Feeding of Submillimeter Microparts Along an Asymmetric Fabricated Surface by Double-Pulsed Femtosecond Laser Process

Atsushi MITANI1, Toshiatsu YOSHIMURA2, and Shinichi HIRAI3

1 Department of Design, Sapporo City University, Sapporo, Japan (Tel : +81-11-592-2300; E-mail: a.mitani@scu.ac.jp)
2Department of Robotics, Ritsumeikan University, Kusatsu, Shiga, Japan (Tel : +81-77-566-1111; E-mail: hirai@se.ritsumei.ac.jp)

Abstract: We previously showed that microparts can be fed along a saw-toothed surface using simple planar symmetric vibrations. Microparts move forward because they adhere to the saw-toothed surface asymmetrically. We used saw-toothed silicon wafers fabricated by a dicing saw applying bevel type blades. We then studied the movement of 0402-type capacitors (size: 2.0 × 1.2 × 0.6 mm, weight: 7.5 mg) and 0603-type capacitors (size: 0.6 × 0.3 × 0.3 mm, weight: 0.3 mg). In this study, we assessed the movement of smaller 0402-type capacitors (size: 0.4 × 0.2 × 0.2 mm, weight: 0.1 mg). A femtosecond laser process was used to fabricate an asymmetric surface. The characteristics evaluated were the differences in profiles of both inclined surfaces, the effect of adhesion decrease, and the friction angle of the 0402-type capacitors in both directions. Using the results of feeding experiments of these capacitors, we assessed the relationship between driving frequency and feeding velocity.

Keywords: asymmetric surface, microparts, unidirectional feeding, femtosecond laser process

1. INTRODUCTION

Devices to feed microparts, such as ceramic chip capacitors and resistors, have become more common, due to their use in sorting mass produced microparts. We have previously shown that a saw-toothed surface with simple planar and symmetric vibrations can be used to feed microparts (Fig. 1) [2]. Because of the difference in the area of surface contact of a micropart with the sloping side of a tooth and with the other side, microparts adhere more strongly in one direction than in the other. This results in the microparts moving in one direction, since adhesion is caused by electrostatic, van der Waal’s, and intermolecular forces, surface tension, humidity, and inertia, all of which influence the motion of the microparts [2]. Previously, we performed feeding experiments with 2012-type capacitors (size: 2.0 × 1.2 × 0.6 mm, weight: 7.5 mg) and 0603-type capacitors (size: 0.6 × 0.3 × 0.3 mm, weight: 0.3 mg) using saw-toothed surfaces with micro-fabricated silicon wafers. The dicing saw, high precision cutting and grinding tool, was applied to process the surfaces by bevel type diamond blades according to each surface profile.

In the present study, we investigated the effect of an asymmetric micro-fabricated surfaces by a femtosecond laser processing tool on the feeding of smaller 0402-type capacitors (size: 0.4 × 0.2 × 0.2 mm, weight: 0.1 mg). The double-pulsed femtosecond laser irradiation technique was used to create asymmetry of the micro-fabricated surface. Following inspection of the micro-fabricated surface by the atomic force microscope (AFM) system, we designed a three dimensional (3D) model of the micro-fabricated surface, and assessed the asymmetry by processing profile models derived from the 3D model. We also evaluated the tribological characteristics of the micro-fabricated surface relative to environmental parameters, especially ambient humidity. The angle of friction of the 0402-type capacitors were examined in both directions under different humidity, as well as the effect of adhesion decrease of the micro-fabricated surface compared with a no-fabricated surface. Finally, we performed feeding experiments of 0402-type capacitors by the micro-fabricated surface. We then showed the relationship between driving frequency and vibration frequency, as well as the effect of feeding velocity on feeding stability.

2. RELATED WORKS

The most popular partsfeeders are vibratory bowl-types [1], which use revolving vibrators to move parts along a helical track on the edge of a bowl. Linear feeders as well as an inclined mechanism and oblique vibrations for unidirectional feeding [1], have also been developed. In all of these systems, the aspect ratio of the horizontal/vertical vibrations must be adjusted to prevent parts from jumping. In our system, however, this adjustment is not necessary because only horizontal vibration is used.

A parts feeding method that employs non-sinusoidal vibrations [2], [3] has been developed. The part moves...
to its target position and orientation or is tracked during its trajectory by using the difference between the static and sliding frictional forces. Our system realizes unidirectional feeding by symmetric vibration of a saw-tooth surface, which yields different contact forces in the positive and negative directions.

Although distributed manipulation systems, using micro-sized air nozzles [?], ciliary systems [?], and vector fields [?], have been evaluated, the dynamics of microparts have not, including the effects of adhesion forces on the motion of the microparts.

The objective of our research was to examine the dynamics of microparts tens or hundreds of micrometer in size. We found that the motion of these parts depends on both inertial and adhesion force.

3. ANALYSIS OF THE MICRO-FABRICATED SURFACE

The feeder surfaces consist of a shim tape, a stainless material 0.5 mm in thickness, 10 mm in width, and 33 mm in length. To process a feeder surface with an asymmetrical profile, we used the double-pulsed femtosecond laser beam irradiation technique. In this technique, a single axis femtosecond laser beam is divided into two by a splitter. One side of the beam has an angle of 20° and a delay of 50 ps. Transpiration of the surface of the material starts 50 ps after irradiation by the first beam. By irradiating with the second beam at the same time, transpiration recoil forces shift in the direction of the incidence angle of the second beam, thus generating an asymmetric surface. Fig. ?? shows a microphotograph of the micro-fabricated surface using the AFM system. There were many periodic convexities on the surface of the material. Analysis of the microphotograph yielded the obtained surface profiles as shown in Fig. ??, The period of the feeder surface was about 0.92 µm and the groove depth as 0.17 µm. The roughness at the top of these convexities was about 0.025 µm. We examined the asymmetry of the feeder surface by evaluating inclinations of both sides of each convexity. Fig. ?? shows the profiles of some of these convexities. As shown in Fig. ??, each convexity could be approximated by the polynomial:

\[ y(x) = a_4x^4 + a_3x^3 + a_2x^2 + a_1x + a_0, \]  

where \( x \) and \( y \) indicate the position and height in Fig. ??, respectively.

To examine the asymmetry of these convexities, we calculated the inclinations of these approximation functions by solving their differential. Each approximation function was transformed to be the maximum value at the position \( x = 0 \) µm. Fig. ?? shows the inclinations around the maximum points of these approximation functions. The averaged inclination was \( y' = 0.43 \) at the position \( x = -0.25 \) µm, while it was \( y' = -2 \) at the position \( x = 0.25 \) µm, indicating that the inclination of the convexity was greater on the right side than the left. That is, the micro-fabricated surface had asymmetry that differed by 32% between the two sides of the convexity.

4. ANGLE OF FRICTION OF 0402-TYPE CAPACITOR

To evaluate directionality, experiments were performed three times using 35 capacitors in the positive and negative directions. For comparison, similar experiments were performed using a non-fabricated surface with only one direction because this surface has no directionality. We put capacitors on these surfaces, which were inclined until these capacitors fell. We then measured the angle of incline at which each capacitor started to fall. Some capacitors, however, remained even when the angle of incline exceeded 90°.

Environmental factors, including ambient humidity and temperature, as well as, van Der Waal’s force and electrostatic forces, can effect adhesion, and also affect the movement of submillimeter-sized or smaller microparts. We therefore performed experiments at 50 %, 60 %, and 70 % ambient humidity and at a temperature of 24 °C. All experimental equipments and capacitors were equilibrated for one day in a sealed room at the desired humidity.

The experimental results are shown in Figs. ?? and ???. To estimate the effect of fabrication on adhesion, we compared the number of capacitors that fell. Despite the ambient humidity, this number was higher on micro-fabricated than on non-fabricated surface. For example, at 60% ambient humidity, 43 capacitors fell from the non-fabricated surface, while the number of capacitors that fell on the micro-fabricated surface was 50 ps.
fabricated surface, whereas 65 and 61 capacitors fell from the micro-fabricated surface inclined in the positive and negative directions, respectively. These results indicate that micro-fabrication leads to decrease adhesion, due to the decrease in contact area between a feeder surface and micropart.

We next assessed the effect of ambient humidity on adhesion. The number of fallen capacitors at 50 %, 60 %, and 70 % ambient humidity was 41, 43, and 25, respectively. When we assessed the difference between non-fabricated and micro-fabricated surfaces at these, we found that the ratio at 50 %, 60 %, and 70 % ambient humidity was 193 %, 147 %, and 154 %, respectively. Therefore, both adhesion of the micro-fabricated surface and the decrease in adhesion caused by micro-fabrication was smallest at 60% ambient humidity.

When we evaluated the effect of ambient humidity on directionality of the angle of friction, we found that, at 50 %, 60 %, and 70 % humidity, the angle of friction in the positive direction was 1.6 %, 24 %, and 14 % smaller, respectively, than the angle in the negative direction. Although there was directionality regardless of humidity, little was observed at 50 % humidity, whereas it was maximum at 60 % humidity.

5. FEEDING EXPERIMENTS OF 0402-TYPE CAPACITOR

Using a micro-fabricated shim tape, we performed feeding experiments of 0402-type capacitors. Fig. ?? shows the relationship between driving frequency and feeding velocity of capacitors at driving frequency $f = 120.5, 121.0, \cdots, 126.5$ Hz and a vibration amplitude $A = 0.5$ mm. Experiments at each frequency were performed four times using 10 capacitors under ambient humidity of 70 % and temperature of 25°C. The symbol represents each averaged velocity, and the symbol $\times$ represents measured velocity. We used a digital video camera at 30 fps to record the movement of the capacitor. Velocity was calculated by counting the number of frames it took for a micropart to move 33 mm along the micro-fabricated surface. In addition, the variance of velocity
velocity [mm/s]

\begin{array}{c}
2.0 \\
4.0 \\
6.0 \\
8.0 \\
\end{array}

\begin{array}{c}
120.0 \\
122.0 \\
124.0 \\
126.0 \\
0.0 \\
\end{array}

capacitors. We performed feeding experiments on 0402-type capacitors using the micro-fabricated surface, and then verified the relationship between feeding velocity and driving frequency. We also verified the variance in measured velocities to determine steadiness of feeding.

Future studies will include:

- optimization of the processing parameters of the double-pulsed femtosecond laser irradiation technique to obtain more appropriate surface for feeding,
- derivation of dynamics including adhesion based on contact model estimated by measurements, and
- simulation of feeding of 0402-type capacitors and comparison with the experimental results to evaluate the derived dynamics.

**REFERENCES**


