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Level Set Based Topology Optimization of Switching Fluidic Device for Incompressible Viscous Flow

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Abstract
The fluidic device is known as the fluid component that the flow direction is switched or controlled by means of the fluid property without the mechanical operating components. These devices such as switch, amplifier or oscillator, have the advantage in the aspect of maintenance and operating life compared to the devices with mechanical actuation controlled by the electronic circuit. Therefore, the structure and function of the fluidic device have been subjected to extensive research up until a few decades ago before the rapid development of the electronic technology. Recently, these fluidic devices are again getting the attention along with the development of MEMS (Micro Electro Mechanical System) technology. However, the structure of fluidic devices are still used as same as the already-suggested one in the past study.
From the aspect of the optimization method, there are a lot of studies on the optimization related to the fluid components. Particularly, the topology optimization technique can be effective method for the optimization technique due to having the potential of topological changing of the hole creation or disappearance through the optimization process. There are a lot of studies on the incompressible viscous flow topology optimization. However because the advection equation is used for extracting the boundary movement between fluid and solid domain, only the shape boundary of the design domain evolves during the optimization process. As a result, most studies are categorized as the shape optimization, strictly speaking.
In this study, in order to develop the energy-efficient structure of the fluidic device, the switching fluidic device is especially focused on for the application of the topology optimization method. And, a level set based topology optimization, incorporating the concept of the phase field method, is applied to steady-state incompressible viscous flow. In this method, arbitrary topology can be implicitly represented by level set function without grayscales. Moreover fictitious interface energy, based on the phase field method, is also introduced for regularizing the topology optimization problem. This topology optimization method has the advantage of allowing not only the shape change but also the topological change, and overcoming the numerical instability such as grayscales and checkerboard patterns.
For generalizing the topology optimization problem for fluid, the generalized expression of the primal and adjoint problem were formulated concretely in terms of minimizing the viscous energy dissipation and the outflow rate as the objective functional in the topology optimization problem in this study. Furthermore, the sensitivity analysis was carried out for each specific objective functional.
As a numerical example, the special switching device configuration was examined. This device is to be designed that the flow automatically chooses either of the outlets depending on the inlet Reynolds number (outlet 1 for high Re, 2 for low Re). This device was optimized by minimizing the difference of the actual and target outflow rate. In the result of the topology optimization, the intended target outflow rate could be obtained under the energy efficient optimal configuration of the switching fluidic device.

Keywords: Topology optimization, Level set method, Incompressible flow, Fluidic device