3-Dimensional Stress Analysis of a Ball Swaging Process Using the Finite Element Method

Panupich Kheunkhieo[1*] *and Kiatfa Tangchaichit*[2]

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาพฤติกรรมการเกิดความเค้น ความต้านทานโมเมนต์บิด และแรงกรัมโหลดที่เกิดขึ้นจากกระบวนการบอลสเวจจิ้ง ซึ่งเป็นประเด็นหลักในการกำหนดคุณภาพของขั้นตอนการประกอบหัวอ่านเขียนสำเร็จเข้ากับแขนหัวอ่านเขียน โดยใช้ระเบียบวิธีไฟไนต์เอลิเมนต์จำลองกระบวนการบอลสเวจจิ้ง โดยเน้นศึกษาถึงอิทธิพลเนื่องจากทิศทางในการยิงลูกบอล ทำการศึกษาโดยการสร้างแบบจำลองไฟไนต์เอลิเมนต์ของกระบวนการในรูปแบบสามมิติ การตรวจสอบความถูกต้องของแบบจำลองไฟไนต์เอลิเมนต์ที่สร้างขึ้นนั้นทำได้โดยการเปรียบเทียบผลการคำนวณค่าความต้านทานโมเมนต์บิด และแรงกรัมโหลดที่ได้จากกการวิเคราะห์ด้วยระเบียบวิธีไฟไนต์เอลิเมนต์กับผลการทดลองที่ได้จากกระบวนการบอลสเวจจิ้ง ผลการศึกษาพบว่าเมื่อนำค่าความต้านทานโมเมนต์บิด และแรงกรัมโหลดของการยิงลูกบอลในทิศทางปกติมาเปรียบเทียบกับผลการทดลองที่ได้จากกระบวนการบอลสเวจจิ้งมีความคลาดเคลื่อนสูงสุดเท่ากับ 10.33 เปอร์เซ็นต์ และ 0.80 เปอร์เซ็นต์ ตามลำดับ เมื่อนำค่าความต้านทานโมเมนต์บิด และแรงกรัมโหลดของการยิงลูกบอลในทิศทางปกติมาเปรียบเทียบกับการกลับทิศทางในการยิงลูกบอล พบว่ามีความแตกต่างสูงสุดเท่ากับ 3.44 และ -0.03 ตามลำดับ

ABSTRACT

The purposes of this research are to explore stress, retention torque, and gram load which occur in the ball swaging process, the main component determining quality of assembly the head gimbals assembly with the actuator arm. Using the finite element method to reproduce the ball swaging process, we repeted to study effect of direction of the ball shooting. The study was done by creating the three dimensionals finite element model. To verify the accuracy of the finite element model, we compared calculated results of the retention torque and gram load from finite element analysis to the testing results. The results demonstrate that when compare the retention torque and gram load values due to the normal ball direction and the ball swaging process, there were 10.33% and 0.80% of maximal error, respectively. Additionally, when compared these parameters between the normal ball direction and the reverse ball direction, there were 3.44 and -0.03 of maximal error, respectively.

คำสำคัญ : ระเบียบวิธีไฟไนต์เอลิเมนต์, หัวอ่านเขียนสำเร็จ, ชุดประกอบหัวอ่านเขียนสำเร็จ

Keywords: Finite element method, Head gimbals assembly, Head stack assembly

[1] *Postgraduate Student, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University.*

[2] *Assistant Professor, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University.*

[*] *Corresponding author, e-mail: joehikaru@hotmail.com*

Introduction

Ball swaging process was the head gimbals assembly (HGA) with the actuator arm by firing the ball through the base plate. The radius of the base plate would be expanded and attached to the actuator arm. There would be the contact pressure between the base plate and the actuator arm. The contact pressure would directly affect its retention torque. After measuring the position and the torque of the gimbals when going through the ball swaging process, it was found that the suspension had roll stack attitude (RSA) and pitch stack attitude (PSA). This resulted in the distance between the gimbals and the platters and the power to press the gimbals or the gram load to be incorrect from the determined values. Previously, there were several remedies such as, changing the diameter of the ball, coating the ball surface to reduce the friction between the ball and the base plate, changing the ball direction, and modifying the surface of the spacer. However, the problems could not be resolved completely because there had been no study about the stress analysis, retention torque, and the gram load that occurred when the ball was fired through the base plate and the actuator arm.

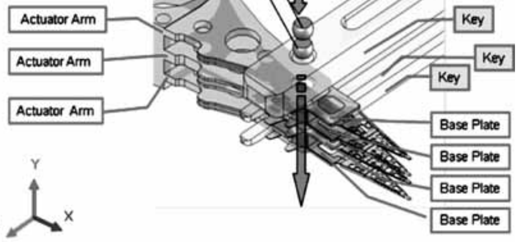

Figure 1. Prototype of the ball swaging process

Presently, the hard disk drive has been deve-loping rapidly in terms of the capacity, the speed and the access time. Moreover, it is versatile. Apart from being the device for storing the data in the computer, it has also been used in the car, mobile phone, or even the food storage, and other materials. Therefore, there is a tendency that the technology development around hard disk drive industry would grow continually. This leads to the constant research and the development around the structural design or the hard disk drive assembly. Pielr (1992) was the initial researcher studying the application of finite element method to analyze the ball swaging process. He found that using the finite element method could compare the stress level and the structure of the prototype. He suggested the manufacturer to develop the prototype that fit the ball swaging process in order to reduce the damage to the prototype. In 1992, Seagate Technology Incorporation patented the process to predict the retention torque after the ball swaging process by using the relationship between the retention torque of the gimbals and the driving pin used in firing the ball in a direct line. Such relationship was applied to the computer system to control the quality of the ball swaging process. In 1999, International Business Machines Corporation patented the application of lubricant on the ball with several substances. It was found that the reduction of the friction generated when the ball was fired through the base plate reduced the distortion on the suspension, position, and the placement of the gimbals plane. Kamnerdtong et al., 2005 used the finite element method to predict the stress behavior and the changes after the ball swaging process. There were 4 parameters used in this research that affected the quality of the ball swaging process; the size of the ball, the firing speed, the ball direction, and the friction between the ball and the base plate. Aoki & Aruga (2007) analyzed the ball swaging process using the finite element method and compared the analysis of ball swaging process with the test result. The interval that the gimbals lifted up or down was from the distortion of the two components supporting each other, which were the base plate and the actuator arm. The distortion of the base plate curved up, similar to an opened umbrella. Surachet et al., (1979) studied the head gimbals assembly using the ball swaging process. The finite element method was used to study the flow of the component, which helped to understand the distortion and the stress happened to the component clearly. The factor being studied was the speed used to fire the ball, the size of the ball, and the direction of the shooting.

This research was to study the behavior of the stress, the retention torque, and the gram load, which occurred in the ball swaging process by using the finite element method (FEM) to apply with the analysis and the prototype of the ball swaging process. This was to predict the behavior that caused the stress and the distortion. The research focused on the 3-dimention model. Also, the result from the finite element method was used to compare with the result from the ball swaging process in order to verify the accuracy of the finite element method.

Methodology

This research studied the variable that affected the quality of the ball swaging process, the ball direction. The analysis considered the retention torque and the gram load, which occurred in the ball swaging process. The result of the changing directions by firing the balls to two directions was analyzed. The first direction was studied as the normal ball direction. The second one was studied as the reversed ball direction. The analysis of the ball swaging process using the finite element method consisted of three main steps, which were the following:

1. Finite Element Method
2. The assessment
3. The analysis of Finite Element Method

Details of each step are elaborated as follow:

1. Finite Element Method

Finite Element Prototype consisted of creating the finite element modthod for each component, dividing the elements, determining the specification of the materials, and determining the criteria and conditions to align with the ball swaging process.

1.1 Creating the finite element method for each component

The steps to create the finite element method for each component in the general readymade finite element program could be done by two steps. First step was to create them from the readymade CAD program, then put in the data file. This research created the prototype from the readymade Solid Works program, then modified and reduced the complexity of the prototype. Second step was to create the prototype from the finite element program.

1.2 Dividing the elements

Choosing the element type to suit the finite element method was required for such particular task in order to yield the accurate and closest result to the reality. For this research, every elements used in the analysis were divided into cube without node in the middle. This was because we used Explicit Algorithm, which would not allow the node in the middle. The analysis of the ball swaging process chose to use Solid 164 element type with 8 nodes that had 9 degrees independent of freedom.

1.3 Define materials properties

The quality of the materials could be determined in two ways. First was to determine the quality of the rigid body materials, which consisted of the ball and the key, not to cause any distortion. And second was to determine the quality of the deformed body materials, which consisted of the base plate, the actuator arm, the gimbals, and the hinge; by having the finite element method with specified quality of bilinear kinematic hardening elastic-plastic material. The material properties were displayed in table 1.

Table 1. Display the materials properties for each material.

Components	Materials	Modulus of Elasticity (GPa)	Poisson's ratio	Density (kg/m^3)	Strain (MPa)
Actuator Arm	Aluminum 6061	71.02	0.33	2,724.00	275
Base Plate	Stainless Steel 304	190.00	0.32	8,017.80	262
Ball	Stainless Steel 304	190.00	0.32	8,017.80	262
Key	Stainless Steel 304	190.00	0.32	8,017.80	262
Hinge	Stainless Steel 304	190.00	0.32	8,017.80	262

1.4 Boundary Condition

The steps to determine the boundary condition for finite element method involved determining the boundary condition in accordance with the type of the ball swaging process as closed as possible. As shown in Figure 2 and 3, after determining the material qualities and the boundary condition, the next step involved determining the pairs between the components to identify the surface of the pair components and to determine the boundary condition. The type of problem being analyzed used the surface to surface contact. The coefficient of the friction between the ball and the base plate was 0.05 and the coefficient of the friction between the actuator arm and the base plate was 0.5.

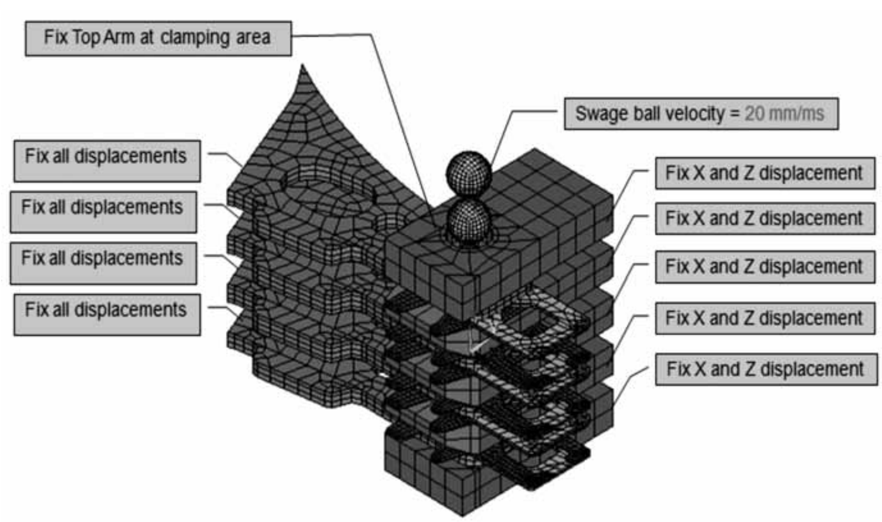

Figure 2. Display the define boundary condition for the finite element method with the normal ball direction.

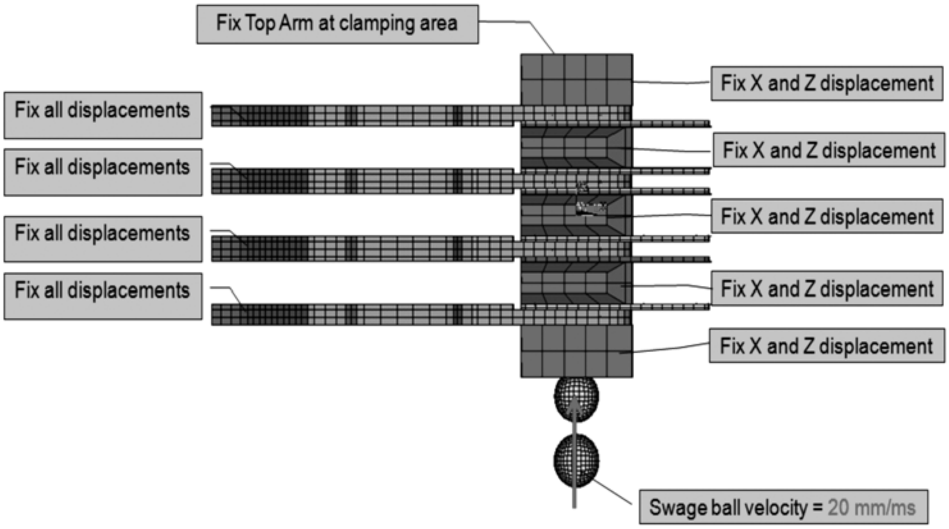

Figure 3. Display the define boundary condition for the finite element method with the reversed ball direction.

2. The assessment

The assessment steps involved using the explicit algorithm, which calculated the function with the time for the materials to be distorted permanently. The calculation involved the dynamic equilibrium with different time, which could be written into the equation as follow:

$$\sum \mathbf{F} = \mathbf{ma}$$

The calculation to find the mass accelerator in each element in different time used central difference as shown in the equation below.

$$\{a_t\} = [M]^{-1} ([F_t^{ext}] - [F_t^{int}])$$

When $[M]^{-1}$ was the mass matrix, $[F_t^{ext}]$ was outer vector force and $[F_t^{int}]$ was an inside force vector.

3. The analysis on the result of the finite element method

The result from the analysis using the finite element method was not able to show the retention torque and gram load, which occurred in the ball swaging process. Therefore, the result from the pressure of the contact between the surface of the base plate and the actuator arm was used to calculate the retention torque and the result from the Z-Height position was used to calculate the gram load.

3.1 Retention Torque

Retention torque from the head gimbals assembly, which occurred in the ball swaging process, was generated from two main variables, which were:

3.1.1 Contact Pressure generated between the surface of the base plate and the actuator arm. The type of the generated pressure contact changed the width of the contact surface because such contact was Incomplete Contact. The contact area had zero pressure as shown in Figure 4.

3.1.2 Friction between the surface of the base plate and the actuator arm, which actually might not be stable in reality throughout the contact area depending on the smoothness of the surface.

Retention torque could be written into the equation as shown below.

$$\mathbf{T = \mu r \int_s PdS}$$

When

T = Retention Torque
μ = Coefficient of the friction
r = Radius of the actuator arm
P = Contact Pressure
S = Contact area

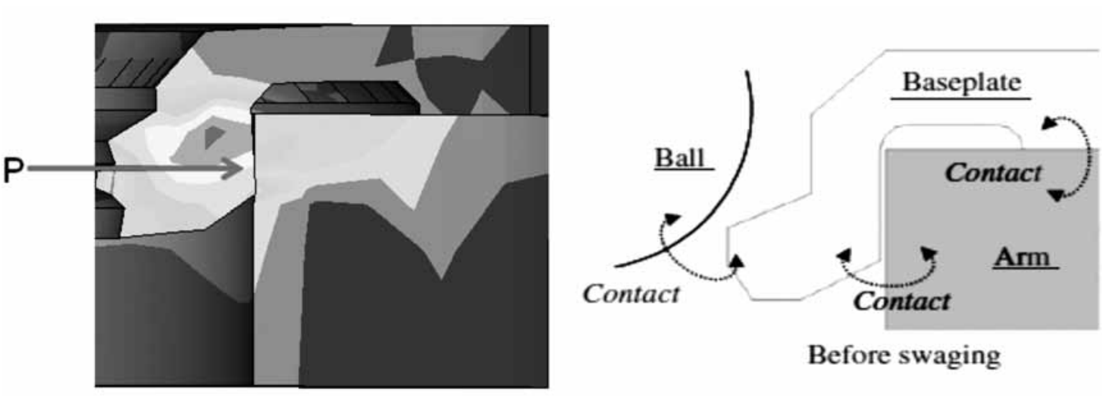

Figure 4. Shown the contact pressure of the surface generated to the actuator arm

4.2 Gram Load

Gram load was the energy generated from the coefficient of the spring. Generally, the gram load was determined as the energy against the gimbals. That gram load pressed the gimbals for equilibrium while functioning. Z-Height position could be written into equation as show below.

$$\Delta Z_{slider} = \Delta Z_{tip} + L \tan \theta$$

When

L = Distance between the edge of the base plate to the gimbals

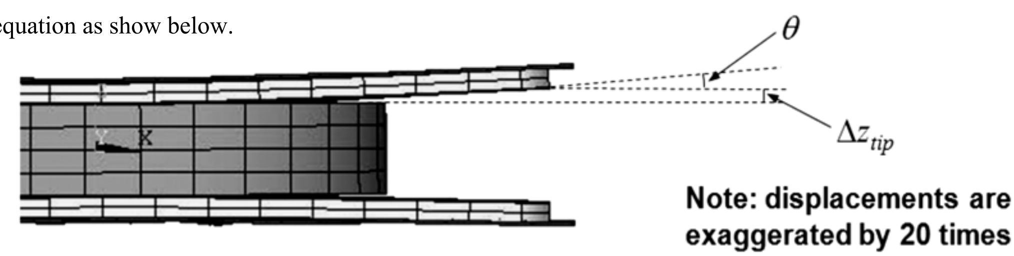

Figure 5. Display the Z-Height position

Gram load could be written into equation as shown below.

$$\text{Gram load} = K\Delta Z_{slider}$$

Research Results

The results from the research on the ball swaging process using the finite element method were divided into 2 cases, which were the result from the normal ball direction and the result from the reversed ball direction. The validation of the finite element method involved comparing the result from the analysis using finite element method with the result from the ball swaging process. The values used for comparisonwere the retention torque and gram load. The detail of the research in each case was described below.

1. The research result from the normal ball direction

1.1 The retention torque

Firing the ball through the base plate caused 2 loads, which were the load generated from the ball size to the radius component, and the load from the size and the friction between the ball and the base plate. The result from both loads caused the retention torque in the base plate and the actuator arm.

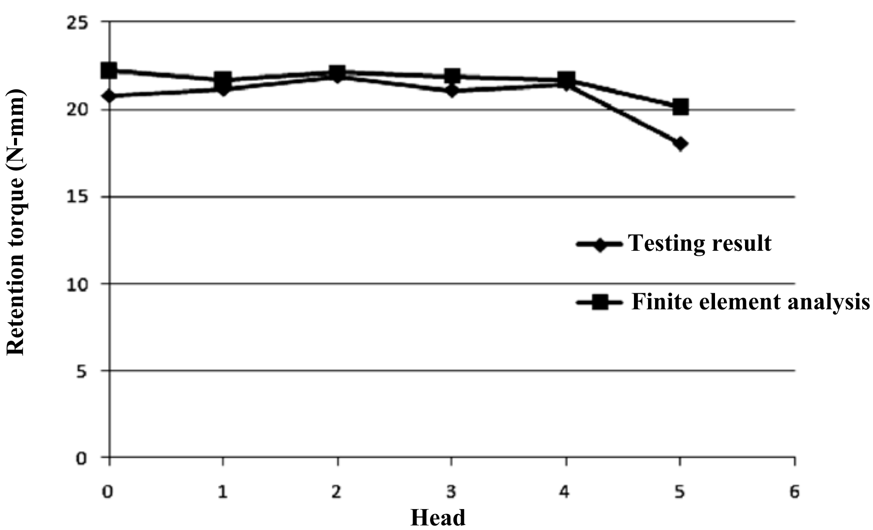

Figure 6. The graph compared the average retention torque between the finite element method and the ball swaging process with the normal ball direction.

According the Figure 6, the comparison of the average retention torque from the analysis of the finite element was extremely close to the average retention torque from the ball swaging process test result. The result confirmed the accuracy of the finite element method. The average retention torque from the analysis using the finite element was higher than the average retention torque from the ball swaging process test result. This was because the type of the swage pin used to push the ball in the ball swaging process each time had unsteady contact. However, the analysis of the finite element method was steady and symmetric throughout the analysis.

1.2 Gram load

Moreover, the result of firing the ball also caused the change in the placement of the plane figure of the actuator arm from the permanent distortion of the base plate. This was because the base plate was weld to the suspension. This caused the suspension to move in the lengthways and crossways. Consequentially, the base plate permanently distorted, which caused the suspension to be lifted. When considering the sturdiness of the base plate weld to the suspension crossways, it was found that the left and the right side had different sturdiness. As result, the distortion on the left and the right side was not even. This caused the plane figure of the gimbals to be twisted lengthways. Figure 7 showed the gram load from the various gimbals' plane figure.

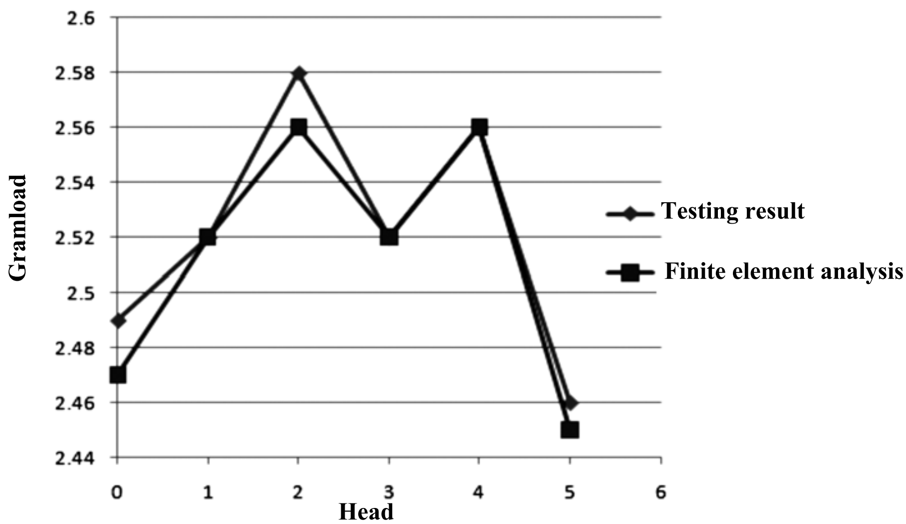

Figure 7. The graph showed the comparison of the gram load from the normal ball direction between finite element method and the ball swaging process.

2. The research result from the reversed ball direction

2.1 The retention torque

The analysis of the reversed ball direction showed that the base plate took the load in the direction different from the normal ball direction. Therefore, the generated stress and the distortion were different. The difference caused the contact space between the base plate and the actuator arm to be different as well. The active load while the ball was moving through the base plate could be divided into 2 parts. As mentioned above, when considering the result from both loads, it was found that the generated contact pressure was affected mainly from the load that came from the radius component. Meanwhile, the load in the direction of the ball movement supported the size of the contact pressure. This was because such load caused the hole in the base pate to be twisted and pressed to the gimbals. The comparison of the average retention torque from the analysis using the finite element method between the normal ball direction and the reversed ball direction was shown in Figure 8.

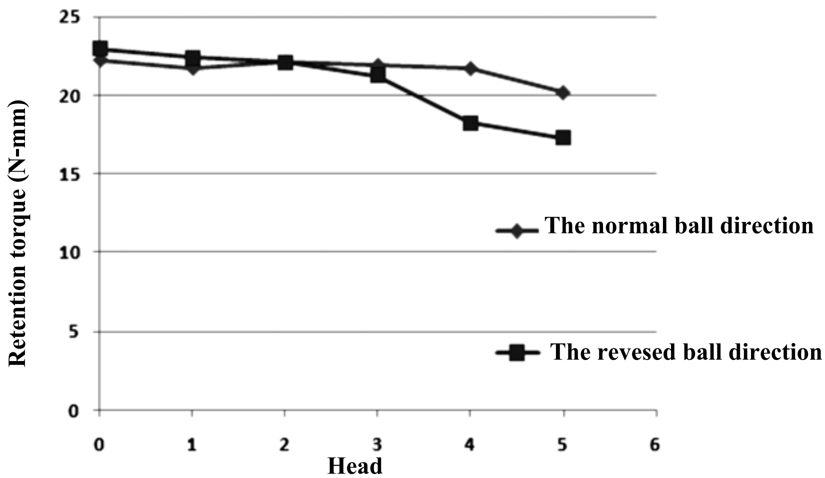

Figure 8. The comparison of the retention torque from the analysis using the finite element method between the normal ball direction and the reversed ball direction.

2.2 Gram load

The result of the changing direction when firing the ball caused the distortion to the base plate to be different. This caused the change to the plane figure of the suspension to be different as well. The gram load could be compared using the analysis of the finite element method between the normal ball direction and the reversed ball direction. The reversed ball direction caused the changes to the plane figure more than the normal ball direction as shown in Figure 9.

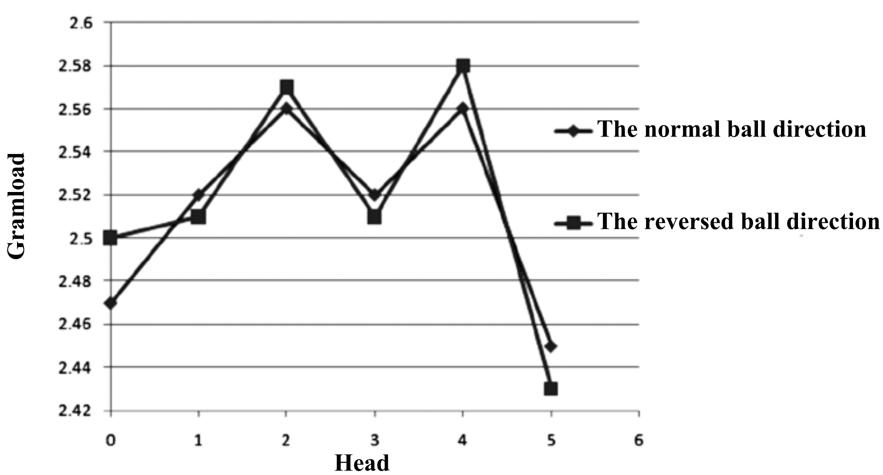

Figure 9. The comparison of the gram load from the analysis using the finite element method between the normal ball direction and the reversed ball direction.

Conclusions

1. The test result from the normal ball direction

The result from the analysis showed that the normal ball direction affected the quality of the base plate to cling to the actuator arm. The percentage deviation of the average retention torque and the gram load was shown in table 6.

Table 6. The percentage deviation of the normal ball direction between the finite element method and the ball swaging process

Gimbals	Percentage deviation of gram load (%error)	Percentage deviation of the average retention torque (%error)
0	0.80	6.60
1	0.00	2.58
2	0.77	4.59
3	0.00	3.63
4	0.00	1.02
5	0.40	10.33

The validation of the created finite element method could be done by comparing the result from the analysis using finite element method with the test result from the ball swaging process. The comparison showed consistency in the results. The percentage deviation of the highest average retention torque was 10.33 percent and the percentage deviation of the highest gram load was 0.80 percent. They were in an acceptable level. The retention torque of the head gimbals assembly, which occurred in the ball swaging process, was generated from 2 main variables, which were the contact pressure between the base plate and the actuator arm, and the friction between the surface of the base plate and the actuator arm. The gram load was generated from the changes on the plane figure of the suspension that lifted the base plate after going through the ball swaging process.

2. The test result from the reversed ball direction

The reversed ball direction affected the average retention torque to be lower and the gram load to be higher. This was because the characteristic of the pressure that caused the stress on the base plate and the actuator arm was different. The distortion and the size of the contact pressure together with the contact space were also different. The percentage deviation of the average retention torque and the gram load was shown in Table 7.

Table 7. The difference between the normal ball direction and the reversed ball direction.

Gimbals	Percentage deviation of the average retention torque	The difference of gram load
0	-0.75	-0.03
1	-0.70	0.01
2	0.01	-0.01
3	0.62	0.01
4	3.44	-0.02
5	2.88	0.02

The research result revealed that the normal ball direction gave the higher quality of the head gimbals assembly than using the reversed ball direction. The generated retention torque and gram load were lower.

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