การศึกษาผลกระทบของการใช้ Used Swage Ball ต่อประสิทธิภาพของชุดหัวอ่านข้อมูล

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บทคัดย่อ

งานวิจัยนี้เป็นการศึกษาประสิทธิภาพของชุดหัวอ่านข้อมูล จากการใช้ Used Swage Ball โดยวิเคราะห์จาก Key Parameter Output Variables (KPOVs) ซึ่งประกอบด้วยค่า Gram load Arm Height Swage Torque Out และ Resonance ด้วยหลักการทางสถิติ นอกจากนี้ยังได้ศึกษาถึงการเปลี่ยนแปลงลักษณะทางกายภาพของ Swage Ball หลังจากผ่านกระบวนการ Ball Swaging จากผลการทดลองพบว่าการเปลี่ยนแปลงลักษณะทางกายภาพของ Swage Ball เกิดขึ้นกับบอลลูกที่ 2 เพียงเท่านั้น โดยค่าความกลม (Roundness) ของลูกบอลจะลดลงเมื่อผ่านกระบวนการ Swaging การเปลี่ยนแปลงของค่าความกลมนี้พบว่าไม่มีผลกระทบต่อค่า KPOVs ของชุดหัวอ่านข้อมูลที่เกิดจากการใช้ Used Swage Ball แต่จะมีผลทำให้ค่า Resonance เพิ่มขึ้น ซึ่งค่าที่เปลี่ยนแปลงไปยังอยู่ในเกณฑ์ของ Hard Disk Drive Servo Stability Margin ข้อมูลที่ได้จากการศึกษาสามารถใช้เป็นแนวทางในการตัดสินใจเพื่อนำเอา Used Swage Ball กลับมาใช้ในกระบวนการ และใช้เป็นข้อมูลสำหรับการศึกษาหาแนวทางปรับปรุงกระบวนการผลิต ตลอดจนวิธีลดปัญหาการเปลี่ยนแปลงค่าความกลมของ Swage Ball หลังผ่านกระบวนการ Ball Swaging ต่อไป

คำสำคัญ : Ball Swaging / กระบวนการ Swaging / Key Parameter Output Variables

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1 นักศึกษาปริญญาโท หลักสูตรการพัฒนาความสามารถทางการแข่งขันเชิงอุตสาหกรรม สถาบันวิทยาการหุ่นยนต์ภาคสนาม

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A Study of Used Swage Ball Effect on Head Stack Performances

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Abstract

This research describes the study of HSA efficiency as a result of recycling used swage ball. Key Parameter Output Variables (KPOVs) of HSA which consists of gram load, arm height, swage torque and resonance were investigated using statistical methodology. Moreover, changes in physical characteristics of swage ball after swaging process were also examined. The results of the analysis showed that only swage ball having a big diameter underwent a physical characteristic change, i.e., ball roundness was decreased. However, KPOVs of HSA using those swage balls were not altered. The resonance of HSA is slightly increased, but the discrepancy is in the range of HDD servo stability margin. The results obtained could be used as guideline for the decision to implement used swage ball in head stack swaging process.

Keywords : Ball Swaging / Swaging Process / Key Parameter Output Variables

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1. Introduction

In Hard Disk Drive (HDD) manufacturing process, swaging using metal balls is commonly used for merging the Head Gimbal Assembly (HGA) to the arm of E-Block called Head Stack Assembly (HSA). Swaging using such balls was introduced in HDD industry and published in 1975 by IBM [7]. This publication describes the analytical method to determine torque-out resistance on head stack that was assembled using such swaging process. After revelation, this swaging process has been continuously developed to iron out associated small drawbacks and thereby increase its effectiveness. For example, lubrication of the swage ball to reduce the stress/friction during the time the ball goes through the base plate hole [4] and the introduction of 3D Finite Element Modeling (FEM) for the analysis of swaging characteristics [1].

Although swage ball is an essential part of the swaging process, it is scrapped after a single use. Thus, causing high assembly cost. This work aims to explore the opportunity of using used swage ball in the swaging process, the changes of swage ball characteristics after swaging, and the impact of using used swage ball on HSA performance. Based on the evidence found, the guidelines for the development and the improvement of head stack assembly process to reuse the swage balls can be obtained. Consequently, the production cost would be reduced and thereby increase the competitive advantage.

2. Ball Swaging

Ball swaging is one of the swaging processes used for assembling a thin sheet component onto other parts by passing a ball through the aligned holes of these components. Basically, the ball diameter is slightly larger than the diameter of the components to be swaged, and when ball passes through the aligned holes, the diameter of the holes expand and induce contact pressure between components. This contact pressure directly affects the torque resistance of the joined components [2]. According to previous studies, it was found that swage ball diameter impacts the friction force between swage ball and base plate and the contact pressure. The larger the swage ball, the higher the contact pressure between the swage ball and the base plate, stress intensity, tilt angle of base plate and torque resistance. Moreover, increasing the friction force between swage ball and base plate can induce more contact pressure between the base plate and Actuator Pivot Flex Assembly (APFA) swage hole and induce stress intensity at the necking zone of the base plate. Subsequently, the torque resistance and the base plate tilt angle are increased [1].

3. Design of Experiment

Design of experiment is tool used to screen out all significant factors impacting the process variation. Factorial design is often employed in the experimental design of process having several suspected input factors to analyze their effects on response or the interaction (treatment) of processes/factors. This method can be categorized as follow:

- Two-Factor Factorial Design: the simple type of factorial designs involve only two factors or sets of treatment. The observation in a factorial experiment can be described by a model as show in (1)

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \begin{cases} i = 1, 2, \ldots, a \\ j = 1, 2, \ldots, b \\ k = 1, 2, \ldots, n \end{cases} \quad (1)$$

Where y_{ijk} is the observed response, i is the level of factor A, j is the level of factor B, kth is the replicate, μ is the overall mean effect, τ_i is the effect of ith level of factor A, β_j is the effect of jth level of factor B, $(\tau\beta)_{ij}$ is the effect of interaction between τ_i and β_j, ε_{ijk} is the random error.

- General Factorial Design: the extended form of two-factor factorial where different levels of factors are presented.
- 2k Factorial Design: It's particularly useful in the early stages of experimental work, when many factors are likely to be investigated. This provides a small run due to the fact that each factor has only 2 levels which are often assigned as high (+1) and low (-1) [3].

4. Research Methodology

The work undertaken was designed and the experiment was conducted using the worst case material conditions such as extreme ended specifications and 6 headers of HSA.

A. Design of experiment

There were two sizes of swage ball and two sizes of APFA swage hole diameter that were used in the experiment according to the group shown in table 1 [3].

Table 1** Treatment of an experiment

Group	APFA Swage Hole Diameter	Swage ball size		
		A (small)	B (Big)	N (Sample)
1	Small	New	New	43*
2	Small	Used ball	New	43*
3	Small	Used ball	Used ball	43*
4	Large	New	New	43*
5	Large	Used ball	New	43*
6	Large	Used ball	Used ball	43*

* *Sample size calculation is referred to two sample-t, where Confident Interval 95%, Difference to detect is based on minimum process capability of KPOVs that can be acceptable.*

** *Design of Experiment is referred to Two-Factor factorial design.*

B. Materials inspection

There were two components which were verified before using, i.e. the APFA swage hole diameter and the used swage ball characteristics.

1) APFA swage hole diameter: swage hole diameter was grouped using extreme ended specification. One group was formed using small swage hole diameter group and the other with large diameter.

2) Used swage ball: 700 pieces of used swage balls were sent to the swage ball manufacturer for verifying the characteristics of the ball. These characteristics included diameter, hardness, roughness and roundness. This information was used as reference for the analysis. The inspection results showed in Fig. 1 and 2 are the histogram of diameter for used swage ball size A and B, respectively. The histogram of roughness for both ball sizes are shown in Fig. 3. Fig. 4 and 5 depict the histogram of both ball sizes for hardness and roundness, respectively. The roughness of both sizes is illustrated in Fig. 6.

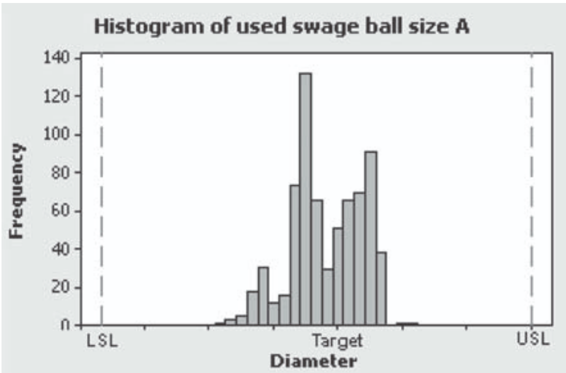


Fig. 1 Inspection result of diameter for used swage ball size A.

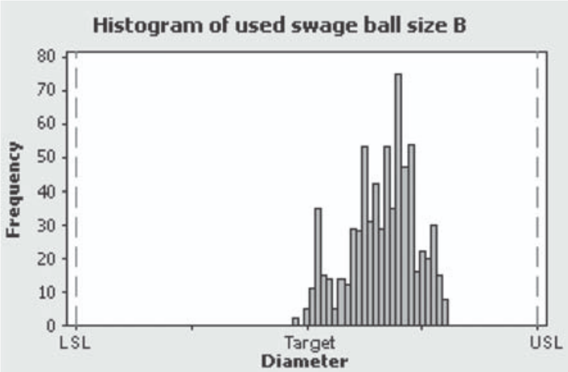


Fig. 2 Inspection result of diameter for used swage ball size B.

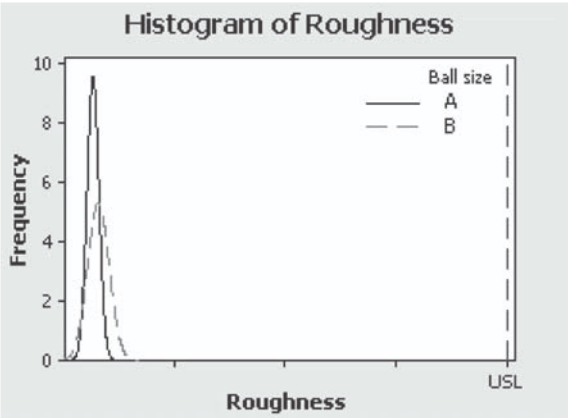


Fig. 3 Inspection result of Roughness for used swage ball size A and B.

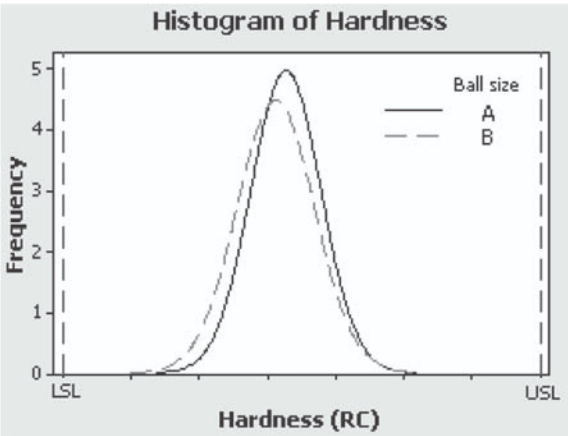


Fig. 4 Inspection result of Hardness for used swage ball size A and B.

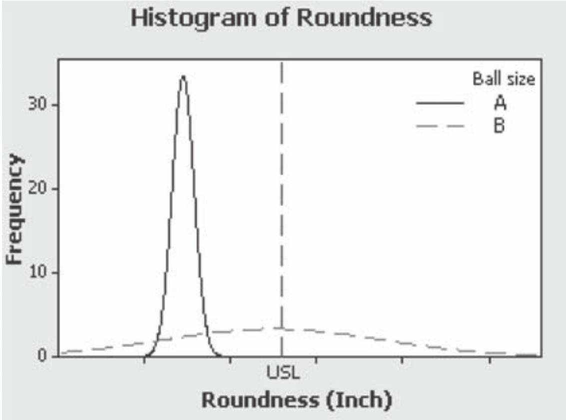


Fig. 5 Inspection result of Roundness for used swage ball size A and B.

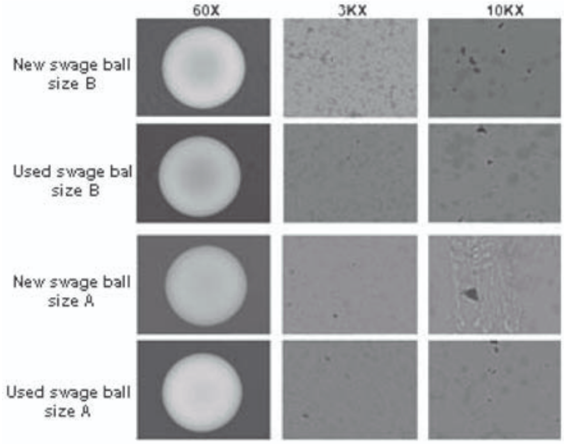


Fig. 6 Inspection result of surface roughness for used swage ball size A and B.

The inspection results of the diameter, roughness, hardness, roundness and surface for used swage ball showed insignificant changes of the examined parameters except for the roundness of used swage ball size B. Referring to Fig. 5, the average diameter for used swage ball size B inch was decreased and had approximately 77% of distribution over specification. This phenomenon was anticipated based on the previous published work [1].

5. KPOVS Analysis

The KPOVs of HSA from the experiment were analyzed as follows:

a) Gram Load: Figs. 8 and 9 show that the average of Gram Load data for each group is insignificantly different. This is regardless of using only 1 swage ball (size A) or both the balls. The effect on gram load was the same for both the groups of APFA swage hole. It was observed that average gram load for the group using small APFA swage hole was deviated from the target. This was due to high contact pressure and high stress intensity causing more tilting of the base plate.

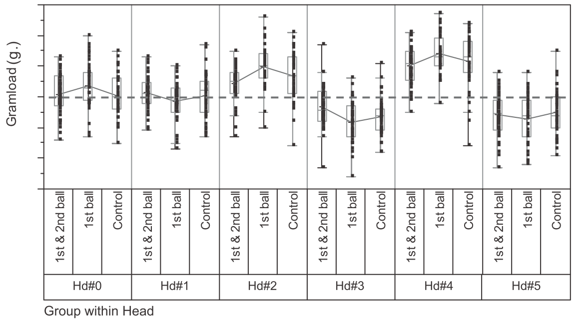


Fig. 7 Gram Load comparison for HSA using small APFA swage hole size.

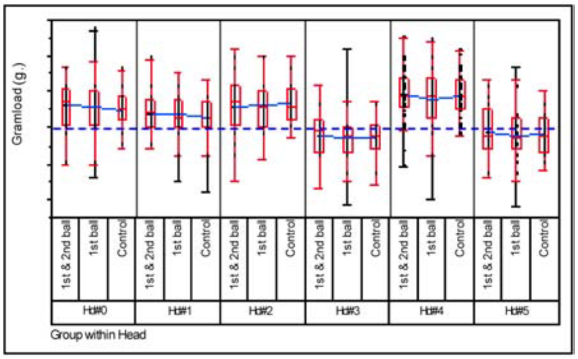


Fig. 8 Gram Load comparison for HSA using large APFA swage hole size.

b) Arm Height: Figs. 9 and 10 indicate that the average of arm height for each group was not affected either in using one recycled swage ball size (size A) or both the swage ball sizes.

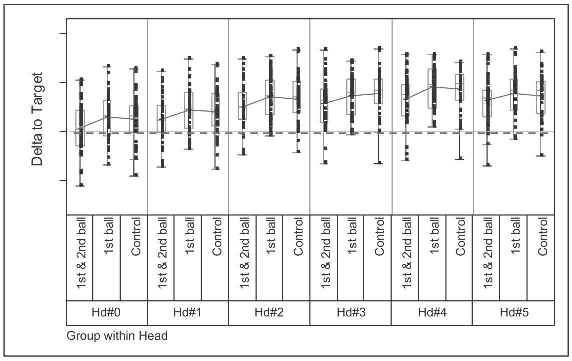


Fig. 9 Arm height comparison for HSA using small APFA swage hole size.

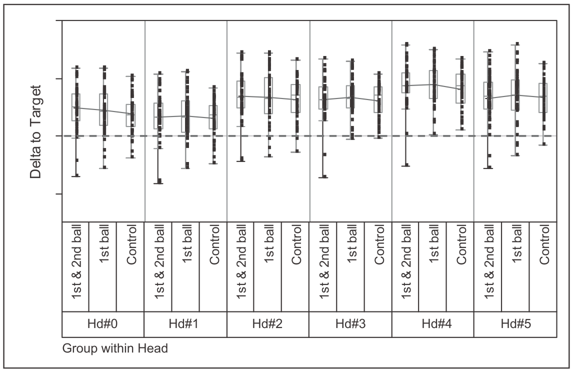


Fig. 10 Arm Height comparison for HSA using large APFA swage hole size.

c) Swage torque out: The average swage torque data for each group was comparable, regardless whether one or both the recycled balls were used. This is demonstrated in Figs. 11 and 12. However, the average swage torque data of HSA from group using small APFA swage hole size is higher than large APFA swage hole size due to high contact pressure and high stress intensity between swage ball and base plate resulting in high contact pressure between the base plate and APFA swage hole.

d) HSA Resonance: The measurement results of system rGM and resonance shown in Figs. 13, 14 and 15 indicate that the resonance of HSA using small APFA swage hole with used swage ball has resonance variation at frequencies of 5.7 kHz and 6.3 kHz which is higher than HSA using new swage ball. All groups give system rGM > 4.3 and resonance rGM > 13 dB. However, these variations do not hold any potential to cause resonance issues or affect the HDD servo stability margin.

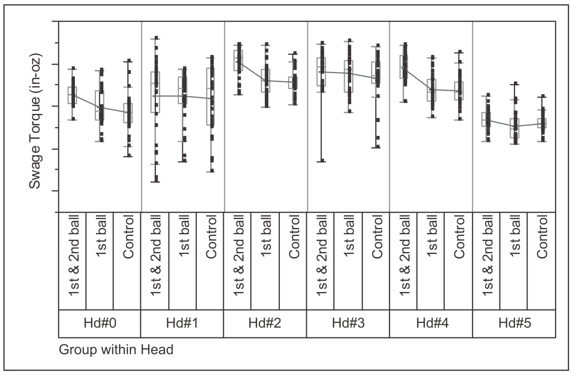


Fig. 11 Swage torque comparison for HSA using small APFA swage hole size.

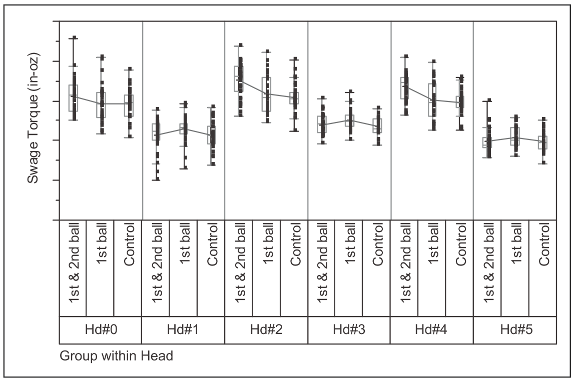
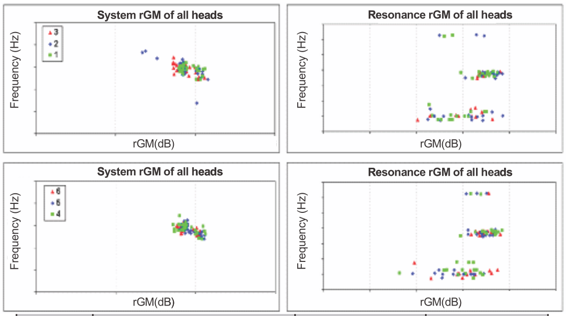


Fig. 12 Swage torque comparison for HSA using large APFA swage hole size.



Group	Swage Hole Diameter	1st swage ball	2nd swage ball
1	Small	New	New
2		Used	New
3		Used	Used
4	Large	New	New
5		Used	New
6		Used	Used

Fig. 13 Measurement ress of System rGM and Resonance rGM.

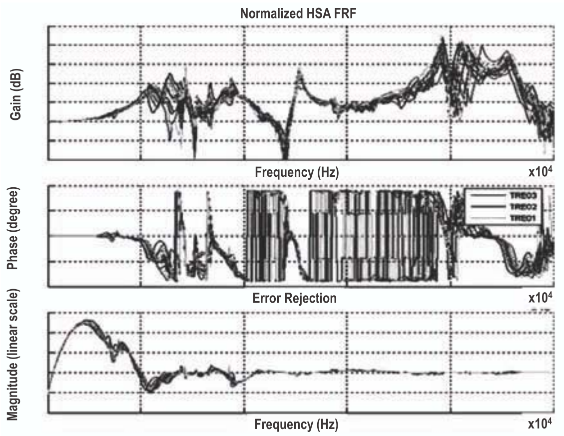


Fig. 14 Measurement result of HSA Resonance H0 of HSA using small APFA swage hole size.

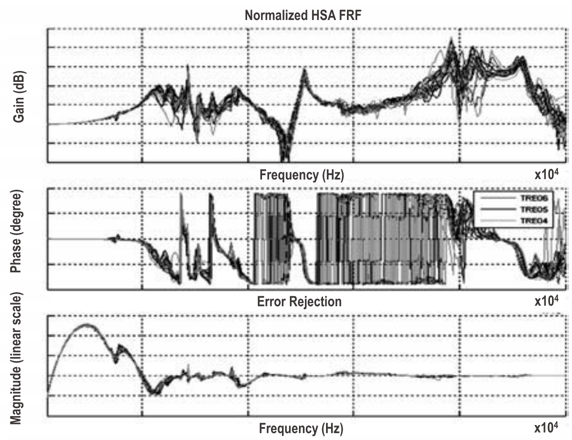


Fig. 15 Measurement result of HSA Resonance H0 of HSA using large APFA swage hole size.

e) Cross sections: Fig. 16 shows the enlargement of boss hub and mating area between outer surface of boss hub and APFA swage hole wall of HSA. Boss hub and mating area for used swage ball group and that using new swage ball are similar regardless whether using only 1 used swage ball (size A) or using both ball sizes. The results conform with the swage torque investigation stated previously.

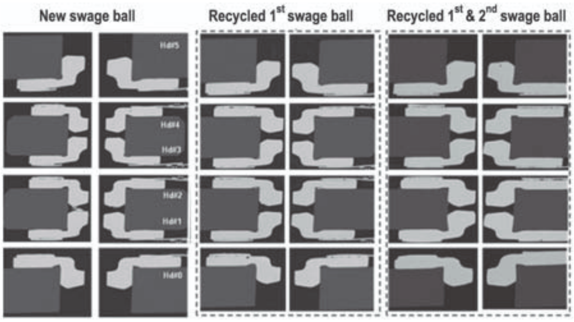


Fig. 16 Cross section of HSA using large APFA swage hole size.

6. Conclusion

The experimental results demonstrated that the change in roundness of used swage ball size B has infinitesimal impact on the KPOVs (Gram Load, Arm height, Swage torque) of HSA for both large and small APFA swage hole sizes. The average and standard deviation of KPOVs of HSA using used swage ball are comparable to HSA using new swage ball. However, using used swage ball for small APFA swage hole size in HSA processes induce more resonance variation compared to new swage ball groups. These variations are insignificant compared to HDD servo stability margin. The cross section examined also showed that the expansion of boss hub and the joint between outer surface of boss hub and APFA swage hole wall of HSA for the used swage ball group are well attached. The cross section for the used swag ball group is similar to cross section on the group using new swage balls. The technique to prevent change in swage ball roundness is subject to further investigation.

7. Acknowledgement

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8. References

1. Kamnerdtong, T., Chutima, S., and Ekintumas, K., 2005, "Effects of Swaging Process Parameters on Specimen Deformation", *The 8th Asian Symposium on Visualization*.

2. Wadhwa, S.K., 1996, "Material Compatibility and Some Understanding of The Ball Swaging Process", *IEEE*, Vol. 32, No. 3, pp. 1837-1842.

3. Montgomery, D.C., 2005, *Design and Analysis of Experiments*, 6th ed., Wiley, New York, pp. 160-254.

4. International Business Machines Corporation, Armonk, N.Y.(US), 2000, Etched/Lubricated Swage Balls for Use in DASD Suspension Arm, *United States Patent No. US 6,035,681*

5. Kenichiro Aoki and Keiji Aruga, 2007, "Numerical Ball Swaging Analysis of Head Arm for Hard Disk Drives", *Microsyst Technol,* 13:943-949, DOI 10.1007/s00542-006-0299-4.

6. Hertzberg R.W, 1996, *"Deformation and Fracture Mechanics of Engineering Material"*, 4th ed., John Wiley & Son, New York, pp. 48-49.

7. International Business Machines Corporation, Ball Staking of a Transducer Assembly Mounting Block to a Positioned Arm, *IBM Technical Disclosure Bulletin*, Vol. 18, No. 1, Jun. 1975, p. 22.