Study of a membrane pump by simulating its fluid-structure interaction in a partitioned way

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The pumping of biological fluids is a challenging problem, mainly because damaging of the particles in the fluid, such as blood cells, has to be prevented. The membrane pump analyzed in this research is ideally suited for biomedical applications and particle-laden flows. This unconventional membrane pump operates without any valves and produces a relatively constant mass flow rate. The pump consists of a cylindrical casing which encloses a flexible circular membrane with a hole at its center. The outer edge of the membrane performs an oscillating motion parallel to the axis of the cylinder, brought about by an electromagnet. As a result, the structure of the membrane behaves as a transverse travelling wave pumping the fluid on both sides of the membrane from the inlet at the side of the cylinder to the outlet at the axis. In order to further improve the design of these types of pumps, deeper understanding of the fluid-structure interaction (FSI) in these pumps is required.

The numerical simulation of such a multi-physics problem is challenging, especially because the deformation of the fluid domain and the interaction between the fluid and the structure are strong due to the flexibility of the structure and the comparable density of the fluid and the structure. In this research, an accurate calculation of the stress on the fluid-structure interface is obtained by solving the flow equations in the Arbitrary Lagrangian-Eulerian formulation on a deforming mesh. A high-quality mesh is maintained by an innovative combination of mesh motion corresponding to the solution of Laplace equations, mesh smoothing and remeshing. The FSI-problem is solved in a partitioned way, i.e. solving the governing equations for the laminar flow of the incompressible fluid and for the deformation of the membrane with two separate codes. These are coupled with the interface quasi-Newton technique with an approximation for the inverse of the Jacobian from a least-squares model (IQN-ILS)[1].

The mean mass flow rate supplied by the pump is 95.6 g/s. An energetic analysis has been performed (Figure 1) and the efficiency of the pump was calculated. This efficiency was found to be relatively low due to a large backflow between the membrane and the casing of the pump. Further, a spectral analysis has been performed. The Fourier analysis of a mass flow rate impulse response revealed the natural frequencies of approximately 6, 24 and 66 Hz. Finally, the mean mass flow rate was found to increase slightly more than linearly with the frequency.

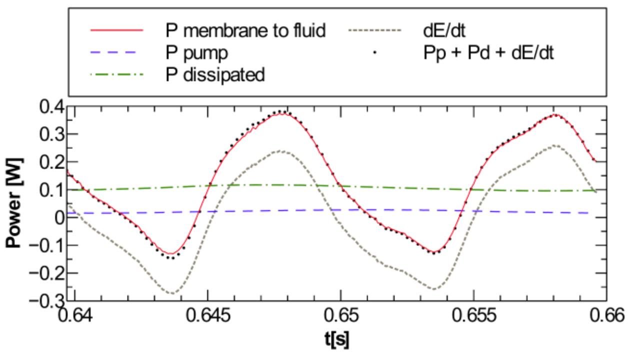

Figure 1. Evolution of the power transferred to the fluid through the membrane, the dissipated power, the pump power, the change in energy stored in the fluid domain per unit of time and the sum of these last three powers during one period of excitation

[1]J Degroote, K-J Bathe, and J Vierendeels. Performance of a new partitioned procedure versus a monolithic procedure in fluid-structure interaction; Computers and Structures 87(11-12): 793-801, 2009.