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A Shape Analysis of Ultrasonically Levitated Droplet with Moving Particle Semi-implicit and Distributed Point Source Method

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Ultrasonic levitation has recently been drawing attention as a way of non-contact transportation of small objects, such as liquid droplets, in bioengineering and manufacturing industry. The small objects in the finite amplitude sound field have been known to be trapped near the pressure node of the standing wave with the effect of acoustic radiation force [1-2]. Many experimental reports [3] are presented related to the droplet levitation and their shape in the air. The droplet with large volume is reported to turn its shape from sphere to spheroid when they are exposed in the intense sound pressure field. Several analytical reports have mentioned this phenomenon [4-6], however, almost no report carried out dynamical simulation on the shape change of the droplet. In this paper, the levitated droplet shape is simulated by coupling two gridless analysis methods, the one is distributed point source method (DPSM, [7]) and the other is moving particle semi-implicit (MPS, [8]) method.

CALCULATION PROCEDURE

Acoustic radiation pressure P_{rad} are expressed by the sound pressure p_a and particle velocity $\boldsymbol{u}_a$, which is calculated by acoustic analysis performed in DPSM as

$$P_{rad} = \frac{|p_a|^2}{4\rho c^2} + \rho\frac{|\mathbf{u}_a|^2}{4}, \quad p_a = \frac{j\omega\rho}{2\pi}\iint V_0 \frac{e^{-jkr}}{r} dS, \quad \mathbf{u}_a = -\frac{\nabla p_a}{j\omega\rho}, \tag{1}$$

where ρ, c, ω, k, and V_0 are the density, sound speed, angular frequency, wavenumber in air, and vibration velocity of the transducer. Calculated acoustic radiation pressure is considered in static fluid analysis, which is simulated in MPS, as

$$\mathrm{div}\mathbf{U} = 0, \quad \frac{D\mathbf{U}}{Dt} = -\frac{\nabla(P + P_{rad} + \sigma\kappa)}{\rho_w} - \nu\nabla^2\mathbf{U} + g, \tag{2}$$

where P, $\boldsymbol{U}$, ρ_w, σ, ν, κ, g is the static pressure, velocity, density, surface tension, dynamic viscosity of the liquid, curvature of the droplet surface, gravity.

Fig. 1 indicates the problem geometry for the ultrasonic droplet levitation. A droplet with initial sphere radius is 1/30 wavelength is levitated in the sound field, which is generated by the ultrasonic transducer and the reflector. The droplet is initially placed at 12 mm above the transducer, and expected to move toward the node of sound field, which is 12 mm, 3/4 wavelength, above the transducer.

RESULTS

Fig. 2 shows the sound pressure distribution for the initial time step. The amplitude of the sound pressure is 2.4 kPa at the antinode of the standing wave. Fig. 3 shows the droplet deformation and radiation pressure at the time 0, 0.2, 0.8 and 8 ms. The radiation pressure vertical and horizontal side the droplet is +22 Pa -126 Pa, respectively. The droplet levitates because the vertical positive static pressure balances the gravity, and the shape turns into spheroid because the horizontal negative static pressure balances the surface tension. The change in shape completes in several miliseconds, and after that the droplet is observed to move toward the node.

CONCLUSION

The shape of an ultrasonic levitated droplet was simulated using MPS and DPSM in three dimensional space. The droplet changed its shape from sphere towards spheroid, which agrees well with the shape experimentally known.

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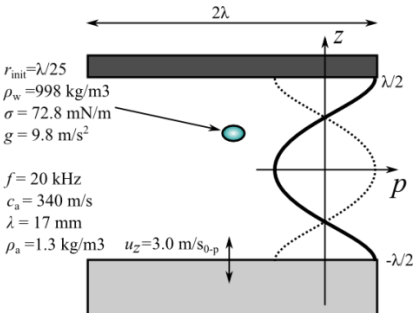

Fig. 1 Problem geometry for the ultrasonic droplet levitation

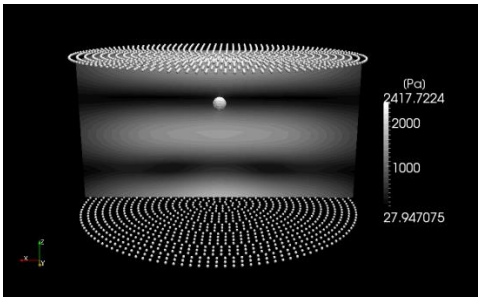

Fig. 2 Sound pressure distribution for the initial time step

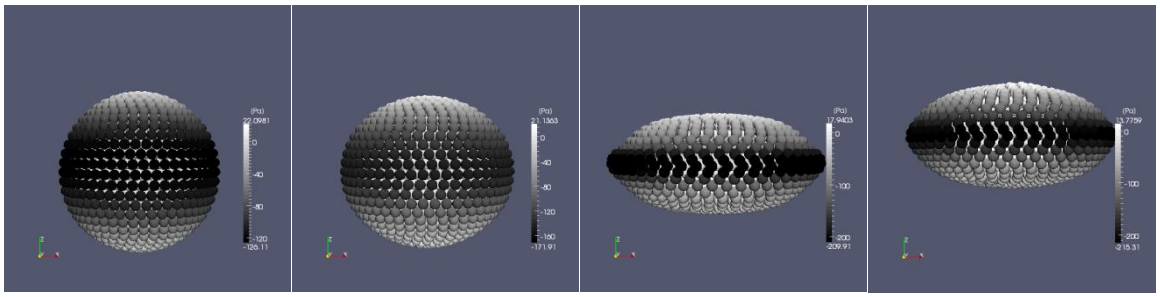

Fig. 3 Droplet deformation and radiation pressure at the time 0, 0.2, 0.8, 8 ms.