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Pump Effect by Ultrasonic Transducer and Opposing Surface
超音波振動子と対向面によるポンプ効果

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1. Introduction

Currently, a variety of pumps: for example, oblique flow pump, and piston pump are used in various applications, such as infrastructures, plants and medical equipments. However these pumps include sliding parts. Therefore, there is a limit of durable life due to friction and wear. To solve this problem, a number of pumps using ultrasonic vibration have been proposed. Hasegawa et al. shown that liquid is sucked into a pipe if the pipe end is faced at an ultrasonic vibrating surface with a small gap in liquid[1]. In addition, they proposed a miniature ultrasonic pump by using bending disk transducer instead of the piston vibration surface[2]. Suzuki et al. proposed an ultrasonic pump with a Langevin transducer combining high-order mode, where the transducer can generate pseudo-saw and trapezoid vibration[3]. Nakanishi et al. proposed a novel pumping method using ultrasound induced pressure differences and cavitation[4]. Increasing the power of the ultrasound, the steady cavitation clouds start forming around the pipe inlet, which can suppress the negative pressure in the vibrating cycle as well as it cause a continuous pumping of water. A common feature of such ultrasonic pumps are having no sliding parts. Therefore, the durable life of these pumps seems longer than that of the conventional pumps, because there is no wear nor damage in use. Since many medical treatments use high magnetic field such as MRI, the ultrasonic pumps have advantages for such medical cases as they can avoid use of magnetic material in their structure. In the present study, pumping effect is improved by applying proper surface shape for the block opposing the transducer.

2. Principle

Fluid medium between two parallel surfaces placed in close each other is considered. This situation is illustrated in **Fig. 1**. When one of the surface is vibrating, fluid repeats inflow and outflow at the end of the two planes[5]. However, in case fluid resistance at the time of inflow and outflow are different, flow in one direction increases. Therefore occurrence of pump effect can be expected. In the present study, it is expected that the flow can be limited in one direction by tapered surface of the opposing surface.

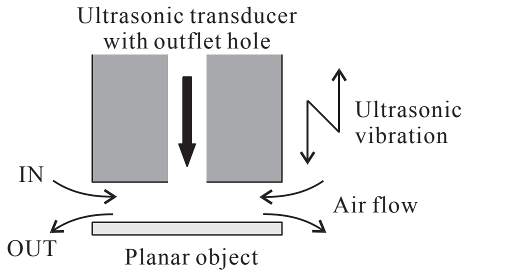

Fig. 1　Principle of pump effect.

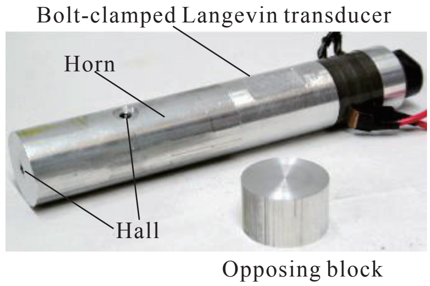

Fig. 2　Experimental devices.

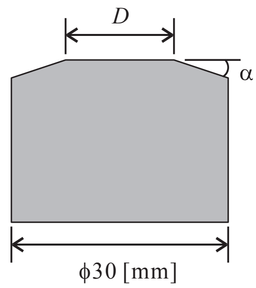

Fig. 3　Schematic view of opposing block.

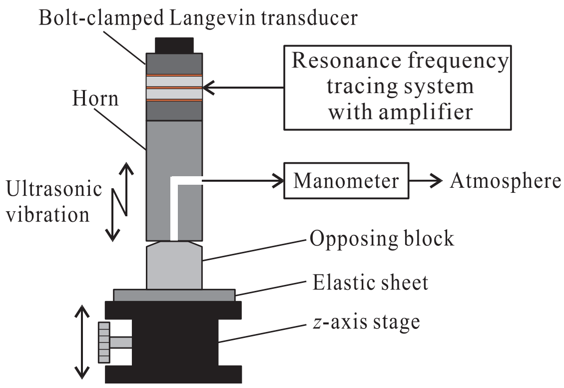

Fig. 4　Experimental configuration.

3. Transducer and opposing surface

Fig. 2 shows an ultrasonic transducer and an opposing block. The bolt-clamped Langevin transducer with resonance frequency of 28 [kHz] was used. A horn whose resonance frequency was matched with that of the transducer was attached on the top of the transducer. Moreover, there was a hole with diameter of 4.2 [mm] in the horn to provide the path for fluid flow. The hole in the side was formed at the node of the vibration which was derived by the finite element analysis to reduce the influence of the vibration. **Fig. 3** shows a detailed view of the opposing block. The opposing surface was formed on the end of an aluminium cylinder. D and α represent the diameter of flat surface and the angle of taper, respectively. In the present study, the multiple opposing blocks with different values of D and α were fabricated.

4. Observation of pumping effect

Fig. 4 shows an experimental configuration for observation of pumping effect. The transducer was drived at its resonance frequency by using a resonance frequency tracing system[6] to obtain the maximum vibrational amplitude. This configuration also measured the gauge pressure by connecting a manometer to the end of the hole at the side of the transducer, and the other end of the meter was released to the atmosphere. To expect unique pumping effect in whole gap between the surfaces, it was necessary to align the block surface in parallel with the transducer surface precisely. A rubber sheet was placed under the opposing block, and the opposing block was pressed to the end of transducer by adjusting z-axis stage. Parallel alignment can be realized by elasticity of the sheet passively. Thereby, a preload was applied to the transducer from the opposing block, and the opposing block contacted with the transducer due to the preload. However, when ultrasonic vibration was applied, a constant gap was generated by the positive pressure resulting from a squeeze effect. On both sides of the flange to fix the transducer, two pieces of strain gauges were installed to estimate the preload during the following observation.

Through the observation, the vibrational amplitude was 1.8 [$\mu m_{p\text{-}p}$] and the preload was 1 [N]. **Fig. 5** shows observation results. Fig. 5 (a) shows the effect of α, and Fig. 5 (b) shows the effect of D on the induced gauge pressure. On the plots, outflow, which is defined by a block arrow in Fig. 1, was defined as positive value. Negative value means inflow. According to the results, pumping effect was observed with the tapered opposing surfaces. Higher gauge pressure was observed, when α = 1.5 [deg] , D = 7.5 [mm].

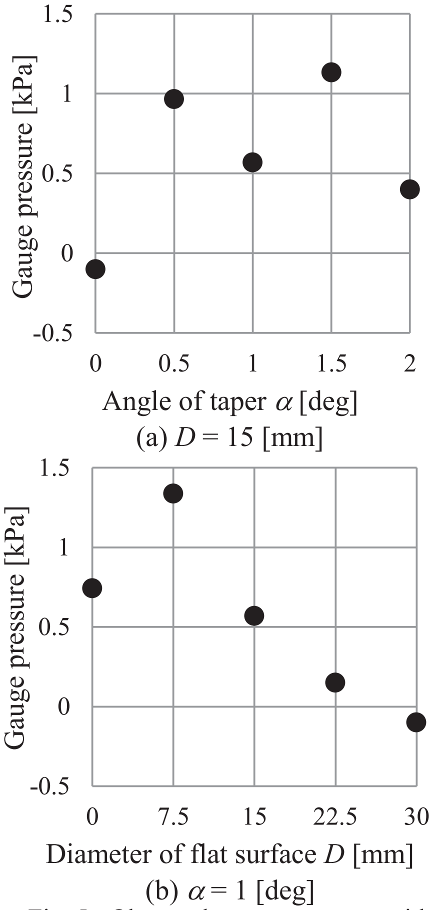

Fig. 5 Observed gauge pressures with the change of α and D.

5. Conclusion

We succeeded in observing occurrence of pumping effect by combining an ultrasonic transducer and an opposing block with tapered surface.

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