STATISTICAL ANALYSIS METHODOLOGY OF SLIDER ALIGNMENT OFFSET

SASIRAPASSR KEMSUP

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF ENGINEERING IN DATA STORAGE TECHNOLOGY
INTERNATIONAL COLLEGE
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หัวข้อวิทยานิพนธ์	การใช้หลักสถิติวิเคราะห์กระบวนการวัดค่าออฟเซตของความเที่ยงตรงของสไลเดอร์
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อาจารย์ที่ปรึกษาวิทยานิพนธ์	รศ.ดร. ปิติเขต สู้รักษา

บทคัดย่อ

ในอุปกรณ์บันทึกข้อมูลแบบแข็ง (Hard disk drive)นั้น มีชิ้นส่วนสำคัญชิ้นส่วนหนึ่งคือหัวอ่านเขียน (HGA) ใน 10 ปีที่ผ่านมานี้ความสูงของการบิน (Fly height) ของหัวอ่านเขียนลดต่ำลง ซึ่งผลักดันให้การประกอบหัวอ่านเขียนต้องทำการติดตั้งสไลเดอร์ให้มีความถูกต้องและแม่นยำมากขึ้นตามไปด้วย ตามหลักการของค่าความเที่ยงตรงของสไลเดอร์ (Slider alignment) นั้นจะวางสไลเดอร์อยู่บนจุดศูนย์กลางของดิมเปิ้ล (Dimple) สำหรับเทคโนโลยีการประกอบชิ้นส่วนหัวอ่านเขียนในปัจจุบัน ไม่สามารถมองเห็นดิมเปิ้ลได้ ค่าออฟเซต (offset) ของความเที่ยงตรงของสไลเดอร์เป็นที่ต้องการเพื่อทำความเข้าใจประสิทธิภาพของกระบวนการผลิต กระบวนการวัดค่าออฟเซตนี้ต้องผ่านการตรวจสอบโดยใช้หลักเกณฑ์ทางสถิติและการหาค่าความถูกต้องและแม่นยำของเครื่องมือวัด ผลลัพธ์ที่ได้คือ เครื่องมือวัดผ่านหลักเกณฑ์มาตรฐานเพื่อใช้วัดค่าชิ้นงานได้และพบว่าค่าออฟเซตของความเที่ยงตรงสไล

เดอร์ที่เกิดขึ้นจะมีค่ามาก หรือน้อยนั้น ขึ้นอยู่กับทิศทางของสไลเดอร์ที่ถูกประกอบไปบนแขนยึดจับเป็นหลักสำคัญ ผลการวิจัยนี้ช่วยให้การวิเคราะห์ผลมีความถูกต้องทำให้สามารถกำหนดแผนการปรับปรุงกระบวนการประกอบสไลเดอร์เพื่อให้มีประสิทธิภาพมากขึ้นได้

Thesis: Statistical Analysis Methodology of Slider Alignment Offset
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Program: Data storage technology
Year: 2015
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ABSTRACT

In hard disk drive, one of key components is Head Gimbal Assembly (HGA). The requirement of lower fly height in the past 10 years drives HGA assembly process having slider placed onto suspension high precision and ultra-high accuracy. This parameter is slider alignment. Concept of slider alignment is that slider must be placed at the center of a dimple. Present technology of HGA assembly process has not recognized the dimple position. The offset of slider alignment data is required for understanding effectiveness of assembly process. With this proposed methodology, the system must be qualified by using statistical test and Gage

R&R. Results show methodology pass criteria for measuring parts and observing. The offset of slider alignment value is large or small depending on direction of slider position placed on the suspension. This work can be utilized for correct data analysis which helps to determine improvement plan for the assembly process.

ACKNOWLEDGEMENT

It is a pleasure to thank those who made this thesis possible. First, I am heartily thankful to my advisor, Assoc. Prof. Dr. Pitikhate Sooraksa, who is given me helpful suggestions and kindly advice for my thesis.

I would like to thank to my supervisor, Mr. Suwit Wongsomsri. Without his advisement, encourage and enabled me to develop an understanding of the subject. This thesis will not be completed.

I am indebted to my colleagues for great support, Ms. Mulchupat Chamsoongnoen, Mr. Naksiripong Nakasiri, Ms. Hoa H Nguyen, Mr. Gino E Gori, Mr. Pitsanu Rachsombat and Ms. Wei Zhu.

Moreover, I would like to show my gratitude to the National Science and Technology Development Agency (NSTDA), Seagate Technology (Thailand), Ltd. and King Mongkut's Institute of Technology Ladkrabang, which provided the full scholarship for studying in the master degree.

Most especially to my family, friends and colleagues words alone cannot express what I owe them for their encouragement and whose patient love enabled me to complete this thesis.

Lastly, I offer my regards to all of those who supported me in any respect during the completion of the project.

Sasirapassr Kemsup

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Recently storage devices become essential for people. In daily life, they have information to keep and share such as works, personal information and social network service (SNS). The huge data store to devices for example as web applications, mobile applications, e-mail, 3D graphic, pictures and clips. Hard disk drive (HDD) is one product of storage devices which it responses customer requirements very well due to it has low cost compare to its density.

The hard disk drive has many components for example cover, disk, print circuit board, filter and actuator. There is one of key components is Head Gimbal Assembly (HGA). See example of HGA in Appendix A. HGA contains read and write components. HGA read and write magnetic field onto disk with 6,000 - 20,000 RPM. More details of Hard Disk Drive components are in “Hard Disk Drive Mechatronics and Control” [1]. HGA comprises a slider and a suspension, a slider is attached on suspension. Example of slider and suspension are in Figure 1.1.

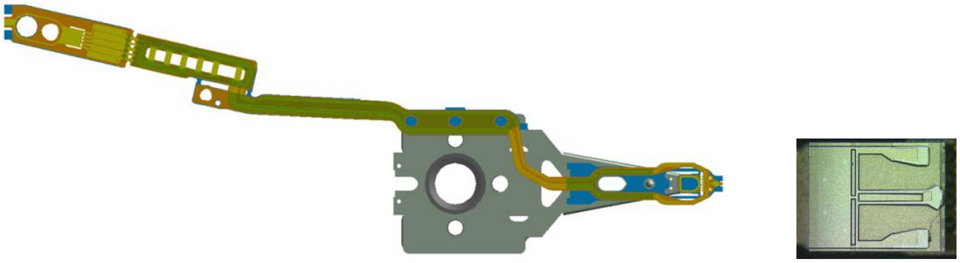


Figure 1.1: A suspension (left) and a slider (right)

Head Gimbal Assembly manufacturers control quality of products referring to requirement from designer and follow Six Sigma concept. The Six Sigma is a method used widely in manufacturer. Many books are written about it for example, Implementing Six Sigma: Smarter Solutions using Statistical Methods [2]. However process variations made poor slider alignment HGAs and it causes defects at downstream process. For example, a HGA had issue of poor slider alignment and it escaped to interconnecting process and failed solder joint as bridging failure in Figure 1.2.

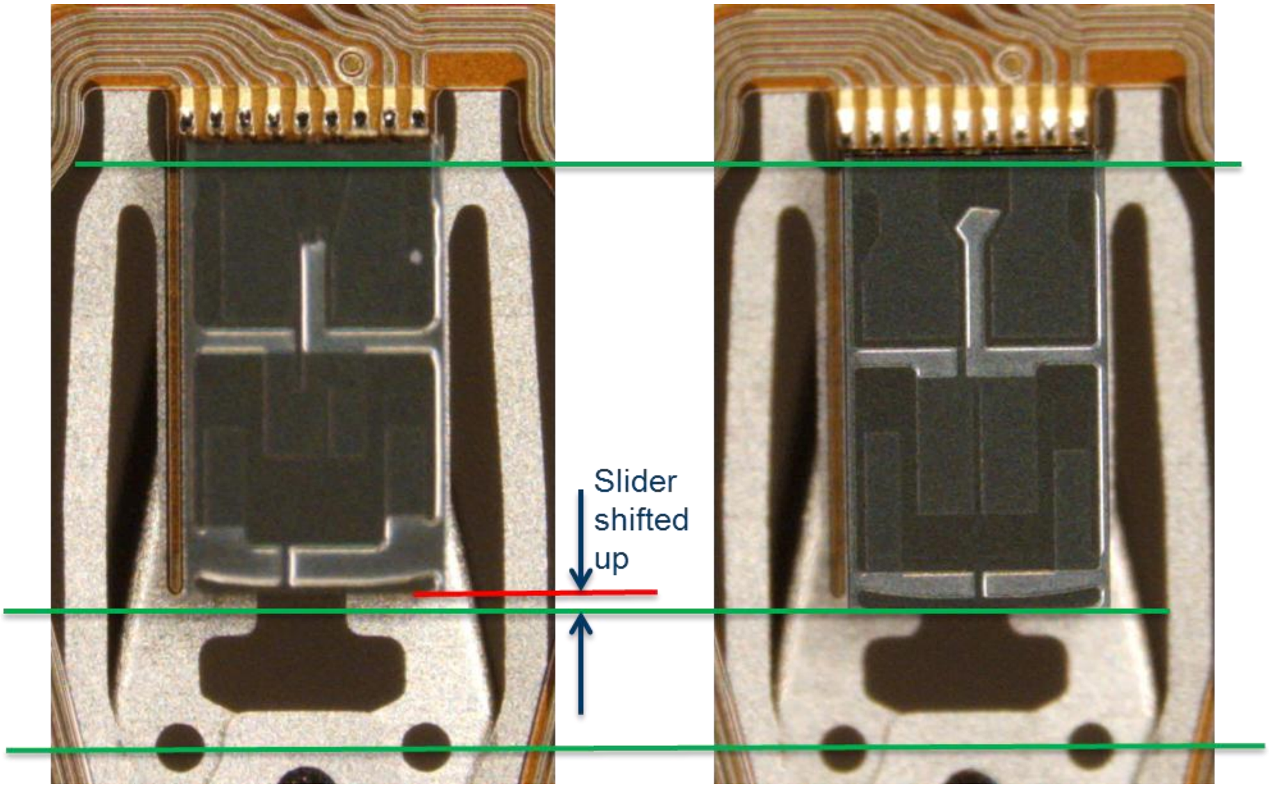


Figure 1.2: Fail slider alignment of HGA. (left) Good slider alignment of HGA. (right)

Since this methodology aims to study offset of slider alignment which less impact to production line, less investment cost and trustworthy results. So measurement of dimple will remain by refers to loadbeam fiducials as same of assembly machine referred when it attached slider on to suspension. Method of measurement or assembly HGA by reference fiducials are acceptable and widely uses in manufacturer.

1.2 OBJECTIVE

Enable methodology and new fixture to measure slider alignment offset to dimple which fixture & programs have to pass qualification process. The result should determine how well of incoming dimple formed on suspension compare to design requirement and also the accuracy of assembly machine that mounting slider on suspension.

1.3 SCOPE OF WORK

Methodology of slider alignment to dimple will develop with existing alignment audit tool, process steps of measurement and new design fixture to flip suspension upward for optically measurement at the dimple.

In Chapter 2, Literature Review describes basic knowledge of fly height, components of Head Gimbal Assembly, slider alignment coordinate and review historical works related to suspension and slider alignment.

CHAPTER 2

LITERATURE REVIEW

2.1 BASIC KNOWLEDGE

The hard disk drive operates by the disk or media rotates with thousand RPM. The air above disk also rotates. The air flow and Gramload create lift force at desired height as called “Fly height” [7]. Method to test optical Fly Height could be refer to “Optical Flying-Height Testing of Magnetic Read-Write Heads” [11]. The fly height is distance between read/write head and disk as shown in Figure 2.1

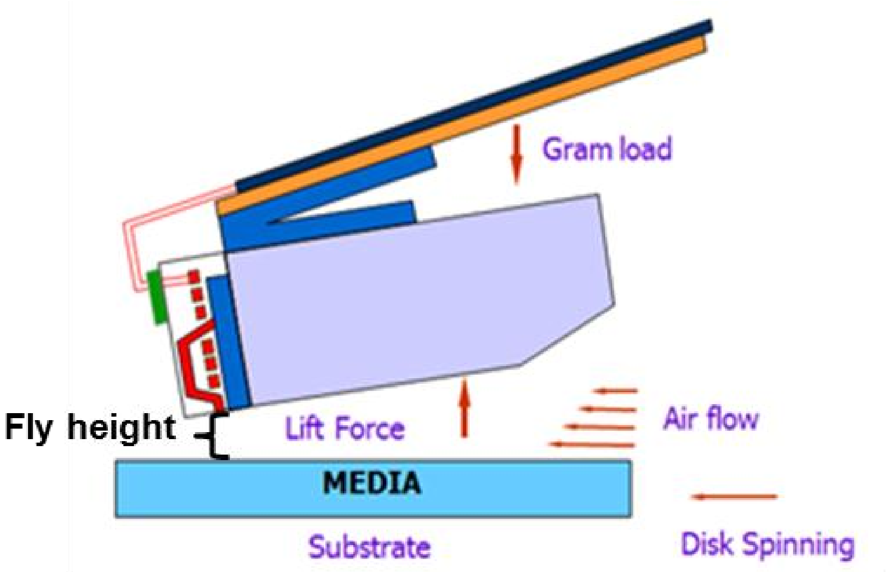


Figure 2.1: Fly height of recording head

To achieve high density of hard disk drive, flying height must be low. Compare to traditional hard disk drive, present technology has fly height in few nanometers. Reducing fly height will help head read and write signal more easily and less error as term of signal-to-noise ratio in acceptable range [8]. With this reason, it drives to HGA assembly process control Key Process Input Variables (KPIVs) more accurate and precise to get low fly height per target.

Key Process Input Variables (KPIVs) of HGA assembly process affects to flying height have many parameters such as HGA Pitch static attitude or HGA PSA, HGA Roll static attitude or HGA RSA, HGA Gramload, Slider alignment, HGA flatness, etc.

All parameters are contributed by assembly process to position of read/write head when hard disk drive operated. For example, HGA PSA, Pitch angle is the angle formed when slider attached onto gimbal as shown in Figure 2.2.

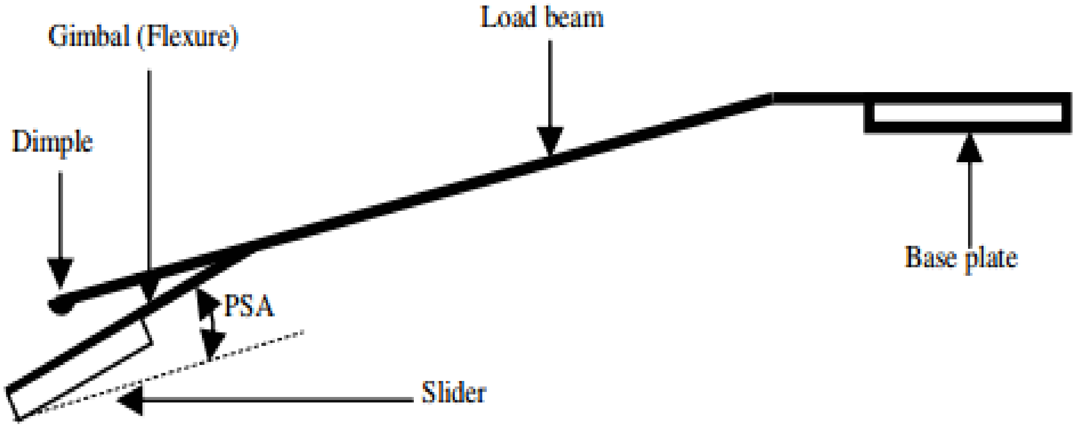


Figure 2.2: The HGA PSA

2.2 SLIDER ALIGNMENT

Slider alignment is parameter measure deviation of actual slider position after attached to suspension compare to design target. Missed alignment will cause to poor fly height. The fly height could increase or decrease depends on direction of slider alignment. Slider alignment is described in three directions as X alignment, Y alignment and T (Theta) alignment.

Slider X alignment is the position of slider shift in line of suspension centerline. Positive value (+) represents the slider shifted toward the lift tab. Negative value (-) represents the slider shifted toward the loadbeam reference. So when Slider X alignment has more positive distance, it means that slider fly over disk closer distance than expected. The fly height is lower than target as shown in Figure 2.3.

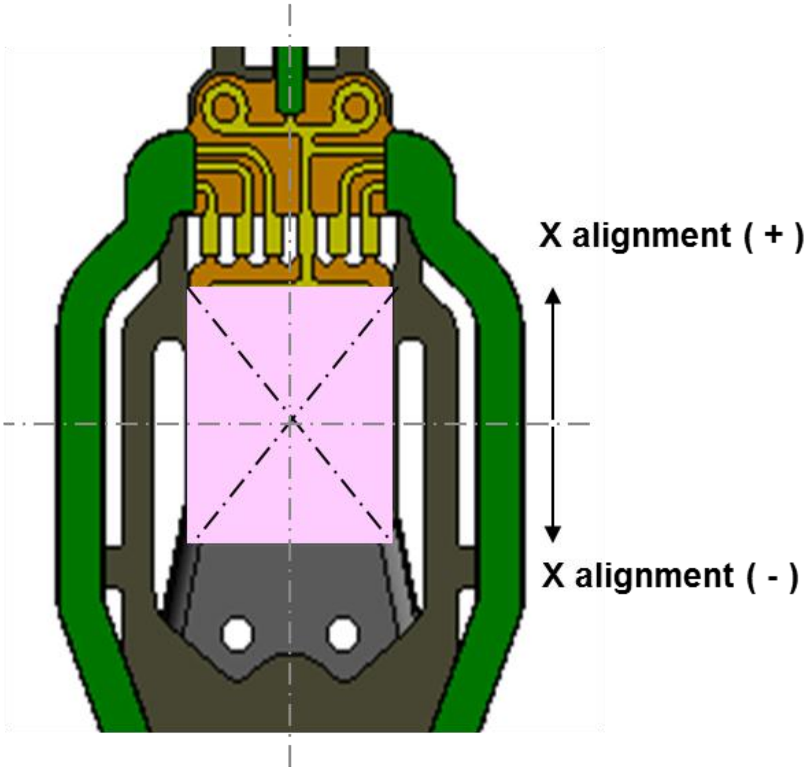


Figure 2.3: Slider X alignment direction

Slider Y alignment is the position of slider shift perpendicular to suspension centerline. Positive value (+) represent slider shifted inner radius of disk (ID). Negative value (-) represent slider shifted to outer radius of disk (OD). If Slider Y alignment has more positive or negative distance, it means that slider missed position to read/write position. Missed Y alignment does not create problems to fly height but errors on read and write track as shown in Figure 2.4.

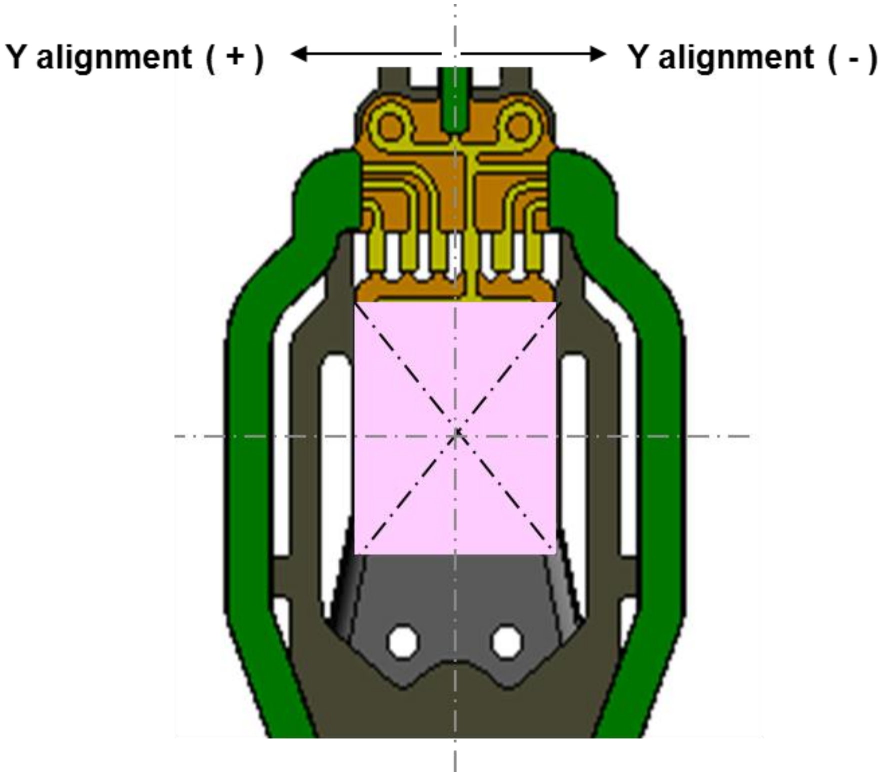


Figure 2.4: Slider Y alignment direction

Slider T alignment is the position of slider twist in angle to suspension centerline. Positive value (+) is in counterclockwise direction. Negative value (-) is in clockwise direction. If Slider T alignment has more positive or negative distance, it means that slider missed position to read/write position. Missed T alignment does not create problems to fly height but errors on read and write track as shown in Figure 2.5.

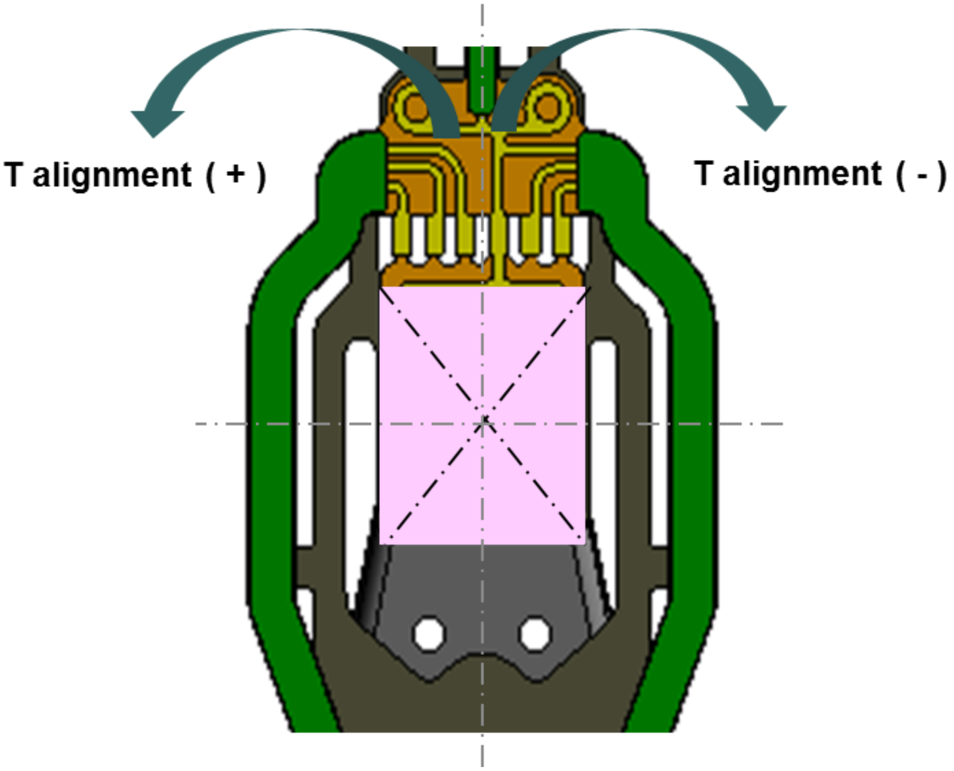


Figure 2.5: Slider T alignment direction

In HGAs assembly process, there is an equipment attach slider onto gimbal. This equipment will grab slider, searching reference fiducials and place slider onto it. The fiducials are formed at flexure and loadbeam with projecting to center of dimple.

As shown in Figure 2.6, suspension front side view has been seen the loadbeam fiducials and gimbal area. For back side view has been seen dimple location. The dimple is formed at load beam piece part which controlled distance to load beam fiducials.

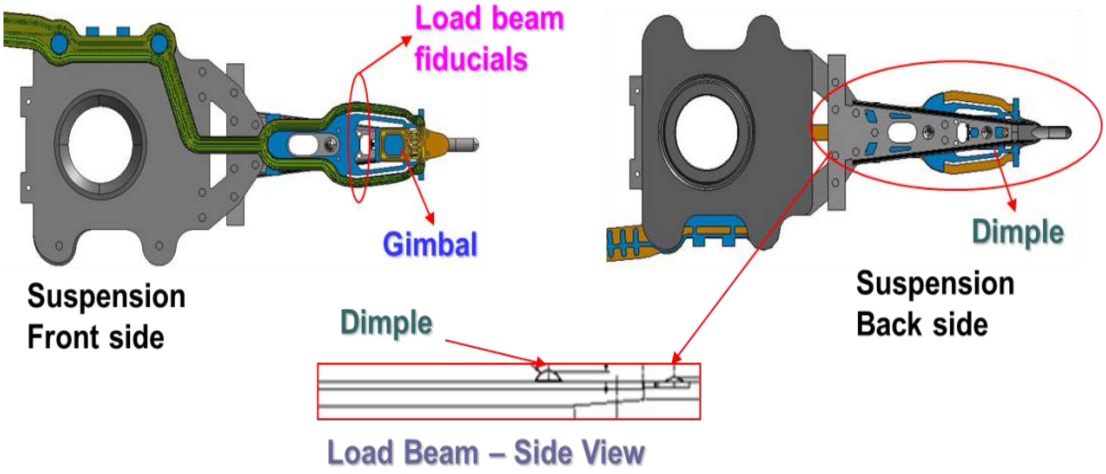


Figure 2.6: Location of the reference points and line

To control Slider alignment, this equipment must attach slider onto gimbal properly. The critical requirement is center of slider must be at center of dimple. A dimple is contact point which slider moves around the dimple when HGA fly above disk. Missed location of slider, it is not balance weight during fly so it causes to downstream defects such poor bonding between slider and suspension and also poor fly height. However missed placed of slider at center of dimple does not cause from machine or equipment alone. There are causes from method and materials too.

Method to attach slider at center of dimple has one potential cause due to equipment does not have vision at dimple. Considering material as suspension, a dimple is formed on loadbeam per design target but it has variation from suspension manufacturing as well. Shift position of dimple will results in increasing variation to fly height. However dimple location is not controlled, measured or inspected at HGA assembly process.

2.3 LITERATURE REVIEW

In 1989, Brandt and Stroud developed “Method for Mounting a Magnetic Head on a Suspension,” U.S patent number 4,866,836 [3]. The suspension has readable indicia near the location that slider to be mounted and 2 reference holes projecting to visible center of dimple. They tried to assembly slider by using computer vision scan and determine exactly position of dimple and slider place. Result of slider alignment has improved accuracy.

As shown in Figure 2.7, the center of dimple is referred to number 2, the dimple is number 10 and the readable indicia is referred 2 holes as number 6 for 1st hole and number 7 for 2nd hole which drawn the line to center of dimple by vision and computer program. Process of mounting slider start by using offset of first line drawn from center of Hole 6, center of Dimple 2 and center of Hole 7 and second line drawn from center of Hole 6 and center of Hole 7. Equipment uses offset value and places slider.

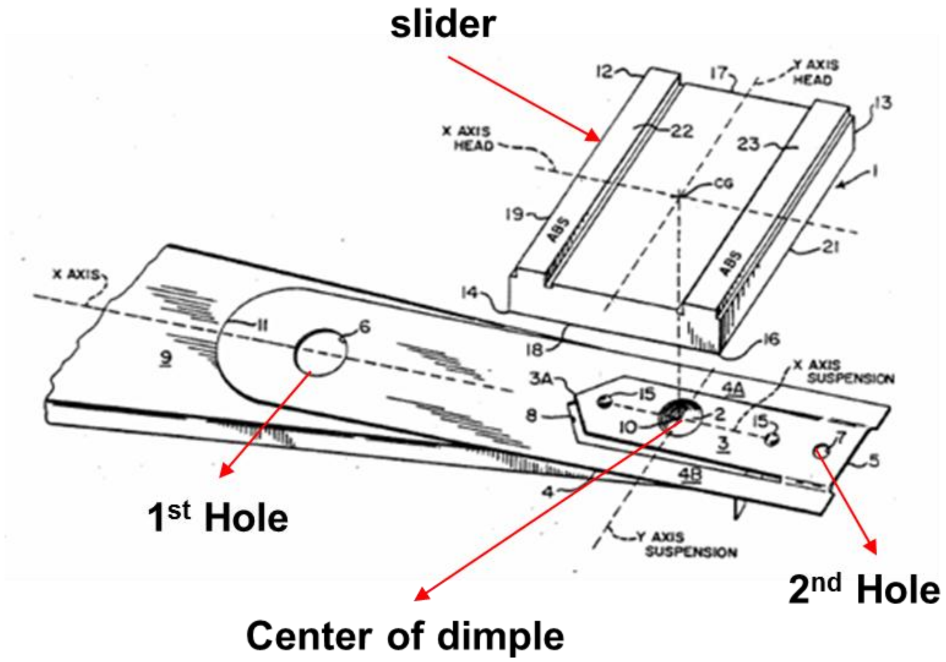


Figure 2.7: Visible dimple on suspension

Four years later, in 1993 Hagen established topic of “Head Alignment Reference Feature in a Hard Disk Drive Head-Gimbal Assembly,” U.S patent number 5,493,463 [4]. This method developed gimbal design with adding features visual confirmation of acceptable slider to dimple alignment. This development helps to provide slider at correct alignment relative to dimple and quick visual inspection.

As shown in Figure 2.8, slider placed on gimbal. This suspension added 2 new features as in number 68 and number 70 for visual inspection whether slider alignment is out of specification or not. These 2 features are relative to the center of dimple.

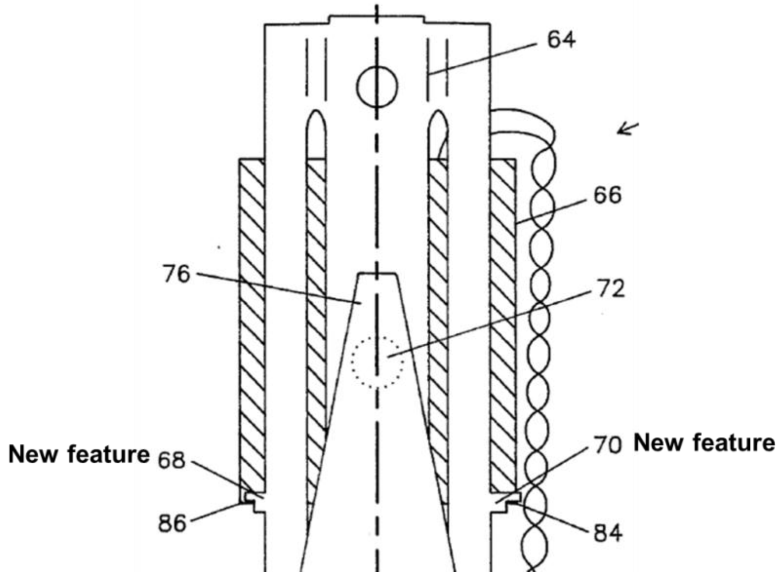


Figure 2.8: Addition features for visual inspection

In 2001, Summers and Vera established topic of "Alignment of Sliders in Head Gimbal Assemblies," U.S patent number 6,212,760 B1[5]. Their invention is to simplify, accurate and less produce time for manufacturing. Due to problems aligning a slider with a dimple in manufacture of head gimbal assemblies for disk drive suspensions are obviated by defining series of optically readable indicia on or about the dimple that serve as a reference for positioning apparatus rather than the dimple.

They provide markers of sharpness and uniformity of distribution that positioning equipment can read and position the slider reference to them, as opposed to the dimple, with increased accuracy, better speed and fewer defects. As shown in Figure 2.9, the markers are provided in form of holes in number 36 which they were etched around dimple in number 26. The sharpness of these markers helps the reading equipment identify position of holes.

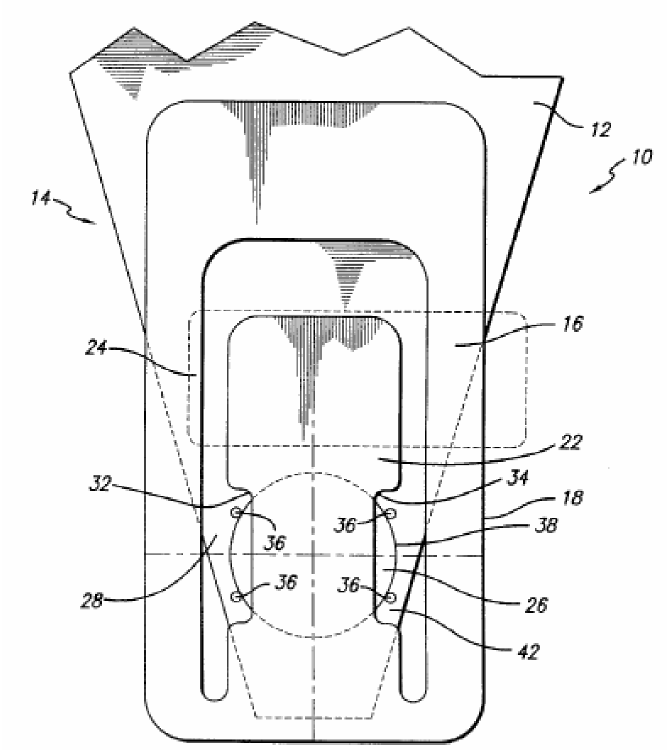


Figure 2.9: Sharpness markers projecting to dimple

With present suspension design, the load dimple is formed on loadbeam covered by gimbal tongue as part of circuit. Load dimple cannot be seen by manufacturing assembly machine. Even suspension design change about dimple position which could not be seen, some patent showed that trend to improve slider alignment capability goes to improve feature for easy inspection instead. For example, adding features on suspension especially at gimbal and loadbeam helps manufacturing machine produce more products and its accuracy along with easily visual inspection for good parts.

Suspension manufacturer and designer also improved their optically readable indicia be adding sharpness features on loadbeam or at gimbal. So that HGA manufacture could determine position of dimple. For X direction line reference, it is common to use center line projecting from feature at loadbeam line up to center of dimple and link to feature at gimbal.

Since equipment cannot do visual exact position of center of dimple. It had been worked to find other solutions to refer dimple position by using new feature at loadbeam or at gimbal. These feature helps to increase output of HGA however results of slider alignment offset to dimple has to be determined.

Relying on machine capability with several machines in production line and along with audit process is not 100% of parts. There will be an escape of poor slider alignment performance to downstream process as worst is those parts are shipped to customers.

Below literature reviews studied about fly height improvement but none of them studied on slider alignment offset.

In 2002, Kurita, Yamazaki, Kohira, Matsumoto, Tsuchiyama, Xu, Harada, Inoue, Su and Kato developed “An Active-Head Slider With a Piezoelectric Actuator for Controlling Flying Height,” [12]. They studied method for reducing margin of fly height for manufacturing tolerance or environmental variation. The sliders carry a piezoelectric micro actuator with 2 types of active-head sliders as four-pad type and five-pad type. They concluded that the active-head sliders can be applied for practical use easily, and flying height will be significantly lower than conventional sliders.

There are 2 advantages of this study. The first, demanding low flying height can extend hard disk drive lifetimes. The second, this slider may reduce touch down height as seen in Figure 2.10.

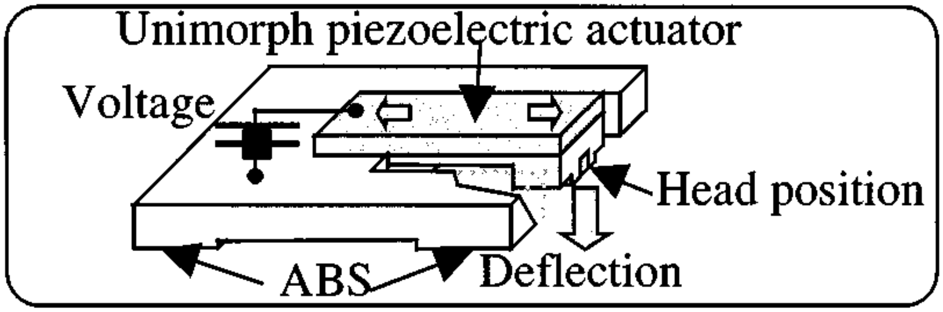


Figure 2.10: Concept of active-head slider

In 2006, Kiely and Hsia established topic of “Three-Dimensional Motion of Sliders Contacting Media.” [13] They studied slider motion induced by contact in 3-dimensional as vertical motion, off-track motion and down-track motion. They measured slider motion using three independent LDV systems and presented analysis of data in real space and spectral decomposition. These measurements indicate that motion in all 3-direction is significant and some case the down-track motion is larger than the vertical motion.

In Figure 2.11 describes slider motion as (a) the down-track direction is the x-axis and the vertical direction is the y-axis, (b) the down-track direction is the x-axis and the off-track direction is the y-axis and (c) the off-track direction is the x-axis and the vertical direction is the y-axis.

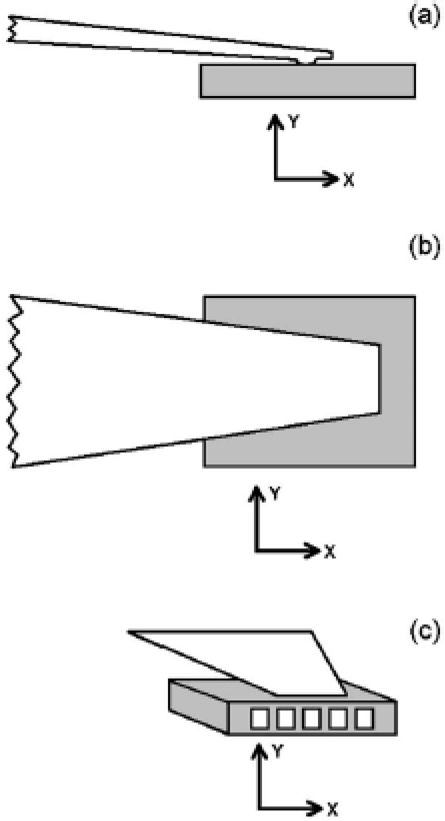


Figure 2.11: The slider motion in 3-dimensional

In 2006, Zhu, Yang, Fu and Cha established topic of "Slider Pitch Moment Associated with Dimple Friction." [14] They studied the pitch moment associated with dimple friction to improve fly height distribution. The effects of the slider pitch moment are dimple friction and ABS friction. They analyzed the pitch moment due to the dimple friction by elementary beam theory. Result shows that the flexure should bend toward the disk to minimize both sensitivities.

In 2010, Yong, Ng E.,Ng W. and Zhou studied topic of "Design and Modeling of Femto Air Bearing Slider." [15] They presented the studies of the performance of an improved femto air bearing slider which is optimized. The optimized slider can be adjusted to achieve a smaller roll variation. The fly characteristics are return to the stable stage. This optimized design of slider had been achieved when compared with results of the pre-optimized slider as shown in Figure 2.11.

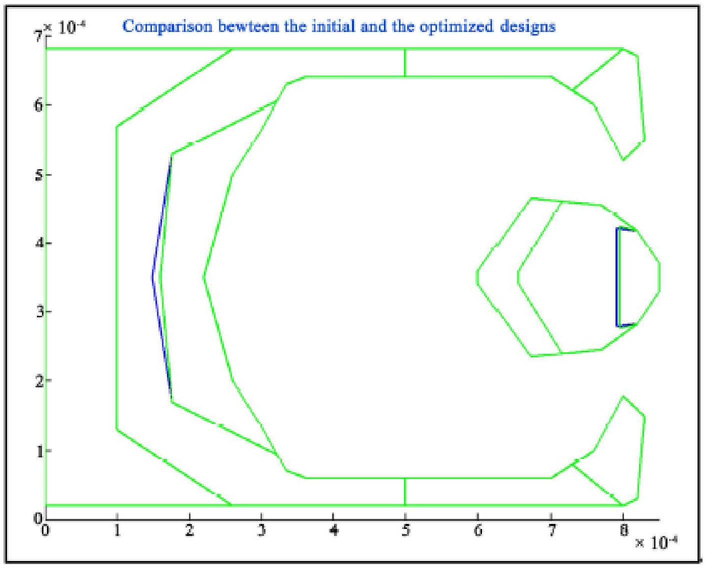


Figure 2.12: Comparison between the initial (green line) and the optimized design (blue line).

To proof and to guarantee for customers, HGA must be assembled with good quality. Head Gimbal Assembly finished goods must have slider alignment value with less offset to dimple. So we have to have new method or audit tool to measure the offset of slider alignment to center of dimple. Next chapter will describe the proposed solution to find offset of slider alignment and methodology concept.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 CONCEPT

Referred to Chapter1 Introduction, method of measure dimple position at backside of suspension could not develop on assembly machine due to high investment and lost productivity output. This method will develop on audit tool. To get trustworthy value of dimple location, it could be measured by referring to fiducials at the suspension. This method will enable dimple view for vision at the audit tool by flip HGA upward as in Figure 3.1.

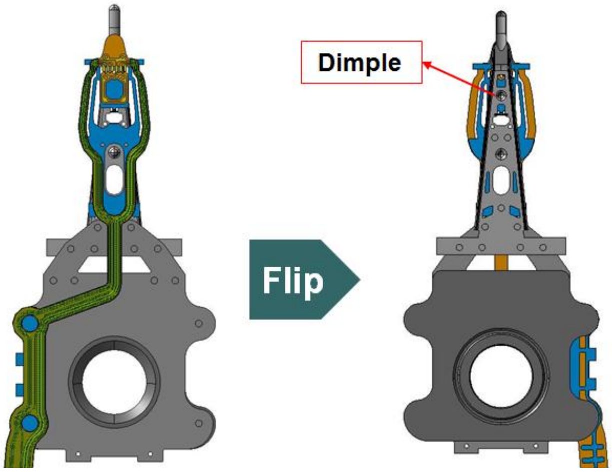


Figure 3.1: Flipped a suspension to enable dimple view

Along with new program which is required to measure dimple location at the backside of the suspension by using same references with slider alignment, 2 fiducials at loadbeam. To identify alignment coordinate, X-Y direction refer to slider attach machine. X reference is lined from center between 2 Load Beam fiducials to the center of the dimple which is design value as shown in Figure 3.2.

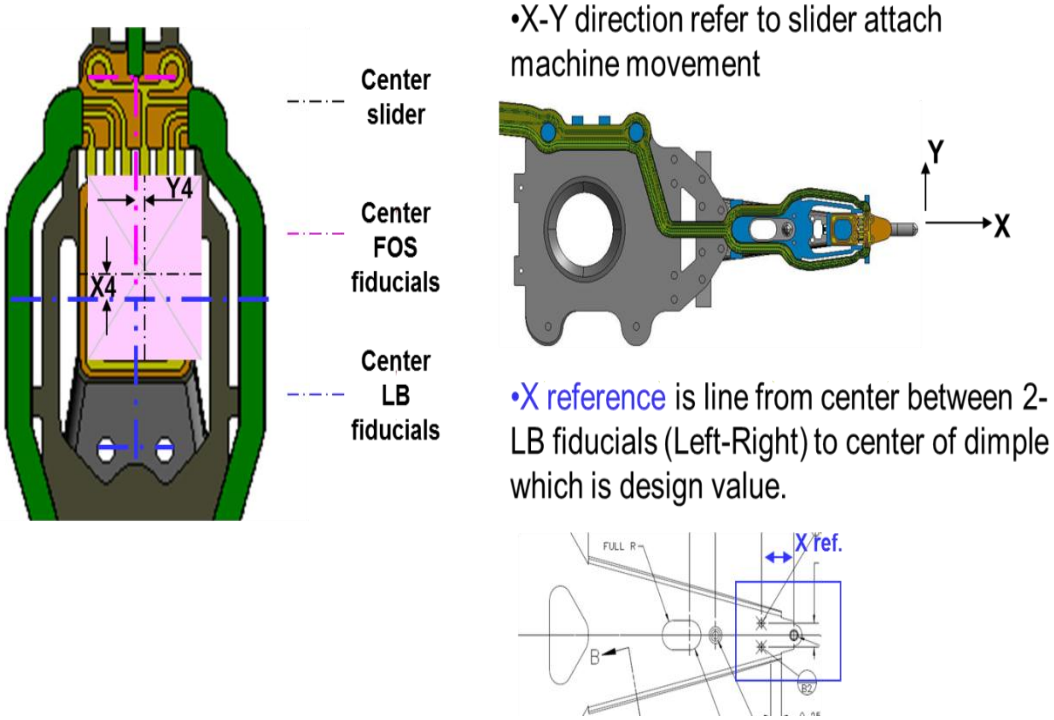

- X-Y direction refer to slider attach machine movement
- X reference is line from center between 2-LB fiducials (Left-Right) to center of dimple which is design value.

Figure 3.2: Alignment reference

To measure dimple location, we require ‘Dimple base fixture’ to control height of alignment fixture once flip with HGAs parts and make its steadily to measure dimple location from the back of the suspension. Data from both measurements will be calculated alignment to dimple values as shown in Figure 3.3.

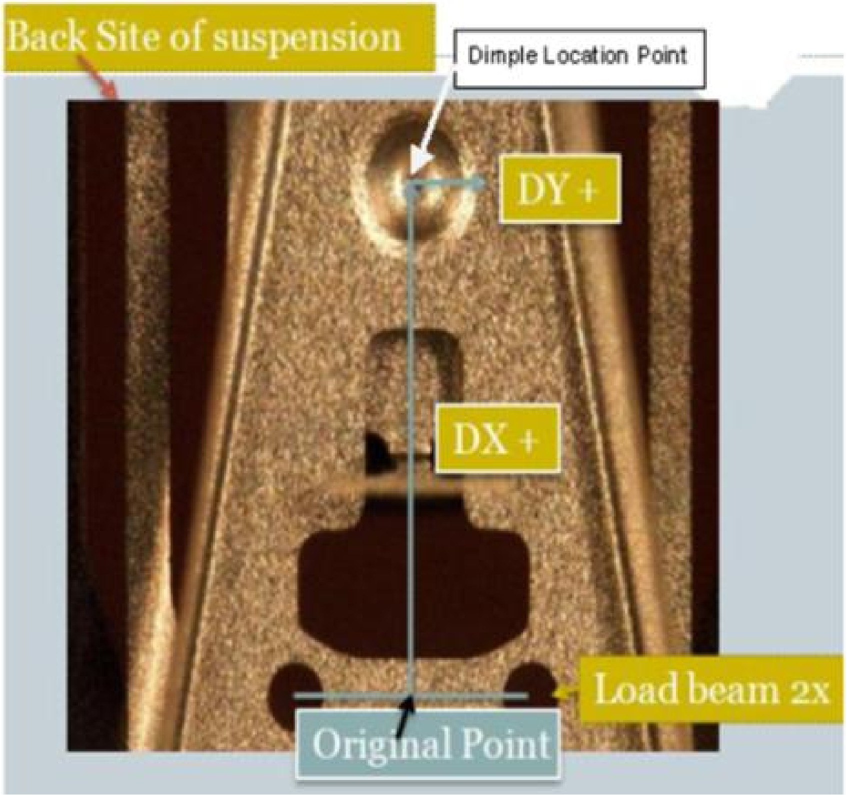


Figure 3.3: Dimple coordinate

To identify dimple coordinate, DX and DY are X and Y distance from original point, which is the center of two load beams fiducials to the center of dimple location as shown in Figure 3.4.

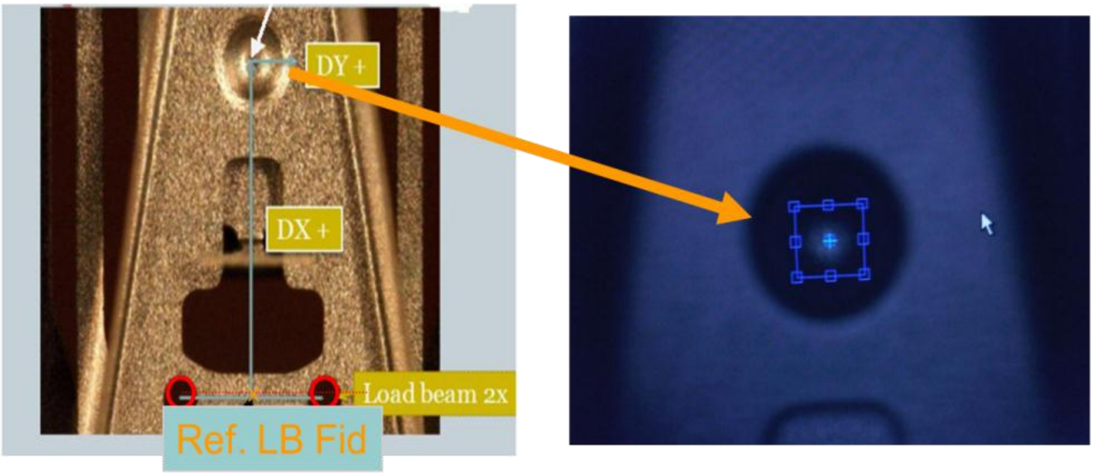


Figure 3.4: Dimple location

3.2 METHODOLOGY

This methodology uses statistic test and GR&R for release [8].

3.2.1 Gage Repeatability & Reproducibility (GR&R)

3.2.1.1 Gage Repeatability

The repeatability of this measurement tool shows the variation. It occurs when repeated measurements are under similar conditions as same part, same operator and same setup as shown in Figure 3.5.

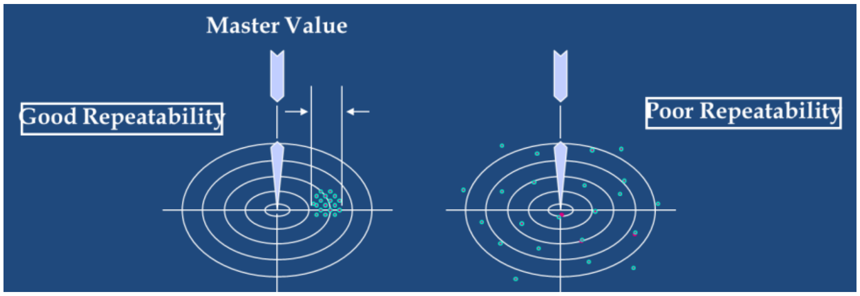


Figure 3.5 : Gage Repeatability [9]

3.2.1.2 Reproducibility

The variation is from measurements are in different conditions as part, operator and setup. In this methodology, there is only one machine and one fixture as shown in Figure 3.6.

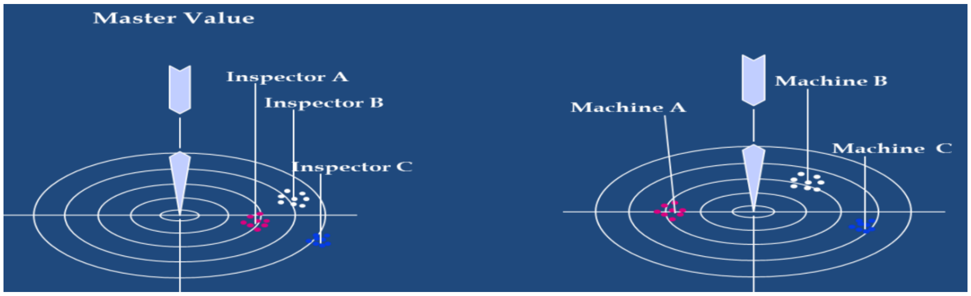


Figure 3.6: Gage Reproducibility [9]

3.2.1.3 Measurement system metrics

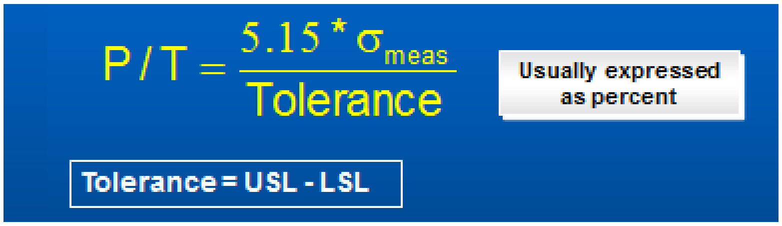
Measurement system variance = Variance of repeatability + Variance of Reproducibility

There are 2 ways of comparison measurement variation.

1. Comparison of measurement system variance with Tolerance

- Precision-To-Tolerance Ratio (P/T)

The P/T value show the percent of the Tolerance is taken up by measurement error. The best case is P/T less than 10% and Marginal acceptable is P/T less than 30% as shown in Figure 3.7.



$$P/T = \frac{5.15 * \sigma_{meas}}{Tolerance}$$

Usually expressed as percent

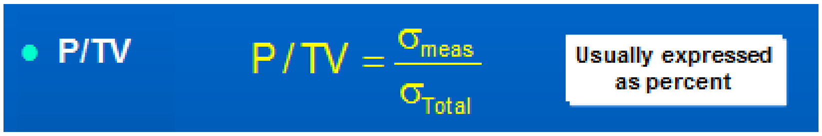
Tolerance = USL - LSL

Figure 3.7: Precision-To-Tolerance Ratio [9]

2. Comparison of measurement system variance with Process Variation (P/TV)

The P/TV addresses percent of the Total variation from measurement error. The best case is P/TV less than 10%

and acceptable case is P/TV less than 30% as shown in Figure 3.8.



- **P/TV**

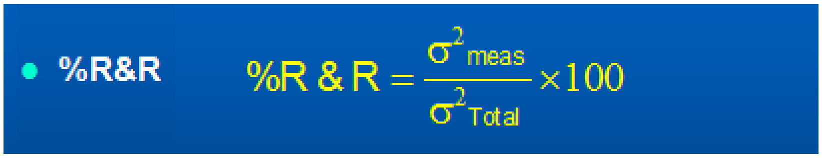
$$P/TV = \frac{\sigma_{meas}}{\sigma_{Total}}$$

Usually expressed as percent

Figure 3.8: Precision-To-Process Variation [9]

- % Repeatability and Reproducibility (%R&R)

%R&R estimates how well of the measurement system performs with respect to the overall process variation as shown in Figure 3.9.



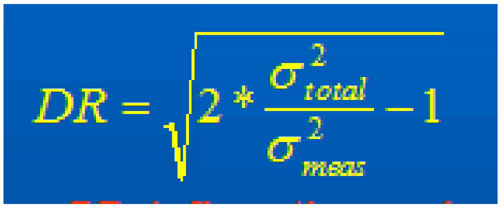
- **%R&R**

$$\%R\,\&\,R = \frac{\sigma^2_{meas}}{\sigma^2_{Total}} \times 100$$

Figure 3.9: %Repeatability and Reproducibility [9]

- Discrimination Index

Discrimination index (DR) defines the number of distinct categories which could be established with the measurement system in the range of process/product variation while making allowance for measurement error. DR should be as large as possible as shown in Figure 3.10.

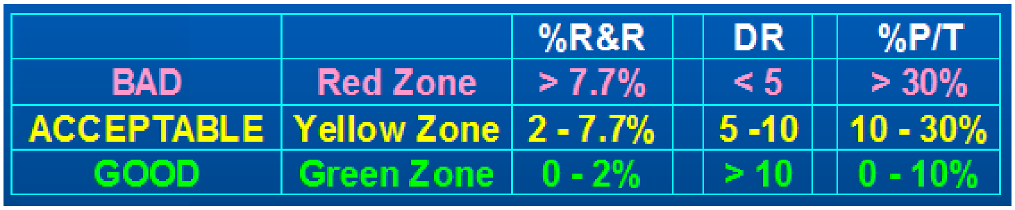


$$DR = \sqrt{2 * \frac{\sigma_{total}^{2}}{\sigma_{meas}^{2}} - 1}$$

Figure 3.10: Discrimination Index [9]

This measurement system use to evaluate parts relative to specifications, Precision-to-Tolerance ratio (%) is chosen for decision making. Qualified system by refer % P/T as shown in Table 3.1.

Table 3.1: Gage study decision rules [9]



		%R&R	DR	%P/T
BAD	Red Zone	> 7.7%	< 5	> 30%
ACCEPTABLE	Yellow Zone	2 - 7.7%	5 -10	10 - 30%
GOOD	Green Zone	0 - 2%	> 10	0 - 10%

3.2.2 Guideline method of Gage repeatability and reproducibility [10]

Step 1: Collect 10 samples that represent the full range of long-term process variation. Identify the operators who use this instrument daily.

Step 2: Calibrate the gage or verify the last calibration date is valid.

Step 3: Set up the data collection sheet for the R&R study. [6]

Column headings: Part ID, Operator, Trial, Measurement(s)

Calc > Make Patterned Data > Simple Set of Numbers (for each input)

Step 4: Ask the first operator to measure all the samples once in random order. Blind sampling, in which the operator does not know the identity of sampled parts, should be used to reduce human bias.

Step 5: Have the second operator measure all the samples once in random order and continue until all operators have measured the samples once (this is trial 1)

Step 6: Repeat steps 4 & 5 for the required number of trials. It is best if these measurements can be done over several days.

Step 7: Enter the data and tolerance information. [6]

Stat > Quality Tools > Gage R&R Study

Stat > Quality Tools > Gage Run Chart

Step 8: Analyze the results by assessing the quality of the measurement system based on the guidelines. Determine follow-up actions.

3.2.3 Measurement system analysis sample guidelines

1. Use 10 samples, 2-4 operators (if several operators use the gauge) and 2-3 trials.
2. One or more gages to be included and depends on the purpose of the study.
3. Select enough samples so that number of samples x number of operators/gages greater than 15.

In this study, the process variability is unknown so the samples will be selected from normal process variation.

3.2.4 Measure slider alignment and gimbal location.

3.2.4.1 Measure slider alignment

- Start process with loading HGA to Slider alignment fixture.
- Carry fixture to audit tool and choose Slider alignment program.
- Vision system focus to reference holes at fixture.
- Vision system focus to reference holes of HGA and then slider location.
- Audit tool program shows result of Slider alignment as X-Y and T alignment as shown in Figure 3.11.

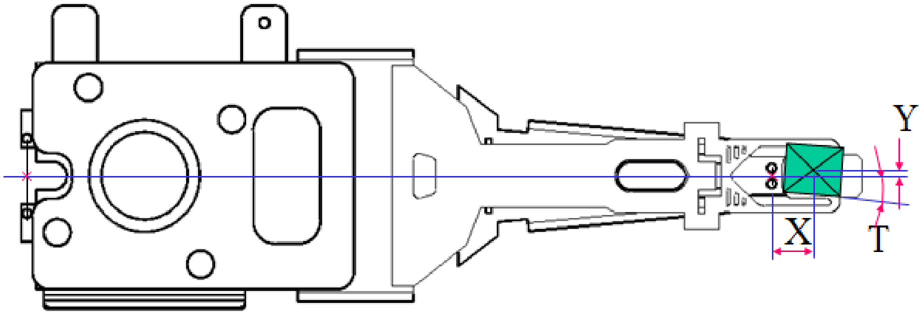


Figure 3.11: Slider alignment

3.2.4.2 Measure dimple location

In the macro process step, the procedure can be described as follows:

1) Start loading slider alignment fixture onto dimple base fixture which it flips HGA upward to visible dimple.

2) Carry fixture to audit tool. Choose program to measure dimple position.

3) Program start to find reference holes at slider dimple base fixture. At Left and right hole and fixture to set reference plane.

4) Continue find reference holes at load beam which these holes have designed distance to dimple location.

5) The audit tool find dimple location and measure center of dimple and vision focus at dimple again to find vertex of dimple.

6) Program measure dimple location, calculate value of distance and report result.

All process steps of measure dimple location showed in Figure 3.12.

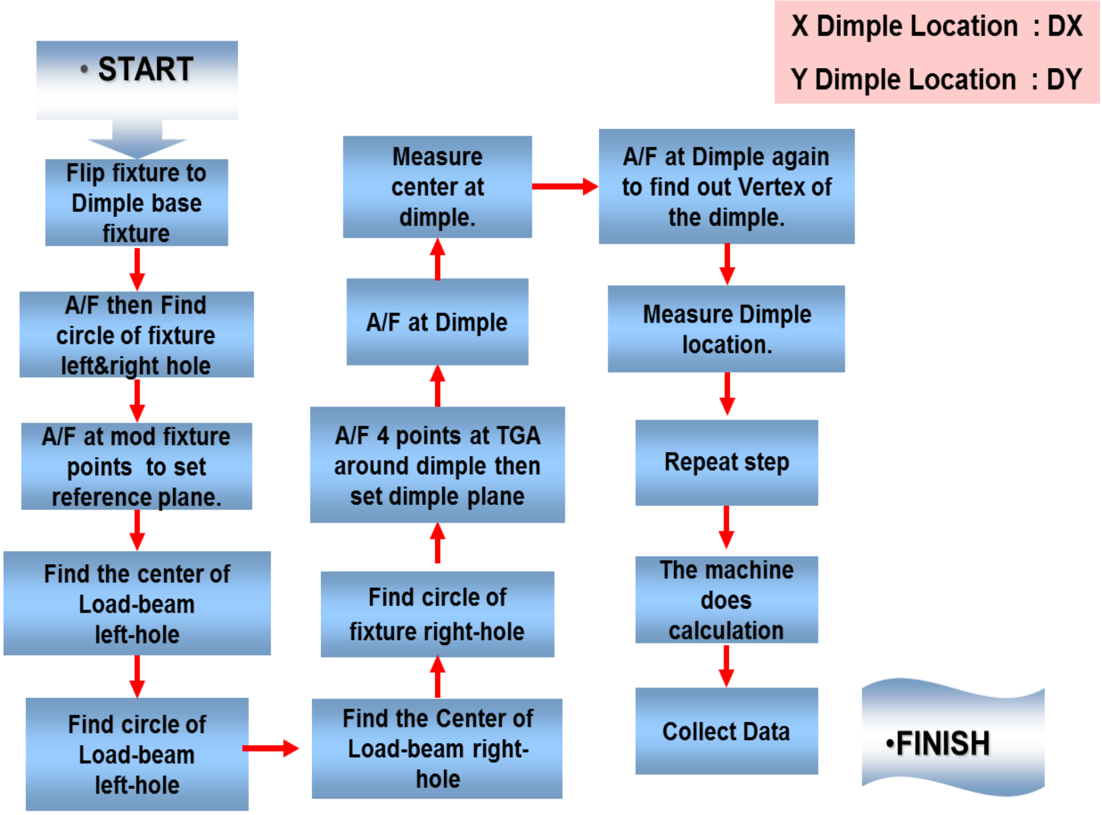


Figure 3.12: Dimple location measurement process flow

3.2.4.3 Calculate slider alignment to dimple data from Dimple Pitch Offset formula

Pitch Offset = DX - X4 (3.1)

Pitch Offset = 0.005 – 0.003 = 0.002 mm, where DX is dimple location in direction of centerline of suspension, positive value means dimple shift away from loadbeam fiducials. Negative value means dimple shift toward loadbeam fiducials as shown in Figure 3.13.

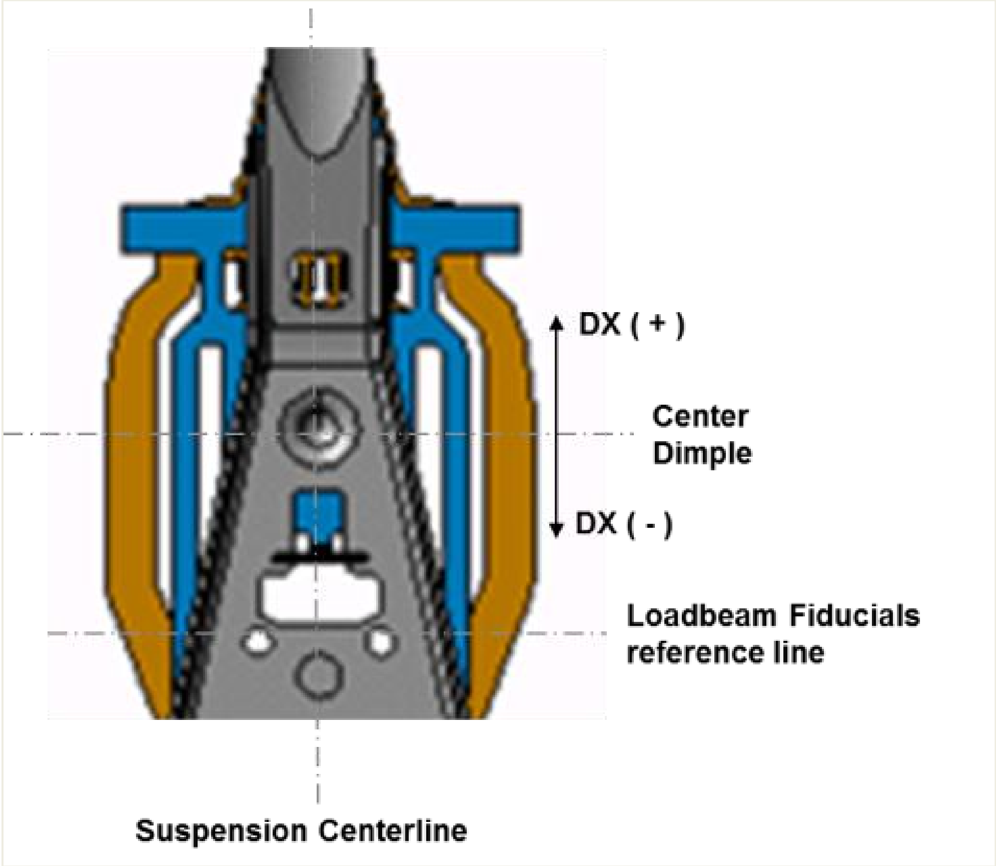


Figure 3.13: Dimple X location

Example of pitch offset value can be illustrated as follows:

1. DX = 0.003 mm and X4 = 0.003 mm.

Pitch Offset = 0.003 – 0.003 = 0 mm.

Meaning of this example, there is no offset between slider and dimple in X direction as shown in Figure 3.14.

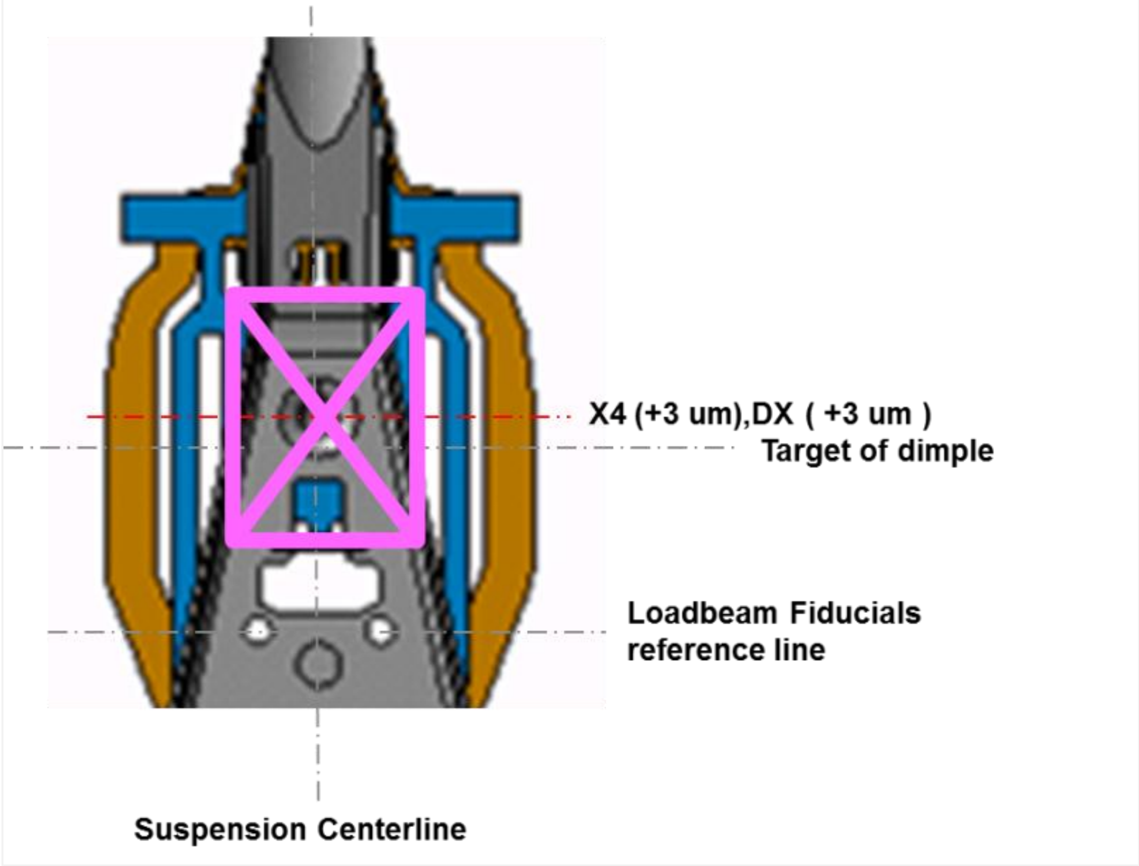


Figure 3.14: Example1 of Pitch Offset

2. DX = 0.003 mm and X4 = - 0.003 mm.

Pitch Offset = 0.003 - (- 0.003) = 0.006 mm.

Meaning of this example, there is offset between slider and dimple in X direction at 0.006 mm which dimple is above slider as shown in Figure 3.15.

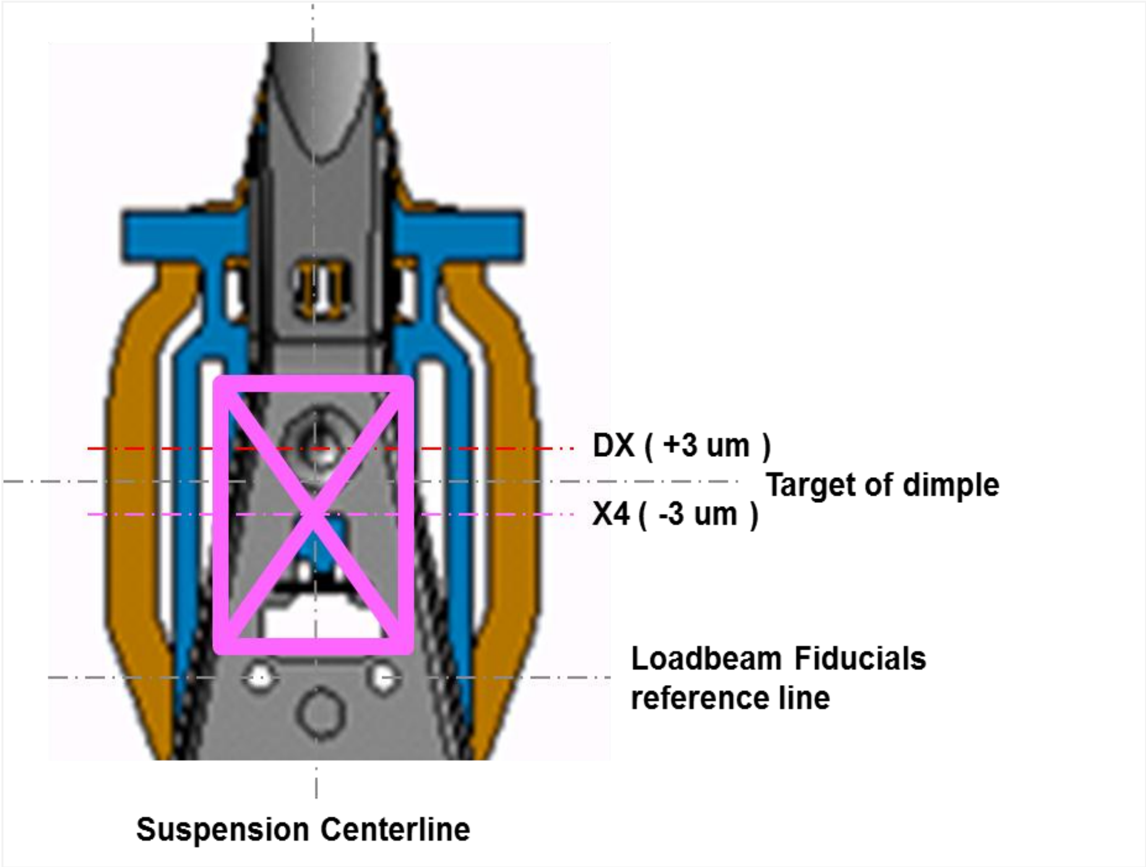


Figure 3.15: Example2 of Pitch Offset

3. DX = - 0.003 mm and X4 = 0.003 mm.

Pitch Offset = - 0.003 - 0.003 = - 0.006 mm.

Meaning of this example, there is offset between slider and dimple in X direction at 0.006 mm which dimple is below slider as shown in Figure 3.16.

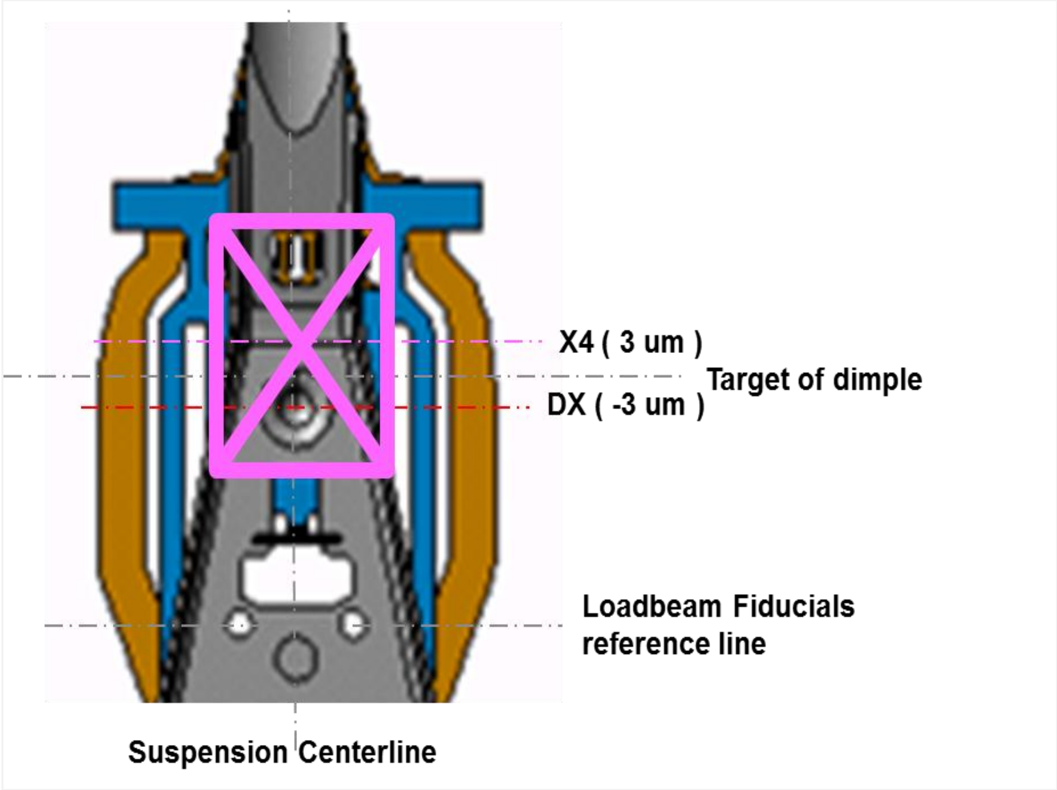


Figure 3.16: Example3 of Pitch Offset

4. DX = - 0.003 mm and X4 = - 0.003 mm.

Pitch Offset = - 0.003 - (- 0.003) = 0 mm.

Meaning of this example, there is no offset between slider and dimple in X direction as shown in Figure 3.17.

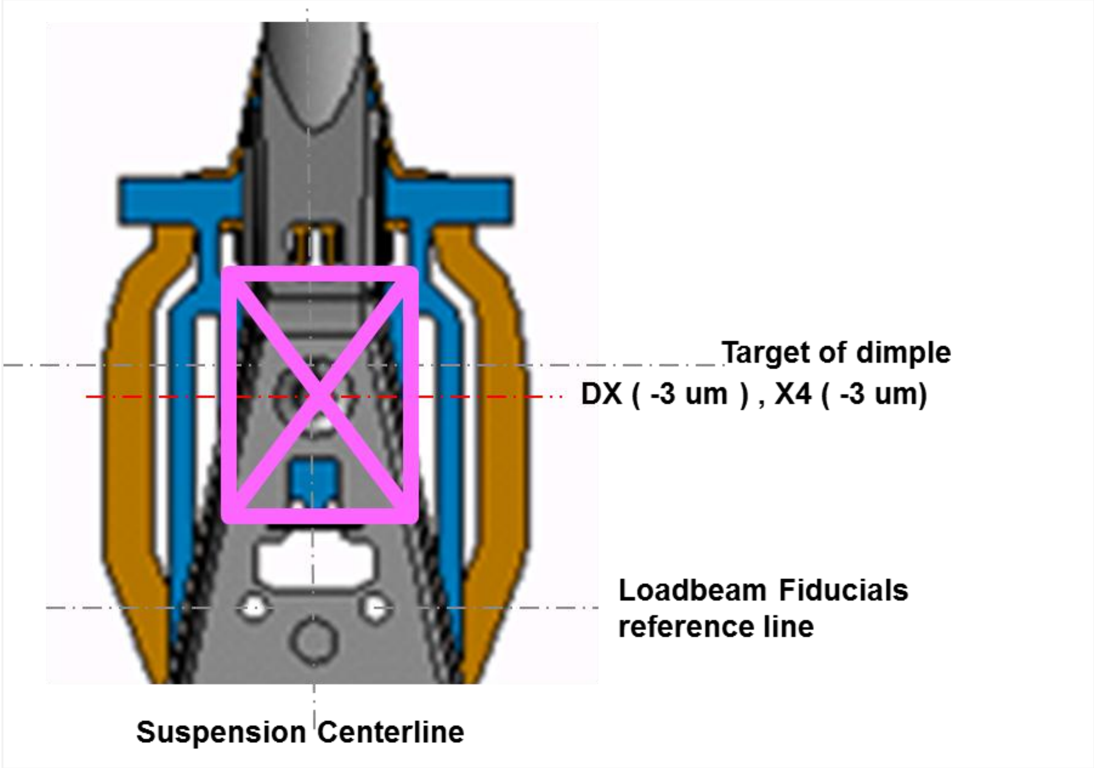


Figure 3.17: Example4 of Pitch Offset

Next step is calculation Slider Alignment to dimple data by using Dimple Roll Offset formula.

Roll Offset = DY - Y4 (3.2)

Roll Offset = -0.004 – (-0.003) = -0.001 mm, where DY is dimple location in direction of ID-OD of disk, positive value means dimple shift to ID. Negative value means dimple shift to OD. Due to suspension is flipped to enable vision then direction is opposite to Slider Y Alignment as shown in Figure 3.18.

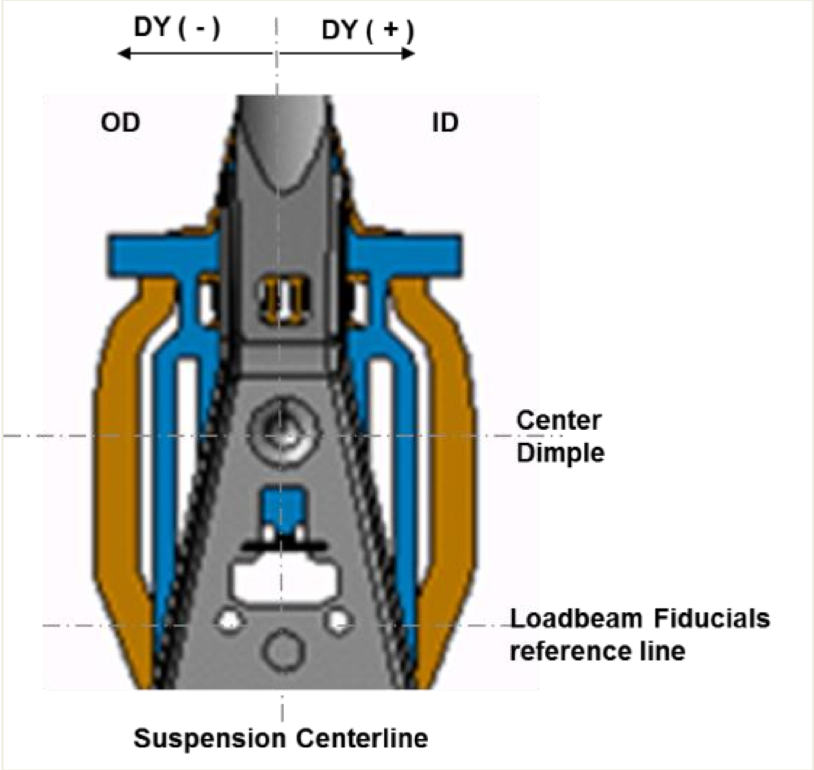


Figure 3.18 Dimple Y location

Example of roll offset value can be illustrated as follows:

1. DY = 0.003 mm and Y4 = 0.003 mm.

Roll offset = 0.003 – 0.003 = 0 mm.

Meaning of this example, there is no offset between slider and dimple in Y direction. See Figure 3.19.

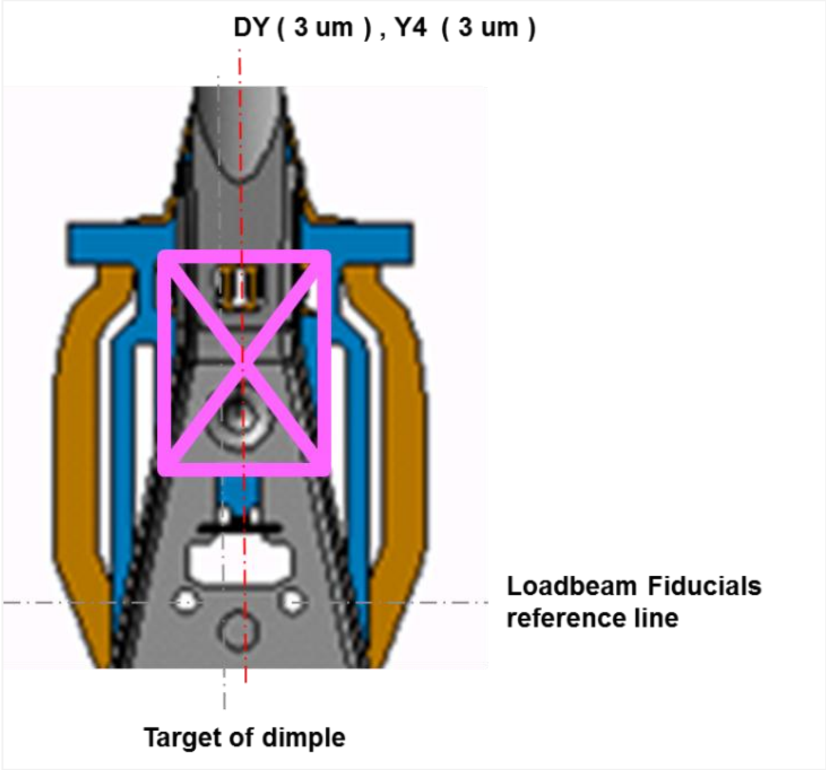


Figure 3.19: Example1 of Roll Offset

2. DY = 0.003 mm and Y4 = - 0.003 mm.

Roll Offset = 0.003 - (- 0.003) = 0.006 mm.

Meaning of this example, there is offset between slider and dimple in Y direction at 0.006 mm. which dimple is closer to ID as shown in Figure 3.20.

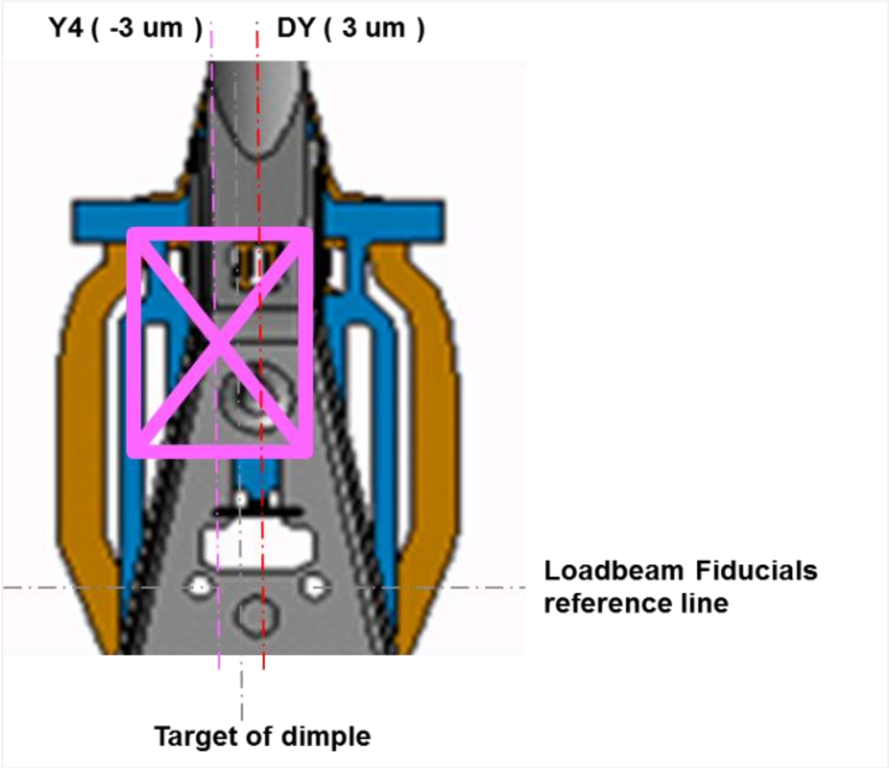


Figure 3.20: Example2 of Roll Offset

3. DY = - 0.003 mm and Y4 = 0.003 mm.

Roll Offset = - 0.003 – 0.003 = - 0.006 mm.

Meaning of this example, there is offset between slider and dimple in Y direction at 0.006 mm. which dimple is closer to OD as shown in Figure 3.21.

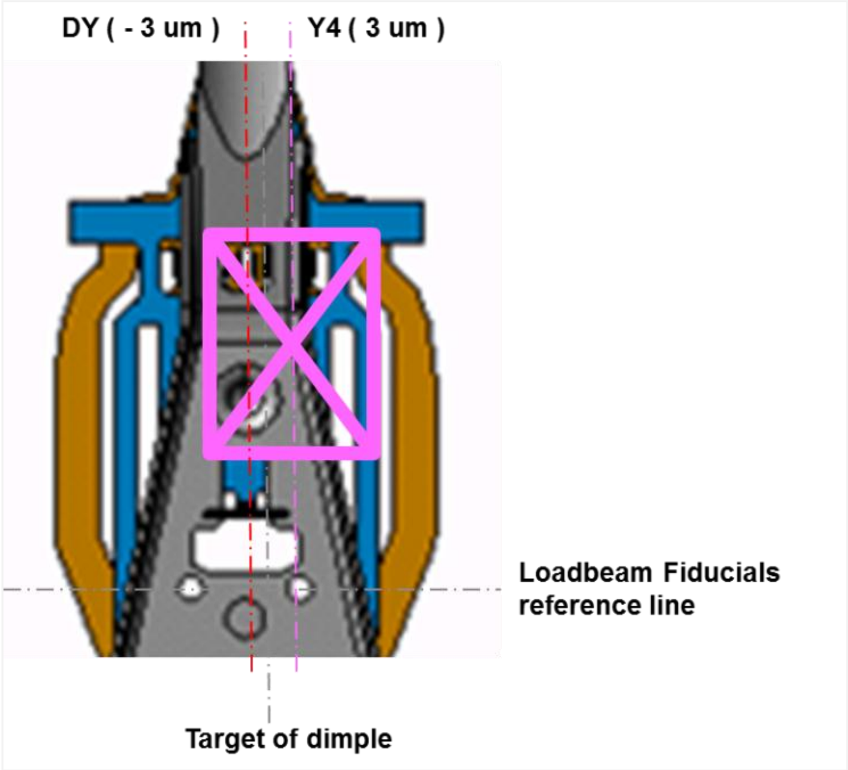


Figure 3.21: Example3 of Roll Offset

4. DY = - 0.003 mm and Y4 = - 0.003 mm.

Roll offset = - 0.003 – (- 0.003) = 0 mm.

Meaning of this example, there is no offset between slider and dimple in Y direction as shown in Figure 3.22.

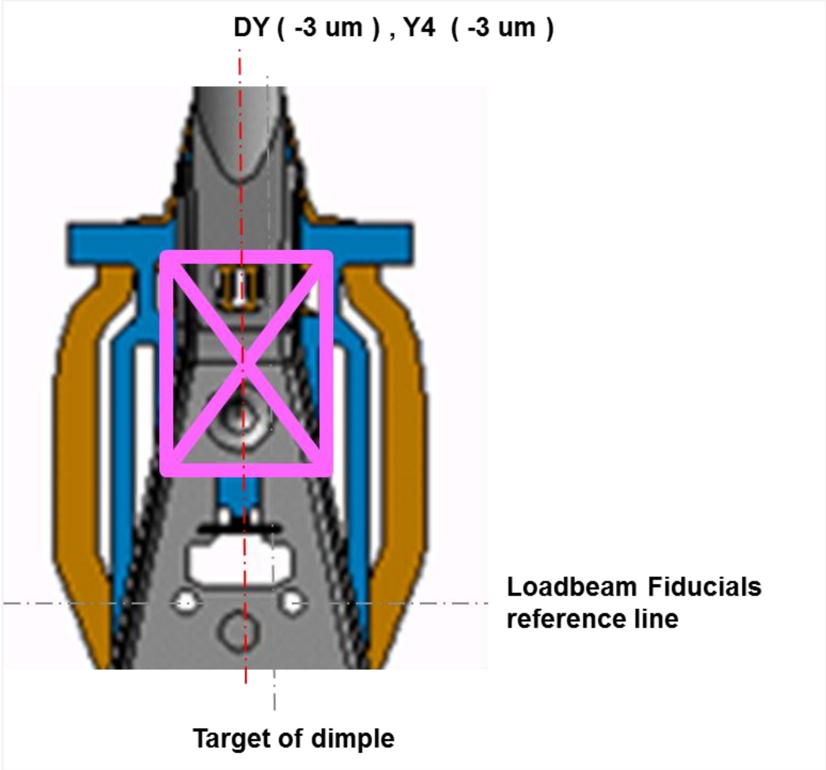


Figure 3.22: Example4 of Roll Offset

3.2.4.4 Gage Repeatability and Reproducibility for Slider alignment

Confirm Gage repeatability and reproducibility of current metrology of slider alignment.

1) Slider X alignment GR&R

Result of GR&R could be described as Total Variation of Slider X alignment measurement data is 51.3463. The Variance from the audit tool is 0.3658 which can separate to Repeatability about 0.0110 and Reproducibility about 0.3548. The Variance from Part-To-Part is 50.98. Variation component showed that 99.21% come from parts and 0.71% from gage.

Total Gage R&R data can be described as 4 categories.

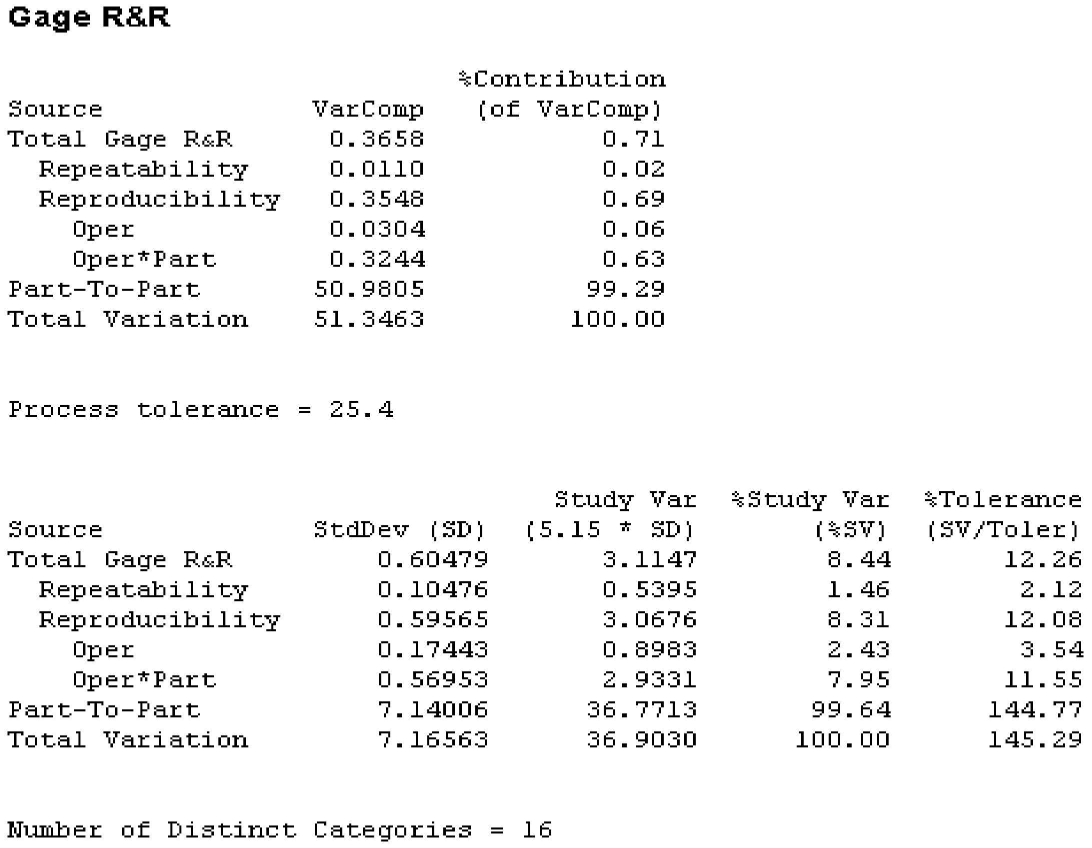
1) The first is standard deviation showed in “StdDev(SD)” column. For example, Standard Deviation of “Total Gage R&R” = 0.60479

2) The second column “Study Var(5.15* SD)” is number of “StdDev” multiplied by 5.15. For example, Study Variance of “Total Gage R&R” = 5.15 * 0.60479 = 3.1147

3) The third column “% Study Var (%SV)” is percentage of GR&R compare to Total Variance. For example, %Study Variance of “Total Gage R&R” = 3.1147 / 36.9030 = 8.44%

4) The forth column is “% Tolerance(SV/Toler)” is number of “Study Var(5.15*SD) divided by Process tolerance number. For example, %Tolerance of “Total GR&R” = 3.1147 / 25.4 = 12.26%

The Total GR&R variation included repeatability and reproducibility contributes about 12.26% compare to tolerance. Refer to Table 3.1, it is in Acceptable range. This metrology tool is acceptable for perform measure Slider X alignment as shown in Figure 3.23.

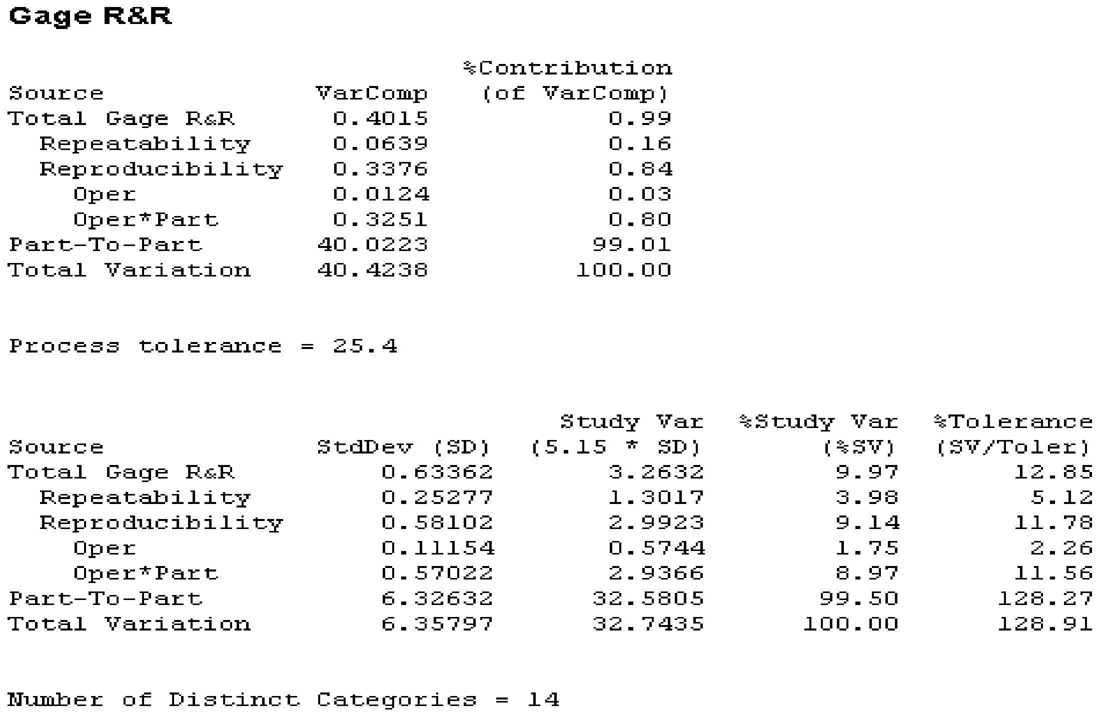


```
Gage R&R

                                 %Contribution
Source                VarComp     (of VarComp)
Total Gage R&R         0.3658             0.71
  Repeatability        0.0110             0.02
  Reproducibility      0.3548             0.69
    Oper               0.0304             0.06
    Oper*Part          0.3244             0.63
Part-To-Part          50.9805            99.29
Total Variation       51.3463           100.00


Process tolerance = 25.4


                                    Study Var  %Study Var  %Tolerance
Source                StdDev (SD)  (5.15 * SD)      (%SV)  (SV/Toler)
Total Gage R&R            0.60479       3.1147       8.44       12.26
  Repeatability           0.10476       0.5395       1.46        2.12
  Reproducibility         0.59565       3.0676       8.31       12.08
    Oper                  0.17443       0.8983       2.43        3.54
    Oper*Part             0.56953       2.9331       7.95       11.55
Part-To-Part              7.14006      36.7713      99.64      144.77
Total Variation           7.16563      36.9030     100.00      145.29


Number of Distinct Categories = 16
```

Figure 3.23: Slider X alignment GR&R

2) Slider Y alignment GR&R

Details of GR&R data analysis has shown in Slider X alignment. Consider to criteria of %Tolerance of Total Gage R&R, it showed that 99.01% come from parts and 0.99% come from gage. Gage variation included repeatability and reproducibility contributes about 12.85% compare to tolerance. Refer to Table3.1, it is in Acceptable range. This metrology tool is acceptable for perform measure Slider Y alignment as shown in Figure 3.24.

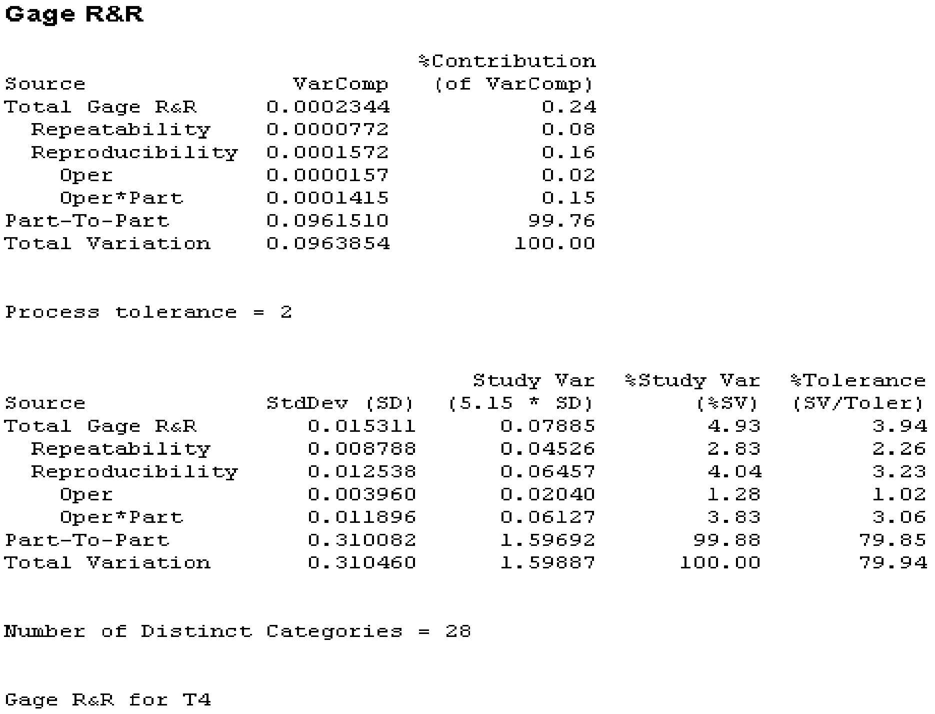


```
Gage R&R

                                %Contribution
Source              VarComp    (of VarComp)
Total Gage R&R       0.4015            0.99
  Repeatability      0.0639            0.16
  Reproducibility    0.3376            0.84
    Oper             0.0124            0.03
    Oper*Part        0.3251            0.80
Part-To-Part        40.0223           99.01
Total Variation     40.4238          100.00

Process tolerance = 25.4

                                    Study Var  %Study Var  %Tolerance
Source              StdDev (SD)  (5.15 * SD)       (%SV)  (SV/Toler)
Total Gage R&R          0.63362       3.2632        9.97       12.85
  Repeatability         0.25277       1.3017        3.98        5.12
  Reproducibility       0.58102       2.9923        9.14       11.78
    Oper                0.11154       0.5744        1.75        2.26
    Oper*Part           0.57022       2.9366        8.97       11.56
Part-To-Part            6.32632      32.5805       99.50      128.27
Total Variation         6.35797      32.7435      100.00      128.91

Number of Distinct Categories = 14
```

Figure 3.24: Slider Y alignment GR&R

3) Slider T alignment GR&R

Details of GR&R data analysis has shown in Slider X alignment. Consider to criteria of %Tolerance of Total Gage R&R, it showed that 99.76% come from parts and 0.24% come from gage. Gage variation included repeatability and reproducibility contributes about 3.94% compare to tolerance. Refer to Table3.1, it is in Good range. This metrology tool is good for perform measure Slider T alignment as shown in Figure 3.25.



```
Gage R&R

                                  %Contribution
Source               VarComp     (of VarComp)
Total Gage R&R      0.0002344             0.24
  Repeatability     0.0000772             0.08
  Reproducibility   0.0001572             0.16
    Oper            0.0000157             0.02
    Oper*Part       0.0001415             0.15
Part-To-Part        0.0961510            99.76
Total Variation     0.0963854           100.00


Process tolerance = 2


                                 Study Var  %Study Var  %Tolerance
Source              StdDev (SD)  (5.15 * SD)     (%SV)  (SV/Toler)
Total Gage R&R         0.015311      0.07885      4.93        3.94
  Repeatability        0.008788      0.04526      2.83        2.26
  Reproducibility      0.012538      0.06457      4.04        3.23
    Oper               0.003960      0.02040      1.28        1.02
    Oper*Part          0.011896      0.06127      3.83        3.06
Part-To-Part           0.310082      1.59692     99.88       79.85
Total Variation        0.310460      1.59887    100.00       79.94


Number of Distinct Categories = 28


Gage R&R for T4
```

Figure 3.25: Slider T alignment GR&R

3.2.5 The statistical test

To consider new methodology pass qualification, tool for justify data is statistic test with below details.

3.2.5.1 Process hypothesis testing

Hypothesis is a statement of decision making procedure by answer statistical question.

1) Hypothesis test

1.1) Null Hypothesis test (H_0) is statement of no change or difference. This statement is assumed true until sufficient evidence is presented to reject it.

Example of Null Hypothesis can be written in Equation 3.3.

$$H_0 : \mu_{sample1} = \mu_{sample2} \qquad (3.3)$$

Meaning of equation 3.3 is sample1 mean is same as sample2 mean.

1.2) Alternative Hypothesis (H_a) is Statement of change or difference. This statement is considered true if Ho is rejected.

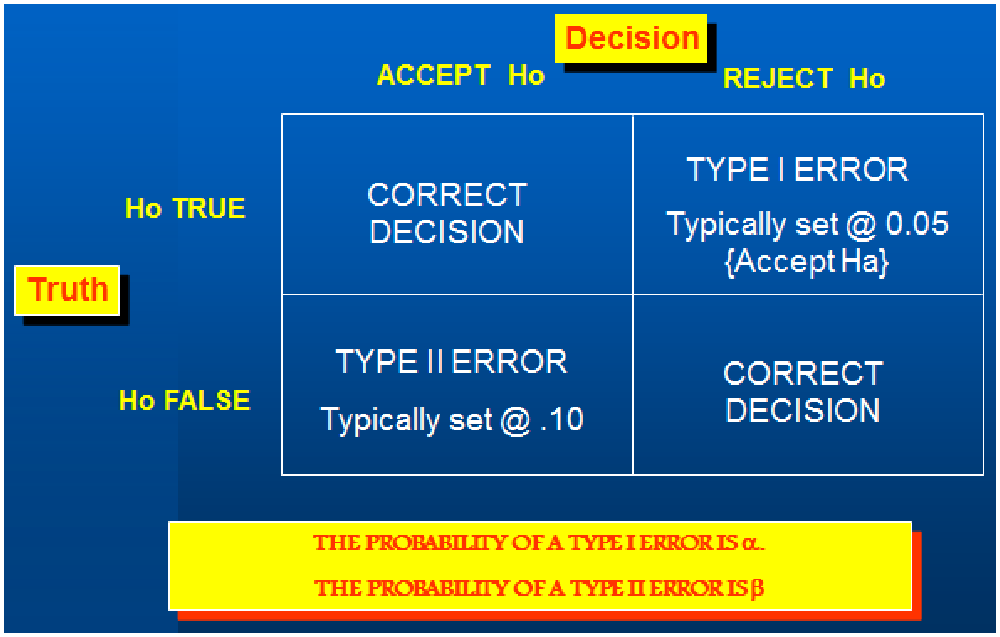
Example of Alternative Hypothesis can be written in Equation 3.4.

$$H_a : \mu_{sample1} \neq \mu_{sample2} \qquad (3.4)$$

Meaning of equation 3.4 is sample1 mean is different from sample2 mean.

2) Alpha error

Alpha error is the probability of concluding the alternative hypothesis is true when, in fact, the null hypothesis is actually true. Or Alpha error is we reject H_0 when H_0 is true and the Application number for manufacturer is 0.05. The Hypothesis testing error could refer to Figure 3.26.



		Decision	
		ACCEPT Ho	REJECT Ho
Truth	Ho TRUE	CORRECT DECISION	TYPE I ERROR Typically set @ 0.05 {Accept Ha}
	Ho FALSE	TYPE II ERROR Typically set @ .10	CORRECT DECISION

THE PROBABILITY OF A TYPE I ERROR IS α.

THE PROBABILITY OF A TYPE II ERROR IS β

Figure 3.26: Hypothesis testing errors [9]

3) p-Value

The probability of making a Type I error (rejecting H0 in error). This is the probability that a value as great as or greater than x-bar is observed, given that H0 is true.

3.2.5.2 t-test

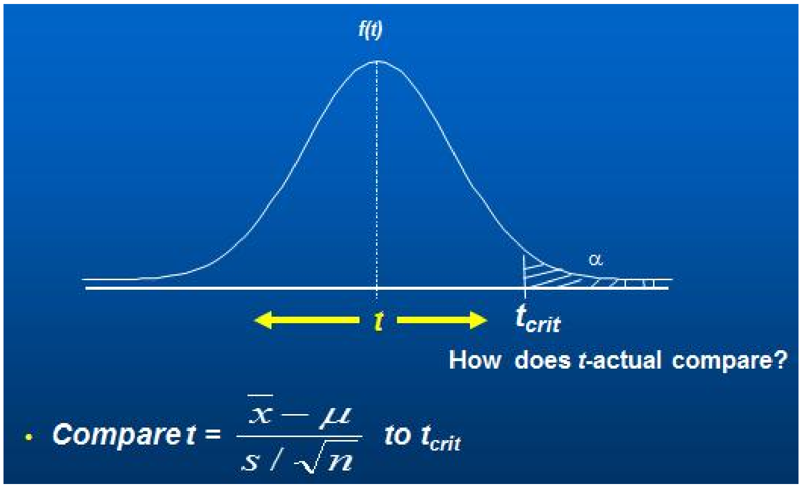
Choose t-test for

- Single mean compared to a target value

Use this method to test mean dimple location compare to product specification.

- Two independent group means comparison

Use this method to test mean of 2 groups for dimple location and slider alignment to dimple as shown in Figure 3.27.



How does *t*-actual compare?

- Compare $t = \dfrac{\overline{x} - \mu}{s / \sqrt{n}}$ to t_{crit}

Figure 3.27: The t Distribution [9]

If $t > t_{crit}$, then reject equality.

t value

$$\bar{t} = (x - \mu) / (s / (n^{1/2})) \tag{3.5}$$

For the t-statistic, x-bar mean of a random sample size n taken from a normal population having a mean μ and an estimated standard deviation s.

Method to test parameter

1) Single parameter testing

State the Null Hypothesis

$$H_0 : \mu_{sample} = \mu_{target} \tag{3.6}$$

State the Alternative Hypothesis

$$H_a : \mu_{sample} \neq \mu_{target} \tag{3.7}$$

Use t to test statistic with p-Value = 0.05

If P-Value < 0.05, then reject H_0

2) Two parameter testing

State the Null Hypothesis

$$H_0 : \mu_{sample1} = \mu_{sample2} \tag{3.8}$$

State the Alternative Hypothesis

$$H_a : \mu_{sample1} \neq \mu_{sample2} \tag{3.9}$$

Use t to test statistic with p-Value = 0.05

If P-Value < 0.05, then reject H_0

In this chapter, it describes concept of dimple position measurement by flipped HGA upward to enable dimple view to the audit tool, we know formula to calculate slider alignment offset in pitch offset and roll offset, we know method to release gage by using Gage Repeatability and Reproducibility and we use Statistical methods to conclude the results that they are different from target or not. Next chapter will show actual results that have been done with methodology.

CHAPTER 4

RESULTS

In Chapter 3, Research Methodology, process step to measure dimple location is identified with qualification requirement for system and using GR&R with %P/T value.

4.1 Run GR&R

Step 1: Load 10 HGAs to dimple base fixture. Start measure parts 3 times.

Step 2: Unload HGAs and load random slot of fixture. Start measure parts 3 times.

Step 3: Repeat step 2. Unload HGAs and load random slot of fixture. Start measure parts 3 times.

Step 4: GR&R data analysis.

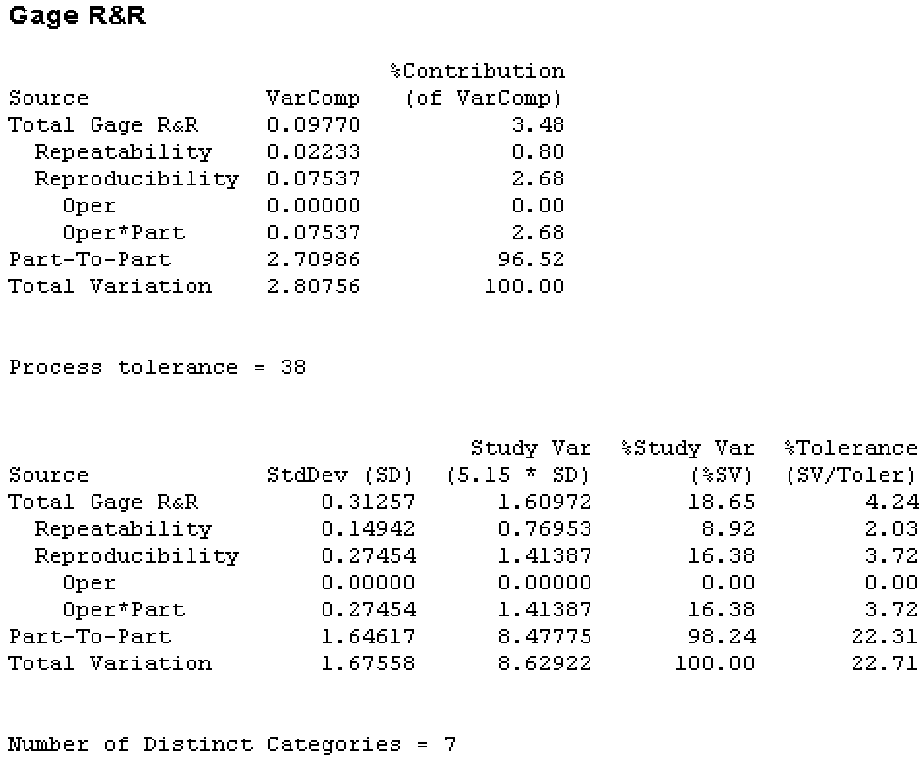
Total data = 10 HGAs x 3 times repeatability x 3 times reproducibility

= 90 data points

4.2 Gage Repeatability and Reproducibility result

4.2.1 Dimple X location GR&R

Details of GR&R data analysis has shown in Slider X alignment in Chapter3. Variation component showed that 96.52% come from parts and 3.48% from gage. Gage variation included repeatability and reproducibility contributes about 4.24% compare to tolerance. Refer to Table 3.1, it is in Good range. This metrology tool is good for perform measure dimple X location as shown in Figure 4.1.

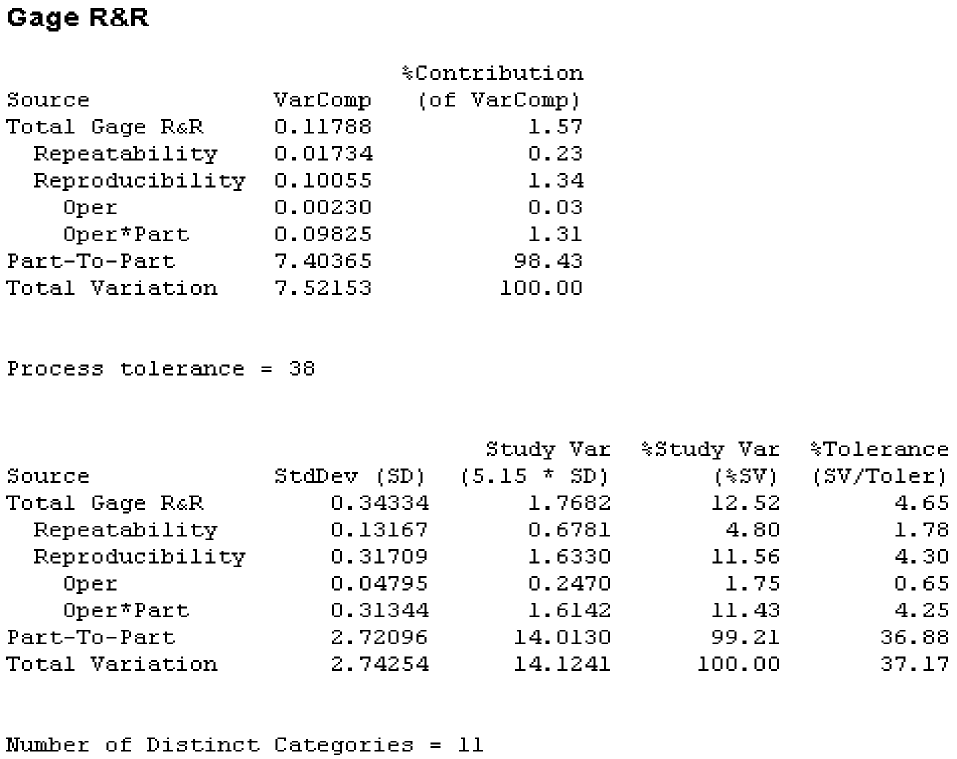


```
Gage R&R

                              %Contribution
Source             VarComp     (of VarComp)
Total Gage R&R     0.09770             3.48
  Repeatability    0.02233             0.80
  Reproducibility  0.07537             2.68
    Oper           0.00000             0.00
    Oper*Part      0.07537             2.68
Part-To-Part       2.70986            96.52
Total Variation    2.80756           100.00


Process tolerance = 38


                                 Study Var  %Study Var  %Tolerance
Source             StdDev (SD)  (5.15 * SD)       (%SV)  (SV/Toler)
Total Gage R&R         0.31257      1.60972       18.65        4.24
  Repeatability        0.14942      0.76953        8.92        2.03
  Reproducibility      0.27454      1.41387       16.38        3.72
    Oper               0.00000      0.00000        0.00        0.00
    Oper*Part          0.27454      1.41387       16.38        3.72
Part-To-Part           1.64617      8.47775       98.24       22.31
Total Variation        1.67558      8.62922      100.00       22.71


Number of Distinct Categories = 7
```

Figure 4.1: Dimple X location GR&R

4.2.2 Dimple Y location GR&R

Details of GR&R data analysis could refer to Slider X alignment GR&R in Chapter 3. However Dimple Y location Total Gage R&R Variation component showed that 98.43% come from parts and 1.57% from gage. Gage variation included repeatability and reproducibility contributes about 4.65% compare to tolerance. Refer to Table 3.1, it is in Good range. This metrology tool is good for perform measure dimple Y location as shown in Figure 4.2.



Gage R&R

```
                              %Contribution
Source             VarComp    (of VarComp)
Total Gage R&R     0.11788            1.57
  Repeatability    0.01734            0.23
  Reproducibility  0.10055            1.34
    Oper           0.00230            0.03
    Oper*Part      0.09825            1.31
Part-To-Part       7.40365           98.43
Total Variation    7.52153          100.00


Process tolerance = 38


                                    Study Var  %Study Var  %Tolerance
Source             StdDev (SD)  (5.15 * SD)       (%SV)  (SV/Toler)
Total Gage R&R         0.34334       1.7682       12.52        4.65
  Repeatability        0.13167       0.6781        4.80        1.78
  Reproducibility      0.31709       1.6330       11.56        4.30
    Oper               0.04795       0.2470        1.75        0.65
    Oper*Part          0.31344       1.6142       11.43        4.25
Part-To-Part           2.72096      14.0130       99.21       36.88
Total Variation        2.74254      14.1241      100.00       37.17


Number of Distinct Categories = 11
```

Figure 4.2: Dimple Y location GR&R

4.3 Data of Slider Alignment to dimple

4.3.1 The first set of slider alignment to dimple data.

Refer to formula calculation

4.3.1.1 Slider X alignment to dimple

To calculate offset of Slider X alignment to dimple, we use equation as below

$$\text{Pitch offset} = DX - Y4 \tag{4.1}$$

Method to measure Slider X alignment to dimple is sampling HGA 30 pieces. Those HGA are attached slider to suspension by refer position to loadbeam fiducials. Measure slider X alignment data and dimple X location and calculate slider X alignment to dimple.

The procedure of pitch offset data analysis can be described as below steps.

1) Average of slider X alignment shift toward LB fiducials 0.005 mm.

2) Convert the number of alignment to be distance from fiducials, slider attached at 0.982 mm away from fiducials.

3) Dimple X location is at 0.9902 mm away from fiducials.

4) Slider X position shift away from the center of dimple at 0.0082 mm, referring to the result of the first Slider X alignment to dimple in Table 4.1.

Table 4.1: The first result of Slider X alignment to dimple

Data	X4 - Slider X alignment (mm)	Convert X align (mm)	DX - Dimple X position (mm)	Pitch offset (mm)
Q'ty	30	30	30	30
Mean	**-0.005**	0.9820	0.9902	**0.0082**
sigma	**0.003**	0.0029	0.0005	**0.0030**

5) Test statistic of Dimple X location (DX) compare to target

Perform 1-sample t By

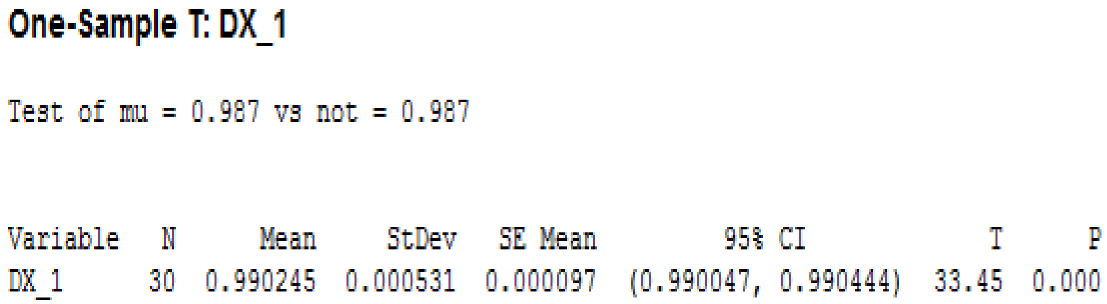
Stat > Basic Statistic > 1-sample t test

6) Data analysis

With sample mean test of Dimple X location, the Null Hypothesis H_0: is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple X location of this sample is different from target as in Figure 4.3.



One-Sample T: DX_1

```
Test of mu = 0.987 vs not = 0.987


Variable   N      Mean     StDev   SE Mean          95% CI              T      P
DX_1      30  0.990245  0.000531  0.000097  (0.990047, 0.990444)  33.45  0.000
```

Figure 4.3: Dimple X location 1-sample t test

Histogram of Dimple X location showed that sample mean is 0.9902 mm while target is 0.987 mm and it is significant different as shown in Figure 4.4.

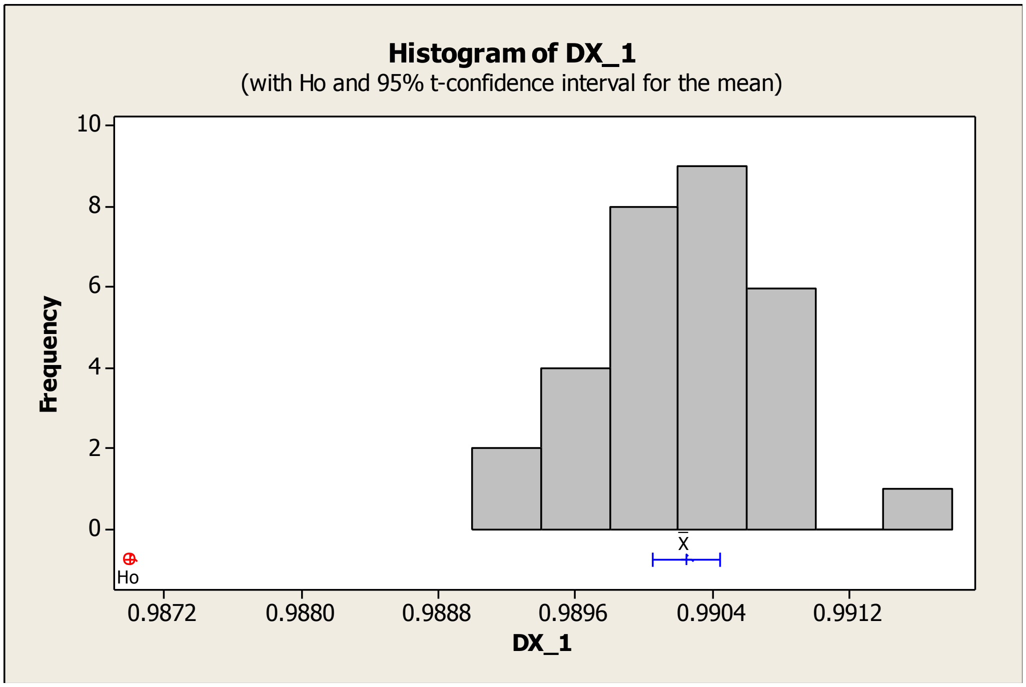


Figure 4.4: Histogram of DX

4.3.1.2 Slider Y alignment to dimple

To calculate offset of Slider Y alignment to dimple, we use equation as below

Roll offset = DY – Y4 (4.2)

Method to measure Slider Y alignment to dimple is sampling HGA 30 pieces. Those HGA are attached slider to suspension by refer position to loadbeam fiducials. Measure slider Y alignment data and Dimple Y location and calculate Slider Y alignment to dimple.

The procedure of Roll Offset data analysis can be described as below steps.

1) Average of Slider Y alignment shift to ID 0.004 mm.

2) Dimple Y location is at 0.004 mm shift to OD.

3) Slider Y position shift away from center of dimple at 0.008 mm. Result of the first result of Slider Y alignment to dimple is shown in Table 4.2.

Table 4.2: The first result of Slider Y alignment to dimple

Data	**Y4 - Slider Y alignment (mm)**	**DY - Dimple Y position (mm)**	**Roll offset (mm)**
Q'ty	30	30	30
Mean	**0.004**	-0.004	**-0.008**
sigma	**0.003**	0.001	**0.003**

4) Statistic test for Dimple Y location (DY)

Perform 1-sample t

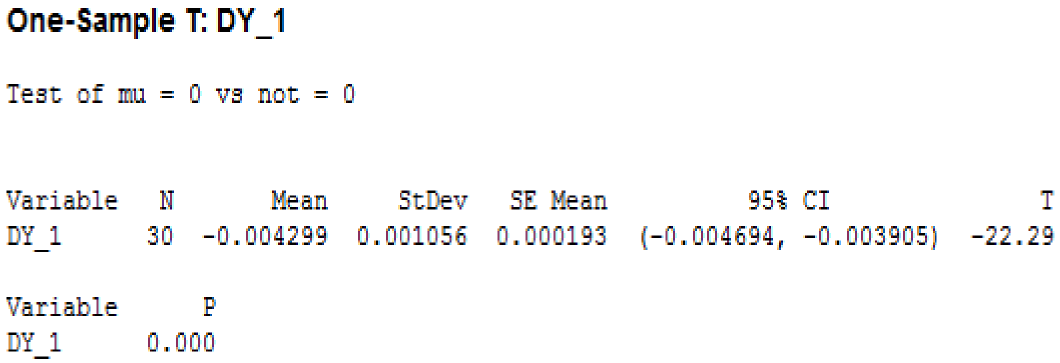
Stat > Basic Statistic > 1-sample t test

5) Data analysis

With sample mean test of Dimple Y location, the Null Hypothesis H_0: is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple Y location of this sample is different from target as in Figure 4.5.



One-Sample T: DY_1

```
Test of mu = 0 vs not = 0


Variable   N       Mean     StDev   SE Mean           95% CI                T
DY_1      30  -0.004299  0.001056  0.000193  (-0.004694, -0.003905)  -22.29

Variable      P
DY_1      0.000
```

Figure 4.5: Dimple Y location 1-sample t test

Histogram of Dimple Y location showed that sample mean is -0.004 mm while target is 0.000 mm and it is significant different as shown in Figure 4.6.

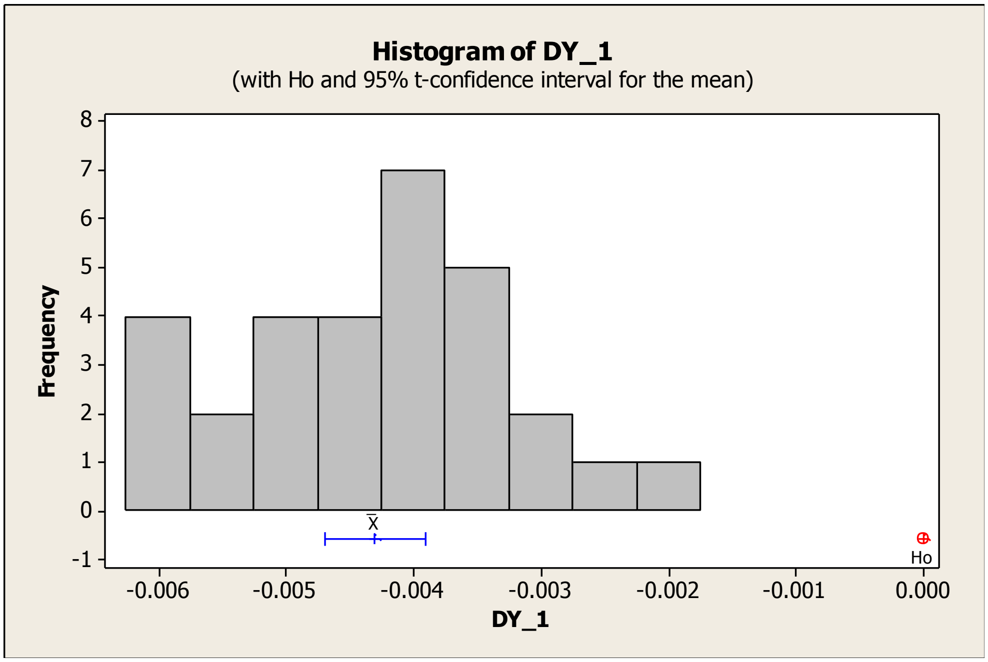


Figure 4.6: Histogram of DY

4.3.2 Data the 2nd set of Slider alignment to dimple

Method to measure slider alignment to dimple is sampling HGA 30 pieces. Those HGA are attached slider to suspension by refer position to loadbeam fiducials. Measure Slider X alignment data and Dimple X location and calculate Slider X alignment to dimple.

4.3.2.1 Slider X alignment to dimple

The procedure of pitch offset data analysis can be described as below steps.

1) Average of Slider X alignment shift toward LB fiducials 0.006 mm.

2) Convert the number of alignment to be distance from fiducials, slider attached at 0.981 mm away from fiducials.

3) Dimple X location is at 0.9904 mm away from fiducials.

4) Slider X alignment shift away from the center of dimple at 0.0094 mm.

See the second result of Slider X alignment to dimple as in Table 4.3.

Table 4.3: The second result of Slider X alignment to dimple

Data	**X4 - Slider X alignment (mm)**	**Convert X align (mm)**	**DX - Dimple X position (mm)**	**Pitch offset (mm)**
Q'ty	30	30	30	30
Mean	**-0.006**	0.9810	0.9904	**0.0094**
sigma	**0.004**	0.0028	0.0005	**0.0027**

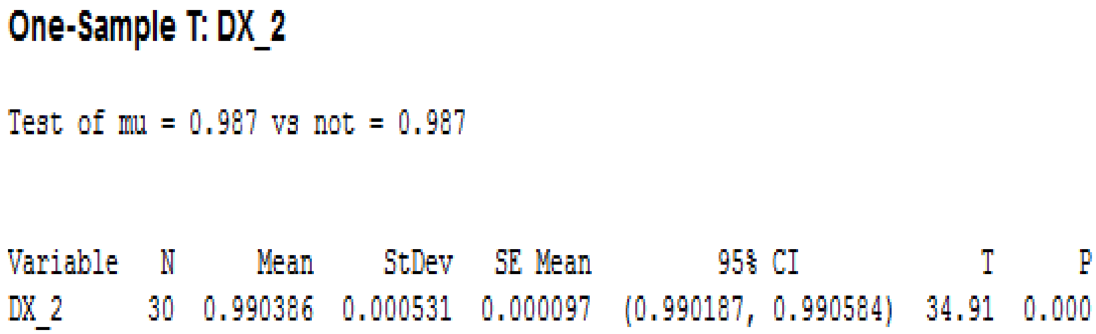
5) Perform statistic test of this group.

6) Data analysis

With sample mean test of Dimple X location, the Null Hypothesis H_0: is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple X location of this sample is different from target as shown in Figure 4.7.



```
One-Sample T: DX_2

Test of mu = 0.987 vs not = 0.987


Variable   N      Mean     StDev   SE Mean         95% CI              T      P
DX_2      30  0.990386  0.000531  0.000097  (0.990187, 0.990584)  34.91  0.000
```

Figure 4.7: Dimple X location 1-sample t test of the 2nd sample

Histogram of Dimple X location of the second sample showed that sample mean is 0.990 mm while target is 0.987 mm and it is significant different as shown in Figure 4.8.

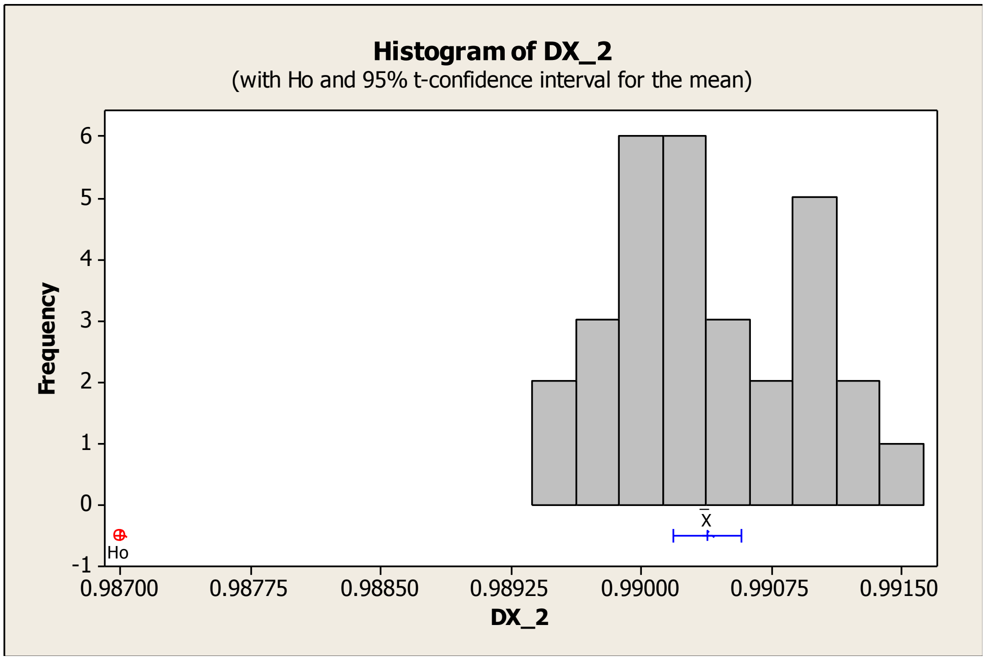


Figure 4.8: Histogram of DX of the 2nd sample

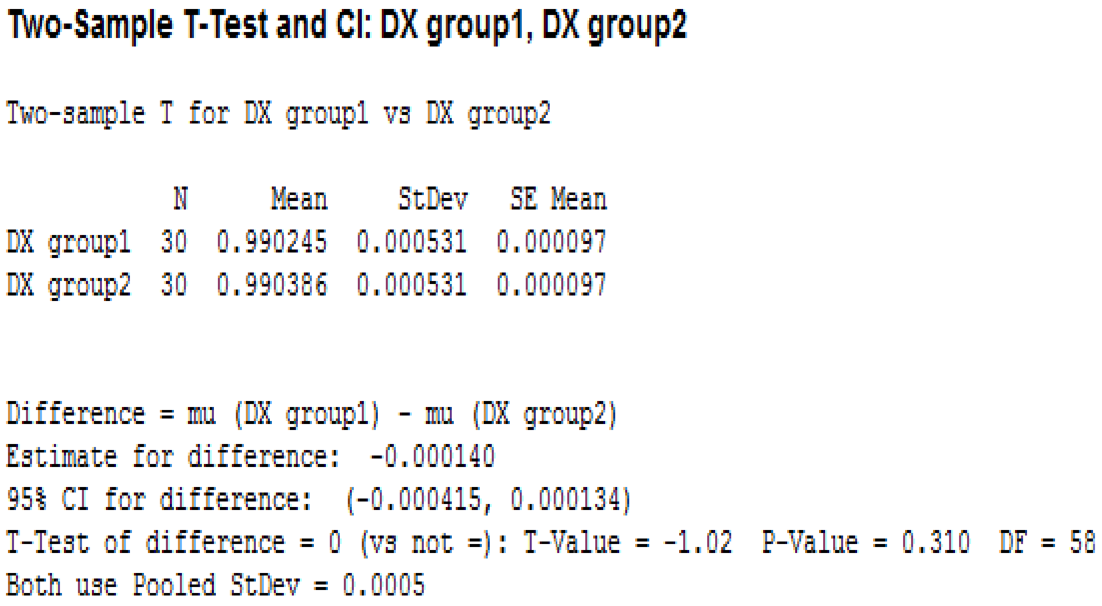
1) Verify whether sample of suspension 2 groups have same dimple X location or not. Use 2-sample t test

Stat > Basic statistic > 2-sample t

2) Data analysis

Result of s-sample t test showed result of p-Value > 0.05 then accept H_0

Meaning of result can be described as Dimple X location of these 2 sample groups are not significant difference. See Figure 4.9.



Two-Sample T-Test and CI: DX group1, DX group2

```
Two-sample T for DX group1 vs DX group2

             N      Mean     StDev   SE Mean
DX group1   30  0.990245  0.000531  0.000097
DX group2   30  0.990386  0.000531  0.000097


Difference = mu (DX group1) - mu (DX group2)
Estimate for difference:  -0.000140
95% CI for difference:  (-0.000415, 0.000134)
T-Test of difference = 0 (vs not =): T-Value = -1.02  P-Value = 0.310  DF = 58
Both use Pooled StDev = 0.0005
```

Figure 4.9: The 2-sample t test of DX

The individual plot of dimple X location between the first group and the second group are shown in Figure 4.10.

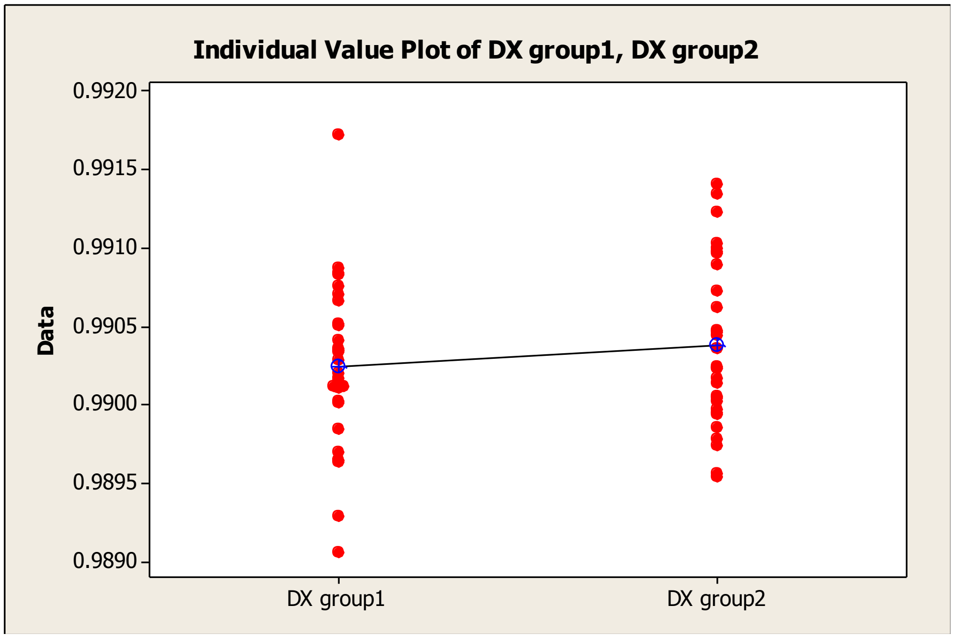


Figure 4.10: Individual plot of DX

4.3.1.2 Slider Y alignment to dimple

The procedure of roll offset data analysis can be described as below steps.

1) Average of Slider Y alignment shift to ID 0.004 mm.

2) Dimple Y location is at 0.003 mm shift to OD.

3) Slider Y position shift away from the center of dimple at 0.007 mm. The second result of Slide Y alignment to dimple is shown in Table 4.4.

Table 4.4: The second result of Slider Y alignment to dimple

Data	Y4 - Slider Y alignment (mm)	DY - Dimple Y position (mm)	Roll offset (mm)
Q'ty	30	30	30
Mean	**0.004**	-0.003	**-0.007**
sigma	**0.004**	0.001	**0.004**

4) Statistic test for Dimple Y location (DY)

Perform 1-sample t

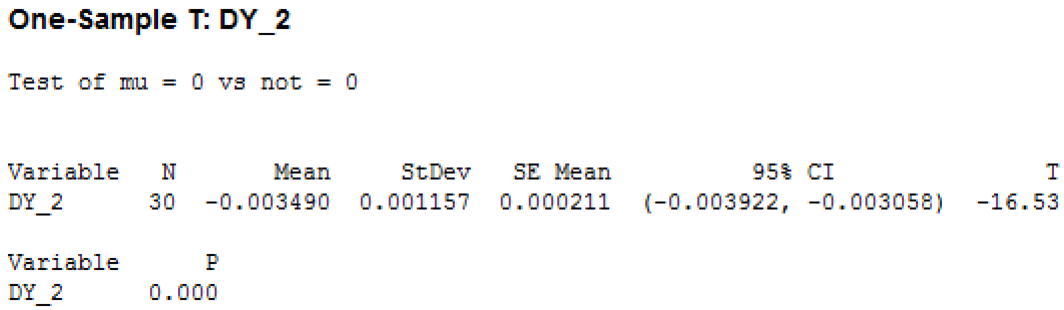
Stat > Basic Statistic > 1-sample t test

Data analysis

With sample mean test of Dimple Y location, the Null Hypothesis H_0: is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple Y location of this sample is different from target as shown in Figure 4.11.



One-Sample T: DY_2

```
Test of mu = 0 vs not = 0


Variable   N       Mean     StDev   SE Mean           95% CI               T
DY_2      30  -0.003490  0.001157  0.000211  (-0.003922, -0.003058)  -16.53

Variable      P
DY_2      0.000
```

Figure 4.11: Dimple Y location 1-sample t test of the 2nd sample

Histogram of Dimple Y location of the second sample showed that sample mean is -0.003 mm while target is 0.000 mm and it is significant different as shown in Figure 4.12.

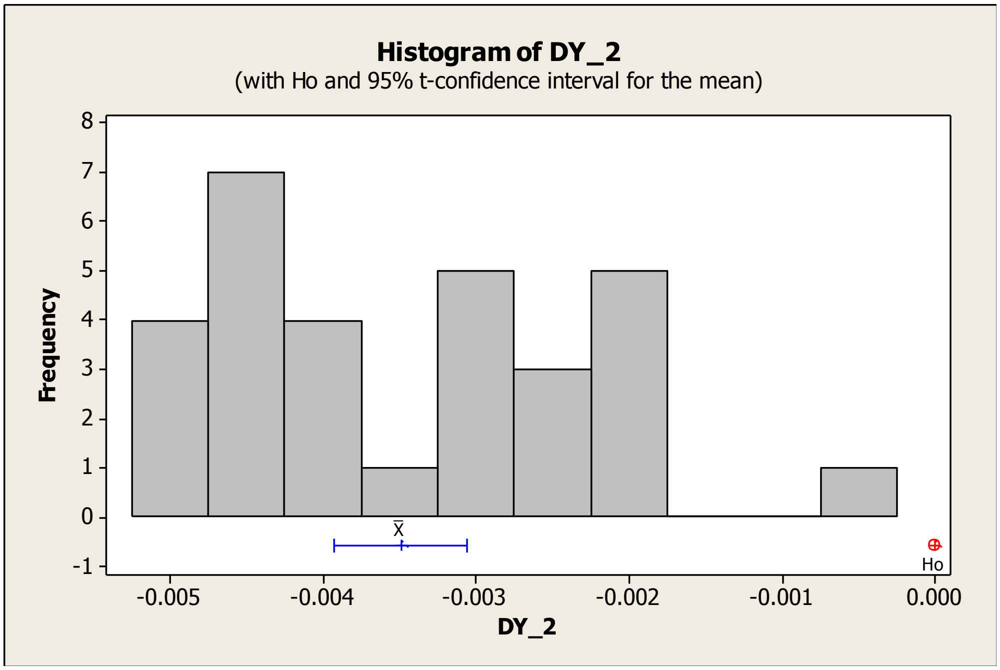


Figure 4.12: Histogram of DY of the 2nd sample

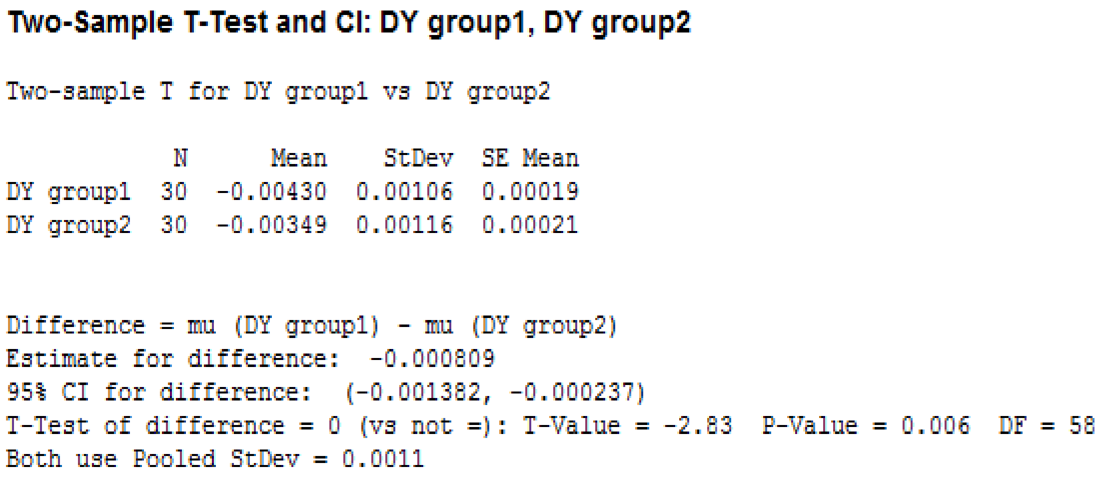
Next step can be described as following details.

1) Verify whether sample of suspension 2 groups have same Dimple Y location or not by use 2-sample t test.

Stat > Basic statistic > 2-sample t

2) Data analysis showed result of p-Value > 0.05 then reject H_0

Meaning of result can be described as Dimple Y location of these 2 sample groups are significant difference. As seen that dimple location of Group1 shifted to OD more than Group2 about 0.001 mm as shown in Figure 4.13.



Two-Sample T-Test and CI: DY group1, DY group2

```
Two-sample T for DY group1 vs DY group2

            N      Mean    StDev  SE Mean
DY group1  30  -0.00430  0.00106  0.00019
DY group2  30  -0.00349  0.00116  0.00021


Difference = mu (DY group1) - mu (DY group2)
Estimate for difference:  -0.000809
95% CI for difference:  (-0.001382, -0.000237)
T-Test of difference = 0 (vs not =): T-Value = -2.83  P-Value = 0.006  DF = 58
Both use Pooled StDev = 0.0011
```

Figure 4.13: Dimple Y location 2-sample t test

Individual plot of Dimple Y location between the first group and the second group are shown in Figure 4.14.

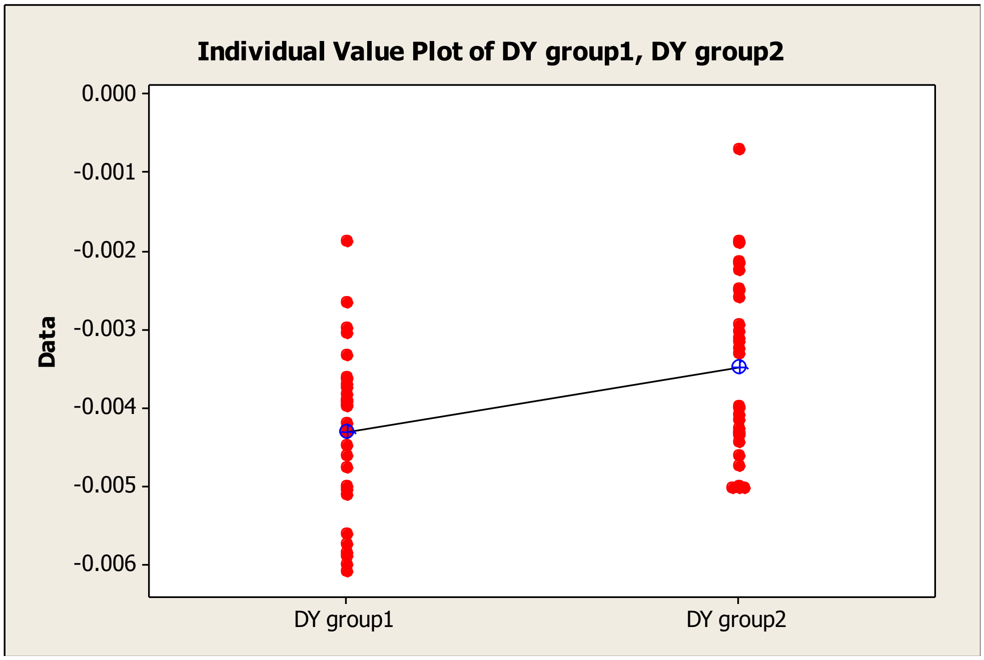


Figure 4.14: Individual plot of DY

4.4 Implementation methodology to other products

This measurement is setup for monitoring alignment offset and dimple location from different suspension shipment lot and different build date. Perform sampling HGAs for slider alignment to dimple measurement 1 time per month for 3 months. This product has different method to measure slider alignment to dimple and different target of dimple location. Concept of slider alignment to dimple is maintained.

4.4.1) Data of the first month

The procedure of pitch offset data analysis can be described as below steps.

1) Average of Slider X alignment shifted from loadbeam fiducials 966.81 μm.

2) Dimple X location is at 959.00 μm away from loadbeam fiducials.

3) Slider were attached shift from dimple 7.80 μm. which the center of dimple position is near loadbeam fiducials as shown in Table 4.5.

Table 4.5: Result of the 1st month (unit in µm)

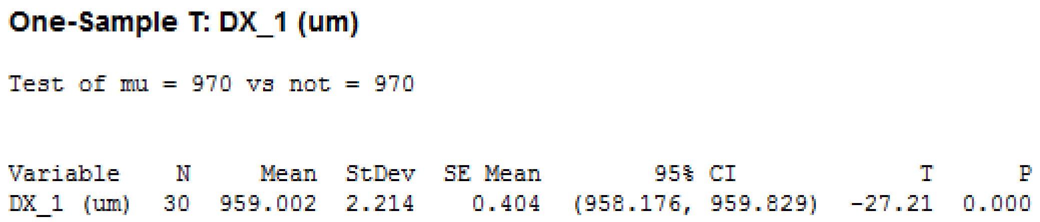
Part	slider alignment		dimple location		slider alignment to Dimple	
	X (µm)	Y (µm)	DX (µm)	DY (µm)	Pitch offset (µm)	Roll offset (µm)
1	968.024	-6.777	954.684	-0.276	-13.34	6.50
2	967.029	-5.699	960.984	3.158	-6.04	8.86
3	967.993	-3.66	953.245	1.672	-14.75	5.33
4	965.233	-6.79	963.16	2.386	-2.07	9.18
5	968.01	-5.515	960.24	0.161	-7.77	5.68
6	967.708	-6.124	954.226	1.905	-13.48	8.03
7	963.947	-2.376	961.079	3.914	-2.87	6.29
8	959.77	-8.597	959.281	3.181	-0.49	11.78
9	964.958	-2.165	958.491	2.646	-6.47	4.81
10	966.752	-0.746	959.23	5.602	-7.52	6.35
11	963.383	-5.742	958.543	2.404	-4.84	8.15
12	966.902	-6.137	958.497	3.237	-8.41	9.37
13	967.009	-9.045	957.802	3.606	-9.21	12.65
14	964.171	-6.432	957.892	2.740	-6.28	9.17
15	966.294	-4.248	959.498	2.756	-6.80	7.00
16	969.057	2.782	960.902	-2.11	-8.15	-4.89
17	970.844	3.407	959.864	-3.238	-10.98	-6.65
18	970.83	1.727	960.232	-3.072	-10.60	-4.80
19	966.527	-2.142	961.099	-5.456	-5.43	-3.31
20	970.842	-0.857	958.736	-3.041	-12.11	-2.18
21	964.554	1.184	960.131	-1.351	-4.42	-2.54
22	969.109	-1.902	958.119	-1.589	-10.99	0.31
23	967.634	1.102	960.343	-5.351	-7.29	-6.45
24	966.695	2.183	962.457	-4.082	-4.24	-6.27
25	966.046	7.856	957.589	-2.353	-8.46	-10.21
26	964.056	0.238	957.865	-1.934	-6.19	-2.17
27	966.581	-2.968	959.885	-3.46	-6.70	-0.49
28	966.847	-2.746	959.743	-2.625	-7.10	0.12
29	965.74	0.523	956.637	-4.686	-9.10	-5.21
30	971.619	-3.186	959.612	0.259	-12.01	3.45
Mean	**966.81**	**-2.43**	**959.00**	**-0.17**	**-7.80**	**2.26**
Sigma	**2.53**	**3.95**	**2.21**	**3.18**	**3.43**	**6.45**

4) Statistic test of DX

Data analysis of the 1st month Dimple X location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple X location of this sample is different from target as shown in Figure 4.15.



One-Sample T: DX_1 (um)

```
Test of mu = 970 vs not = 970


Variable     N      Mean  StDev  SE Mean        95% CI               T      P
DX_1 (um)   30  959.002  2.214    0.404  (958.176, 959.829)  -27.21  0.000
```

Figure 4.15: Dimple X location 1-sample t test of the 1st month

The procedure of roll offset data analysis can be described as below steps.

1) Average of Slider Y alignment shift to OD 2.43 µm.

2) Dimple Y location is at 0.17 µm shift to OD.

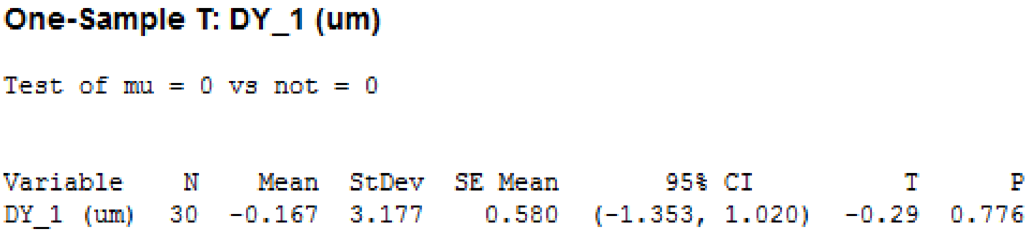
3) Slider Y position shift away from the center of dimple at 2.26 µm.

4) Statistic test

Data analysis of the 1st month Dimple Y location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value > 0.05, Accept H_0

Dimple Y location of this sample is not different from target as shown in Figure 4.16.



```
One-Sample T: DY_1 (um)

Test of mu = 0 vs not = 0


Variable     N    Mean  StDev  SE Mean        95% CI            T      P
DY_1 (um)   30  -0.167  3.177    0.580  (-1.353, 1.020)  -0.29  0.776
```

Figure 4.16: Dimple Y location 1-sample t test of the 1st month

4.4.2) Data of the second month

The procedure of pitch offset data analysis can be described as below steps.

1) Average of Slider X alignment shifted from loadbeam fiducials 968.14 µm

2) Dimple X location is at 955.80 µm away from loadbeam fiducials.

3) Slider is attached shift from dimple 12.34 µm which the center of dimple position is near loadbeam fiducials as shown in Table 4.6.

Table 4.6: Result of the 2nd month (unit in µm)

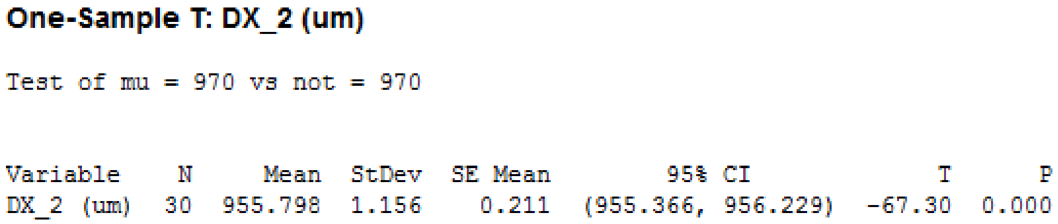
Part	**slider alignment**		**dimple location**		**slider alignment to Dimple**	
	X (µm)	**Y (µm)**	**DX (µm)**	**DY (µm)**	**Pitch offset (µm)**	**Roll offset (µm)**
1	966.564	8.161	954.913	-2.037	-11.65	-10.20
2	967.387	12.079	956.264	-1.008	-11.12	-13.09
3	967.579	8.409	957.067	2.146	-10.51	-6.26
4	970.338	11.709	958.597	-0.278	-11.74	-11.99
5	971.508	8.291	955.474	-2.261	-16.03	-10.55
6	968.969	10.923	955.034	1.638	-13.94	-9.29
7	969.577	6.871	955.252	2.132	-14.33	-4.74
8	970.512	3.415	956.003	0.265	-14.51	-3.15
9	969.283	5.405	955.845	-2.923	-13.44	-8.33
10	967.175	4.712	955.51	0.030	-11.67	-4.68
11	970.024	7.125	955.919	0.455	-14.11	-6.67
12	967.227	3.346	955.082	-2.568	-12.15	-5.91
13	967.121	2.056	954.952	-0.875	-12.17	-2.93
14	972.137	2.998	956.03	-2.098	-16.11	-5.10
15	968.049	-5.188	954.39	-3.562	-13.66	1.63
16	963.945	-10.249	957.405	-5.242	-6.54	5.01
17	965.367	-6.598	954.914	-0.09	-10.45	6.51
18	969.987	-6.432	956.083	-3.752	-13.90	2.68
19	961.238	-7.317	954.384	-2.992	-6.85	4.33
20	967.114	-8.052	956.96	-2.834	-10.15	5.22
21	971.583	-8.195	954.883	-3.969	-16.70	4.23
22	970.768	-10.259	955.323	-2.135	-15.45	8.12
23	969.621	-7.438	954.175	-5.692	-15.45	1.75
24	970.134	-7.549	957.163	-4.963	-12.97	2.59
25	964.078	-4.802	955.858	-1.041	-8.22	3.76
26	968.645	-10.327	954.04	-6.679	-14.61	3.65
27	963.293	-4.686	956.454	-3.829	-6.84	0.86
28	970.092	-6.988	955.748	-2.031	-14.34	4.96
29	971.862	-7.28	955.584	-2.911	-16.28	4.37
30	962.89	-5.612	958.622	-1.468	-4.27	4.14
Mean	**968.14**	**-0.72**	**955.80**	**-2.02**	**-12.34**	**-1.30**
Sigma	**2.87**	**7.62**	**1.16**	**2.23**	**3.22**	**6.29**

4) Statistic test

Data analysis of the 2nd month Dimple X location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple X location of this sample is different from target as shown in Figure 4.17.



One-Sample T: DX_2 (um)

```
Test of mu = 970 vs not = 970


Variable    N     Mean  StDev  SE Mean        95% CI              T      P
DX_2 (um)  30  955.798  1.156    0.211  (955.366, 956.229)  -67.30  0.000
```

Figure 4.17: Dimple X location 1-sample t test of the 2nd month

The procedure of roll offset data analysis can be described as below steps.

1) Average of Slider Y alignment shift to OD 0.72 µm.

2) Dimple Y location is at 2.02 µm shift to OD.

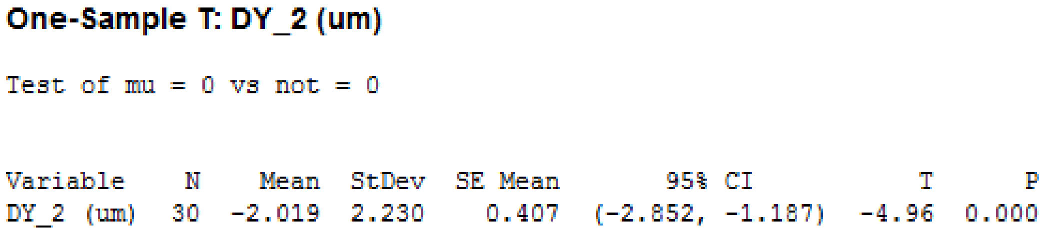
3) Slider Y position shift away from the center of dimple at 1.30 µm.

4) Statistic test

Data analysis of the 2nd month dimple Y location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple Y location of this sample is different from target as shown in Figure 4.18.



```
One-Sample T: DY_2 (um)

Test of mu = 0 vs not = 0


Variable     N    Mean  StDev  SE Mean       95% CI            T      P
DY_2 (um)   30  -2.019  2.230    0.407  (-2.852, -1.187)  -4.96  0.000
```

Figure 4.18: Dimple Y location 1-sample t test of the 2nd month

4.4.3) Data of the third month

The procedure of pitch offset data analysis can be described as below steps.

1) Average of Slider X alignment shifted from loadbeam fiducials 965.93 µm

2) Dimple X location is at 966.45 µm away from loadbeam fiducials.

3) Slider were attached shift from dimple 0.52 µm which center of dimple position is near loadbeam fiducials as shown in Table 4.7.

Table 4.7: Result of the 3rd month (unit in μm)

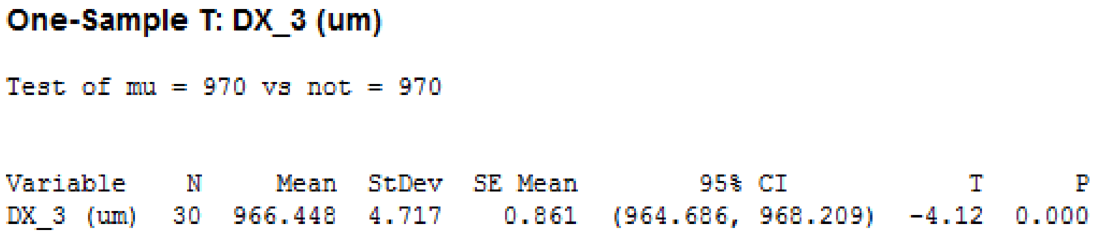
Part	slider alignment		dimple location		slider alignment to Dimple	
	X (μm)	Y (μm)	DX (μm)	DY (μm)	Pitch offset (μm)	Roll offset (μm)
1	960.737	-4.021	964.287	0.278	3.55	4.30
2	966.469	-2.607	965.729	-1.026	-0.74	1.58
3	969.297	-1.258	965.094	-0.550	-4.20	0.71
4	968.084	-2.044	961.533	-2.525	-6.55	-0.48
5	963.749	-2.664	963.955	-2.060	0.21	0.60
6	968.909	-2.532	962.875	-1.051	-6.03	1.48
7	967.158	0.137	963.57	0.619	-3.59	0.48
8	972.783	-5.05	961.835	-2.084	-10.95	2.97
9	968.857	-3.836	962.69	-2.771	-6.17	1.07
10	971.058	-10.476	962.168	-3.368	-8.89	7.11
11	960.341	-5.191	962.966	2.526	2.63	7.72
12	967.544	-9.765	961.733	-1.168	-5.81	8.60
13	969.37	-0.57	958.882	-2.872	-10.49	-2.30
14	964.219	-8.855	959.753	0.775	-4.47	9.63
15	962.654	-6.827	962.183	-3.779	-0.47	3.05
16	967.112	-0.004	969.557	-1.028	2.45	-1.02
17	964.936	-3.516	959.492	-1.403	-5.44	2.11
18	963.937	0.116	972.284	-0.367	8.35	-0.48
19	970.602	-5.917	971.225	0.265	0.62	6.18
20	965.257	-8.498	968.818	-0.165	3.56	8.33
21	965.321	-9.425	972.352	0.331	7.03	9.76
22	958.959	-5.204	969.389	0.179	10.43	5.38
23	965.354	-5.372	968.933	-0.165	3.58	5.21
24	965.109	-5.778	972.929	-0.586	7.82	5.19
25	966.336	-3.55	968.652	0.908	2.32	4.46
26	964.858	-7.284	971.802	2.404	6.94	9.69
27	967.15	-3.806	971.578	-1.656	4.43	2.15
28	965.084	-4.553	972.906	0.059	7.82	4.61
29	963.012	-0.504	971.859	-1.377	8.85	-0.87
30	963.5	-0.467	972.408	1.614	8.91	2.08
Mean	**965.93**	**-4.31**	**966.45**	**-0.67**	**0.52**	**3.64**
Sigma	**3.20**	**3.12**	**4.72**	**1.58**	**6.34**	**3.54**

4) Statistic test

Data analysis of the 3rd month Dimple X location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple X location of this sample is different from target as shown in Figure 4.19.



One-Sample T: DX_3 (um)

```
Test of mu = 970 vs not = 970


Variable     N     Mean  StDev  SE Mean         95% CI              T      P
DX_3 (um)   30  966.448  4.717    0.861  (964.686, 968.209)  -4.12  0.000
```

Figure 4.19: Dimple X location 1-sample t test of the 3rd month

The procedure of roll offset data analysis can be described as below steps.

1) Average of Slider Y alignment shift to OD 4.31 μm.

2) Dimple Y location is at 0.67 μm shift to OD.

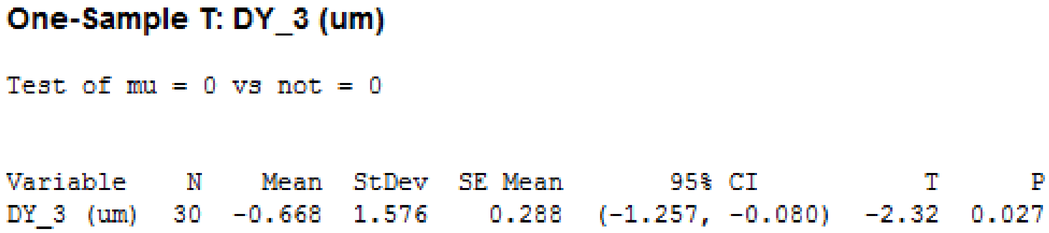
3) Slider Y position shift away from the center of dimple at 3.64 μm.

4) Statistic test

Data analysis of the 3rd month Dimple Y location with the Null Hypothesis H_0 is sample mean equal to target.

p-Value <0.05, Reject H_0

Dimple Y location of this sample is different from target as shown in Figure 4.20.



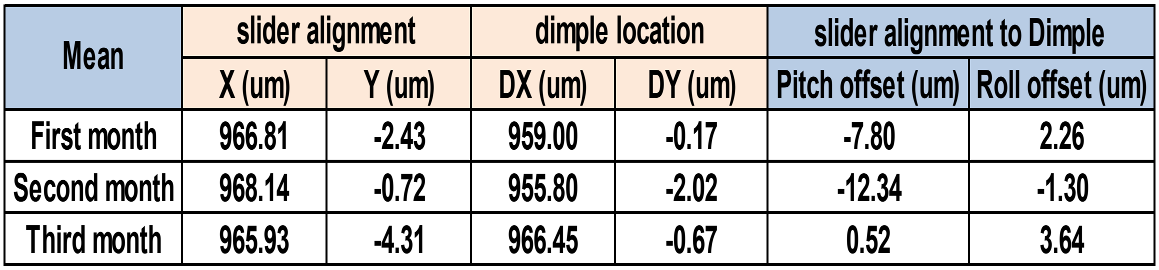
One-Sample T: DY_3 (um)

```
Test of mu = 0 vs not = 0


Variable     N    Mean  StDev  SE Mean       95% CI            T      P
DY_3 (um)   30  -0.668  1.576    0.288  (-1.257, -0.080)  -2.32  0.027
```

Figure 4.20: Dimple Y location 1-sample t test of the 3rd month

HGA assembly process placed slider with mean shift at x direction about 2 μm – 5 μm. It is lower than target at 970 μm. Dimple location in X direction also shifted toward loadbeam fiducials. This result in larger pitch offset at the 2nd month as shown in Table 4.8.

Table 4.8: Mean of slider alignment to dimple



Mean	slider alignment		dimple location		slider alignment to Dimple	
	X (um)	Y (um)	DX (um)	DY (um)	Pitch offset (um)	Roll offset (um)
First month	966.81	-2.43	959.00	-0.17	-7.80	2.26
Second month	968.14	-0.72	955.80	-2.02	-12.34	-1.30
Third month	965.93	-4.31	966.45	-0.67	0.52	3.64

In the meantime Slider Y alignment varies from 1 µm to 4 µm shifted to OD. Dimple Y location shifted 0.2 µm to 2 µm to ID then roll offset is smaller than pitch offset as in Table 4.9.

Table 4.9: Sigma of slider alignment to dimple

Sigma	slider alignment		dimple location		slider alignment to Dimple	
	X (um)	Y (um)	DX (um)	DY (um)	Pitch offset (um)	Roll offset (um)
First month	2.53	3.95	2.21	3.18	3.43	6.45
Second month	2.87	7.62	1.16	2.23	3.22	6.29
Third month	3.20	3.12	4.72	1.58	6.34	3.54

This chapter describes results of gage repeatability and reproducibility of dimple location measurement pass qualification both Dimple X location and Dimple Y location by use %Process to Tolerance (%P/T) ratio. Results of slider alignment offset also show that Dimple X location shifted away from target significantly and cause to higher slider alignment offset in X direction while less offset found in Y direction.

CHAPTER 5

CONCLUSIONS

Refer to Chapter 1, Introduction, a slider is attached onto suspension by refer to fiducials projecting to dimple. Assembly machine could not see dimple so failure HGA occurs.

In Chapter 2, Literature review describes basic knowledge of HGA components, fly height, slider alignment coordinates and review patents related to improvement of suspension fiducials helping to attach slider easily and assumed it is at the center of dimple.

In Chapter 3, Methodology showed that the methodology enable method to measure dimple location by flipping HGA upward and measure position of center dimple to reference points. Release condition of this tool use gage repeatability and reproducibility and use precision to tolerance as criteria.

In Chapter 4, Results show that gage repeatability and reproducibility with criteria of %Process to Tolerance of dimple location in X and Y direction are pass in acceptable range. Result of dimple location measurement showed that suspension formed dimple location missed from target. It contributed to Slider alignment offset from dimple. Results show actual slider alignment offset happened from dimple location shifted in X direction more than Y direction.

With these results, process capability of dimple formed at suspension manufacturer should add in KPIVs list of the slider alignment offset.

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APPENDIX A

Example of Head Gimbal Assembly and suspension back side view and front side view as shown in Figure A.1 and Figure A.2

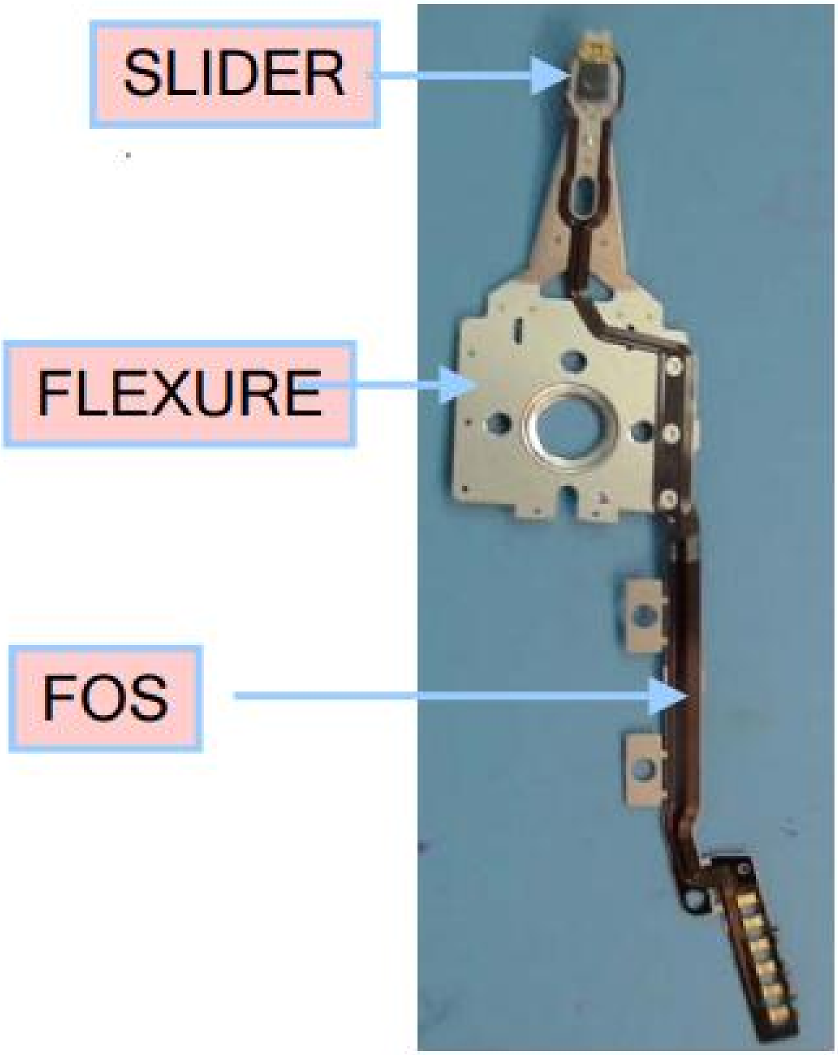
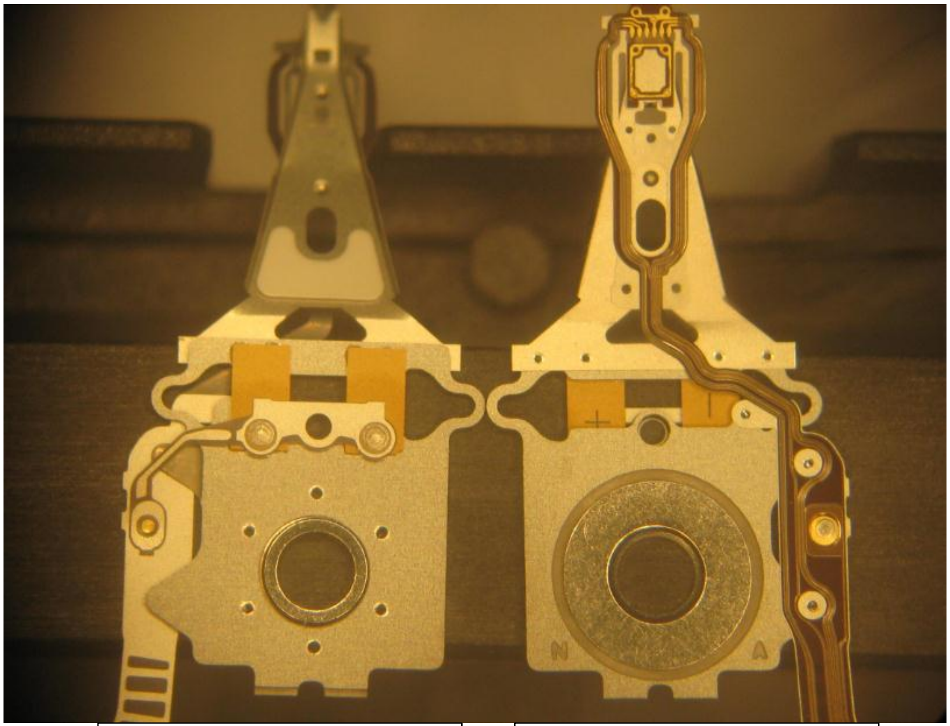


Figure A.1: Head gimbal assembly



Back side view

Front side view

Figure A.2: Suspension back side view (left) and front side view (right)

APPENDIX B

PLUBLICATION

This thesis topic has also published and presented at the session IV Production and Operation of the 5th International Data Storage Technology Conference at The Sukosol, Bangkok, Thailand during February 14-15, 2013.

DST-CON 2013

The 5th International Data Storage Technology Conference

Conference Topics

1. Recording Head & Media Technology
2. Mechatronics & Servo Systems
3. Read Channel Technology
4. Automation Technology
5. ESD & Contamination
6. Tribology in HDD
7. Data Storage Technology & Applications
8. Production and Operation Management
9. Mechanical Component Design
10. Other Related Areas

14-15 February 2013

The Sukosol, Bangkok, Thailand

Important Dates

Paper Submission : 30 October 2012

Notification of Acceptance: 30 November 2012

Final Submission : 15 December 2012

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Methodology of Slider Alignment to Dimple

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***Abstract* — For manufacturing of Head Gimbal Assembly (HGA), one of parameters which critical to upstream process is slider alignment. Key requirement at HGA level is slider must be mounted at center of dimple.**

Even mounting slider at center of dimple is more important, existing of assembly machine has no function to get image of dimple and then mount slider on it. Regarding suspension manufacturer developed the accuracy of distance of dimple to reference point, seems to adding vision system of dimple in assembly machine will cause of high investment and lose HGA output.

This methodology concept is to develop existing audit alignment tool. Current metrology is used for measure slider alignment at HGA level. New methodology is to create new fixture to flip HGA upward and optical see dimple for measurement center dimple to reference points. As a result, this methodology could determine the value of slider alignment to dimple as Pitch offset and Roll offset.

***Index Terms* — Slider Alignment, Dimple, Head Gimbal Assembly, Metrology, Methodology.**

1. INTRODUCTION

Manufacturing of Head Gimbal Assembly (HGA), one of parameters which critical to upstream process is slider alignment. Key requirement at HGA level is slider must be mounted at center of dimple. A misplaced slider, that is a slider that is not properly or predictably and are a costly defect that reduces manufacturing yield. Taking additional time to properly place the slider increases costs in a very cost conscious industry. [1]

However mounting slider at center of dimple is more important, existing of assembly machine have no methodology to identify exactly location of center dimple and then mount slider on it. Add this feature in existing machine will cause of high investment and lost output.

HGA assembly process comprising of suspension and slider, mounted on gimbal which movement around a dimple. With existing method to attach slider, we do not know exactly of the dimple center due to dimple is covered by gimbal. However center of dimple can be referenced from Load beam fiducials due to it is assembled on Load beam piece part

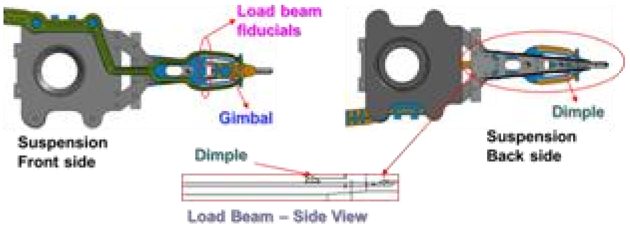


Fig. 1

For slider alignment metrology, machine is an existing tool in manufacturing. It is an offline tool, increasing time to measure HGA does not affect to product output.

Machine consists of vision system, unit as mm (results in micron), alignment fixture and program.

2. OBJECTIVE

Enable methodology and new fixture to measure slider alignment offset to center dimple which fixture & programs have to pass qualification process.

The result should determine how well of incoming dimple formed on suspension compare to design requirement and also how accuracy of assembly machine that mounting slider on suspension.

3. CONCEPTS

In automatic assembly machine, the dimple could not be seen due to gimbal area is on it. To develop new function of optical system beneath the gimbal is costly and lost HGA output. Refer to literature review, machine is assembly slider at center of dimple by refer to reference load beam indicia. To find out exactly location of dimple, HGA has to be flip upward to see dimple then metrology could measure distance of center dimple to load beam indicia.

At First, we will measure slider alignment at existing metrology. Starting to load HGA one by one until ten HGAs are on Alignment fixture. Continue to select alignment program, then program will find the reference points which is load beam indicia and line then it is calculated value of slider alignment.

Next step is manually flip fixture of dimple base. Now dimple has to be seen. Select program to measure dimple location refer to load beam indicia. Machine will report value in X and Y direction. We could calculate by simple mathematic equation to get the value of alignment to dimple.

4. LITERATURE REVIEW

In 2001, Robert N. Summers et al., established patent to US patent #US 6,212,760 B1 as Alignment of sliders in head gimbal assemblies. Problems aligning a slider with a dimple in manufacture of head gimbal assemblies for disk drive suspensions are obviated by defining a series of optically readable indicia on or about the dimple that serve as a reference for positioning apparatus rather than the dimple.

They provide markers of such sharpness and uniformity of distribution that positioning equipment can read and position the slider reference to them, as opposed to the dimple, with increased accuracy, better speed and fewer defects.

Base on this patent information, Suspension manufacture improved their optically readable indicia about the dimple on load beam. So that HGA manufacture could determine position of dimple by refer to load beam indicia.

Regarding in present hard disk drive has higher areal density but size is smaller, key parameter is fly ability. The slider alignment becomes more sensitive to fly ability. To prove accuracy of automatic assembly machine of slider on suspension is developed by this methodology.

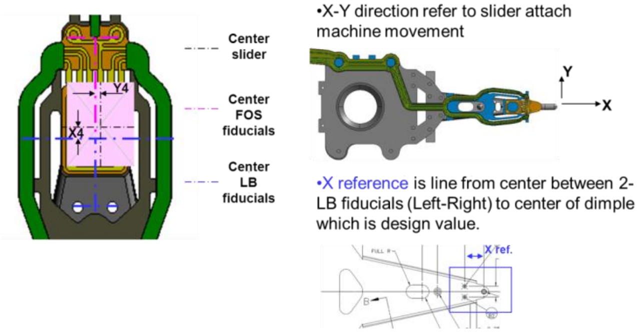
5. RESERCH METHODOLOGY

Direction is to combine slider alignment with dimple position to calculate alignment to dimple values. To perform this we will use two different programs, same fixture, and same parts.

One program to measure dimple location at product Z-Height from the back of the suspension, and another program to measure slider alignment (AAB pattern). Data from both measurements will be calculated alignment to dimple values.

To measure dimple location, we required 'Dimple base fixture' to control height of alignment fixture once flip with HGAs parts and make its steadily to measure dimple location at product Z-Height from the back of the suspension.

To identify alignment coordinate, X-Y direction refer to slider attach machine. X reference is line from center between 2 Load Beam fiducials to center of dimple which is design value as shown in figure 2.



•X-Y direction refer to slider attach machine movement

•X reference is line from center between 2-LB fiducials (Left-Right) to center of dimple which is design value.

Fig. 2

To identify dimple coordinate, DX and DY are X and Y distance from original point, which is center of two load beams fiducials to the center of dimple location.

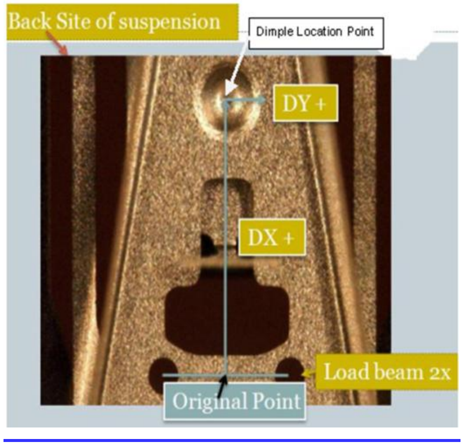


Fig. 3

Calculate Dimple Offset Formula
Pitch offset = DX – X4
Roll offset = DY – Y4

Remark:
Pitch offset = Slider X alignment to dimple
Roll offset = Slider Y alignment to dimple
DX = X Dimple Location
DY = Y Dimple Location
X4 = Slider X Alignment
Y4 = Slider Y Alignment

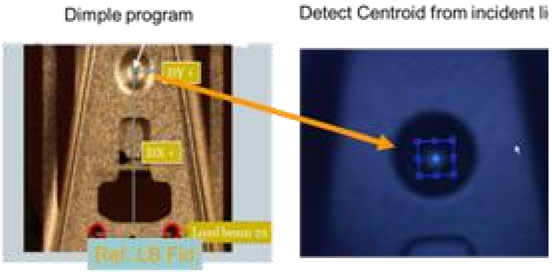


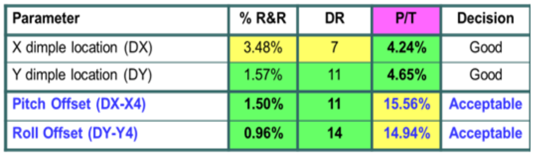
Fig. 4

6. RESULTS

A. GR&R study

TABLE I

RESULT OF GR&R

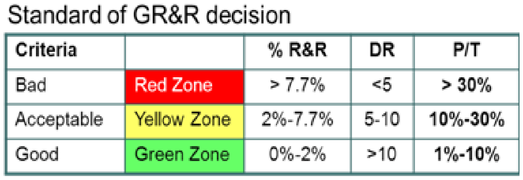


Parameter	% R&R	DR	P/T	Decision
X dimple location (DX)	3.48%	7	4.24%	Good
Y dimple location (DY)	1.57%	11	4.65%	Good
Pitch Offset (DX-X4)	1.50%	11	15.56%	Acceptable
Roll Offset (DY-Y4)	0.96%	14	14.94%	Acceptable

This measurement system is used to evaluate parts relative to specifications, %Tolerance variation may be a better measure.

TABLE II

STANDARD OF GR&R DECISION



Standard of GR&R decision

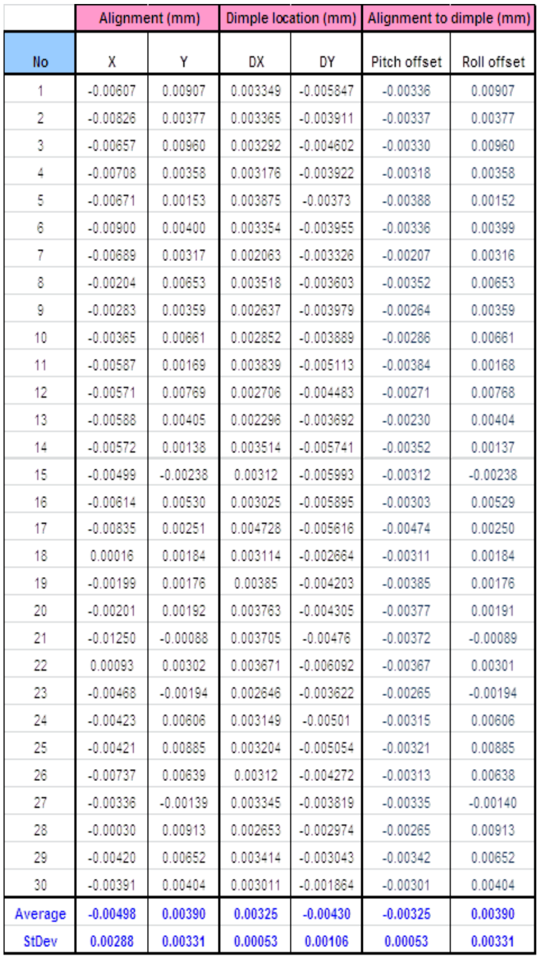
Criteria		% R&R	DR	P/T
Bad	Red Zone	> 7.7%	<5	> 30%
Acceptable	Yellow Zone	2%-7.7%	5-10	10%-30%
Good	Green Zone	0%-2%	>10	1%-10%

B. Data Analysis

Result of slider alignment to dimple as in table below:
Note: Data of dimple location DX and DY in table had been calculated with output from program and design value which it is not show design number in this table.

TABLE III

DATA ANALYSIS



	Alignment (mm)		Dimple location (mm)		Alignment to dimple (mm)	
No	X	Y	DX	DY	Pitch offset	Roll offset
1	-0.00607	0.00907	0.003349	-0.005847	-0.00336	0.00907
2	-0.00826	0.00377	0.003365	-0.003911	-0.00337	0.00377
3	-0.00657	0.00960	0.003292	-0.004602	-0.00330	0.00960
4	-0.00708	0.00358	0.003176	-0.003922	-0.00318	0.00358
5	-0.00671	0.00153	0.003875	-0.00373	-0.00388	0.00152
6	-0.00900	0.00400	0.003354	-0.003955	-0.00336	0.00399
7	-0.00689	0.00317	0.002063	-0.003326	-0.00207	0.00316
8	-0.00204	0.00653	0.003518	-0.003603	-0.00352	0.00653
9	-0.00283	0.00359	0.002637	-0.003979	-0.00264	0.00359
10	-0.00365	0.00661	0.002852	-0.003889	-0.00286	0.00661
11	-0.00587	0.00169	0.003839	-0.005113	-0.00384	0.00168
12	-0.00571	0.00769	0.002706	-0.004483	-0.00271	0.00768
13	-0.00588	0.00405	0.002296	-0.003692	-0.00230	0.00404
14	-0.00572	0.00138	0.003514	-0.005741	-0.00352	0.00137
15	-0.00499	-0.00238	0.00312	-0.005993	-0.00312	-0.00238
16	-0.00614	0.00530	0.003025	-0.005895	-0.00303	0.00529
17	-0.00835	0.00251	0.004728	-0.005616	-0.00474	0.00250
18	0.00016	0.00184	0.003114	-0.002664	-0.00311	0.00184
19	-0.00199	0.00176	0.00385	-0.004203	-0.00385	0.00176
20	-0.00201	0.00192	0.003763	-0.004305	-0.00377	0.00191
21	-0.01250	-0.00088	0.003705	-0.00476	-0.00372	-0.00089
22	0.00093	0.00302	0.003671	-0.006092	-0.00367	0.00301
23	-0.00468	-0.00194	0.002646	-0.003622	-0.00265	-0.00194
24	-0.00423	0.00606	0.003149	-0.00501	-0.00315	0.00606
25	-0.00421	0.00885	0.003204	-0.005054	-0.00321	0.00885
26	-0.00737	0.00639	0.00312	-0.004272	-0.00313	0.00638
27	-0.00336	-0.00139	0.003345	-0.003819	-0.00335	-0.00140
28	-0.00030	0.00913	0.002653	-0.002974	-0.00265	0.00913
29	-0.00420	0.00652	0.003414	-0.003043	-0.00342	0.00652
30	-0.00391	0.00404	0.003011	-0.001864	-0.00301	0.00404
Average	**-0.00498**	**0.00390**	**0.00325**	**-0.00430**	**-0.00325**	**0.00390**
StDev	**0.00288**	**0.00331**	**0.00053**	**0.00106**	**0.00053**	**0.00331**

Per result of slider alignment in X direction has average value at 0.00498 mm shifted closed to load beam indicia. Pitch offset average is 0.00325 mm shifted from center dimple.

Slider alignment in Y direction has average value at 0.0039 mm. shift to outer disk. Roll offset average is 0.0039 mm. Shifted from center of dimple.

In design point of view, the value to Pitch offset and Roll offset both fit for use to put in fly model.

7. CONCLUSION

New methodology of measure slider alignment to dimple has pass Gage qualification criteria and output data can represent actual value which in previous slider mounted on center dimple value is undetermined.

ACKNOWLEDGMENT

This research is supported by Seagate Technology (Thailand) Ltd.

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