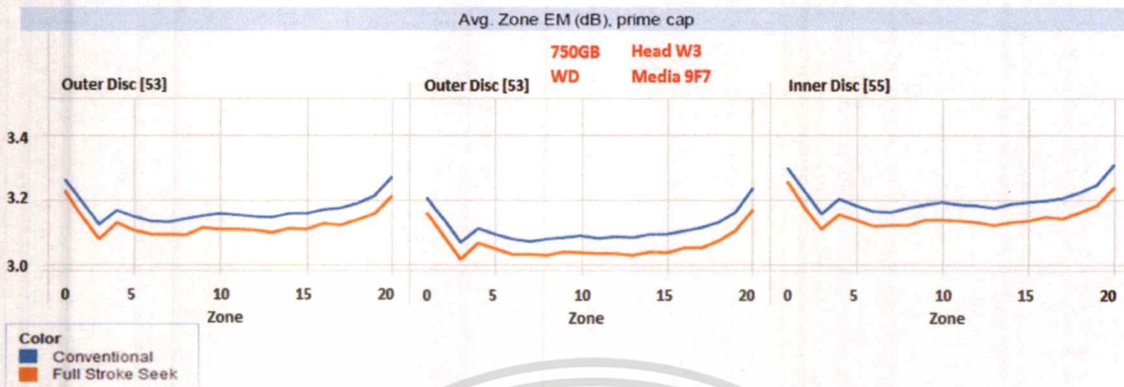


Fig. 5.6 Comparison of the average zone EM plot between the current method and the proposed method.

Figure 5.7 shows the standard deviation between the current method and the first proposed method. We can get the data from test log (GIDs) and then use WD's tool to plot the report. The blue colors are the data plots from the current method. The red colors come from the proposed method. We can see that raw data and interpolated TDCal power distribution both ReadTD and WriteTD power are not significantly different for all Outer Disc (OD), Middle Disc (MD), and Inner Disc (ID) regions. The standard deviation between raw data and Interpolated is in an acceptable level.

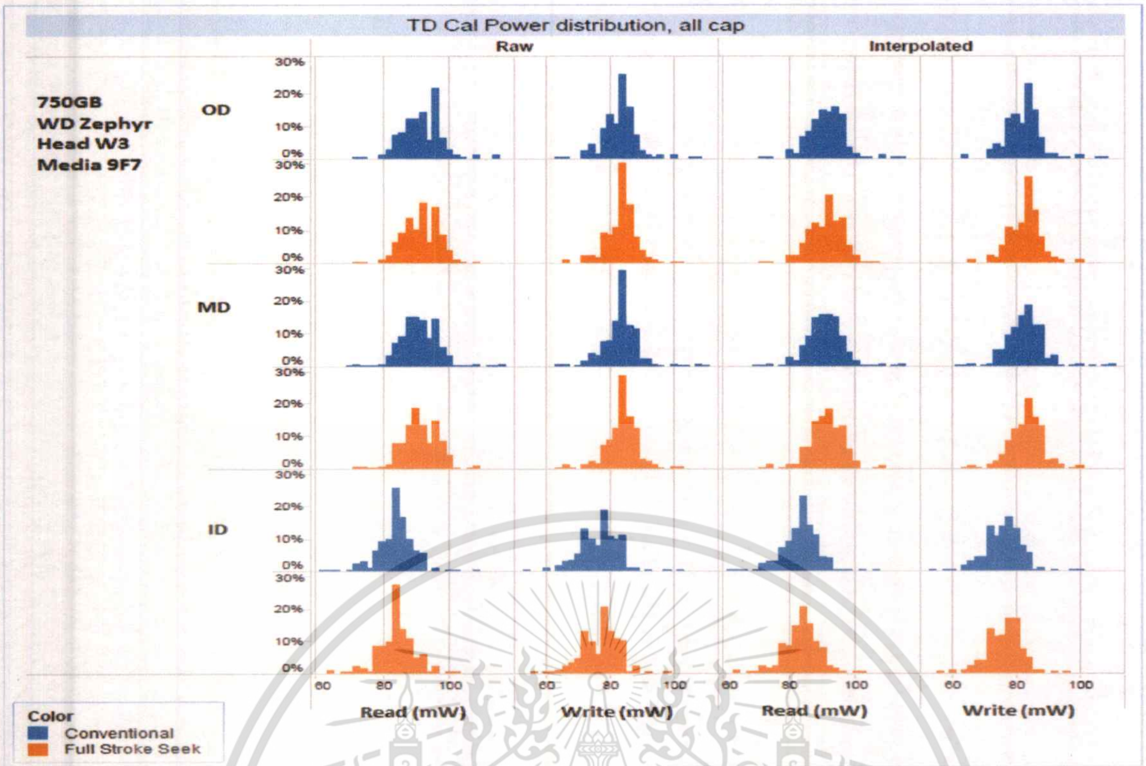


Fig. 5.7 Comparison of TDCal power distribution plot between current method and FSSK method.

Figure 5.8 shows the Read and Write of TouchDown Drive Verification Test (TDDVT) power between at the OD and ID. We can see that the distribution of TD power is not significantly different between the current method and the first proposed method (FSSK). The distribution of TDDVT power is within an acceptable level.

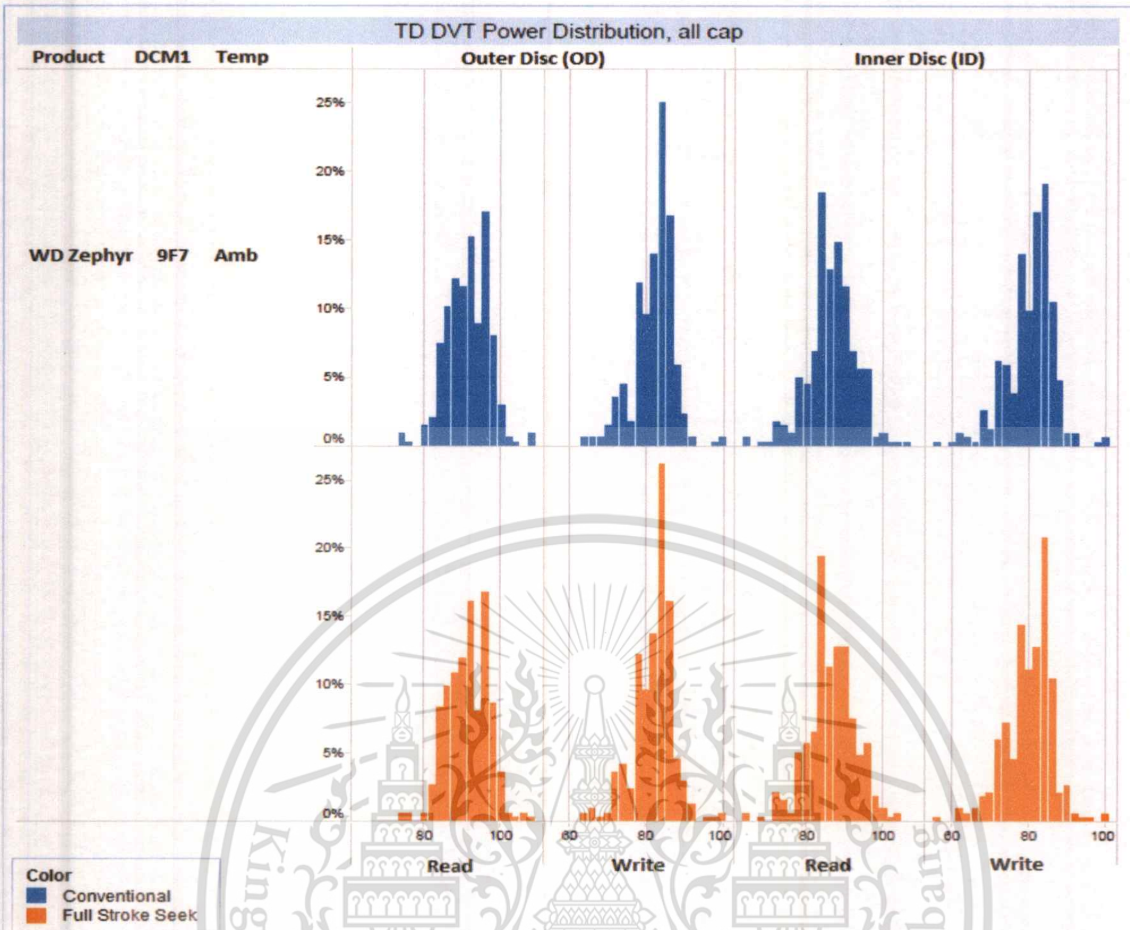


Fig. 5.8 Comparison of TDDVT power distribution plot between current method and FSSK method.

In the filler process, we also measure touchdown power at the beginning of the test and at the end of the testing process. The filler process is one of the processes of HDD test to write the servo signal. This can help backend process and guarantee that the writing process stays on track and is written correctly. Figure 5.9 shows a comparison of ReadTD power between the control lots which has passed backend test with the current method and the experiment drives which are tested with the first proposed method. The X axis is backend touchdown. The Y axis is ReadTD (in mW). It is obvious that the HDD from the current method and the first proposed method (FSSK) is not significantly different in term of ReadTD population between the filler and the backend test process.

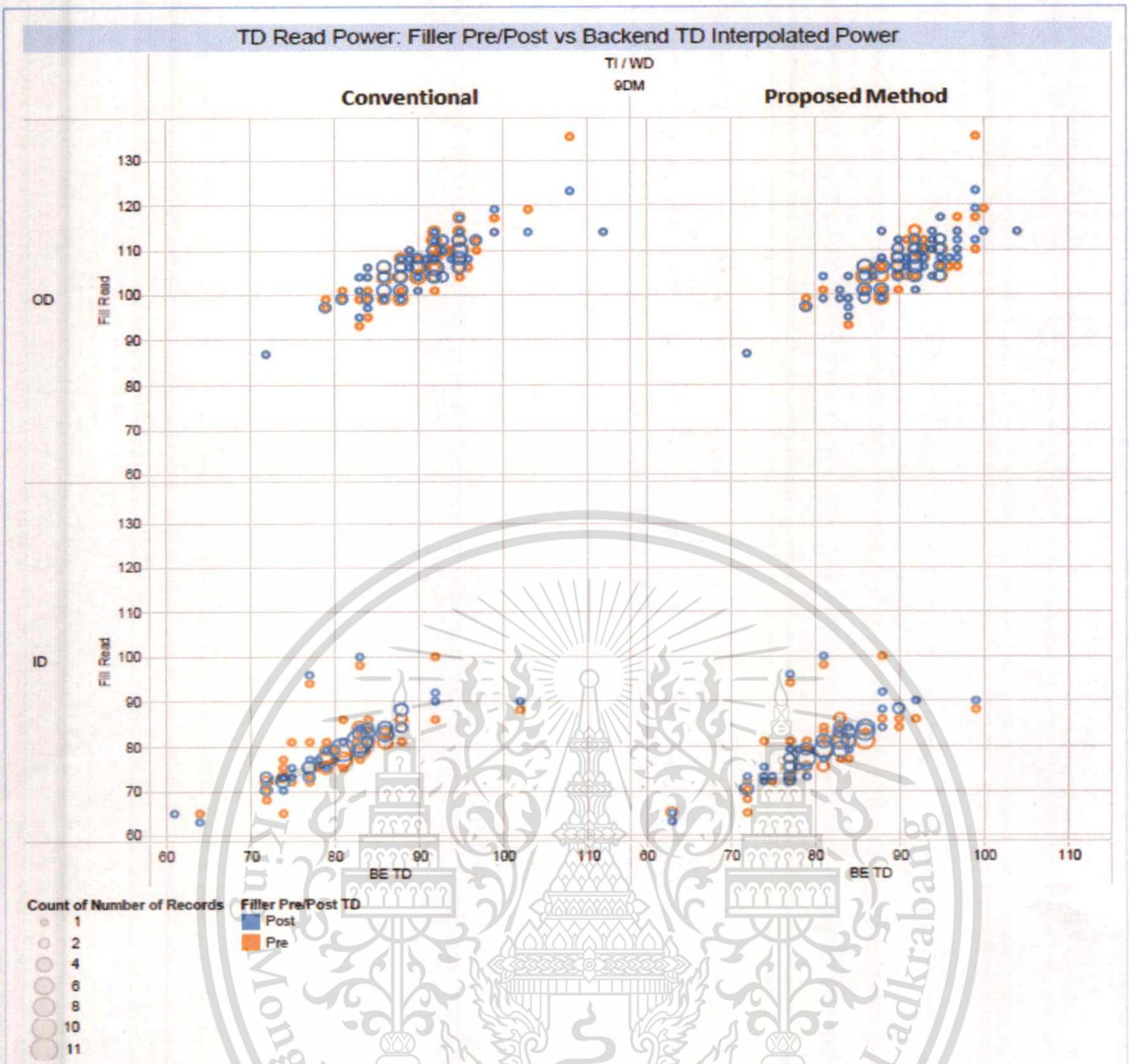


Fig. 5.9 Comparison of ReadTD Power between filler process and backend process.

Figure 5.10 shows the standard deviation of HMS (Head Media Spacing) distribution between the current method and the proposed method. The X axis is the location of the media, OD, MD, and ID respectively. The data is collected from Burn-In (BI) and Final Station Test (FTS). We can see that the standard deviation between the current method is not significantly different in comparison with the proposed method. The distribution of HMS is still within variation.

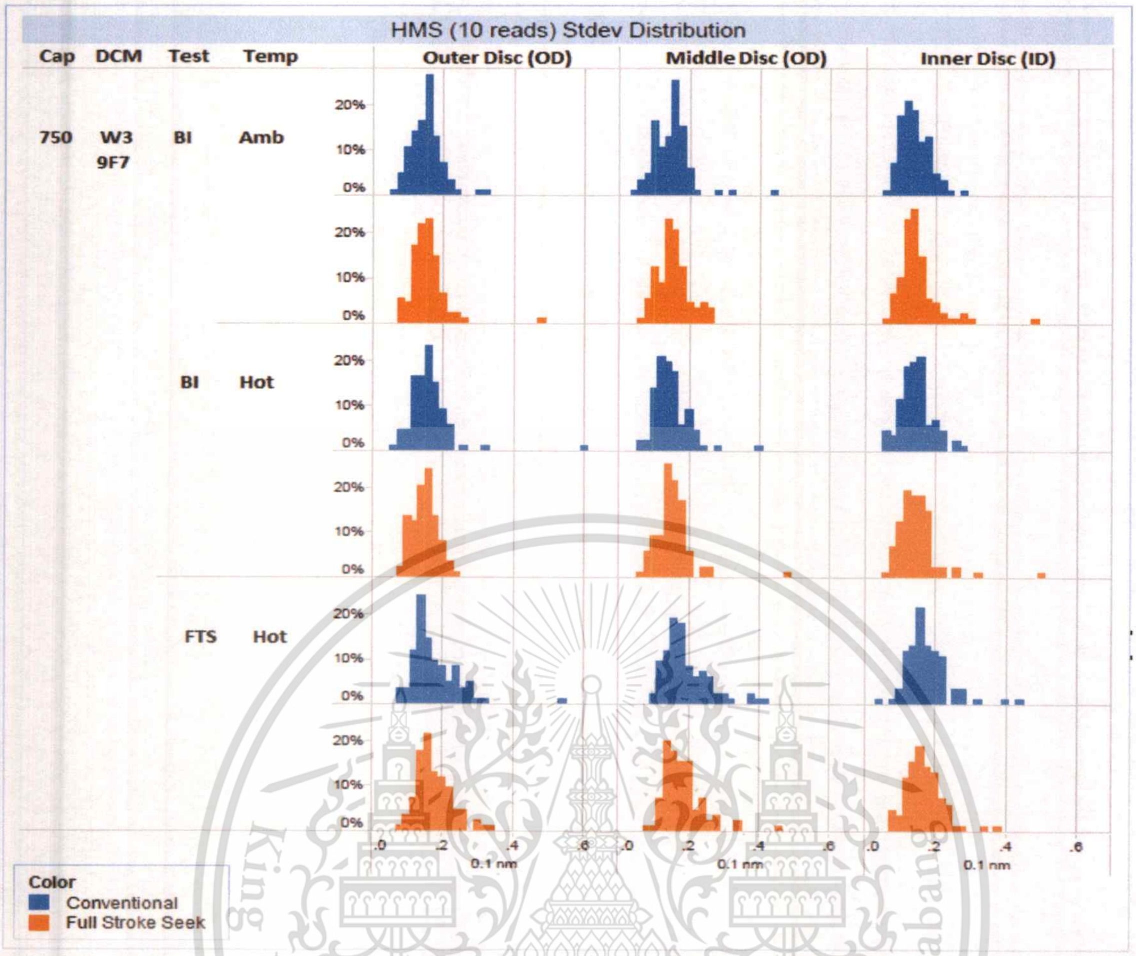


Fig. 5.10 Comparison of HMS between the current method and the proposed method.

5.4 Summary

The touchdown calibration process is essential for drive tests and drive operation. However, the particles can affect the touchdown calibration test and cause the drive touchdown failure. In this work, we investigate the particle contamination on the heads of the failed drives from the touchdown calibration test. Therefore, an additional test process by sweeping the head toward ID and toward OD back and forth before starting series of the HDD test can help improve touchdown failures. The experiments result shows that we obtain a better test utilization since the percentage of TDDVT delta exceeded limit is reduced. The proposed method can gain productivity as we see that touchdown failure is improved by 0.3-0.4% from the proposed method.

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Publications:

1. T. Supahdech, S. Pornchai, "A Study of Low Touchdown Improvement in Prependicular Disk Drive". The 5th International Data Storage Technology Conference. Thailand – Conference, February 14-15, 2014

A Study of Low Touchdown Improvement in Perpendicular Disk Drives

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A common approach for read/write heads to increase the areal density in disk drives is to reduce the fly height. The objective of such reduction is to improve the signal quality. Since a lower fly height is prone to damage the media due to particle contamination, in this work, we investigate the effects of media contamination on the unreliable test results. An additional test sequence is then proposed to remedy such events. We perform an experiment on the additional test command before doing touchdown calibration at the backend test process. Finally, we monitor further on the drive yield and quality to ensure that no side effect occurs. The experimental results show that touchdown(TD) profile is significantly improved by using the proposed method.

***Index Terms* — Particle contamination, Fly height, Touchdown (TD), Wallace equation, Head-Disk interface (HDI)**

I. INTRODUCTION

To push more areal density in magnetic recording systems such as hard disk drives(HDDs), the magnetic spacing between the slider and the disk should be as close as possible. In reality, hard disk drives are not free of particles, which are generated due to various causes such as manufacturing debris, slider loading and unloading process, fluctuation of lithography manufacturing process and its occasional contact onto the head. These particles range in sizes from several nanometers to several micrometers. In the present article, we focus on the particle motion in the head–disk interface (HDI), which is the region between the slider and the disk called "fly height" as shown in Fig. 1.

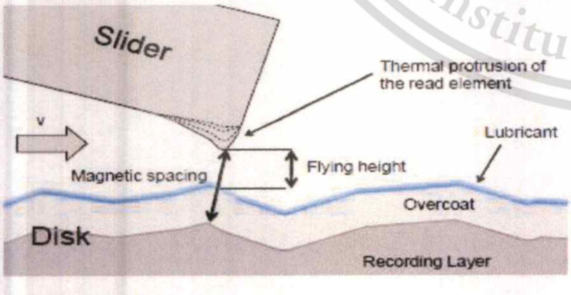

Fig.1. Fly height definition. The change in magnetic spacing corresponds to a change in flying height which requires a constant carbon overcoat and lubricant thickness. The region between the slider and the disk is called the head–disk interface. A coordinate system is set up with the z axis perpendicular to the disk.

The head/media spacing (HMS) is a distance between the head pole tip and the magnetic surface in current disk drives; it has now crossed the 10-nm height, therefore, only particles smaller than this can enter the HDI. The fly height disturbance is also caused by altitude, temperature, external shock, media defect and contamination. The slider contact with the disk could cause the loss of data stored on the disk. This is referred as a "high fly write." Hence, particle contamination on the slider can be critical to the HDD reliability [1-4]. To increase the areal density, a stable low fly height is necessary to achieve low bit error rates [5-6]. In [7], the method for estimating fly height is studied on amplitude based servo or a timing based servo.

Before the fly height of each head-media can be specified, the touchdown calibration (TD_CAL) process needs to be made. It aims to achieve the specific target of head/media spacing. The optimal dynamic fly height (DFH) power for drive operation of each head is determined by the touchdown (TD) power minus back-off power. An optimization is successful when a TD value(within the limit) with acceptable BER levels is chosen and the total capacity is still unchanged. However, during the calibration, often, the failed drives do not repeat the touchdown failure. It is possible that the particles may appear during hard drive assembly (HDA) in the cleanroom process and cause the failure of the touchdown delta exceeded limit test. In this work, we investigate the drive failure issues related to the touchdown calibration and the particle contamination. We propose to modify the test process during the touchdown calibration to improve the repeatability of the touchdown behaviors.

The remainder of this paper is organized as follows. Section II describes the principles and procedures of the calibration method of head/media spacing reduction in perpendicular magnetic recording (PMR). The Wallace equation is extensively used in estimation of head-to-disk spacing. Section III discusses the proposed method to improve the TD profile. Section IV shows the experimental results and the product yields. Finally, the conclusions are given in Section V.

II. DYNAMIC FLY HEIGHT CONTROL

A. Touchdown Calibration

The touchdown calibration is used to determine the maximum power that can be applied to the heater element for each head (in a drive) before the touchdown occurs. This is accomplished by continually applying the power to lower the heads until they make contact with the media or until the maximum allowable power is reached. The head-to-media contact typically only occurs during the calibration process for test purposes. The head is not supposed to touch the media during the normal read-write operations. As the head touches the media, the stress will be registered at the servo flex bias component, measured and saved to a log file for analysis. In addition, the maximum power corresponding to the reader/writer for each head/zone combination will be saved to a database. The execution time of the TD_CAL test is dependent upon the number of heads being tested. Currently, the execution time of touchdown calibration is around 2 minutes per head, and the number of typical test zones is defined in the input data structure, usually, 10 zones are tested at the outer diameter (OD) and the inner diameter (ID) areas for each head.

B. Dynamic Fly Height Calibration

Dynamic fly height (DFH) is required to maximize the performance of current disk drives. The current method is to control the temperature of the head. The calibration involves checking if the head contacts the surface (head touchdown). If head touchdown is not detected, then the calibration is complete. If the head touchdown is detected, the DFH control power is incrementally de-applied until head touchdown is no longer detected. A servo data scan is initially performed without the heater voltage applied. The average flex bias is calculated on a full revolution of servo data samples. A flex bias threshold is chosen to indicate the head touchdown. The normal heater voltage is then applied and if head touchdown is detected, the test iterates until head touchdown disappears.

A calibration cycle for DFH will be required at the power-up and at the specified periods of time. The cycle consists of choosing a head and a test track and then performing an internal-mode servo data scan while reading consecutive sectors on the track. The servo data and the logged error register contents are passed directly to the channel firmware for analysis. The channel firmware makes a decision to adjust the dynamic fly height (DFH) base offset for the head and zone, then it updates the DFH data file which is used to apply DFH control under normal operation. The controller firmware monitors the flex bias during the servo data scan to detect the touchdown.The head switches require that DFH is re-applied for the new head as shown in Fig.2.

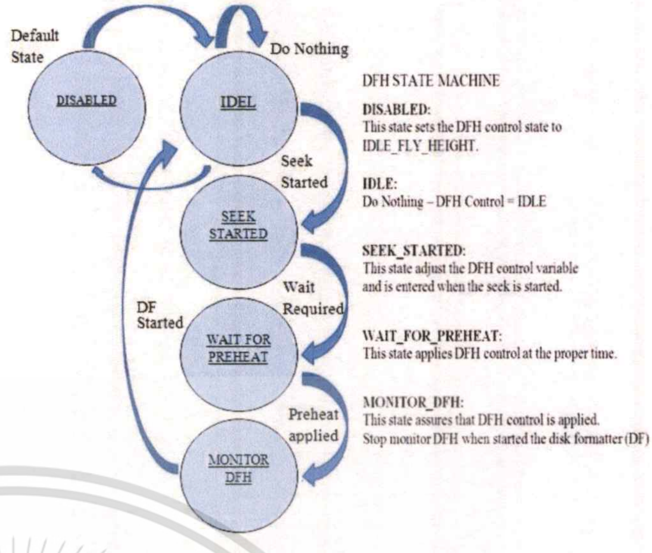

Fig.2. State machine of DFH control engine.

Most of the reported fly height algorithm estimation is derived from some specific data patterns that are written onto the disk. The servo sectors on the disk are used to determine the off-track position of the read/write head with respect to the track center. The estimation scheme for the measurement of the variation of flying height can be an amplitude based servo or a timing based servo. This is required the change in magnetic spacing and a constant overcoat and lubrication thickness. Based on the above assumptions, the change in the fly height can be computed from the Wallace equation. For simplicity, we will consider the read back signal voltage in the frequency domain of two serve bursts, Φ_A and Φ_B, *i.e.*,

$$\Phi_A(k,z) + \Phi_B(k,z) = \left(\Phi_A(k,0) + \Phi_B(k,0)\right)e^{-kz} \quad (1)$$

where $k = \frac{2\pi}{\lambda}$ is the wave number, and z is the fly height

The change in fly height $\Delta z = z - z_{ref}$ can be calculated from

$$\Delta z = \frac{\lambda}{2\pi}\left(\frac{\Phi_A(\lambda,z) + \Phi_B(\lambda,z)}{\Phi_A(\lambda,z_{ref}) + \Phi_B(\lambda,z_{ref})}\right) \quad (2)$$

At sub 1-nm spacing ,the touchdown dynamics become extremely critical. First, it affects the accuracy of the spacing setting or the TD detection. Secondly, it affects the hard disk drive reliability, such as writing modulation,wear, instability, etc. Here, we focus on the contamination because we observe that most of the touchdown (power) delta exceeded limit failed drives are due to the particle contamination. As mentioned in Section. I, the TD_Cal process aims to achieve the specific target of head/media spacing. It is problematic that some particles hold onto the head tip pole during the touchdown calibration process. In the test process, the touchdown delta exceeded limit failure is used to determine pass or fail drive. This is computed from (3) and must in range of +/-15mW.

$$TD\,failure \;=\; (TD\_DVT - TD\_Cal) \qquad (3)$$

Below table is an example, how to compute the TD delta exceed limit failure (TD failure).

Head	Zone	Type	TD_Cal (Amb)	TD_DVT (Amb)	TD_DVT- TD_Cal
0	1-20	ReadTD	90.3	89.5	-0.80
1	1-20	ReadTD	68.2	93.2	25.00
0	1-20	WriteTD	78.4	78.4	0
1	1-20	WriteTD	57.5	78.4	20.90

III. TD PROFILE IMPROVEMENT METHOD

The Touchdown Calibration test requires Advanced Read Channel Optimization (ARCO) and Read Write Gap Calibration (RDWRgap). The test process will require the hardware together with the controller firmware for the DFH optimization process.

A. Current Method

Currently, the TD_Cal and the touchdown test sequence will perform a series of functions to collect all the information and data necessary to determine the maximum power can be applied to the heads as shown in Fig. 3(a).

The flash firmware is a process to install the controller firmware (FW) into the drive. The FW consisted of initial test parameters to command the spin up drive. The Mini-ARCO is an optimization process in the reserve cylinders zone (zone 0), this is essential area which uses to keep the factory test data and the user can not access. The RDWRgap process is to calibrate the track width to be matched with the head reader &the writer of each head.The touchdown calibration process is a process to calibrate a "zero" head / media spacing (flying height), and the optimal DFH powers for drive operation is uses the touchdown power minus back-off power (back-off power is constant value define by factory). The touchdown power is the power needed by the heater to physically make the head to be in contact with the disk. The track per inch calibration (TPI Cal) is an important process to assure the drive selects proper TPI, this process will need to total of Logical block address (LBAs) from each zone to determine if capacity is met and then go to KFCI adjustment. The variable kilo flex change per inch (VKFCI)adjustments will be made across individual zones and the heads to meet target capacity. The full ARCO will optimize data Zone 1 to 20 at Ambient& hot temperature, this process is the same Mini-ARCObut will do in uses area.

B. Proposed Method

The proposed method will apply an additional test module before running Mini_ARCO. The test command will first seek the heads from the OD to the ID with a number of cycles then continue as normal with the following steps as shown in Fig. 3(b).We suspect that the low TD mostly occurs when failed heads aquire particles during the flex bias test. It is well understood that particles are able to move out since some failed drives do not repeat the failure during the re-test. The flowchart showing the comparison between the current and the proposed methods is illustrated in Fig. 3.

In principle, there are two options to perform the slider movement. One is inserting the Servo_seek test before performing TD_Cal process but this requires a new servo code to execute the test module. The other is adding Random_average_seek procedure in Pre-Test. In this work, we choose to use the add-in Random_average_seek in Pre-Test. Here we run the Touchdown Drive Verification Test (TD_DVT) with the original track per inch and kilo flex change per inch (TPI/KFCI) value instead of overwriting with new TPI/KFCI. There are two cases which can occur as follows.

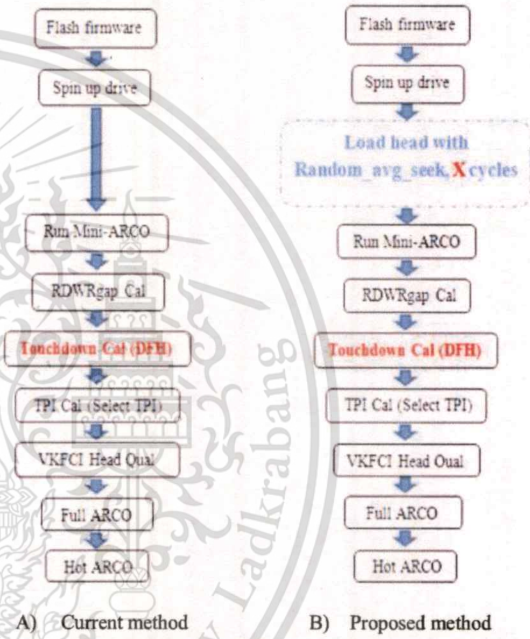

Fig.3. The Optimization Sequence of Touchdown Calibration and Flow chart of comparison between (a) current method and (b) proposed method.

Case1. The test is able to repeat low TD, i.e., the TD power repeats the original value when reprocessing the drives with the original TPI/KFCI. In this case, the failed heads will exhibit the poor bit error rate (BER) because the head is degraded during the test. As a result, we will send the defective head to supplier for investigating cause of degradation.

Case2. The test is not able to repeat low TD, i.e., the TD power does not repeat the original value after reprocessing the drives with the original TPI/KFCI. In this case, we suspected the particle may move away for the re-test.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

Here we make an reprocess experiment on the TD failed drives by selecting 16 samples of failed drives to reprocess and measure the TD power. The results show that 16 out of

20drives does not duplicate the low TD failure. The TD value looks normal. It is possible that the particles have moved away. Fig. 4 shows an example of the inspected defective drive made by using the scanning electron microscope (SEM) with a 200000x magnification rate and found the white speck on Hd1.

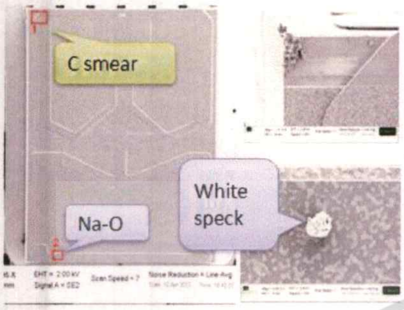

Fig.4. The inspection from the scanning electron microscope (SEM).

Fig. 5 shows the comparison of TD_Cal power between the original and two reprocessed drives labeled as drive 1 and 2. Apparently, the TD_Cal power on the failed head (Hd1) becomes higher after reprocessing both Read-Write TD denoted by the lines with triangles and the squares. The horizontal axis represents the touchdown value on the problematic Hd1 between read and write operation in the 10 test zones as mentioned in Section II, Hd0 is normal.

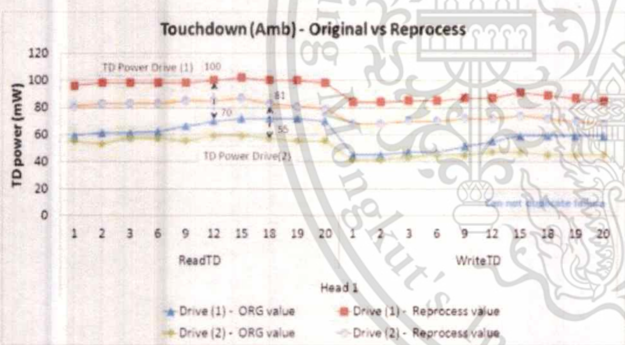

Fig.5. TD power comparison between the original and reprocess drive.

Fig. 6 shows the drive repeat low TD failure. The TD_Cal power value does not look as good as Fig. 5. We suspect the

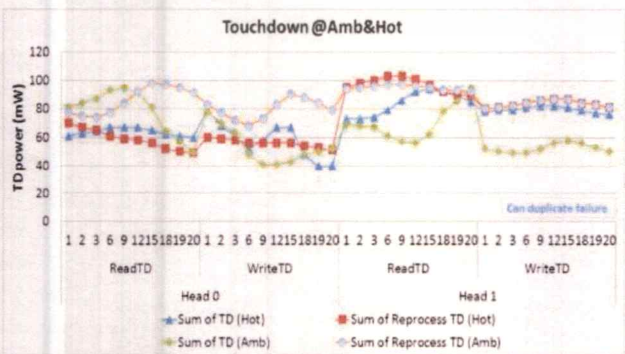

Fig6. TD power comparison between Ambinet (24C°) & Hot (50C°) temp.

head (Hd0) has degraded while Hd1 looks normal. To analysis on the root cause of the degradation issue, we will send the drive to the supplier to investigate to see the head degradation is related to the headstack process or the drive process.

We perform the experiments on different cycles. We found out that the head seek from OD to the ID with 5000 cycles shows a good optimal result. The test time increases by about 20 seconds and 28 second for 5000 and 7000 cycles, respectively, but the product yield has not much improved. Table I shows the yield comparison and the percentage of the TD delta exceed limit failure with different cycles between the current and proposed method. Table II shows the data comparison with a bigger population of the HDDs. The TD failure has improved while the percentage of failure rate (%FR) is reduced from ~0.9% to be ~0.5%. This is clear that the proposed method performs better than the existing one.

Table. I show the data comparison with different test cycle (X cycles).

Head: Type A
Media: Type B

		Seek head from outer to inner disc with X Cycle				
	Test package	500	2000	5000	7000	10000
%FR - TD_DVT Delta Exceed Limit	Current	1.33%	1.12%	0.98%	1.20%	0.85%
	Experiment	1.21%	1.27%	0.65%	0.82%	0.54%
% Improve		0.12%	-0.15%	0.33%	0.38%	0.31%
Test Time (Second)		8	15	20	28	36

Table.II shows the data comparison with different Head/Media type.

Test package: Experiment (5000 cycles)

	TYPE	%FR - TD_DVT Delta Exceed Limit: Current test package	Experiment test package	% Improve
Head	A	0.92%	0.55%	**0.37%**
Media	B			
Head	C	1.13%	0.73%	**0.40%**
Media	D			
Head	E	0.84%	0.60%	**0.24%**
Media	F			
Head	G	1.45%	1.12%	**0.33%**
Media	H			

V. CONCLUSION

Touchdown calibration is essential for drive tests and drive operation. However,the particles can affect the touchdown calibration test and causes the drive touchdown failure. In this work, we investigate the particles on the heads of the failed drives from the touchdown calibration test. An additional random average seek is inserted before the ARCO test in order to improve low TD. The experiments on the failed drives show that we obtain a better test utilization since the percentage fallout is reduced.

ACKNOWLEDGMENT

The authors would like to thank Western Digital (Thailand) Co., Ltd. for providing some technical assistance and financial support. This work was supported in part by College of Data Storage Innovation, King Mongkut's Institute of Technology Ladkrabang.

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APPENDIX

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A Study of Low Touchdown Improvement in Perpendicular Disk Drives

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Abstract— A common approach for read/write heads to increase the areal density in disk drives is to reduce the fly height. The objective of such reduction is to improve the signal quality. Since a lower fly height is prone to damage the media due to particle contamination, in this work, we investigate the effects of media contamination on the unreliable test results. An additional test sequence is then proposed to remedy such events. We perform an experiment on the additional test command before doing touchdown calibration at the backend test process. Finally, we monitor further on the drive yield and quality to ensure that no side effect occurs. The experimental results show that touchdown (TD) profile is significantly improved by using the proposed method.

Keywords— Particle contamination, Fly height, Touchdown (TD), Wallace equation, Head-Disk interface (HDI)

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