วิศวกรรมสาร มข. ปีที่ 37 ฉบับที่ 1 (47 - 53) มกราคม - มีนาคม 2553 บทความวิจัย
KKU Engineering Journal Vol.37 No.1 (47 - 53) January - February 2010

Evaluation of Head Stack Assembly Pitch Static Attitude by Means of Finite Element Analysis: A Case Study of 2.5-in Hard Disk Drives

Rattaphom Khlaiaksorn [1] and Sujin Bureerat [*2]

Abstract

This paper is aimed at demonstrating the use of finite element analysis for simulating a swaging process of a head stack assembly (HSA) in a hard disk drive (HDD). The swaging process is a material processing technique using swage balls to connect a head gimbals assembly (HGA) to an actuator arm becoming the so-called head stack assembly. The finite element model is three-dimensional where solid Lagrangian elements and the explicit dynamics simulation are used. The computational results of tip height and pitch are compared to the experiment. Subsequently, a pitch static attitude (PSA) value is evaluated. The simulation results are compared to those obtained from experimentation. Based on the comparison, the result obtained from performing FE analysis is said to be acceptable.

Keywords: Finite element analysis, Swaging process, Hard disk drive, Contact analysis

---

[1] Post Graduated Student, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Thailand, 40002

[*2] Association Professor, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Thailand, 40002, Corresponding Author, E-mail: sujbur@kku.ac.th

1. Introduction

Ball swaging process is one of the most important manufacturing processes in the hard disk drive industries. Such a process is employed to assemble head gimbals assemblies (Aoki and Aruga, 2007) onto an actuator arm resulting in the so-called head stack assembly. Typical HDD swaging process components are illustrated in Figs. 1 & 2. The so-called swage boss on the base plate as illustrated in Figure 1, which is the part of a HGA, is inserted into the hole on the arm. Then, stainless steel balls swage it. The swaging ball has a larger diameter than the base plate's inner diameter. The boss and arm are plastically deformed and joined to each other through frictional contact forces. Jointing strength is defined as retention torque. To hold the HGA in place, the interface between the base plate and actuator arm must develop to have a suitable retention torque value. A specific value of retention torque at the joint is demanded to withstand the vibrations of the actuator arm that are induced by high-speed unstable airflow in the drive. A view of the assembly is shown in Fig. 2

The swaging process can result in plastic deformation of the HGA base plate and of the actuator arm. It also leads to unrecoverable changes of the base plate and arm tip geometry, consequently leading to deviation of pitch static attitude on sliders. This considerably affects read/write head performances, and alters the desired value of retention torque. Since pitch static attitude and retention torque are the critical parameters affecting the HDD performance, studying the swaging process to determine base plate and arm deformation characteristics, pitch static attitude, and retention torque changes are of general interest.

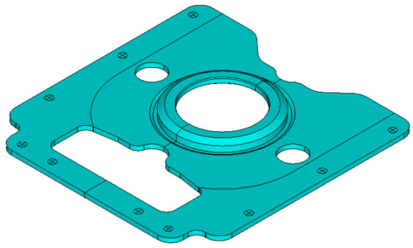


Fig. 1 *Baseplate*

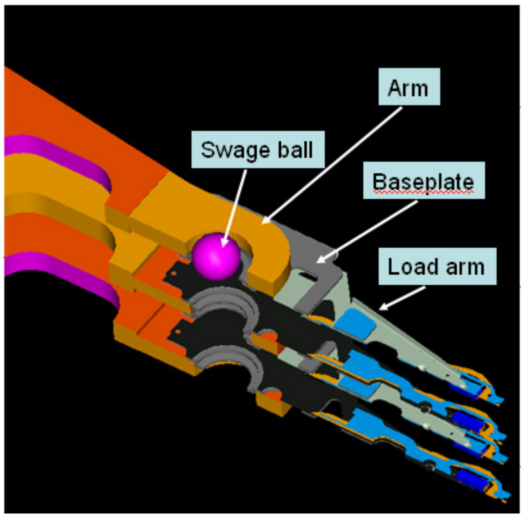


Fig. 2 *The assembly for swaging process (Aoki and Aruga, 2007)*

Wadhwa (Wadhwa, 1996) analyzed the ball swaging process numerically using an axially symmetric model of the ball swaging process of the in-plane deformation. Aoki and Aruga (Aoki and K. Aruga, 2007) reported a three-dimensional finite element analysis based on a symmetrical model of an actuator inner arm and two attached base plates and clarified that the baseplate is influenced by the arm deformation due to the asymmetric stress. Kamnerdtong et al. (Kamnerdtong, Chutima and Ekintumas, 2005) numerically verified the deformation of the entire arm and HGA. They studied the effects of swaging process parameters including the size, velocity and shooting direction of the swage ball by using an axis-symmetric finite element analysis (FEA). More work relating to a swaging process and finite element contact mechanics can be found in (Yang, Lin and Tabrizi, 2007), (Jongpradist, Rotbunsongsri, Sukkana and Sungtong, 2009), (Zhong, 2009), (Cho, Song, Noh and Jeon, 2005),(Piela and Grosman, 1996), (Elabbasi, Hong and Bathe, 2004). The review of literature however shows that an investigation of the swaging process with bi-directional swaging by using 3-Balls induced PSA and retention torque change is still open.

The aim of this work is to determine the effects from the swaging process by initiating a three dimensional finite element model to predict the base plate CTQ and retention torque changes during swaging, and then to predict the pitch static attitude. In this work, the swaging process is studied by performing an explicit dynamic finite element analysis (FEA) using a commercial program. Both one-sided arm (top and bottom) and two-sides in the assembly are opted as a prototype to be studied. A 3-Balls bi-directional swaging process is considered. The ball diameters are 0.0080” (1st pass), 0.0810” (2nd pass), 0.0830” (3rd pass flip) and their velocity is maintained as constant at 0.7 in/s in the top-to-bottom direction.

2. Finite Element Modeling

The FEA of a swaging process can be thought of as a collection of continua being in the dynamic equilibrium state such that contact constraints (no penetration between bodies) are imposed. With the use of finite element formulation, the contact behavior of such continua described by non-linear differential equations can be simplified to become a matrix form as: (Zhong, 1993)

$$\mathbf{M\ddot{U}} + \mathbf{KU} = \mathbf{F} + \mathbf{F_c} \quad (1)$$

Where $\mathbf{M}$ is a mass matrix, $\mathbf{K}$ is a stiffness matrix, $\mathbf{F}$ is a vector of external forces, and $\mathbf{F}_c$ is a vector of contacting forces to be determined during the FEA process. Also, the kinematics constraints on contact surfaces are of the form:

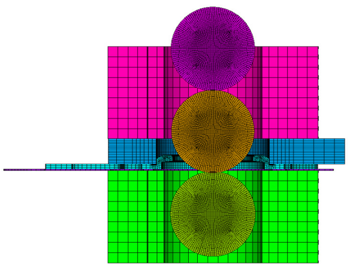
$$\mathbf{QU} + \mathbf{G} = 0 \quad (2)$$

Where $\mathbf{Q}$ is a coefficient matrix due to finite element grid, $\mathbf{G}$ is a vector computed from initial gaps of the nodes.

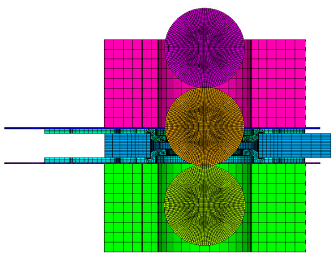
The contact constraints (2) can be dealt with by using a classical optimization approach such as the Lagrange multipliers method, the augment Lagrangian method, and the penalty function method.

The finite element model is 3D and the cross sectional views for the ball swaging process of the two outer and inner arms are shown in Figure 3. There are eight parts involved in the swaging process. The model includes an arm tip, base plate with part of the hinge, swage key and three swage balls. To deal with the elastic-plastic behavior, the actuator arms made of aluminum (Al) are modeled as bilinear kinematics and the stainless steel baseplates are modeled as bilinear isotropic hardening. The swage keys are modeled as rigid bodies for simplicity while the other components including the swage ball, arm tip, base plates and hinges are deformable parts.

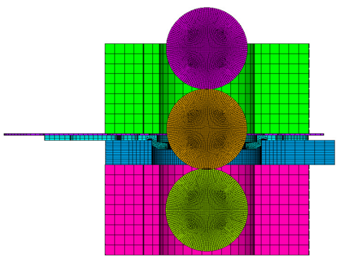
The explicit dynamics simulation consists of two stages i.e. swaging and ejecting clamping. At the first stage, the HGA (base plate and hinge) and the arm tip are clamped by the keys. The balls pass through the swage hole on the base plate from top to bottom directions by the first two balls (size 80, 81mils), and pass through from bottom to top directions by the last ball (size 83mils). At the second stage, the keys are removed allowing base plate(s) and hinge(s) and arm to proceed to final deformation. The Raleigh damping coefficients (α & β) are also included in the analysis. The FEA program automatically chooses the simulation time step, and it is related to the characteristic length of the finite element mesh and wave propagation speed in the analyzed parts



(a.) Swage process on top arm



(b.) Swage process on middle arm



(c.) Swage process on bottom arm

Fig. 3 *Cross-section of ball swaging process*

The analysis is performed through the following steps. Firstly, a compressive clamping force is applied to the prepared area on top of the spacer key. Next, the swaging ball is driven through only in Z- direction. After the ball has passed through, the clamping force is then released after which the spacer key is ejected to allow final deformation of the assembly. The deformation is represented by base plate final deformation where the base plate CTQ was evaluated. In this paper, the base plate shape and profile, which is used in the model shown in Figure 4, is chosen to investigate.

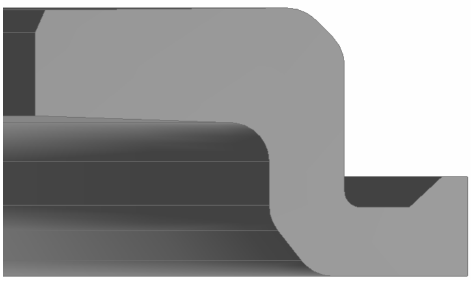


Fig. 4 *Boss tower profile in the model*

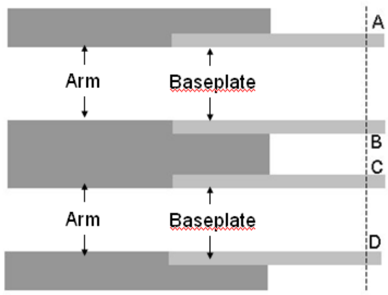


Fig. 5 *Tip height measurement section*

3. Finite Element Results

Figure 5 shows the points where the base plates tip heights were measured. Points A and D are for the outer arms while the others are for the inner arms. Figure 6 shows the FEA results of base plate and arm tip deformation due to the swaging process induced plastic deformation. For the outer arms, the base plate was bent away from the disk.

But for the inner arms, both base plates are bent to the disk. Note that the displacements are magnified by 25 times.

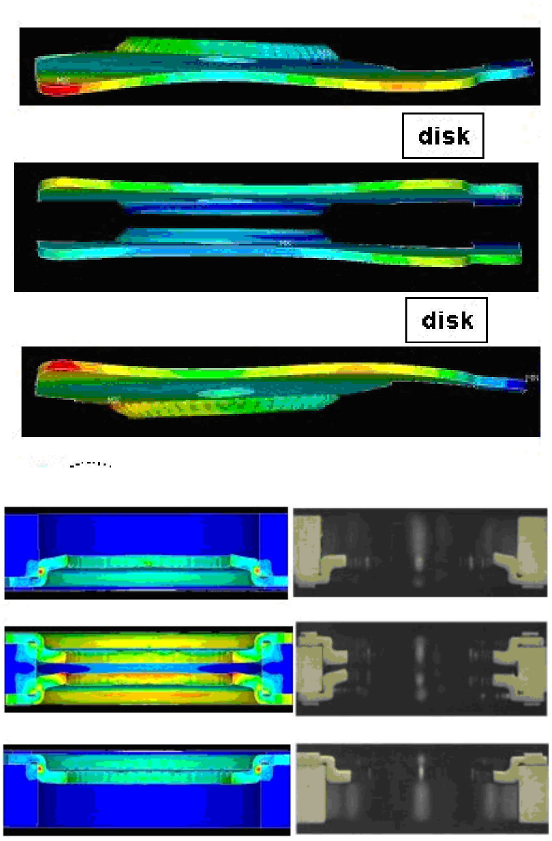


Fig. 6 *FEA result model*

The values of tip height and tip pitch obtained from both FEA simulation and experimentation are given in Table 1. It can be seen that the computational results are reasonable when compared to the testing data.

Table 1. *Simulation and experiment results*

Parameters		Tip Height (inch)		Tip Pitch (degree)	
		FEA	Actual	FEA	Actual
Head 0	Outer arm	0.00018	0.00040	-0.152	-0.219
Head 1	Inner arm	-0.00032	-0.00022	0.035	0.030
Head 2	Inner arm	0.00029	0.00047	-0.085	-0.055
Head 3	Outer arm	0.00041	0.00030	0.311	0.234

4. PSA Simulation

The PSA on the sliders can be simulated by creating the finite element model of a suspension in a free state as shown in Figure 7. Then, input the load on the suspension becoming at a loaded state at the working z-height and finally calculate the pitch static attitude on the sliders by using the tip height and the tip pitch input from the previous FE simulation. Table 2 shows the comparison PSA obtained from FE simulation and experiment. According to the comparison, it can be seen that the computational results are fairly different from the experiment. This is caused by structural imperfection in the real HSA, and the approximate bi-linear material models. A more accurate model can be obtained if the proper material models are employed. The use of rigid fixed boundary conditions also has an impact on the calculation results. Moreover, material properties identification needs to be performed to obtain more precise material properties. Based on the deformed shape of the suspension, the FE model is said to be usable although some parts of the model need to be improved.

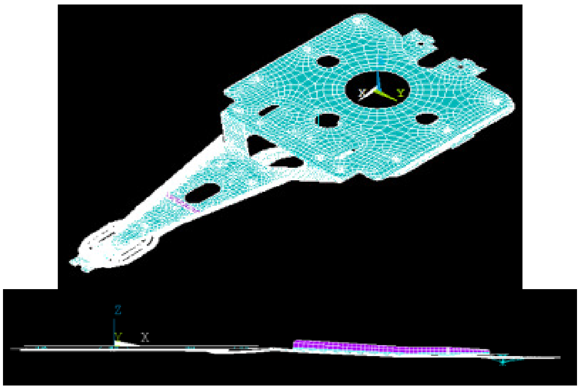


Fig. 7 *3-D view of the finite element model used for PSA simulation of suspension*

Table 2 *PSA Simulation and experimental results*

Parameter		Pitch Static Attitude (degree)		
		FEA Result	Experiment data	%Difference
Head 0	Outer arm	-0.064	-0.080	21%
Head 1	Inner arm	-0.046	-0.044	-4%
Head 2	Inner arm	-0.069	-0.093	26%
Head 3	Outer arm	0.073	0.060	-21%

5. Conclusion

The FE simulation results of a swaging process of a HGA and base plate model are compared with the experiment results. It is found that the present finite element model gives reasonable results. This means that it can be used for further investigation. In this work, finite element simulation was performed to simulate the ball swaging process by using the commercial FEA software and the numerical result was used to define the base plate and arm tip deformation to get the tip height, tip pitch and then the PSA value. The effects of the ball swaging process on the resulting retention torque of the HGA and the effect of other swaging parameters will be investigated in the future.

6. Acknowledgment

This study is supported by Cooperate Project between National Electronics and Computer Technology Center (NECTEC) and Seagate Technology (Thailand) via Industry/University Cooperative Research Center (I/UCRC) in HDD Component, Khon Kaen University.

7. References

Jian Yang, Chen-Chi Lin, Shahab Tabrizi (2007), Finite Element Simulation of Ball Swaging Process of Jointing HGA With Actuator Arm and Gram Load Calculation, ASME Information Storage and Processing Systems Conference, Santa Clara, CA.

Jongpradist, P., Rotbunsongsri, R., Sukkana, C., Sungtong, W (2009), Parametric Study of Baseplate Geometry Using Finite Element Analysis, DST-CON , Bangkok, Thailand

J.R. Cho, J.I. Song, K.T. Noh and D.H. Jeon (2005), Nonlinear finite element analysis of swaging process for automobile power steering hose, Journal of Materials Processing Technology, Volume 170, Issues 1-2 , 14 December , Pages 50-57

K. Aoki and K. Aruga(2007), Numerical Ball Swaging Analysis of Head Arm for Hard Disk Drives," Microsyst. Technol., vol. 13, pp. 943-949.

Nagi Elabbasi, Jung-Wuk Hong and Klaus-Jürgen Bathe (2004), On the Reliable Solution of Contact Problems in Engineering Design, International Journal of Mechanics and Materials in Design Volume 1, Number 1 / March

Piela A.; Grosman F.(1996), Spatial modelling of swaging process using finite element method applied to axially-symmetrical problems, Journal of Materials Processing Technology, Volume 60, Number 1, 15 June, pp. 517-522(6)

S. K. Wadhwa(1996), Material Compatibility and Some Understanding of the Ball Swaging Process, IEEE Trans. Magn., vol. 32, no. 3, pp. 1837-1842.

T. Kamnerdtong, S. Chutima and K. Ekintumas (2005), Effects of Swaging Process Parameters on Specimen Deformation, Eighth Asian Symposium on Visualization, Chiangmai, Thailand, pp.50.1-50.7

Zhi-Hua Zhong (1993), Finite element procedures for contact-impact problems, Oxford science publication, Oxford