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Studies on the dynamics of microsphere suspensions observed by dynamic ultrasound scattering method at high PRF
動的超音波散乱法による懸濁微粒子ダイナミクスの高 PRF における粒径依存性

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1. Introduction

We have developed a novel particle-sizing technique called dynamic ultrasound scattering (DSS) method. This technique enables us to measure the sedimentation velocity of micron-sized particles dispersed in a suspension via the time evolution of the scattered amplitude and phase of ultrasound waves. In the DSS method, although PRF (pulse repetition frequency) is responsible for the time resolution of time-correlation functions, the high PRF leads to unexpected flow induced by excess ultrasound energy, resulting in overestimation of the sedimentation velocity.

In our previous study, we showed the effects of PRF and incident beam energy on DSS data observed from horizontal and vertical setups, and clarified the effect of PRF to the data.[1)] Though the results suggest that low PRF is suitable for DSS experiments, the threshold is not fully understood. In order to elucidate the effects under various experimental conditions such as transducer characteristics and the sample properties, further investigations are crucial. In this study, we study the effects of PRF on the dynamics of microparticles having different particle diameters.

2. Theory

As an ultrasound pulse propagates through a cell containing a suspension of microspheres, four reflected echoes A1, A2, A3, A4 from the cell walls are observed as shown in **Fig. 1**. If the scattering contributions from the microspheres are noticeable, the complicated scattering patterns could be observed between A2 and A3 as well. The pulse wave ψ for the scattering component may be written as:

$$\psi(t) = A(t)\cos\left[2\pi f_c t + \Phi(t)\right]$$

where t is the field-time, f_C is the central frequency, A and Φ are respectively the amplitude and phase of the temporal pulse. In the case of the backscattering geometry, t contains the spatial information of the scatters along the beam direction enabling us to obtain the information on the location of the particles as indicated by the line A in **Fig. 1**. The time-evolution of the pulse can be visualized as an image of the sound field by successive recording of pulses at an interval ΔT (~ms). As the results, we obtain the time fluctuations of the scattered signals along the axis of the evolution-time, T, as indicated by the arrow B. The characteristic time of the fluctuations may be evaluated [2)] by the time-correlation function $g_y^{(1)}(\tau)$ defined by:

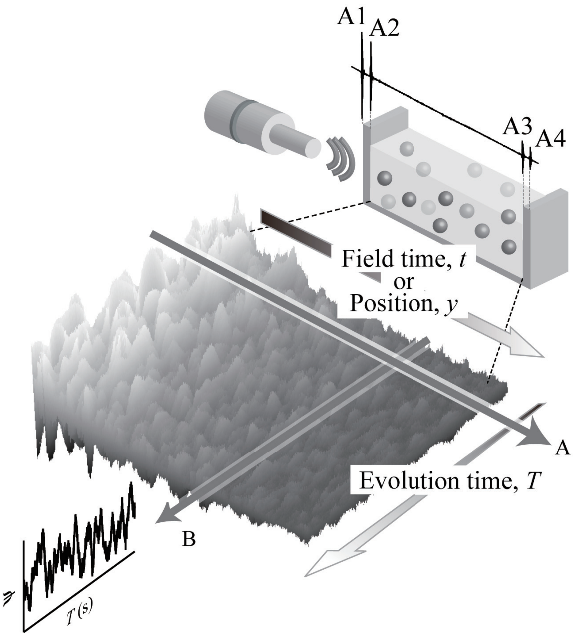

Fig. 1 Schematic illustration of the DSS experiments.

$$g_y^{(1)}(\tau) = \cos\left(q\langle V\rangle\tau\right)\exp\left(-\frac{1}{2}q^2\langle\delta V^2\rangle\tau^2\right)$$

Here after we employ $\Delta V \equiv \langle\delta V^2\rangle^{1/2}$ as a measure of the velocity fluctuations which are related to the particle diameter.

3. Experimental

3.1 Samples

Four kinds of monodisperse polydivinylbenzene microspheres with the particle diameters d= 5, 10, 15 and 20 μm (purchased from Sekisui Chemical Co. Ltd) were used. These particles were dispersed in in 0.2 wt% sodium dodecylsulfate aqueous solution. The particle concentration was fixed at 1 wt%. The suspension was injected in a rectangular vessel made by polyphenylenesulfate with the dimension 15 x 30 x 25 mm^3.

3.2 Apparatus

Negative impulse emitted from a pulser/receiver (iSL-Pulser) was transferred to a 30MHz-longitudinal plane wave transducer (30K1I) immersed in a water bath to generate broadband ultrasound pulses. The same transducer received the reflected or scattered ultrasound waves. The obtained signals were then amplified by the receiver, followed by successive recording with a 14bit high-speed digitizer (Compuscope CS14200) at the sampling rate 200 Ms/s. The PRF was varied in range 10 Hz to 10 kHz. (**Fig. 2**)

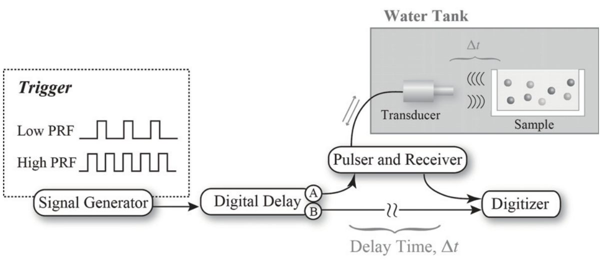

Fig. 2 Schematic illustration of the DSS Apparatus.

4. Results and discussions

Fig. 3 shows the images of the velocity field constructed by the phase-mode DSS technique.[3] As the PRF became higher, the domain structures inherent in micron-sized suspension disappeared. In other words, the velocity field became more homogenous due to excess ultrasound energy. The velocity field observed at 200 Hz for d = 5μm was similar to that at 500 Hz for 15 μm. It is suggested that the sedimentation velocity of larger particles are more stable against the external flow.

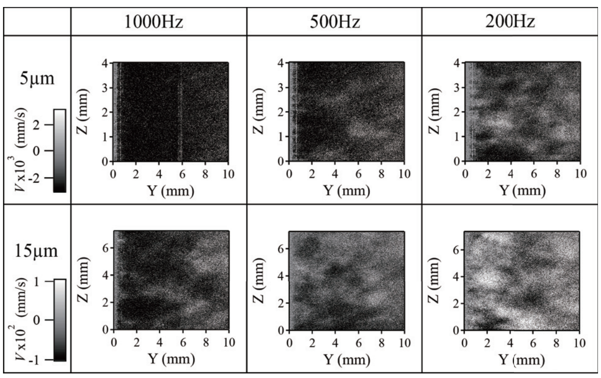

Fig. 3 Images of the velocity field.

In order to quantitatively investigate the effect of PRF, the diameter dependence of the velocity fluctuations were examined in more detail.

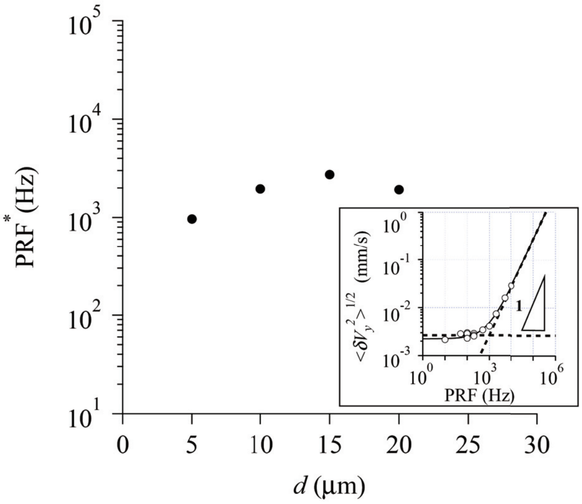

Fig. 4 Diameter dependence of the crossover frequency.

Fig. 4 shows the particle diameter dependence of the crossover-frequency, PRF*, determined by the intersection of ΔV vs. PRF plot exhibited in the inset. The crossover frequency increased with the particle diameter, suggesting the large particle size is more stable against the ultrasound energy.

5. Conclusion

The diameter dependence of PRF effect for monodipersed polydivinylbenzene microspheres with the diameter range 5 – 20 μm was investigated by means of DSS. The velocity fluctuations were overestimated at extremely high PRFs for all the particles. Although the transition point of PRF increased with the diameter, PRF remained in 1 – 3 kHz which was much higher than the typical frequency employed in most of the practical applications of DSS.

Reference

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