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Fluid and van-der-Waals Forces in MEMS Production

INTRODUCTION

The "NEXUS Market Analysis for MEMS and Microsystems III, 2004-2009" report predicts a CAGR (Compound Annual Growth Rate) of 16% for 1st level packaged MEMS components with a market of $25 billion in 2009. These production volumes demand a highly automated assembly line. At the same time the dimensions of the components have been shrinking over the last years, e.g. in the field of minimally invasive surgery, which increasingly challenges the handling of devices. To ensure a cost-effective production, a highly reliable assembly process is vital for a smooth material flow. In this paper, we analyze the motion of sub millimeter sized parts in the material flow technology.

EXPERIMENTAL SETUP

Often the downscaling of material flow technology is an appropriate and inexpensive approach to deal with smaller part dimensions. This downscaling method reaches its limit when the surface related forces are dominating, because the mass decreases with the third power in contrast to the surface related forces which only scale with the second power.

To examine the downscaling effects of material flow technology, experiments were conducted exemplary with a vibratory conveyor. In 80% of the cases a vibratory feeder is used for conveying and orientating bulk goods in assembly processes. For that reason the experimental setup includes a vibration exciter with an aluminum channel, a high-speed camera for analyzing the motion and a laser scanning vibrometer, which measures the conveyor's displacement and acceleration.

FLUID FORCES

Previous experiments have shown that small silicon parts with dimensions of 1x1x0.4 mm^3 stick to the vibratory channel even though the acceleration is greater than twice the acceleration of gravity (>2g).

The vertical component of the channel's motion is described by

$$y(t) = \hat{y} \cdot \sin(\omega t) \qquad (1)$$

where $\hat{y}$ is the vibration amplitude and ω the angular frequency, leading to the vertical channel acceleration:

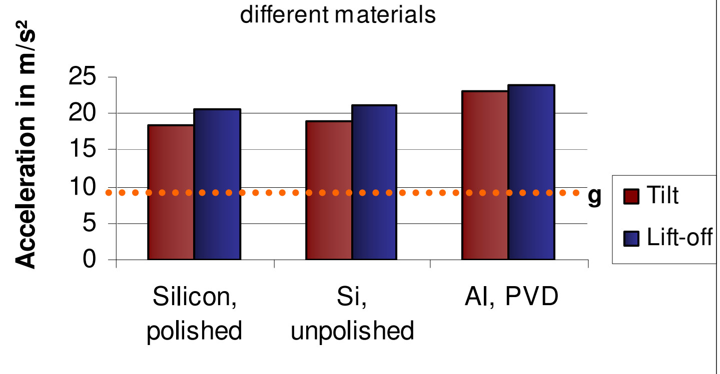
$$\ddot{y}_{max} = \hat{y}\omega^2 \qquad (2)$$

The channel was vibrating at a preset frequency of 12 Hz (Figure 1). Classic theory would predict a lift off as soon as the plate overcomes the acceleration of gravity. The forces that are twice the amount of what would have been expected prevent the part from lifting off and are the subject of this research project.

Figure 2 illustrates all components of the adhesion forces and the fluid forces.

Experiments have shown that capillary forces can be very strong if the relative humidity is too high (>80 % RH). They can be orders of magnitudes higher than the remaining interactions [1]. But while regulating the relative humidity down, the influence of electrostatic forces is growing rapidly. Therefore, measures for ESD-protection (electrostatic discharge) are essential for the setup.

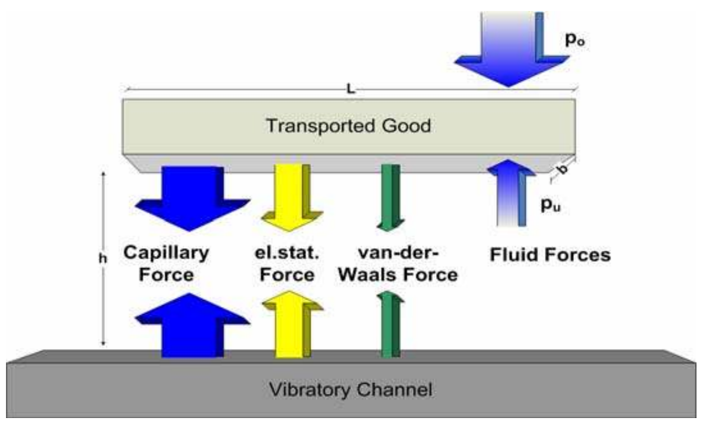
Figure 1: Lift-off of the micropart at f = 12 Hz for different materials



It is difficult to calculate the exact amount of the van-der-Waals forces (vdW force), but it is possible to make assumptions about the order of magnitude. In general, the vdW force decreases with the third power of the distance between two planes [2]. But the rough surface topography of the two surfaces makes it difficult to calculate the accurate distance between the two areas.

Various experiments have proven that fluid forces are mainly responsible for high interaction forces. They only occur during the motion of the feeder. This is indirectly approved by increasing the frequency from 12 Hz step-by-step to 100 Hz. As expected it is more and more difficult to compensate the low pressure between the vibrating plate and the micropart bottom surface in the available period of time. Finally the lift-off acceleration reaches more than 5g at a frequency of 100 Hz.

Figure 2: Components of Interaction Forces



EFFECT OF PART SIZE

To investigate the effect of part sizes we used three different microparts with the same thickness. The dimensions for the parts are 370 x 370 x 200 µm^3, 540 x 540 x 200 µm^3, and 740 x 740 x 200 µm^3, respectively. Since the parts were extremely difficult to move on a flat surface, the surface of silicon vibratory channel was patterned by photolithography and deep reactive ion etching to reduce the area of contact with microparts. The resulting surface has 35% contact area compared to the flat surface.

Figure 3: Effect of Part Size

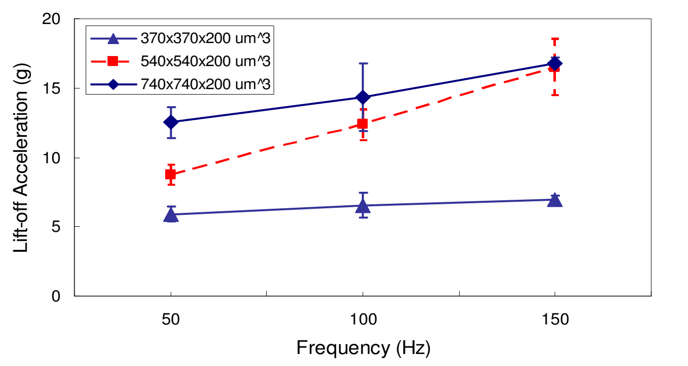


Figure 3 shows the experimental results. As the part size decreases the liftoff acceleration also de-creases despite the decreased mass. This result indicates that the surface area related forces dominate the motion of the parts. The lift-off acceleration increases with frequency, which is consistent with the previous results.

EXPRIMENTAL RESULT AT A DECREASED PRESSURE

For additional proof the experimental setup was arranged inside a vacuum chamber. The experiment was conducted without changing the parameters of the vibration exciter, but this time the air pressure was decreased to 7 mbar. As a result the micropart lifted off the surface at a much lower acceleration of 1.3g instead of the previous acceleration of 2g. The reason is that the fluid force (4) is directly dependent on the dynamic viscosity η of the surrounding medium [3]:

$$\dot{V} = -b\frac{1}{12\eta}\frac{dp}{dx}h^3 \tag{3}$$

$$\Rightarrow F(h) = -b\eta v\frac{L^3}{h^3} \tag{4}$$

($\dot{V}$ volume flow, L length of gap, b width of gap, h height of gap, $\frac{dp}{dx}$ pressure gradient)

In this setup the viscosity begins to decrease at a pressure lower than 100 mbar, because the air changes the friction property from viscous to molecular. Since the fluid force decreases with the third power it is no longer relevant as soon as the distance between the two surfaces is large enough. But this experiment proved the strong influence of fluid forces on microparts that are transported with a vibratory feeder.

The conventional model for macroscopic parts is extended to flow forces (4) and vdW forces and explains the observed effects with microparts. The results improve the understanding of the different forces that are influencing the material transport and how they are determined by frequency, amplitude, humidity, surface roughness etc.

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