Shape Memory Alloy Micro-Actuator for Handling of Head Gimbal Assembly

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Abstract
This study proposes a methodology to design a shape memory alloy micro-actuator as a new handling device of Head Gimbal Assembly (HGA). The actuator consists of several finger-like Nitinol-and-Polyimide bimorph beams that are able to deflect at high temperature due to thermally induced strain mismatch between these two materials. To design the geometry of micro-actuator, various beam dimensions including lengths, widths and thicknesses are evaluated using ANSYS program. Furthermore, the contact force between micro-actuator and HGA is also studied. The simulation results suggest the feasibility of using the proposed micro-actuator for HGA handling application.

Keywords: *Head Gimbal Assembly, Micro Actuator, Shape Memory Alloy, Finite Element Method*

1 Introduction

In Hard disk drive industry, one of the key manufacturing processes is an assembly process of Head Gimbal Assembly (HGA) with an arm coil (Figures 1a-b). In general, a vacuum chuck handler is used to pull up and insert the HGA between base plates of the arm coil. After the HGA is attached with the arm coil using a ball swaging process, the vacuum chuck handler will release the HGA. However, this current technique encounters dead-end problems due to a tendency of miniaturization of the hard disk. Such problems are a vacuum leakage due to a misalignment between the vacuum chuck and a small pad on HGA, and long time interval to hold and release due to a requirement of lower vacuum pressure. To resolve such problems, the employment of micro-actuators is proposed since they are advantageous for handling small objects [1-11], and may be able to be extended to use in this assembly process. A number of actuation principles such as conductive polymer [1, 2], piezoelectric single crystal [3], electrostrictive polymer [4, 5] and shape memory alloy (SMA) [6-11] were proposed and implemented. Among these methods, SMA is outstanding since it can provide large stress and strain while requiring low operating voltage about 1-3 V which is desirable in hard disk drive industries as well as electronics manufacturing. This work aims to design and demonstrate the feasibility of using shape memory alloy micro actuator as a micro-gripper for HGA handling application. The effects of micro actuator dimensions on its deflection and force exerting on HGA are also investigated by using ANSYS software.

2 Design of micro-actuator

Shape memory alloy is referred to an alloy that restores its original shape when heated. At low temperature, the phase of the SMA material is martensite that is soft and deformed easily by external stress. However, by heating the material above its transformation temperature, the material experiences phase change from martensite to high strength austenite resulting in a restoring of material's original shape. In this work, a SMA micro-actuator is proposed to use as the gripper that consists of several finger-like bimorph beams as shown in Figure 2a. Nitinol (NiTi) and polyimide

(PI) polymer are selected for two layers of the bimorph beam. Polyimide is designed to be an underneath layer to avoid a direct contact between the NiTi layer and the HGA. The design helps preventing damages from heat and current leakage from the NiTi layer. When temperature is changed, the beam will be folded or unfolded due to the strain mismatch between two materials as shown a cross-sectional diagram of one pair of beams in Figure 2b. Various methods are used to control the beam's temperature. In this work, the direct Joule heating of NiTi layer is used to control the temperature of micro actuator by flowing current through the NiTi structure that is designed as a coil circuit as shown its top view configuration in Figure 2c. The operating procedures are briefly described as follows. Firstly, electric current is flowed through the NiTi coil resulting in an increment of beam temperature, and the beam then folds up due to the mismatch of thermally elongation between two materials. After that, the folded gripper will be inserted into the HGA boss hole, and then the electric current is released resulting in cooling down of beam temperature. When temperature is low enough, the gripper unfolds and presses down on an inner wall of boss hole. With exerting force, the gripper is able to hold and handle the HGA to assemble to the arm coil. For releasing step, the heat is applied on NiTi again. The gripper will be folded up and then moved away. This work aims to investigate the effects of beam length, width and thickness on folding deflections as well as magnitude of force exerting on the HGA wall, and find viable dimensions of micro-actuator for this application. All parameters are examined at 80°C that is not too high and feasible for hard disk drive industries. One criterion to assure its feasibility is a size of folding beam that is needed to insert into the boss hole whose diameter is about 1.30 mm. Another criterion is the exerting force of the unfolding beam on the inner wall of boss hole. Minimally, the force should be large enough to hold the HGA weight which is about 40 mg or 0.39 mN.

3 FEM analysis

3.1 Deflection

The static structural mode of ANSYS software is used to investigate the effect of micro actuator's dimensions on its folding deflection when temperature rises from room temperature about 25 to 80°C. In this analysis, the micro actuator is modeled as a NiTi (Ni:Ti composition = 1:1) and polyimide bimorph cantilever beam with one fixed end. The number of mesh is about 2,400 mesh (40x10x6 mesh) with mesh size of 0.25 to 37.5 µm. The deflection of NiTi and polyimide bimorph cantilever beam is a result of the strain mismatch between two materials due to temperature rising. Upon the temperature rise, shape memory alloys will have both elongation and shrinkage due to thermal effect and shape memory effect, respectively, while polyimide has only thermal elongation. To simplify the analysis, for NiTi material, the shrinkage due to shape memory effect and elongation due to thermal effect are combined together and represented as an equivalent thermal expansion coefficient. Basically, the coefficient of thermal expansion (CTE, α) of NiTi is equal to 9 ppm/°C. Thus, when the temperature rises from 25 to 80°C (ΔT = 55°C), the thermal compressive strain (ε) is given as

$$\varepsilon = \alpha.\Delta T, \qquad (1)$$

and the thermal compressive stress (σ_{CTE}) can be subsequently expressed as

$$\sigma_{CTE} = \varepsilon.E, \qquad (2)$$

where Young's modulus (E) of NiTi is equal to 75 GPa at 80°C.

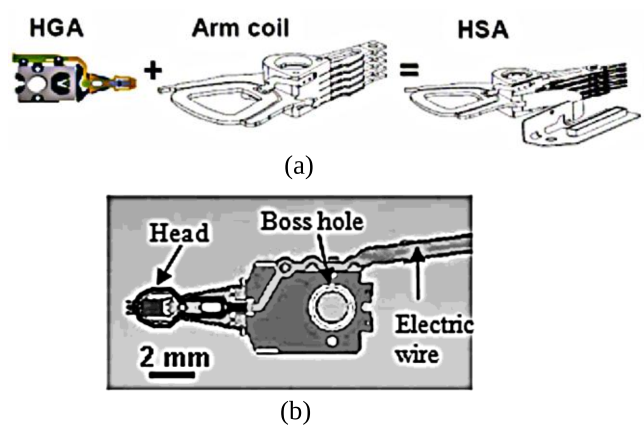
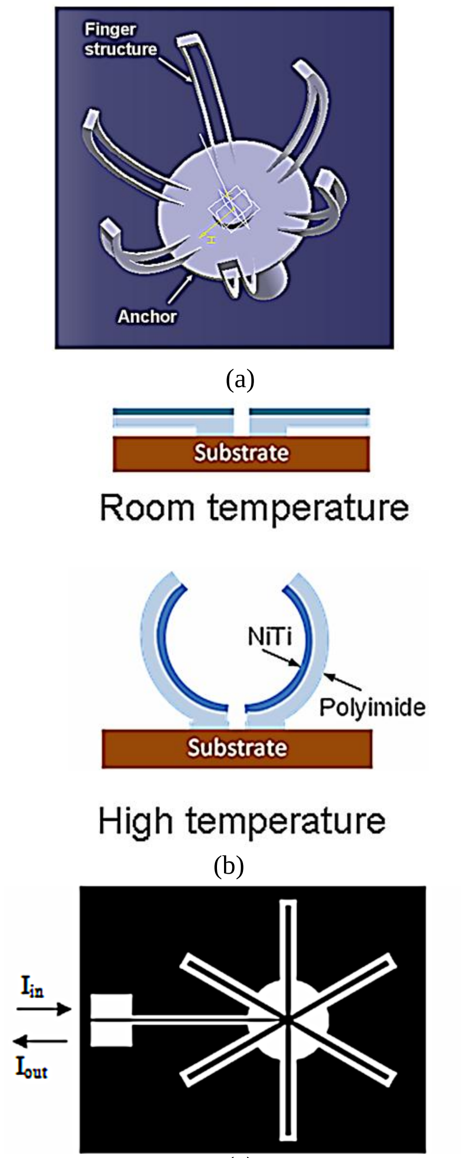


Figure 1: Assembly of HGA with an arm coil; (a) assembly process of Head Stack Assembly (HSA), (b) magnified image of HGA and its components.



(c)

Figure 2: Shape of designed finger-like SMA micro-actuator; (a) gripper's configuration, (b) cross sectional diagram of a single bimorph beam structure, (c) top view of NiTi coil circuit.

On the other hand, the shape memory effect will cause the increasing of tensile stress on NiTi from 50 MPa at 25°C to 400 MPa at 80°C [6] or the compressive stress (σ_{SME}) at 80°C is equal to -400 MPa. Thus, the total compressive stress (σ_{Total}) when heating from 25 to 80°C can be written as

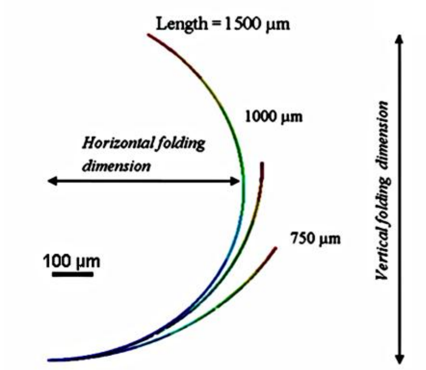
$$\sigma_{Total} = \sigma_{CTE} + \sigma_{SME} \tag{3}$$

As a result, the equivalent coefficient of thermal expansion (α_{eqv}) can be derived from

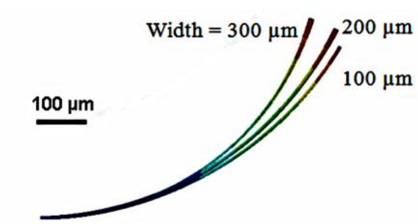
$$\alpha_{eqv} = \sigma_{Total}/(E.\ \Delta T) \tag{4}$$

From this model, the equivalent coefficient of thermal expansion of NiTi is equal to -88 ppm/°C while the coefficient of thermal expansion of polyimide is equal to 20 ppm/°C. In addition, Young's modulus of NiTi at 25 and 80°C are 30 and 75 GPa, respectively, while that of polyimide is 2.3 GPa. The examined parameters of actuator are length, width and thickness as mentioned earlier. In this study, the beam length is varied as 750, 1,000 and 1,500 µm, and the beam width is varied as 100, 200 and 300 µm. For thickness, the thickness of polyimide is varied as 5, 10 and 15 µm while that of NiTi is kept constant at 1 µm for all cases. Figures 3a-c show the folding shapes of various beam dimensions at the target operating temperature of 80°C. For 100 µm wide and 5 µm thick polyimide beams (Figure 3a), the increasing of beam length results in larger deflection in both horizontal and vertical directions as well as shorter radius of curvature. For 750 µm long and 5 µm thick polyimide beams (Figure 3b), only small difference in folding deflection is found when its beam width is varied from 100 to 300 µm. Moreover, thicker polyimide layer results in a smaller deflection for the beam length of 750 µm and width of 300 µm as shown in Figure 3c. The horizontal and vertical folding dimensions at 80°C are critical parameters in selection of beam dimensions for a given boss hole's diameter. The simulation results of the horizontal and vertical folding dimensions for all cases are summarized in Figures 4a and 4b, respectively. According to the results in Figure 4a, when the polyimide thickness is increased, the folding dimension in horizontal direction becomes larger for a given beam's width and length. In addition, for 5 µm thick polyimide layer, the horizontal folding dimension is not much different for all investigated beam lengths and widths, and the horizontal folding dimension is varied in the range between 500-700 µm for all cases. However, this deviation in the horizontal folding dimension for different beam lengths will be larger for thicker polyimide layer.

Unlike beam length and polyimide thickness, the change of beam width has relatively small effects on the actuator's horizontal folding dimension. However, at 5 µm polyimide layer, the effect of width is relatively large, and it shows that a wider beam has smaller horizontal folding dimension. The effects of beam's dimensions on its folding dimensions in the vertical direction at 80°C are similar with that in the horizontal direction as shown in Figure 4b. Briefly, it shows relatively small effects of width and strong effects of beam length and polyimide thickness on the folding dimensions.



(a)



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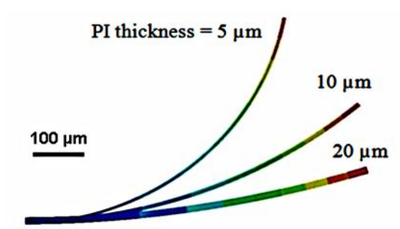
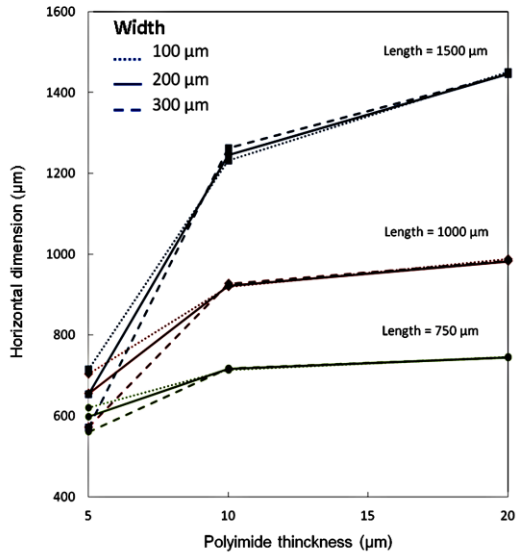
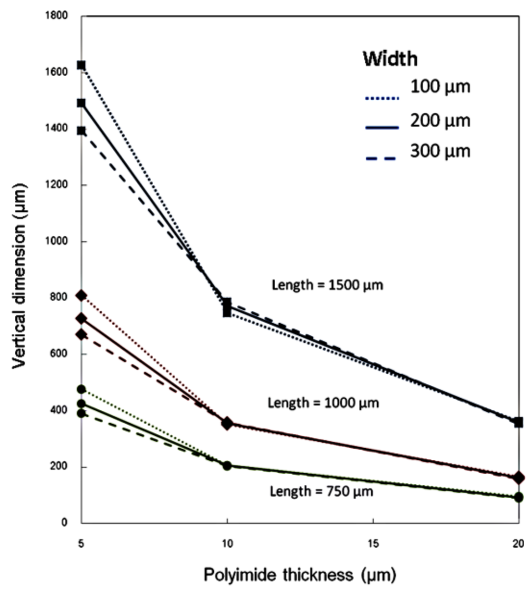


(c)

Figure 3: Folding shapes for various beams; (a) various lengths with the fixed width of 100 µm and polyimide thickness of 5 µm, (b) various widths with the fixed length of 750 µm and polyimide thickness of 5 µm, (c) various polyimide thicknesses with the fixed length of 750 µm and width of 300 µm (all cases have NiTi thickness equal to 1 µm).



(a)



(b)

Figure 4: Folding dimensions of micro-actuator for different lengths, widths and thicknesses; (a) horizontal folding dimension, (b) vertical folding dimension.

As mentioned earlier, one of the important constraints for selection of micro-actuator is the boss hole's diameter of 1.30 mm. Regarding this issue, the total folded gripper dimension should be smaller than 1,300 µm, i.e. the folding horizontal dimension of single finger should be shorter than 600 µm or 1,200 µm for two fingers, with a fixed anchor part on the substrate of 100 µm. From simulation results, only a few actuators with the dimensions (length x width x polyimide thickness) of 1,500 x 300 x 5 μm^3, 1,000 x 300 x 5 μm^3 and 750 x (200 or 300) x 5 μm^3 are small enough for this critical dimension when folding at 80°C.

3.2 *Contact force*

The force analysis is used to predict the contact force between the unfolding micro-actuator and HGA's inner wall of boss hole. This contact force will suggest the feasibility of using the designed micro-actuator as a handling device of HGA, and, as mentioned earlier, the target of the force magnitude is about 0.39 mN. For the simulations, the static structural mode is used with an initial shape of the cantilever beam as same with that from the results of Section 3.1. Figure 5 shows the simulation domain that consists of two objects, i.e. the curved cantilever beam and the vertical wall as a representative of the HGA wall. The actuator with the dimensions of 1,000 x 100 x 5 μm^3 is examined. Smaller mesh sizes are used in this analysis with overall mesh about 33,583 elements. A relatively denser mesh between two contact surfaces is provided in order to obtain accurate results. In the simulation, the temperature is decreased from 80°C to 25°C. During the temperature decreases, the beam unfolds and contacts onto the HGA wall, and the magnitude of exerting contact force is examined. From the analysis, it is found that the force is approximately equal to 1.6 mN from the single beam as shown in the simulation domain. This force is about four times higher than the HGA's weight. Therefore, this simulation result suggests that the micro-actuator with a few fingers is capable of handling of HGA. However, in real situation, the necessary force for handling the HGA will be changed for different orientations as well as motion conditions. Therefore, a further study should be conducted in order to examine a limitation of a usage in real situations.

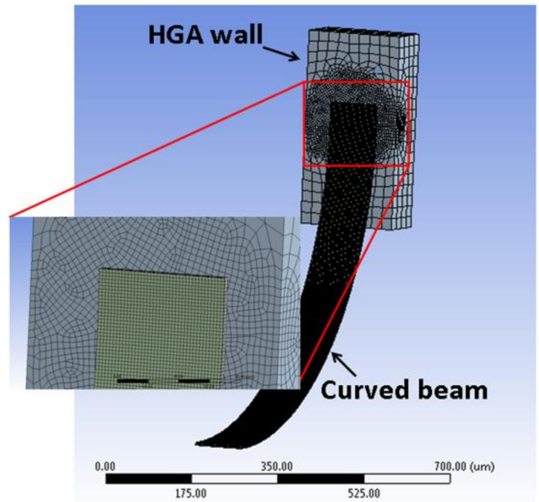


Figure 5: Simulation domain of contact force between micro-actuator and HGA.

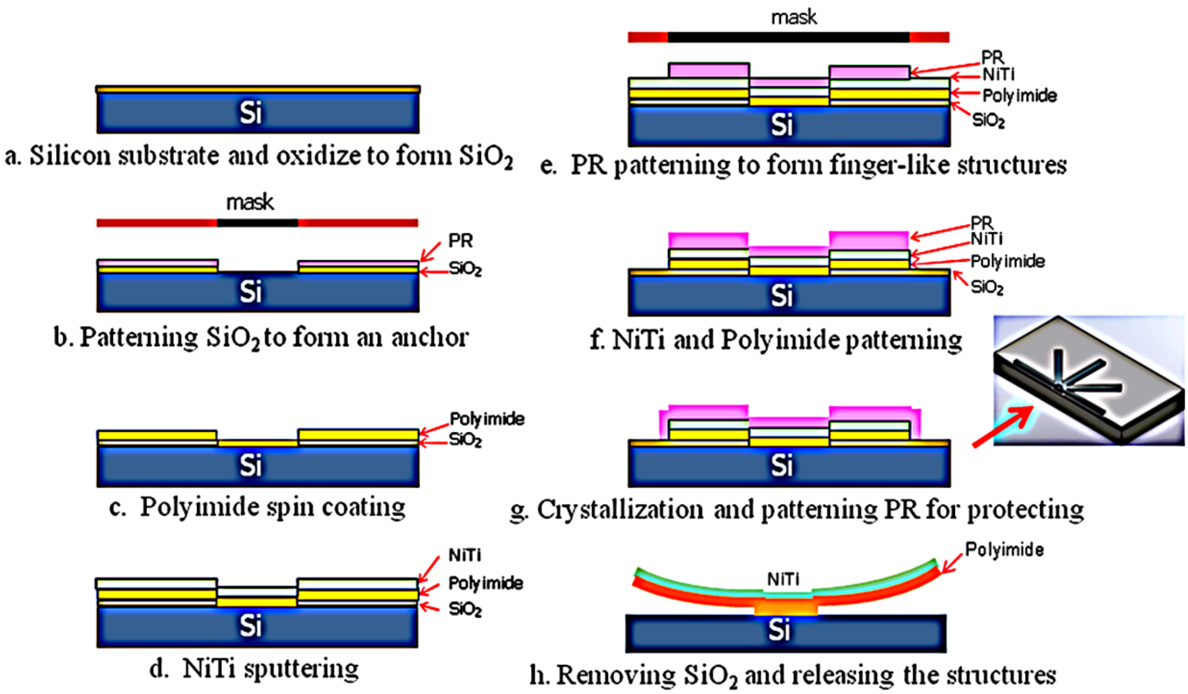
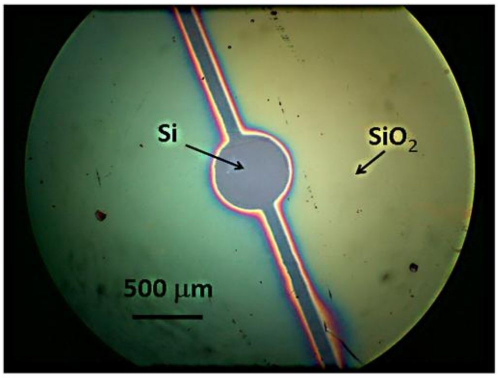


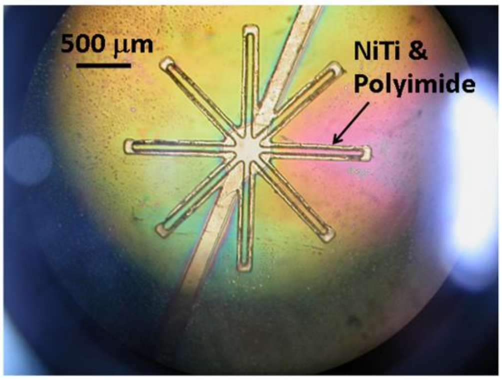
Figure 6: Micro fabrication processes for the proposed micro-gripper.

4 Fabrication process

The fabrication process is shown in Figure 6. It starts with cleaning a Silicon (Si) substrate, and oxidizing the substrate to form a 0.5-µm SiO_2 film as a sacrificial layer (Figure 6a). After that, a photolithography process is performed to form an anchor of the actuator finger on the substrate by etching SiO_2 layer with HF solution (Figure 6b). Polyimide is then spin-coated on the substrate, and followed by NiTi sputtering (see Figures 6c-d). After that, the finger-like structure of actuator is formed with photolithography process of photoresist (PR) and wet etching for NiTi and Polyimide, subsequently (see Figures 6e-f). Then, NiTi layer is crystallized at high temperature about 600°C for 30 min. Finally, the SiO_2 sacrificial layer is removed with an additional protective photoresist layer to release the actuator structure out of the Si substrate (see Figures 6g-h). However, in the real fabrication, Chromium (Cr) is employed instead of polyimide due to its ease of processing, low cost and availability. Several sizes of the actuator are manufactured in order to investigate a limitation of actuator sizes in the fabrication process. The current achievement of this fabrication is at a formation of NiTi and polyimide structure as shown magnified images in Figures 7a-b. Fabrication issues that were found are poor adhesion between two materials, irremovable sacrificial structure and oxidation of materials at high temperature. From the experiments, it suggests that larger cantilever beam is more difficult to successfully manufacture.



(a)



(b)

Figure 7: Magnified images of ongoing fabrication process; (a) SiO_2 layer patterning to form an anchor, (b) NiTi and Chromium structures after wet etching.

5 Conclusions

This work aims to develop a new method for handling of HGA in the assembly process by employing finger-like micro-actuators to grasp HGA at the boss hole. The proposed bimorph micro-actuator consists of two materials: shape memory alloy (NiTi) and polyimide. The working principle of this micro-actuator relies on the temperature control which induces the strain mismatch of these two materials resulting in the folding and unfolding of the micro-actuator. In this work, the deflection of the micro-actuators with a variety of beam dimensions at the target temperature of 80°C was simulated using a finite element program (ANSYS). The simulation was used to find the geometry of the actuator which can be inserted into the HGA boss hole with an inner diameter of 1.30 mm. Furthermore, the contact force between a micro-actuator and the HGA was also studied when it unfolds. The simulation results showed that the micro-actuators with beam dimensions (length x width x polyimide thickness) of 1,500 x 300 x 5 μm^3, 1,000 x 300 x 5 μm^3 and 750 x (200 or 300) x 5 μm^3 with NiTi thickness of 1 µm are able to be inserted into the HGA boss hole. Moreover, the contact force between the micro-actuator with dimensions of 1,000 x 100 x 5 μm^3 with NiTi thickness of 1 µm and the HGA boss hole was found to be approximately 1.6 mN. This study proposed the methodology to design a micro-actuator, and the simulations results suggest the feasibility of using the proposed micro actuator for HGA handling application.

Acknowledgments

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