# 非対称表面を用いたマイクロパーツの対称振動輸送
## 振動振幅および表面形状が輸送速度に及ぼす影響の解析。

# Analysis of the Velocity of Micro–parts on Vibration Surface with the Vibrating Amplitude and Geometry Parameters

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In this work, we study experimentally the effect of the non-dimensional parameters of saw-tooth surface and micro-part and the effect of amplitude vibration on the motion of micro-parts. The dimensionless quantities are functions of the range of saw-tooth pitch, *p*, and micro-part length, *l*. The experiments are performed for these scale with a range of 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. In addition, the method to determine the value of amplitude vibration at a range of exciting frequency is also introduced. The experimental 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. It seems that the motion of micro-part depends on characteristic surface velocity *pf* than the relative scale *l*/*p*. We also observed that the feeding velocity of the micro-part and the amplitude were maximum in the same frequency range.

***Key Words*:** Micro-parts feeding, saw-tooth surface, unidirectional motion.

## 1. 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.

## 2. EXPERIMENT

### 1.1 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 and as in Figs. 3 2(a) and (b). The fabricated surfaces were measured by the microscope system (Fig. 2). 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. 3(a) is in trapezoidal shape. However, it has asymmetric characteristic as the profiles shown in Fig. 3(b)-(d), since the flat portion of Fig. 3(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 × w × h = 0.4 × 0.2 × 0.2 mm), 0603 (l × w × h = 0.6 × 0.3 × 0.3 mm), and 1005 (l × w × 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, we also perform experiment for vibration according to a range of exciting frequency. The feeding system is similar to the system described in our previous paper [13] as in Fig. 1.

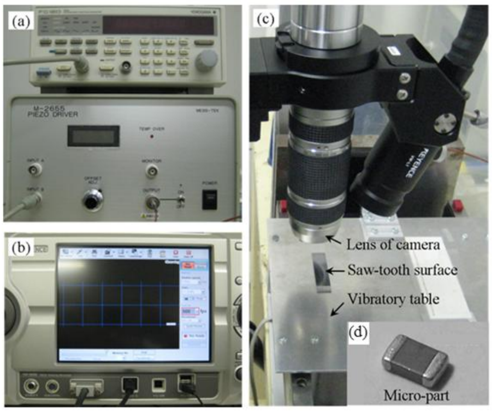



Fig. 1 Experiment system: (a) function generator, (b) micro-scope, (c) feeding system and (d) a typical of micro-part.

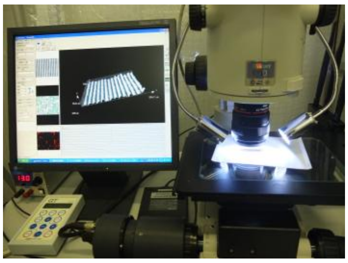


Fig. 2 Microscope system

Table 1 Dimension of the used saw-tooth

| | | | |
|---|---|---|---|
| *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 |

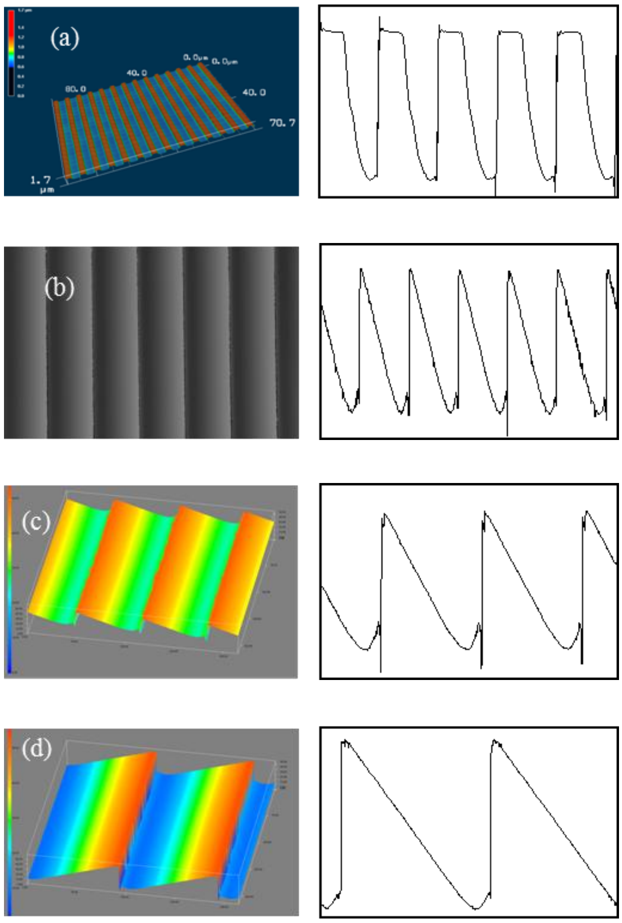



Fig 3. Real surfaces and profiles with different saw-tooth pitches: (a) p = 0.01 mm, (b) p = 0.05 mm, (c) p = 0.1 mm and (d) p = 0.15 mm.

## B. 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. 4.

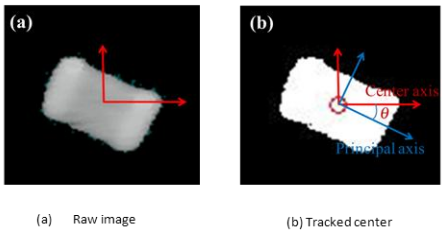



Fig. 4 Procedure for detecting position and rotation of micro-parts.

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. 4(a). Finally, the center of the micro-part is determined as the centroid of the image identified by the circle in Fig. 4(b). The orientation of the micro-part is obtained by determining the principal axis of the image [17]. The steps shown in Fig. 4(a) and (b) are executed using MATLAB libraries.

## 3. RESULTS AND DISCUSSION

### A. Amplitude of the vibrating saw–tooth surface

In the experiment equipment, the surface is vibrated by an actuator under sinusoidal voltage. To obtain the amplitude of the vibrating surface A, we fix a white point on the surface, and then track the motion of this point by PTV method. Figure 5 shows the time-dependent amplitude of the surface with the exciting frequency of 100 Hz. Although the driving voltage to the actuator is sinusoidal, the amplitude has numerous supposed frequencies. Therefore, it is difficult to determine accurately amplitude by the direct observation from time–dependent series. Fortunately, by the use of Fourier transform as shown in Fig. 6, we observe that the main contribution to the amplitude is from the frequency of 100 Hz and the other frequencies are as the white noise. It implies that the peak at 100 Hz is the amplitude, for instance, about 0.025 mm in this case.

Figure 7 plots the response of amplitude to the exciting frequency. The amplitude increases to uncertain frequency and then decreases as increasing frequency. This behavior of the amplitude can be approximated as a mass–spring vibration as

$$A = \frac{C_1\omega}{\sqrt{(\omega-\omega_0)^2+(2C_2\omega)^2}}$$

where the coefficients C1, ω0, and C2 are the constants to determine, respectively, the amplitude, the resonant frequency, and damping of the oscillation response of motion micro-part. These coefficients are obtained by using a nonlinear curve fitting technique.

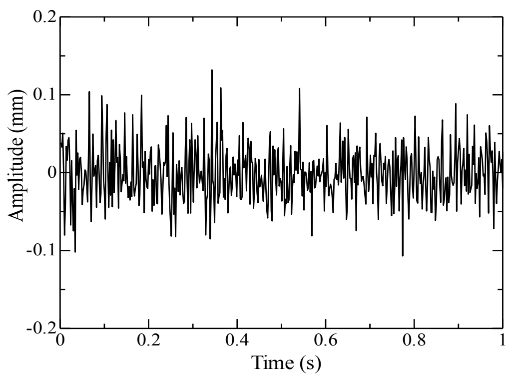



Fig. 5. The experimental amplitude with time at 100 Hz

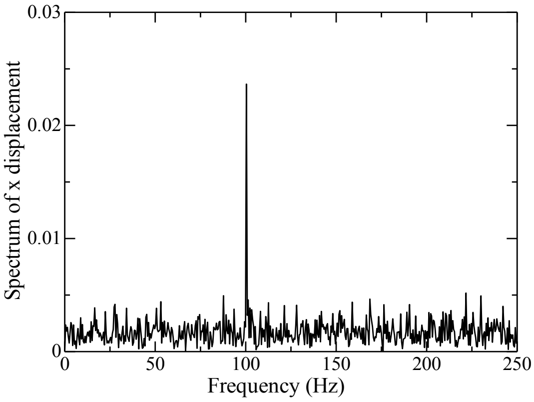



Fig. 6. The spectrum of x displacement with frequencies at 100 Hz.

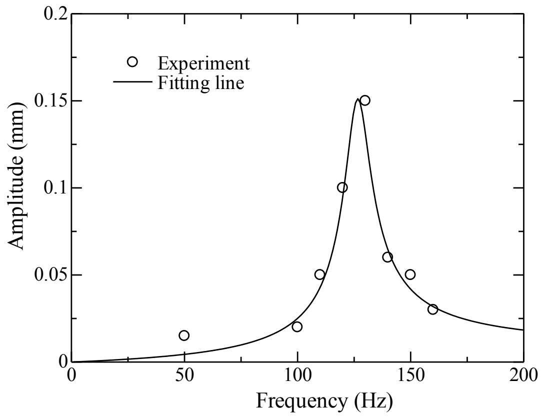



Fig. 7. The experiment amplitude for range of frequency.

### B. Response of feeding micro–part velocity

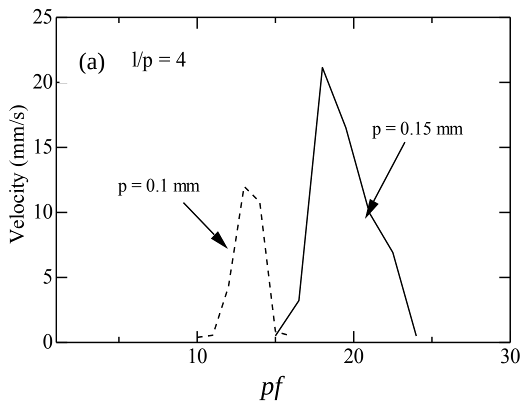
We conducted experiments for range of frequency from 110 Hz to 160 Hz with the interval of 10 Hz. To compute the ensemble-averaged velocity, each experiment setup is repeated eight times.

Figure 8 shows the ensemble averaged velocity of micro-part along horizontal direction at the same ration l/p for different pitches p. Figure 8(a) shows the case of l/p = 4 with p = 0.15 mm and p = 0.1 mm. Figure 8(b) plots the results of the case l/p = 10 with p = 0.05 mm and p = 0.1 mm. The velocity of micro-part are maximum around 120 Hz, 130 Hz. 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, Fi, caused by each saw-tooth covered by the micro-part as

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

where N ≈ l/p is number of saw-tooth covered by the micro-part as illustrated in Fig. 9. Therefore, the right shift of the profiles for smaller p shown in Fig. 8 indicates that Fi is smaller for smaller p. Consequently, to accelerate the micro-part, the saw-tooth with smaller pitch requires a higher asymmetry rate pf.



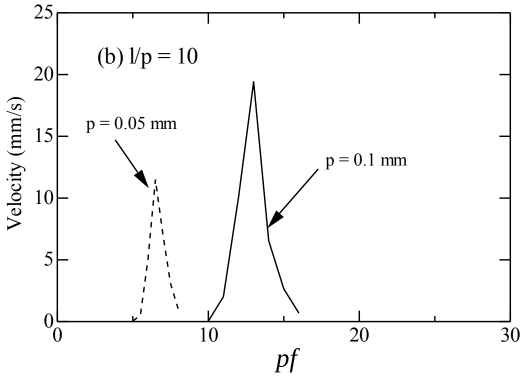



Fig. 8 The analysis feeding micro-parts for the same value of ratio *l/p* runs with frequencies: (a) *l/p* =4, (b) *l/p* = 10.

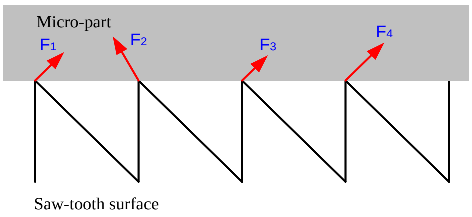



Fig. 9 Diagram of individual asymmetrical force on a micro-part.

## CONCLUSION

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 creates smaller asymmetric force on the micro-part. Additionally, the feeding of micro-part and the amplitude vibration are maximum at the same frequency range. It seems that larger amplitude provides a larger feeding velocity.

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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