Design and Optimization of a Valveless Micropump under Uncertainties using Evolutionary Algorithms

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ABSTRACT

This paper demonstrates the design-optimization, with and without uncertainties, of a 3D valveless micropump [4], for use in medical and biochemical processes [1]. Its dimensions are of the magnitude of millimeters and its design should be precise, for the pump to be as accurate and efficient at fluid transportation. The fluid's flow is induced by a periodically moving diaphragm, which determines the pump's proper function. A mechanism vibrates the diaphragm, either with a sinusoidal movement or with a pressing movement along the axis of the flow. In this paper, mathematical models for the second type of motion are proposed. The parameters of the models describing the membrane motion will be the design variables of the optimizations. For the simulations, the flow is considered to be incompressible. A Computational Fluid Dynamic (CFD) solver, which handles moving walls, is used for the 3D unsteady simulations. The simulations are computationally expensive, even though the CFD codes run on GPUs, because many real time-steps have to be solved. The presented optimization problem aims at minimizing the backflow of the micropump's outlet, while maximizing the net mass flow rate within each period. The optimization is carried out using Evolutionary Algorithms (EA). Due to the high computational cost of each evaluation, metamodels assist the EA by reducing the calls to the expensive CFD tool. The Principal Component Analysis method [2] is also used as a technique to cut-off insignificant design variables for the EA, further reducing the overall optimization cost. Moreover, the micropump's design have to be robust to slightly changing flow conditions. An optimization under uncertainties, with the inlet or outlet pressures as the uncertain variables, is carried out. For the quantification of uncertainties, the non-intrusive Polynomial Chaos Expansion (PCE) method is used. The new objective function includes the mean value and the standard deviation of the objective function of the previous optimization without uncertainties. The PCE method is coupled with the aforementioned EA to perform the optimizations under uncertainties, [3]. The resulting designs are compared with the ones produced by the optimization without uncertainties. The resulting pumps and the interpretation of the optimal diaphragm motions are discussed.

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