SAND97-2835C
CONF-980514--

World Automation Congress '98, Anchorage, Alaska, May 10-14, 1998.

Micro-Grippers for Assembly of LIGA Parts

John Feddema, Marc Polosky, Todd Christenson, Barry Spletzer, Ron Simon[1]
Sandia National Laboratories
P.O. Box 5800, MS 1003
Albuquerque, NM 87185

ABSTRACT

This paper describes ongoing testing of two micro-grippers for assembly of LIGA (Lithographie Galvanoformung Abformung) parts. The goal is to place 100 micron outside diameter (OD) LIGA gears with a 50 micron inner diameter hole onto pins ranging from 35 to 49 microns. The first micro-gripper is a vacuum gripper made of a 100 micron OD stainless steel tube. The second micro-gripper is a set of tweezers fabricated using the LIGA process. Nickel, Permalloy, and copper materials are tested. The tweezers are actuated by a collet mechanism which is closed by a DC linear motor.

KEYWORDS: Robotics, Micro-grippers, Micro-manipulation, Micro-assembly

INTRODUCTION

Sandia is currently developing processes to make surface machined silicon and LIGA (Lithographie Galvanoformung Abformung) parts with 100 micron outside diameter (OD) and submicron tolerances for use in weapons surety devices. LIGA parts are of special interest because they can be made of metals which makes them stronger (in tension) than surface machined silicon, and also they can contain iron which allows them to be configured as miniature electromagnetic motors. The disadvantage of LIGA parts is that they must be assembled. The required precision, operator stress and eye strain associated with assembling such minute parts under a microscope precludes manual assembly from being a viable solution. An automated assembly system is needed.

There are several issues that cause micro-assembly to be a difficult assembly problem. As discussed in [1][2], the relative importance of the forces in microassembly is very different from that in the macro world. Gravity is almost negligible, while surface adhesion and electrostatic forces dominate. To some extent these problems can be reduced by clean parts and grounding surfaces. However, the effects of these forces are still visible during even the simplest of tasks.

To date, several different approaches to teleoperated micromanipulation have been attempted. Miyazaki [3] and Kayono [4] meticulously picked up 35 polymer particles (each 2 microns in diameter) and stacked them inside of a scanning electron microscope (SEM). Controlling the contact surface of a gold plated needle allowed them to pick up and release the particles. Mitsuishi [5] developed a teleoperated, force-

---

[1] This work performed at Sandia National Laboratories was supported by the U.S. Department of Energy under contract DE-AC04-94AL85000.

DISCLAIMER

reflecting, micromachining system under a SEM. Sulzmann [7] teleoperated a microrobot using 3D computer graphics (virtual reality) as the user interface.

Even with these efforts, grasping and releasing micron sized parts continues to be a largely unsolved problem. For some tasks, vacuum grippers appear to be adequate. Zesch [7] used a vacuum gripper to pick up 100 micron size diamond crystals and deposit them to arbitrary locations. However, for other tasks involving metallic parts with irregular shapes, more dexterous microtweezers are needed. Keller [8] developed a high aspect ratio molded polysilicon (hexsil) tweezers. These tweezers are actuated by in-situ phosphorous doped thermal expansion beams. Piezoresistive polysilicon strain gages are integrated into the tweezers for tactile feedback. Ballandras [9] developed LIGA fabricated micro-grippers. These tweezers where actuated with a PZT (piezoelectric transducer).

This paper evaluates two grasping techniques which are being used to place 100 micron OD LIGA gears with 50 micron inner diameter (ID) holes on LIGA posts with diameters ranging from 35 microns to 49 microns. The first technique uses a simple vacuum gripper with a pair of three-way valves which provide negative pressure to pick up the part and positive pressure to release the part. The second grasping technique is a LIGA fabricated tweezers which is actuated by a linear ball-and-screw DC motor and a collet style closing mechanism. These two techniques are discussed in the following two sections. Afterwards, our micro-assembly workcell is described along with experimental results. Finally, conclusions and suggested future research are presented.

VACUUM GRIPPER

The vacuum gripper used in our tests is a 304 stainless steel tube approximately 10 mm long and 100 microns in outside diameter. It is pressure fit into a brass housing. Air flow to create vacuum and force are supplied through the housing by an air line connected to the rear of the housing and a hole through the housing. The strength of the flow is controlled by a needle valve inline with the air line. The vacuum gripper exits the housing at an angle of approximately 30 degrees. This allows use of the vision system to monitor the location of the tip, and operations taking place when the parts are picked up or dropped.

Initial testing demonstrated high reliability in acquisition of the parts (permalloy gears with 50 micron ID, and 100 micron OD). Releasing of the parts was more difficult. In the absence of physical constraints in the drop location, the quantity of flow required to blow the part off the tip guaranteed the part would be blown far from the desired drop point. This did not seem consistent with the ease with which the part was acquired, using very little vacuum pressure to pick it up.

To test the possibility that other forces were responsible for part acquisition, the vacuum was turned off during part acquisition. The vacuum gripper was positioned above the part. Incremental (10 micron steps) approaches to the part were used to determine if acquisition was possible through contact forces when the gripper touched the part. Part acquisition occurred approximately 50 microns above the part. This test was repeated several times with the same result. Further investigation showed the vacuum gripper was magnetic.

Although 304 stainless is supposed to be non-magnetic, it appears a permanent magnetic field was introduced onto the tubing when it was manufactured, possibly when cold drawn. We have begun to search for non-magnetic materials to be used as tubing, concentrating at this point on glass. The required size of the tubing is a severe constraint, but we believe it can be found in the medical community.

LIGA FABRICATED TWEEZERS

The second grasping technique utilizes a LIGA fabricated tweezers, a linear ball-and-screw DC motor, and a collet style closing mechanism (see Figure 1). For those unfamiliar with a collet, a brief description is provided. A collet is a holding fixture normally used in a lathe to constrain raw stock for machining. It is best described as a tube split longitudinally along two thirds its length into three equal sections. The end of the tube that is split has an external taper while the other end is treaded externally. A sleeve with an internal taper is fitted over the treaded end of the tube and engages the tapered split ends. As the sleeve is advanced, the three equally-spaced split sections move radially inward thus providing a clamping mechanism for material positioned inside the tube.

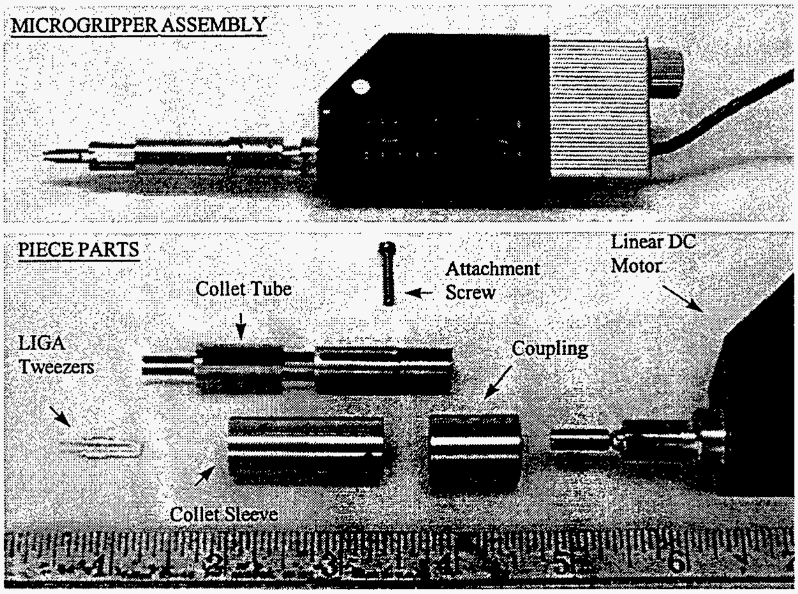

Figure 1. Micrognipper.

The tube used in the collet mechanism has two split ends versus three. As the sleeve is advanced forward, the split halves move directly toward each other, similar to a closing pair of tweezers. As the sleeve is advanced in the reverse direction, the split halves reopen (see Figure 2). Machined into the tips of the spit halves are features used to constrain a smaller pair of tweezers fabricated using the LIGA process. The LIGA process enables the fabrication of an infinite number of tweezer variations (with submicron tolerances) at a moderate price. Many variations of LIGA tweezers can be interchangeably used with this collet mechanism. Thus tweezers can be fabricated for easy manipulation of parts with unique profiles. Parts ranging in size from several millimeters to tens of microns can be handled (this part size range was a requirement for this design).

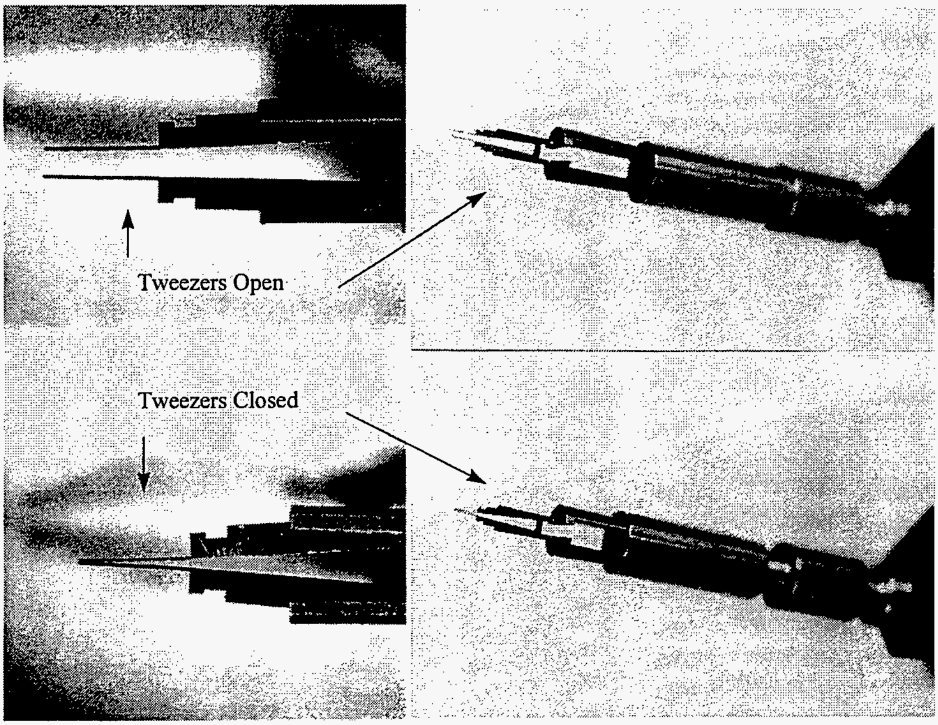

Figure 2. LIGA Tweezers.

A Newport 850F HS linear DC motor is used to hold the collet tube and drive the collet sleeve. The encoder resolution is 0.59 microns. Maximum speed is 4750 mm/sec, and maximum axial load is 2.3 kg. Backlash is listed as less than 15 microns and bidirectional repeatability is better than one micron when backlash is compensated by the controller. For a 1.5 degree collet taper, a value for the resolution in the gripping direction is calculated to be 0.025 microns (see Figure 3 and Equation (1) below).

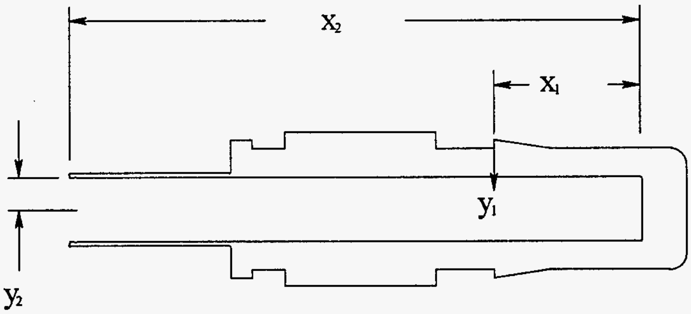

Figure 3. LIGA Tweezer.

$$y_2 = \frac{x_2}{x_1} y_1 = \frac{x_{grip}}{x_{collet}} \Delta X \tan(\theta) \tag{1}$$

where: x_1 = 13.1 mm
x_2 = 21.1 mm
y_1 = $\Delta X \tan(\theta)$ (Displacement of Collet)
ΔX = 0.59 mm (DC Motor Resolution)
θ = 1.5 deg. (Collet Tube Taper)
y_2 = Resolution in the Gripping Direction

To accommodate interchanging tweezers, a tweezer tool holder has been designed (see Figure 4). The holder will accommodate six different tweezer designs and enable the tweezers to be loaded robotically. The tweezers are first driven closed, inserted into the tool holder, and then driven to the halfway open position. A notch on the front end of the tweezer is captured in a slot located inside the tool holder. The collet mechanism is then driven to the fully open position, which releases the tweezers, and withdrawn from the tool holder. To load a new pair of tweezers, the process is repeated in the reverse order.

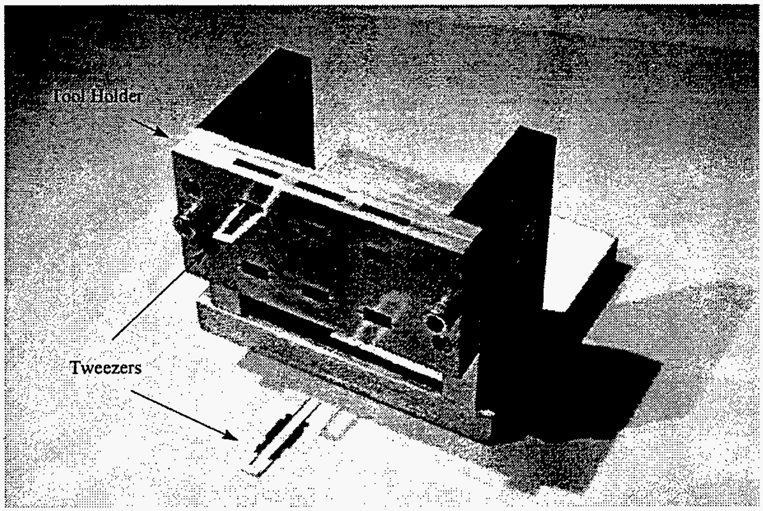

Figure 4. LIGA Tweezers Tool Holder.

Three materials have been used to fabricate the LIGA tweezers: copper, nickel, and Permalloy 78/22 (78%Nickel, 22% Iron). Permalloy possesses the best mechanical properties and functions best mechanically; while copper is nonmagnetic and eliminates adverse effects due to residual magnetism inherent in Permalloy and nickel parts.

In experimental tests, we have demonstrated the ability to pick up and stack LIGA and polysilicon gears using these tweezers. Initially, machine vision was the only method of detecting when the gear is inside the tweezers. Since there was no force feedback, it was very difficult to estimate how good of a grasp was being made. Recently, micro-strain gauges have been added to the tweezers' fingers to eventually detect when a part is grasped and to help guide the gear onto the post.

Thin film silicon strain gauges were fabricated onto each finger of the LIGA tweezers. The physical size of the strain gauges required that the width of the surface, where the strain gauges were mounted, be at least 200 microns. Because of this restriction, we had to settle with mounting the strain gauges on the top and bottom of each tweezer finger approximately 6 mm from the ends of the finger tips. While this precludes force sensing in the directions required for grip detection, it does provide sensing which can be used when approaching the working surface in a guarded move. Thirty-eight gauge single stranded wire is jumpered from the strain gauges to pads on the fingers of the tweezers. The bridge is completed, balanced and temperature compensated using a small PC board and a 22 cm pigtail from the pads. Power (5Vdc) and ground is applied to the PC board, and the bridge output is fed to an input A/D amplifier for sampling and detection. Software was written to poll the A/D output and provide certain types of motion interrupts as required.

The force sensor was tested by positioning the tweezers slightly above the surface of a glass slide holding several of the desired parts. The gripper was incrementally lowered to the glass surface, while readings were taken from the force sensor at each location. Figure 5 shows the force measured as a function of position. The tweezers act as a cantilevered beam as they are pushed against the glass surface. The apparent spring constant of the tweezers during the guarded move is 39 N/m. We are currently fabricating tweezers which are 200 microns thick and will allow strain gages to be mounted perpendicular to the grasping direction. These strain gauges will be used to measure the grasping force.

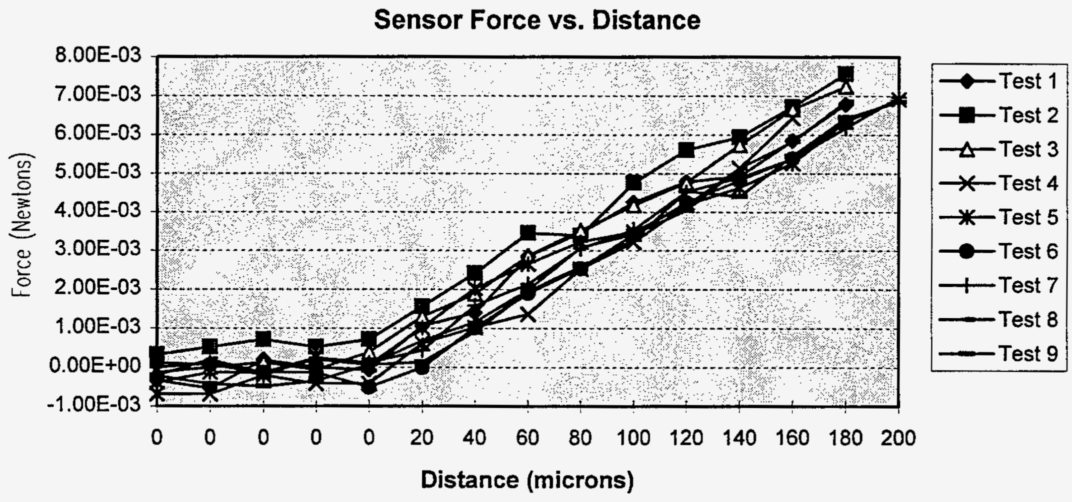

Figure 5. Measured Force vs. distance.

MICRO-ASSEMBLY WORKCELL

Our microassembly workcell consists of a 4 DOF (Degree of Freedom) AdeptOne robot arm, a 4 DOF precision stage, micro-tweezers, and a long distance microscope (see Figure 6). The AdeptOne has a repeatability of 25 microns and is thus used as a gross motion device. The precision stage has a repeatability of approximately 1 micron and is used for fine motion. The microscope is fixed above the stage and has an electronically adjustable zoom and focus.

During assembly operations, the AdeptOne positions the micro-tweezers above the stage and within the field of view of the microscope. The precision stage is used to move the LIGA parts between the fingers of the tweezers. The tweezers are closed on the part, the stage is lowered, and the mating part on the stage is brought into the field of view. The stage is then raised into position and the part in the tweezers is release.

A teleoperated interface was developed to test simple pick and place operations. The AdeptOne, the 4 DOF precision stage, the tweezers, the vacuum gripper, and the focus, magnification, and lighting of the microscope are controlled through a custom developed user interface built within the Adept A-series VME controller. The image as seen by the microscope is displayed on the computer screen. The x and y position of the robot and stage are controlled by the operator by dragging a cursor on the graphical display. Sliders are used to control the z position and theta orientation of the robot and stage as well as the microscope focus, magnification, and lighting.

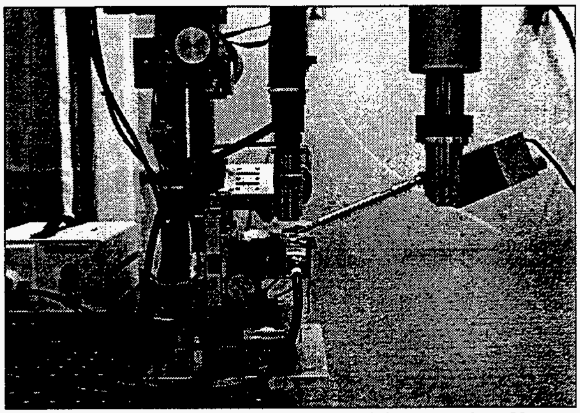

Figure 6. Micro-Assembly Workcell.

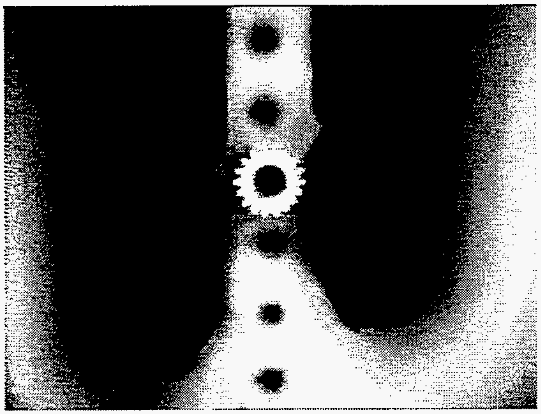

Figure 7. LIGA tweezers placing LIGA gear on a 44 micron OD shaft.

This teleoperated interface has been used to pick up and place 100 micron OD LIGA gears with 50 micron holes on pins ranging from 35 to 49 microns (see Figure 7). To date, we have manually placed a LIGA gear on a 44 micron pin using the teleoperated interface. The main difficulty we are encountering is that the LIGA pins are easily removed from the substrate. Because of the way the wafer holding the pins is processed, only 0.05 microns of metal holds the pins to the substrate. As an alternative, we are investigating the use of inserting conventionally machined pins into a LIGA-fabricated pegboard.

In addition, we are also working on automating the assembly sequence by using CAD information about the parts to generate reference control features. We have written an image synthesizer which generates synthetic microscope images using Fourier optics [10]. These synthetic images are used off-line to test and evaluate image processing routines which will be used during the assembly. An augmented assembly plan which includes the reference image features is then downloaded to the robotic system where it is executed.

CONCLUSIONS

Experimental tests show that the LIGA tweezers is currently a better choice for manipulating the LIGA parts than the vacuum gripper. Even if the material of the vacuum gripper could be made nonmagnetic, the LIGA tweezers have the following advantages. First, by picking up the part from the side, the tweezers allow a machine vision system to view the parts from above and make fine adjustments to their position. Second, strain gages can be fabricated onto the tweezers, thus allowing the grasping force to be monitored and controlled. Third, the collet arrangement allows the robotic system to change tweezer geometries for the particular task at hand. However, there are still several areas which could be improved. First, material composition and coatings should be chosen to reduce sticking effects caused by surface tension, Van der Waals forces, electrostatics, and electromagnetics. Second, the DC linear motor is oversized for the task and contains some backlash in it's gearbox. In the future, it could be replaced by a more compact motor or a PZT actuator as in [9]. These are improvements that we will continue to pursue.

REFERENCES

[1] R. Arai, D. Ando, T. Fukuda, Y. Nonoda, T. Oota, "Micro Manipulation Based on Micro Physics - Strategy Based on Attractive Force Reduction and Stress Measurement," *Proc. of ICRA 1995*, pp. 236-241.
[2] R.S. Fearing, "Survey of Sticking Effects for Micro Parts Handling," *Proc. of IROS '95*, Pittsburgh, PA, August 1995, Vol. 2, pp. 212-217.
[3] H. Hiyazaki, T. Sato, "Pick and Place Shape Forming of Three-Dimensional Micro Structures from Fine Particles," *Proc. of ICRA 1996*, pp. 2535-2540.
[4] K. Koyano, T. Sato, "Micro Object Handling System with Concentrated Visual Fields and New Handling Skills," *Proc. of ICRA 1996*, pp. 2541-2548.
[5] M. Mitsuishi, N. Sugita, T. Nagao, Y. Hatamura, "A Tele-Micro Machining System with Operation Environment Transmission under a Stereo-SEM," *Proc. of ICRA 1996*, pp. 2194-2201.
[6] A. Sulzmann, H.-M. Breguett, J. Jacot, "Microvision System (MVS): a 3D Computer Graphic-Based Microrobot Telemanipulation and Position Feedback by Vision," *Proc. of SPIE Vol. 2593*, Philadelphia, Oct. 25, 1995.
[7] W. Zesch, M. Brunner, A. Weber, "Vacuum Tool for Handling Microobjects with a Nanorobot," *Proc. of ICRA 1997*, pp. 1761-1766.
[8] C.G. Keller, R.T. Howe, "Hexsil Tweezers for Teleoperated Micro-Assembly," *Proc. MEMS97*, 1997.
[9] S. Ballandras, S. Basrour, L. Robert, S. Megtert, P. Blind, M. Rouillay, P. Bernede, W. Daniau, "Micrograppers fabricated by the LIGA technique," Sensors and Actuators A 58 (1997) 265-272.
[10] J.T. Feddema, C.G. Keller, R.T. Howe, "Experiments in Micromanipulation and CAD-Driven Microassembly," *Proc. of SPIE Vol. 3209*, Pittsburgh, Oct. 14-15, 1997.

M98001266

Report Number (14) SAND--97-2835C

CONF-980514--

Publ. Date (11) 199711

Sponsor Code (18) DOE/CR, XF

UC Category (19) UC-900, DOE/ER

DOE