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Extraction of biologic particles by pumping effect in a π-shaped ultrasonic actuator

Junhui Hu *, Jianbo Yang, Jun Xu, Jinlong Du

School of Electrical and Electronic Engineering, Nanyang Technological University, S1-b1b-36, Nanyang Avenue 50, Singapore 639798, Singapore

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Abstract

This paper presents a new method of extracting biologic particles from a mixture of particles. The method is based on the pumping effect in a π-shaped ultrasonic actuator, which has a gap between its two vibrating metal plates. An adhesive tape is placed at a proper position in the gap. Due to the pumping effect which is induced by the sound field in the gap, the particles with smaller mass and radius in the mixture can be pumped up to reach the adhesive tape; while the ones with larger mass cannot. Therefore, the particles with smaller mass and radius can be extracted from the mixture. A theoretical model which can well explain the operation principle and experimental phenomena is developed. By the experimental results and the theoretical analyses based on the model, the validity of the method in extracting small particles from a mixture of solid particles in air is confirmed, and the effects of the actuator's vibration, adhesive tape height, contents of the mixture and viscosity of fluid on the extraction are clarified. Also, it is theoretically predicted that the method will work under the microgravity condition in air.

Keywords: Pumping effect; π-shaped ultrasonic actuator; Extraction; Particles

1. Introduction

In bioengineering and many other fields of research, it is useful to separate particles from liquid or a mixture of particles. Small particles of interest include molecules such as amino acids and vitamins, macromolecules such as proteins and nucleic acids, and particulate products such as animal cells and bacteria. Because of the variety of biologic particles in size, adsorption and sedimentation, various bio-separation methods are needed. As an emerging technology, ultrasonic separation has been used in the filtration of biologic particles such as cells [1–9]. In the technology, a properly controlled sound field enhances the agglomeration of particles and transports the agglomerated particles to a desired location by gravity, flow, and position change of the acoustic pressure nodes.

We had developed a π-shaped ultrasonic actuator for the purposes of trapping and transporting small particles in air and water. The operating mechanism, vibration distribution and characteristics of the actuator were already investigated and reported [10]. During the experiments, it was unexpectedly found that rice powder could be pumped up between the two vibrating metal plates of the actuator while heavier particles could not. We called this phenomenon as pumping effect.

Inspired by the above phenomenon, we proposed a new method of extracting biologic particles from a mixture of solid particles, which has a totally different operating principle from other methods of ultrasonic separation. In our method, the π-shaped ultrasonic actuator is used to pump the particles with smaller mass and radius in the mixture to a higher position in the gap, and collect them by an adhesive tape at a proper height in the gap. By this method, shrimp eggs were extracted from a mixture of shrimp eggs and fine salt crystals or grass seeds without wetting the

* Corresponding author. Tel.: +65 6790 4522; fax: +65 6793 3318.
E-mail address: ejhhu@ntu.edu.sg (J. Hu).

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shrimp eggs and the mixtures. No fine salt crystals and grass seeds were mixed in the extracted shrimp eggs.

2. Construction and operating principle

2.1. Construction

Fig. 1 shows the method which exploits a π-shaped actuator to extract small particles from a mixture of solid particles. Two metal plates made of aluminum sandwich a multilayer piezoelectric vibrator by a bolt structure. The multilayer piezoelectric vibrator is formed by two opposite poled piezoelectric ceramic rings, which have an outer diameter of 12 mm, inner diameter of 6 mm and thickness of 2.4 mm. The piezoelectric rings have the electromechanical coupling factor k_{33} of 0.71, piezoelectric charge constant d_{33} of 325×10^{-12} m/V, mechanical quality factor Q_m of 2000, and dissipation factor $\tan\delta$ of 0.3. Each metal plate is 50 mm long and 20 mm wide. The thickness of the upper part of each metal plate is 3 mm, and the length of the tapered part is 30 mm. The operating frequency of the actuator is about 86 kHz. Small particles near the sharp edges of the metal plates can be pumped up to a higher location in the gap between the two metal plates.

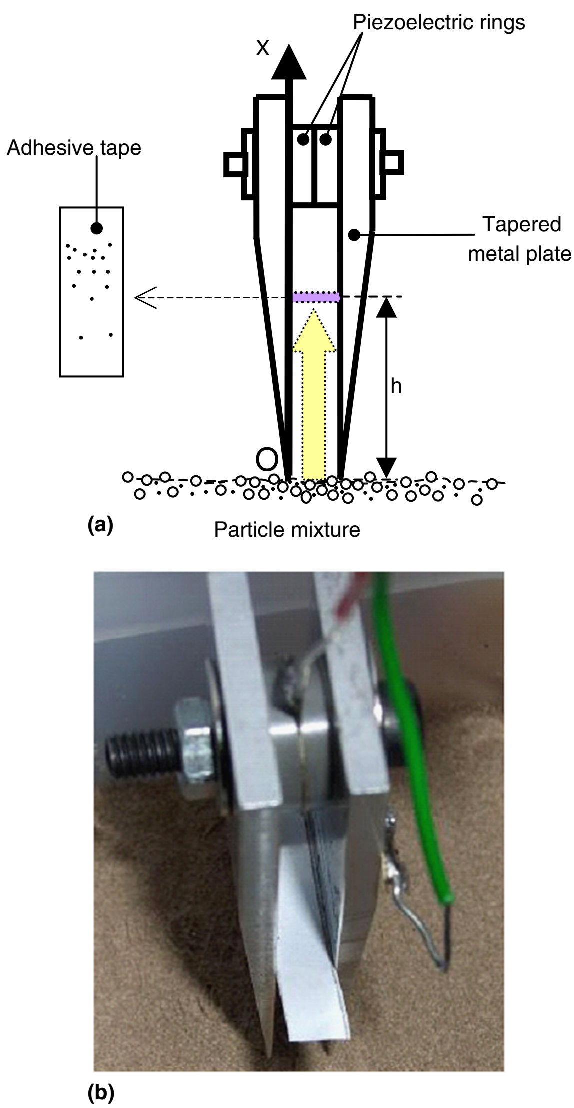

Fig. 1. Extraction of biologic particles by the pumping effect in a π-shaped ultrasonic actuator: (a) schematic diagram and (b) photo.

2.2. Operating principle

When the thickness vibration is excited in the upper part of the actuator, the lower part of the metal plates may operate at a flexural vibration mode. This flexural vibration was confirmed by scanning the sound pressure distribution on the surface of the metal plates in water. A 1 mm needle hydrophone (SN945, Precision Acoustics, UK) was used in the measurement. According to this measurement, the x-direction wavelength of the flexural vibration is about 66.6 mm. Using 6300 m/s as the sound velocity in the aluminum plates, we estimated the theoretical wavelength to be about 73.2 mm at 86 kHz. So the experimental and theoretical values agree quite well. The two sharp edges of the metal plates have a large vibration due to the taper structure [10]. Due to this large vibration, the particles near the sharp edges may be swept up into the gap and the space outside the actuator. In the gap, the swept up particles will experience an upward acoustic radiation force due to the large sound field in the gap and go to a higher location.

Based on the model shown in Fig. 2, the sound field in the gap, the acoustic radiation force acting on the particles, and the upward motion of the particles are analyzed as follows.

2.2.1. Analyses of acoustic radiation force

The three-dimensional sound field in the gap can be solved by the following wave equation and boundary conditions [11]:

$$\frac{\partial^2\varphi}{\partial t^2} = c_0^2\nabla^2\varphi \tag{1}$$

$$-\left.\frac{\partial\varphi}{\partial y}\right|_{y=0} = V_{Ay} \tag{2}$$

$$-\left.\frac{\partial\varphi}{\partial y}\right|_{y=h_a} = -V_{By} \tag{3}$$

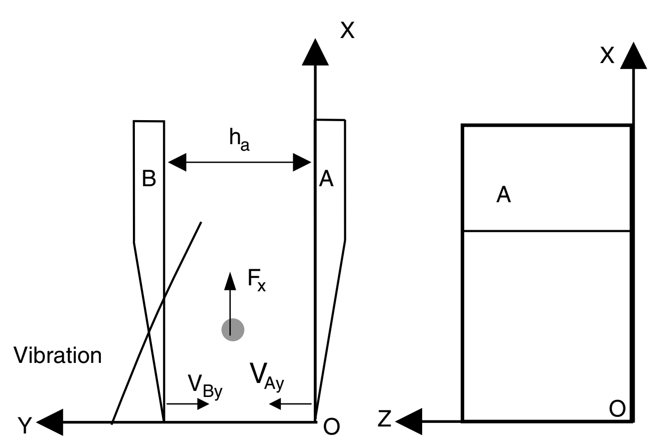

Fig. 2. A model for analyzing the operation.