Advanced Materials Research Vol. 740 (2013) pp 99-104
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.740.99

Experiment of Micro-parts Feeding on Saw-tooth with the Effect of the Surface Geometry Parameters

Phuong Hoai Le [1, a], Thien Xuan Dinh [2, b], Atsushi Mitani [3,c], and Shinichi Hirai [1,d]

[1] Robotics Dept., Ritsumeikan Uni., Kusatsu, Shiga, 525-8577, Japan

[2] Fluid Dynamics Dept., Ritsumeikan Uni., Kusatsu, Shiga 525 – 8577, Japan

[3] Design Dept., Sapporo City Uni., Sapporo-Hokkaido, 005-0864, Japan

[a]gr0081se@ed.ritsumei.ac.jp, [b]thien@cfd.ritsumei.ac.jp, [c]a.mitani@scu.ac.jp, [d]hirai@se.ristumei.ac.jp

Keywords: Micro-parts Feeding, Saw-tooth Surface Feeder, Experiment.

Abstract. In this work, we study experimentally the effect of the geometry parameters of saw-tooth surface and micro-part on the motion of micro-parts. The experiments are performed for a range of saw-tooth pitch, *p*, micro-part length, *l*, and exciting frequency applied to the surface, *f*. By the use of particle tracking velocimetry method, we can achieve time-dependent velocity, and then ensemble-averaged velocity of the micro-parts. The results show that for different *l* and *p* but the same relative scale *l*/*p*, the profiles of micro-part velocity against the characteristic surface velocity *pf* are similar. However, they shift along *pf* axis depending on *p*. Furthermore, the profiles are the similar for the relative scale *l/p* of 4 to 100. It seems that the motion of micro-part depends on characteristic surface velocity *pf* than the relative scale *l*/*p* for *l*/*p* larger than a certain value.

Introduction

In the micro-assembly, automatically controlling and orienting micro-objects (i.e. ceramic chip capacitors and resistors) play an important role. Therefore, the transportation of micro-parts has received considerable scientific attention.

In transporting micro-parts, the working principle is relied on creating an asymmetrical force on the micro-parts. According to [1], there are three such principle asymmetries. First principle is the fast/slow driving of the plate in the horizontal plane (*x-y-yaw*) in which the asymmetry is in the time of slipping in one direction versus another to create a net frictional impulse on the part over a cycle. By using this principle, micro-parts can move in different directions on the one-degree-of-freedom linear conveyors [2], [3] and a planar (*x-y-yaw*) shaker plate [4], [5]. The second principle is the simultaneous driving of the plate in the horizontal plane (*x-y-yaw*) and out of the horizontal plane (*z-roll-pitch*). This principle is used in the asymmetry in the linear vibratory conveyors [3], [6] and programmable linear motion cells [7] where the asymmetrical force arises from the changing normal force over a cycle due to the time-varying out-of-plane acceleration. The third principle, an anisotropic texture of the support plate, is exploited by Mitani *et al.* on linear vibratory transport of small electrical components [8-12]. They proposed a micro-part feeder that has asymmetric structure on a surface. The micro-parts are moved in one direction with only horizontal oscillation. Their study was carried out for individual change of saw-tooth geometry parameters, exciting frequencies. They also examined the motion of micro-parts on different profiles of the asymmetric structure which are achieved by the ability of fabricated technologies.

In the previous work [13], we have investigated the effect of profile of saw-tooth surface on the motion of micro-parts. The dynamic planar motion of the micro-parts on different asymmetrical structure profiles was analyzed by particle tracking velocimetry (PTV) method. We found that micro-part can move better on the surfaces which have the asymmetrical structure profile closer to saw-tooth shape. The dynamic of micro-part have also investigated, including two linear motions and rotation orientation, using an experimental procedure and a proposed simulation model [14].

In this work, we focus on the use of saw-tooth asymmetric structure surface to transport micro-parts. The effect geometry parameters such the micro-part length *l*, pitch of saw-tooth profile *p*, and frequency *f*, on the velocity of micro-part is investigated. These parameters are considered in a combining manner as relative scale *l*/*p*, and surface characteristic velocity *pf*. We conduct the experiments for different size micro-part's length *l* = 0.4mm, 1.0mm on the uniform sub-millimeter saw-tooth surfaces which are fabricated accurately *Mitani at el.* [15]. The pitches of saw-tooth are added the pitch. The surface is selected so that the asymmetric structure profile is closed to saw-tooth profile. The time-dependent micro-part velocity is measured by the particle tracking velocimetry technique.

Experiment

Experiment Surface. The asymmetric structures of the surface considered in this work have different pitches depending on the fabrication technologies such as dicing or etching process as in Figs. 2(a) and (b). These selected asymmetric structures are the closest to the ideal saw-tooth profile which has been proved that it can transport the micro-parts better than other profiles [13]. The profile shown in Fig. 2(a) is in trapezoidal shape. However, it has asymmetric characteristic as the profiles shown in Fig. 2(b)-(d), since the flat portion of Fig. 2(a)'s profile has negligible asymmetric effect on the motion of micro-parts. Therefore, we assume that all profiles have the same saw-tooth profile.

We performed experiment on several micro-parts with different size such as ceramic chip capacitors 0402 ($l \times w \times h$ = 0.4 × 0.2 × 0.2 mm), 0603 ($l \times w \times h$ = 0.6 × 0.3 × 0.3 mm), and 1005 ($l \times w \times h$ = 10 × 0.5 × 0.5 mm), where *l*, *w*, and *h* are length, width, and depth of the capacitors respecting to *x*, *y*, and *z* direction. The *x*-direction is defined along the vibration motion of the surface. The *z*-direction is normal direction of the surface.

The considered parameters are micro-part length, pitch of saw-tooth, and exciting frequencies. We assume that the asymmetry effect of all saw-teeth covered by the micro-part on the micro-part is proportional to the asymmetry effect of each saw-tooth. Therefore, we consider the relative scale *l*/*p* as a parameter. The second parameter is *pf* since it is the velocity of asymmetry. Table I shows two relative scales: *l/p* = 4 and *l/p* = 10. For each of the relative scale, we have two different capacitor lengths and saw-tooth pitches. Additionally, it is not shown in the table, we also perform experiment for other relative scales up to 100. The feeding system is similar to the system described in our previous paper [13] as in Fig. 1.

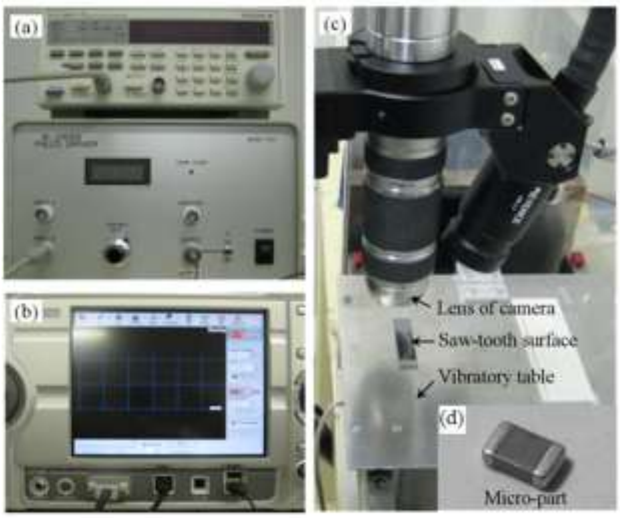


Fig. 1 Experiment system: (a) function generator, (b) micro-scope, (c) feeding system and (d) a typical of micro-part.

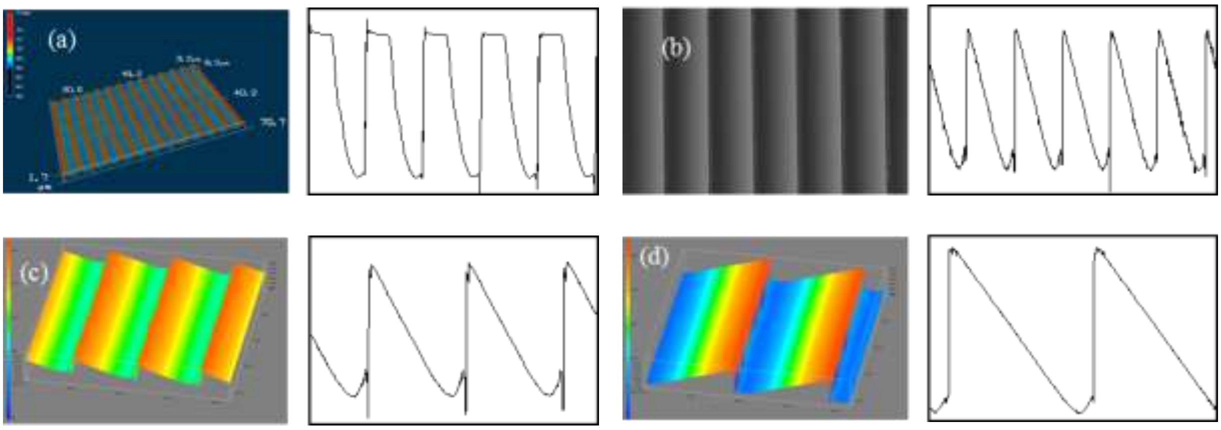
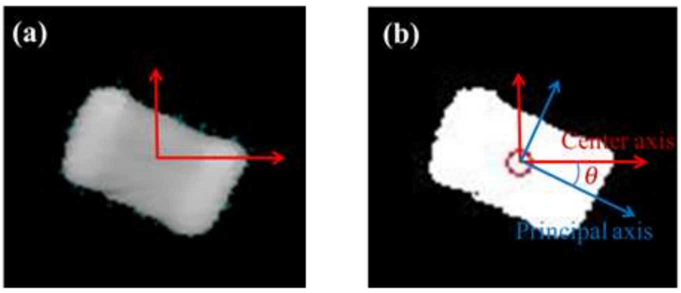


Fig 2. Experimental surfaces and profiles with different saw-tooth pitches: (a) p = 0.01 mm, (b) p = 0.05 mm, (c) p = 0.1 mm and (d) p = 0.15 mm.

Table 1 The relative scale with different saw-tooth pitches

l/p = 4	Case 1	l	0.6 mm
		p	0.15 mm
	Case 2	l	0.4 mm
		p	0.1 mm
l/p ≅10	Case 1	l	1.0 mm
		p	0.1 mm
	Case 2	l	0.6 mm
		p	0.05 mm

Tracking Method. The particle-tracking velocimetry (PTV) technique is used to determine the velocity of an object in this study. The center of a micro-part is detected in two successive images, and the velocity is calculated from the consecutive locations of the center. The steps of the PTV technique in this study are illustrated in Fig. 3.



(a) Raw image (b) Tracked center

Fig. 3 Procedure for detecting position and rotation of micro-parts.

A series of images of a micro-part moving within the focused region of a microscope are recorded by the microscope. First, a raw image is extracted from the recorded image series, and then, a global image threshold determined by Otsu's method [16] is used to convert the intensity image into a binary image, as shown in Fig. 3(a). Finally, the center of the micro-part is determined as the centroid of the image identified by the circle in Fig. 3(b). The orientation of the micro-part is obtained by determining the principal axis of the image [17]. The steps shown in Fig. 3(a) and (b) are executed using MATLAB libraries.

Results

We conducted experiments for range of frequency from 110 Hz to 160 Hz with the interval of 10 Hz. To compute the ensemble-averaged velocity, each experiment setup is repeated eight times.

Figure 4 shows the ensemble averaged velocity of micro-part along horizontal direction at the same ration l/p for different pitches p. Figure 4(a) shows the case of $l/p = 4$ with $p = 0.15$ mm and $p = 0.1$ mm. Figure 4(b) plots the results of the case $l/p = 10$ with $p = 0.05$ mm and $p = 0.1$ mm. For the same value of l/p, the profiles of velocity against *pf* are quite similar. Velocity increases up to a certain value of *pf* and then decreases with increasing *pf*. The peaks of the profiles are different. The possible reason is that the frequency interval of 10Hz maybe is too large. It is also observed that the profiles are shifted to the right along *pf* axis for smaller *p*.

We assume that the total force, F, on the micro-part is equal to the sum of the individual asymmetrical force, F_i, caused by each saw-tooth covered by the micro-part as

$$F = \sum_{i=1}^{N} F_i$$

where $N \approx l/p$ is number of saw-tooth covered by the micro-part as illustrated in Fig. 5. Therefore, the right shift of the profiles for smaller p shown in Fig. 4 indicates that Fi is maybe smaller for smaller *p*. Consequently, to accelerate the micro-part, the saw-tooth with smaller pitch requires a higher asymmetry rate *pf*.

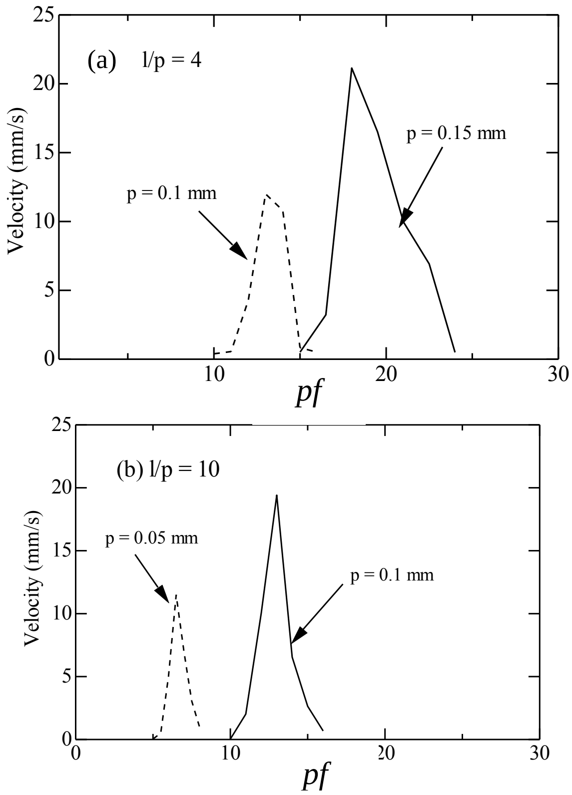


Fig. 4 The analysis feeding micro-parts for the same value of ratio l/p runs with frequencies: (a) l/p =4, (b) l/p = 10.

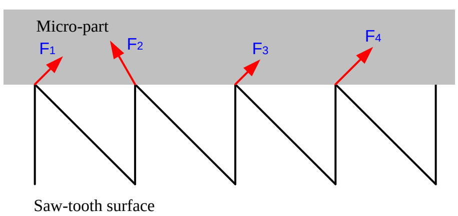


Fig. 5 Diagram of individual asymmetrical force on a micro-part.

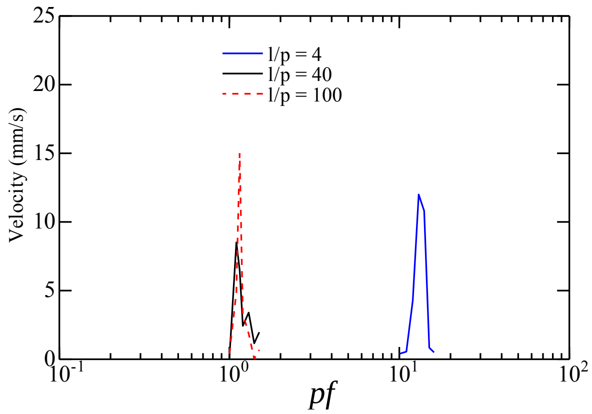


Fig. 6 Velocity of micro-part with *pf* for the different ratio *l/p*.

Figure 6 plots the profiles of the velocity of micro-part against *pf* for *l/p* = 4, 40 and 100. The maximum values of the micro-part velocities are occurred at *pf* = 13, 1.2 and 1.3. It shows that for certain value of *l/p* where the micro-part length is several times larger the pitch of the saw-tooth. The velocity of the micro-part is independent to *l/p* but strongly dependent on asymmetry rate *pf*.

Conclusions

We have studied experimentally the effect of the geometry parameters of asymmetrical structured surface and micro-part on the motion of micro-parts. The experiment was carried out for the sub-millimeter surfaces whose asymmetric structure is closed to the saw-tooth shape for various frequency *f* applied on the surface. The velocity of the micro-part is obtained by PTV method. The length of micro-part, *l*, and pitch of the saw-tooth, *p*, were selected so that constitute to several ratio of micro-part length to the saw-tooth pitch. We found that the profiles of feeding micro-part against *pf* are similar for the same relative scale *l/p*. The profiles are right shifted along *pf* axis. It indicates that smaller pitch maybe creates smaller asymmetric force on the micro-part.

In the future work, we need to perform experiment with smaller frequency interval change. Additionally, the effect of these parameters on the motion micro-part will be considered with more *l/p* values.

Acknowledgment

This work is partially supported by Monbukagakusho scholarship, the Japan Society for the Promotion of Science.

References

[1] P Umbanhowar et al. “The effect of anisotropic friction on vibratory velocity fields”, IEEE International Conf. on Robotics and Automation, USA, 2012.

[2] S. Okabe et al.: “Vibratory feeding by non-sinusoidal vibration-optimum wave form”, J. Vib. Acoust. Reliab. Des., Vol. 107, pp. 188-195 (1985)

[3] P. Umbanhowar and K. M. Lynch, “Optimal vibratory stick-slip transport,”IEEE Transactions on Automation Science and Engineering, vol. 5, no. 3, pp. 537-544, 2008.

[4] D. Reznik and J. Candy, “A flat rigid plate is a universial planar manipulator,” in IEEE International Conference on Robotics and Automatic, 1998, pp. 1471-1477.

[5] D. Reznik and J. Candy, “C’mon part, do the local motion!” in IEEE International Conference on Robotics and Automatic, 2011, pp. 2235-2242.

[6] G. Boothroyd, Assembly Automation and Product Design. Marcel Dekker, Inc., 2005.

[7] Peter U. Frei , Markus Wiesendanger , Roland Büchi , Lorenz Ruf, "Simulataneous planar transport of multiple objects on individual trajectories using friction forces," in Distributed Manupulation, K. F. Bohringer and H. Choset, Eds. Kluwer Academic Publishers, 2000, pp. 49-64.

[8] A. Mitani, N. Sugano, and S. Hirai: "Micro-parts feeding by a sawtooth surface", IEEE/ASME Trans. Mechatronics, Vol. 11, No. 6, pp. 671-681 (2006)

[9] A. Mitani, N. Sugano, and S. Hirai: "Feeding of submillimeter-sized microparts along a saw-tooth surface using only horizontal vibration: Analysis of convexities on the surface of microparts", in Proc. IEEE/ASME Int. Conf. Automation Science and Engineering, Scottsdale, AZ, USA, pp. 69-76 (2007)

[10] A. Mitani and S. Hirai: "Analysis of contact between feeder surface and microparts based on measurements for microparts feeder using an asymmetric surface", in Proc. IEEE/ASME Int. Conf. Automation Science and Engineering, Key Bridge Marriott, Washington DC, USA, pp. 720-725 (2008)

[11] A. Mitani and S. Hirai: "Evaluation of asymmetric microfabricated surfaces using femtosecond laser process for microparts feeding", in Proc. IEEE Int. Conf. Mechatronics, Malaga, Spain, (April 2009)

[12] A. Mitani and S. Hirai: "Feeding submillimeter microparts using an asymmetric fabricated surface with symmetric vibrations: Examination of influence of feeder surface materials on feeding", www.scientific.net/KEM, Vol. 467-469, pp. 1297-1302 (2011)

[13] P. H. Le, T. X. Dinh, A. Mitani, and S. Hirai: "A study on the motion of micro-parts on a saw-tooth surface by the PTV method", JSME J. System Design and Dynamics, Vol. 6, No. 1 (2012)

[14] Phuong Le, Xuan Thien Dinh, Atsushi Mitani, and Shinichi Hirai, Experiment and Simulation of Micro-parts Dynamics with Roughness Effect, 2012 IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics (AIM 2012), Kaohsiung, Taiwan, July 11-14, 2012

[15] A. Mitani and Y. Matsuo :"Feeding of Micro-parts Along an Asymmetric Surface Using Horizontal and Symmetric Vibrations – Development of Asymmetric Surfaces using Anisotropic Etching Process of Single-Crystal Sillicon" Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on, pp. 795 - 800

[16] Otsu, N., "A Threshold Selection Method from Gray-Level Histograms," IEEE Transactions on Systems, Man, and Cybernetics, Vol. 9, No. 1, 1979, pp. 62-66.

[17] William K. Pratt: "Digital Image Processing", Third Edition, pp 597-605.