Simulation of Pearl-Chain Formation in Acoustics, Including Inter-Particle Forces and Collisions

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Abstract

Acoustic standing waves can be used to manipulate micrometer sized particles, cells and organisms. In most applications these objects are driven towards pressure nodal lines, predominantly by the primary acoustic radiation force. Interestingly, at intermediate particle concentrations, detailed phenomena of line-formation and inter-line repulsion occur. Such phenomena are believed to be caused by secondary (inter-particle) acoustic forces, initially not observable due to the movement of particles toward the nodal line, they become apparent close to the nodal line. In addition to this attractive and repulsive acoustic particle interaction, collisions between particles play an important role in the pattern formation and should be included in numerical simulations.

In own unpublished (submitted) work, we coupled a contact algorithm with analytical solutions for the secondary forces yielding good results. In this work, we use a novel and efficient combination of COMSOL Multiphysics® and MATLAB® to solve the multi-scattering problem and acquire the acoustic radiation force numerically. This allows for a higher accuracy and to incorporate non-spherical particles at a later stage. The interaction between the particles and the fluid is simulated using the Acoustic-Structure-Interaction interface. Acoustic reflections at the outer domain boundaries are minimized using perfectly matched layers. After acquiring the acoustic radiation forces they are exported to MATLAB® using LiveLink™ for MATLAB®. The dynamic time-stepping, which includes the unilateral contacts between the particles is done in MATLAB®. The new positions are fed back to COMSOL to update the acoustic radiation force, hence closing the time-stepping loop.
At this time we have restricted ourselves to 2D simulations, in the future we will expand to 3D simulations incorporating more generally shaped particles.

Our method allows us to analyze complex acoustic particle interactions, effectively explaining particle chain formation. Using the COMSOL Multiphysics software we were able to determine the trajectories of acoustically interacting particles a)-c) and we could compare them to experimental results d) (Figure 1). First results of the scattering simulations and the COMSOL modeling are shown in Figure 2.

In conclusion, we show a full numerical simulation of multiple particles, taking into account acoustic forces from multi-particle scattering and contact forces.

In the future, the principles will be transferred to 3D simulations and particle-wall interactions. Furthermore viscosity and acoustic streaming will be included (2D).
The improved accuracy of refined and increasingly complete simulations shows the power of COMSOL Multiphysics and the synergistic use of using LiveLink™ for MATLAB®, will be of great use in acoustic manipulation and acoustic self-assembly technology.

Figures used in the abstract

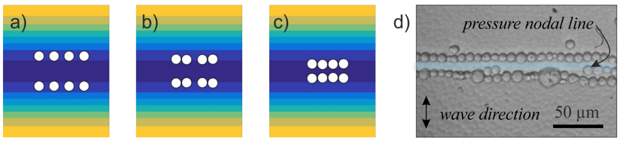

Figure 1: Particle positions of 100 µm diameter aluminum particles are shown for 0 s, 0.15 s and 0.75 s at a) b) and c), respectively. The background shows the amplitudes of the Gor'kov potential in yellow (high) and blue (low). d) The steady state reached in an experiment with glass particles, clearly showing the line-formation.

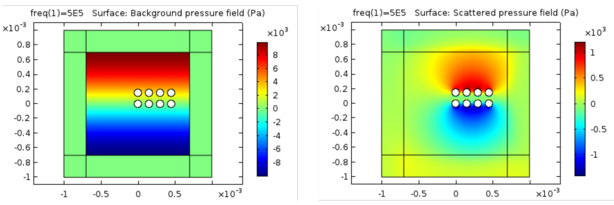

Figure 2: Showing the general COMSOL setup, typically a background pressure field is used as input to acquire the resulting scattered pressure. These values are then used to compute the resulting acoustic radiation forces.