Experimental Study of Micro-feeding of Fine Powders by a Vibrating Capillary Tube

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ABSTRACT

Micro-feeding of fine copper powders was experimentally studied by using a vibrating capillary tube. Three glass capillaries with different inside diameters were used in the experiment and the powder flow rate under different frequencies was investigated. The mechanism of powder flow was also explained. Further analysis is needed to verify that the flow rate is maximized at the natural frequencies..

Keywords: powder dispensing, capillary, vibration

1 INTRODUCTION

In solid freeforming, micro-sensor design, and many other industry applications, small amount of very fine powders are often needed to be deposited at. The flow characteristics of fine powders flow in capillaries are far from well understood at this time. The adhesion force between powder particles tends to make them agglomerate and this force is usually large compared with the gravity force. It is also unpractical to push the fine powders out of the capillary tip by applying a back pressure, like inkjet printing. Several research groups in Japan and USA have tried to use vibration (below ultrasonic frequency range) [1], ultrasonic vibration [2-8], and acoustic streaming [9] to dispense powder with different capillaries. In this paper, micro-powder feeding at below ultrasonic frequency is investigated and discussed.

2 EXPERIMENTAL SETUP AND PROCEDURES

Our experimental setup is stimulated by Yong Yang et al. [8]. Three different 30mm long glass capillaries as shown in Table 1 (Friedrich & Dimmock, Inc., O.D. =3mm) are used and each capillary is supported by an aluminum plate. The bevel edge ($\theta=30^\circ$) of the trapezoidal piezoelectric plate (PSI-5A4E, Piezo Systems, Inc) is in tight contact with the outer surface of the glass capillary as shown in Figure 1. The other end of the piezoelectric plate is also fixed to the aluminum plate. When a high-frequency alternating voltage is applied to the piezoelectric plate, the periodical friction force between the bevel edge of the piezoelectric plate and the glass capillary will vibrate the system. When a critical frequency is reached, the fine powder in the hopper can be dispensed smoothly. The signal source consists of a function generator (4011A, B&K Precision Corporation) and a power amplifier (PZD 350, Trek Inc.). The fine copper powder (as shown in Table 1.) was bought from Acupowder International.

Although the 15-micron average diameter of the copper powder (see Table 2) is much smaller than the diameter of the capillary, there is no powder flow out of the capillary without the actuating force of the piezoelectric plate. The reason for this phenomenon is that when the powder is very fine, gravity force no longer dominates. Instead, the adhesion force between fine powder particles tends to agglomerate the particles. The vibration can destroy the so-called "clots" and then the gravity force overcomes the adhesion force and the powder flows out of the capillary.

Table 1. Glass capillaries used in the experiment

Capillary	ID (mm)	OD (mm)	Length (mm)
1	0.279	3	30
2	0.305	3	30
3	0.330	3	30

Table 2. Specifications of the fine copper powder

Particle shape	Average Particle size—microns		
	10%(1)	50%(2)	90%(3)
spherical	8	17	28

(1) 10% of particles are finer than stated Micron value. (2) 50% of particles are finer than stated Micron value. (3) 90% of particles are finer than stated Micron value

The average powder flow rate is measured by electronic high precision balance with a readability of 0.001g (Sartorius LP 1200S, Northern Balance and Scale). The total dispensed powder mass is measured for every twenty seconds and the flow rate is calculated.

3 RESULTS AND DISCUSSION

Although the experimental setup was very similar to that in [8], different flow phenomenon was observed: when the powder flew out of the capillary tip, all particles vibrate randomly rather than in a rotating pattern. It should be noted that the vibrating frequencies (below 20000Hz) used in this study are not in ultrasonic range.

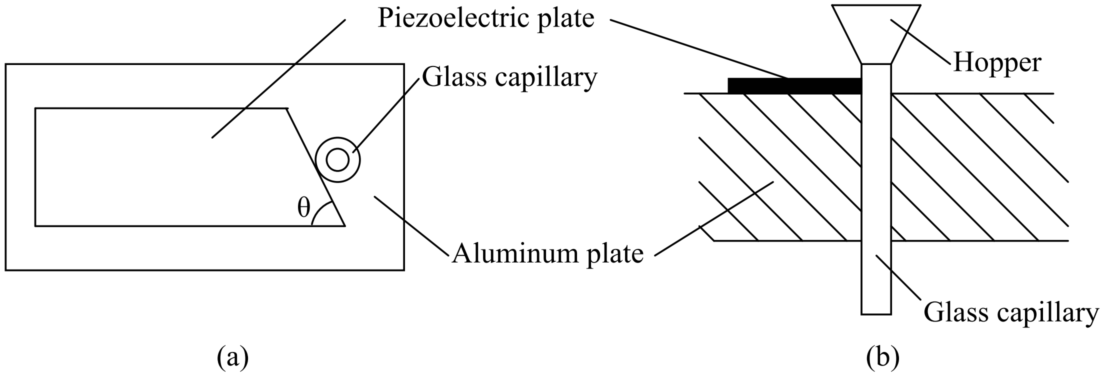

Figure 1. Schematic diagram of the powder actuator (a) Top view, (b) Section view

As shown in Figure 2 for the capillary with ID=0.305mm, the largest flow rate takes place when the excitation frequency is about 5750Hz. At this frequency, the copper powder could flow out of the capillary much faster than expected. This critical frequency can be used for faster motion system. The flow rates for two other capillaries (ID=0.297mm, and 0.330mm) are also measured (Fig 3. and Fig 4.). Very similar phenomenons were observed but the critical frequencies are different.

In the frequency range 2000-3500Hz, the average powder flow rate stays at a very even level. But the flow stability is the best at 3500Hz: the printed pattern width and thickness are very uniform. 3500Hz is the proper excitation frequency for our motion system setup.

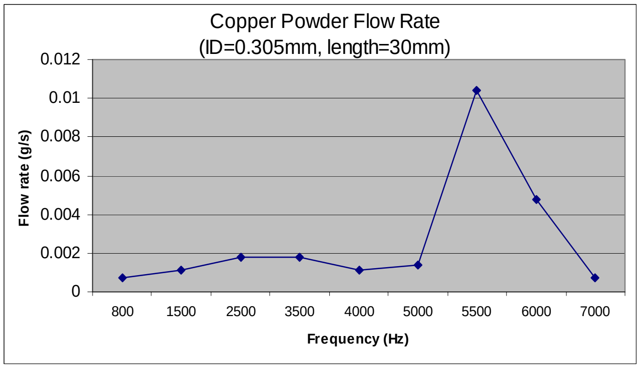

Figure 2. Copper powder flow rate for 0.305mm ID capillary

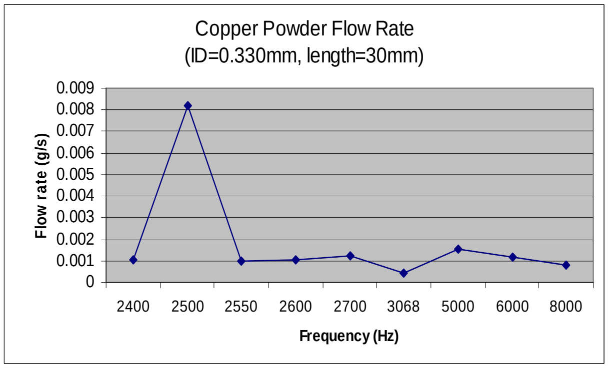

Figure 3. Copper powder flow rate for 0.330mm ID capillary

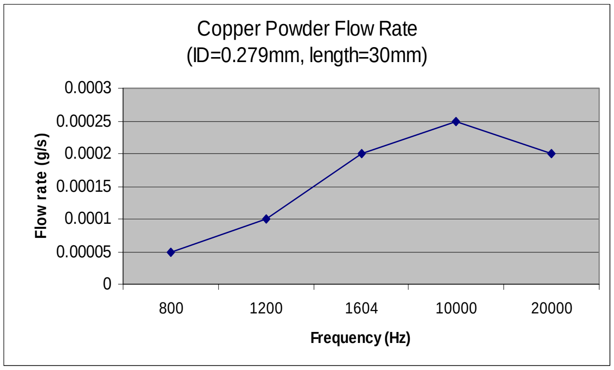

Figure 4. Copper powder flow rate for 0.279mm ID capillary

Figure 5 is the printed “NDSU” pattern by using a 0.305mm ID glass capillary. The average width of the pattern is about 0.3mm.

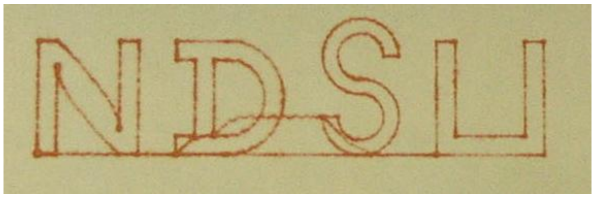

Figure 5. Printed fine copper powder pattern

As it is observed in this experimental study, the powder dispensing takes place due to gravity when the adhesion force between the powder particles is overcome by the high-frequency vibration. Based on mechanical vibration theory, each object has several natural frequencies and the amplitude of vibration is maximized at those natural frequencies. Therefore, 5750Hz may be one of the natural frequencies of the 0.305 ID capillary setup. Further analysis is needed to verify this assumption.

4 CONCLUSION

Micro-dispensing of fine metal powders was experimentally studied and the external excitation at the natural frequencies is assumed to cause continuous flow. Compared to the other known powder dispensing method [1-8, 10], this method has the advantage of very compact structure, low cost, and very stable powder flow so it is a very good candidate to be integrated into other systems. Based on our experience, the powder dispensing performance is affected by several factors such as the powder properties (material, particle size and shape), the capillary properties (diameter and material), and the structure of the whole system (vibration frequency). It is not possible to predict the powder dispensing performance just by theoretical calculation. This powder dispensing system is one of the key subsystems of our micro-sensor design system and it can also be applied to other applications such as pharmaceutical industry and chemical industry when a very small dose of fine powder is needed to be prepared periodically.

5 ACKNOWLEDGEMENT

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