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Fluid Coupling Effects Of An Array Of Oscillators Vibrating In Close Proximity To A Solid Surface

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Abstract

High speed non-contact Atomic Force Microscope (AFM) comprising a single cantilever beam is used to track the motion of live-cells as it ensures no damage to soft biological samples [1]. PRONANO arrays [2] consisting of multiple cantilever beams have been used to achieve faster scan rates. However, the technology has not been established for fluids yet, in which the biological samples are preserved. AFM comprises of a micro-cantilever beam with a fine tip which is raster scanned over the sample surface to obtain high resolution images at atomic scale. Hence, in an initial investigation we study the fluid flow between cantilevers at their tips which reduces our initial investigation to studying the fluid flow of rectangular cross-sectional plates vibrating in a two-dimensional plane.

Vibrations of a single cantilever beam in an infinite fluid domain (unbounded fluid) and in close proximity to the wall (bounded fluid) is well established in literature [3, 4]. However, very little knowledge currently exists on array of cantilevers in fluid [5, 6, 7]. To our knowledge, no literature exists on arrays vibrating in close proximity to a solid surface in fluids. The following assumptions are made for developing the computational model: (a) the fluid is stationary, incompressible and viscous; (b) the rectangular beams are made of linearly elastic, homogeneous and isotropic material. We employ the commercial software COMSOL to simulate the fluid coupling effects of an array of oscillators.

We employ a two-dimensional model as shown in Figure 1 with an equivalent mass and equivalent spring stiffness to approximate the three-dimensional beam. The beams are free to vibrate about their mean positions. Each individual element of the array is driven by a harmonic force. This will give rise to an attractive or repelling interaction between each beam and its nearest neighbors via fluid which will generate a fluid-coupled system. A systematic analysis has been carried out to study the effect of various parameters (gap widths, heights from the surface, excitation conditions, non-neighboring beams and varying wall configurations) on the collective response of the system as a whole.

The analysis yields first qualitative results about pressure, flow field and time history of displacement and forces exerted by fluid on individual members of the array. Figure 2 shows the time history plot of a two beam array for a chosen gap width, with one beam driven by a harmonic force, vibrating in close proximity to a flat wall. Figure 3 shows the pressure plot when beams vibrate closer to the wall resulting in a huge backward pressure, restricting the beams' motion. Figure 4 shows the pressure plot when two beams are vibrating in close proximity to a stepped wall configuration, with both beams driven by a harmonic excitation force, resulting in a cavity formation creating a pressure gradient.

The computational results will guide the choice of parameters for the experiments to be performed at a later stage to gain a deeper insight on the collective dynamics of arrays in fluids which will help interpret biological images with high precision.

Reference

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[2] IW Rangelow et. al., Thermally driven multi-layer actuator for 2D cantilever arrays, Applied Physics A, 102(1):61-68, October 2010.

[3] JE Sader et. al., Experimental validation of theoretical models for the frequency response of atomic force microscope cantilever beams immersed in fluids, Journal of Applied Physics, 87(8):3978, 2000.

[4] T Naik et. al., Dynamic response of a cantilever in liquid near a solid wall, Sensors and Actuators A, 102:240-254, 2002.

[5] A Raman et. al., Hydrodynamic coupling between micromechanical beams oscillating in viscous fluids, Physics of Fluids, 19(1):017105, 2007.

[6] M Kimber et. al., Experimental study of aerodynamic damping in arrays of vibrating cantilevers, Journal of Fluids and Structures, 25(8):1334-1347, November 2009.

[7] C Intartaglia et. al., Hydrodynamic coupling of two sharp-edged beams vibrating in a viscous fluid, In Proceedings of the Royal Society, December 2013.

Figures used in the abstract

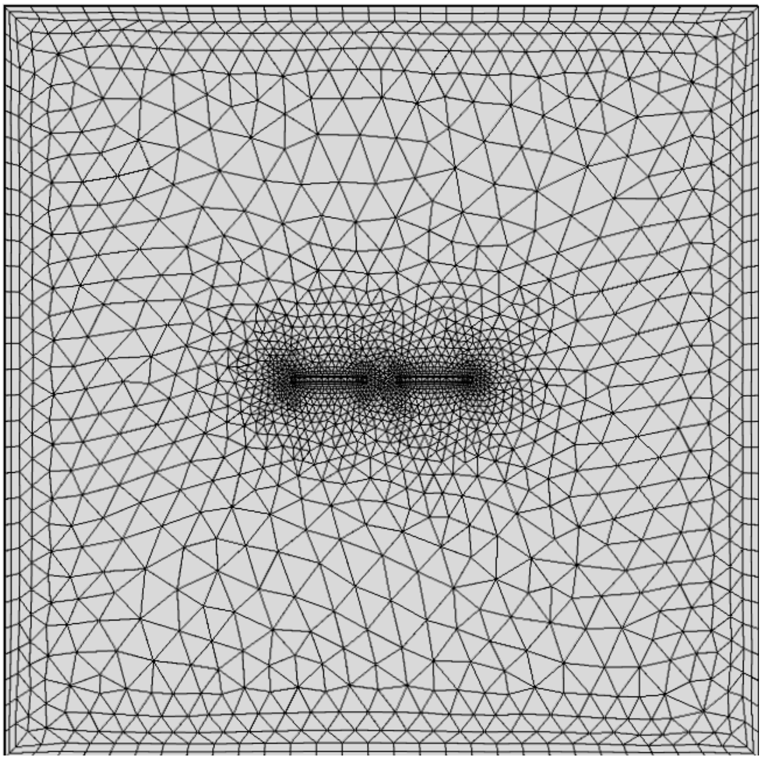

Figure 1: Meshed model of two cantilever cross-sections vibrating far from the wall in a fluid domain

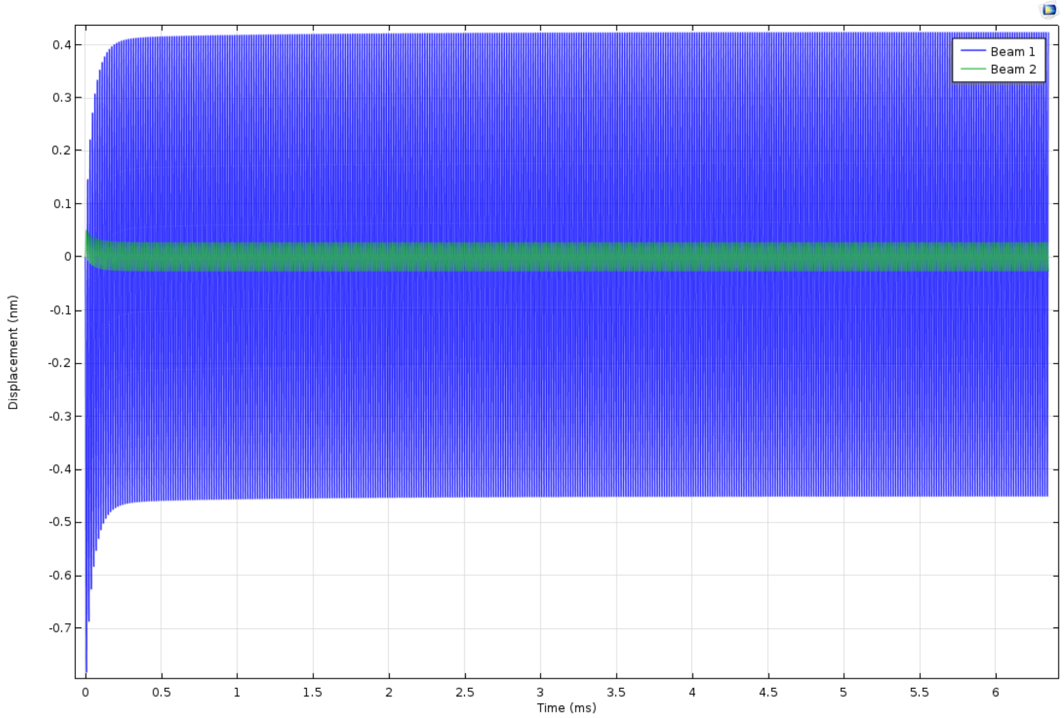

Figure 2: Displacement of two beams vibrating in close proximity to a flat wall, gap width g = 0.4*b, where b is the width of the beam

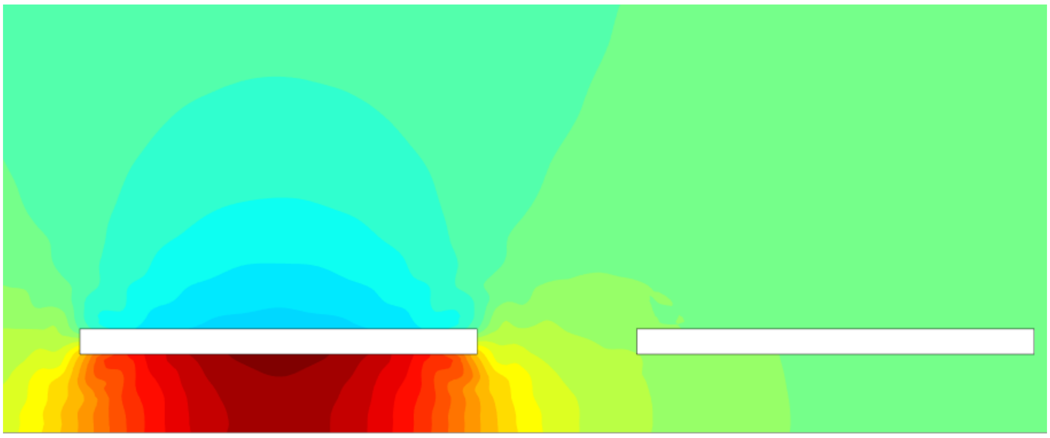

Figure 3: Pressure contour of two beams vibrating in close proximity to a flat wall at t = 0.0063492 s

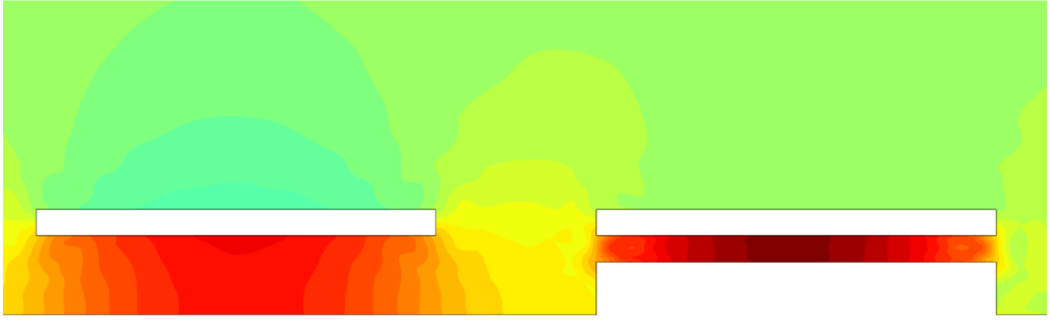

Figure 4: Pressure contour of two beams vibrating in close proximity to a stepped wall at t = 0.0063492 s