Imposing Manufacturing Constraints in Topological Optimization of 2D Fuel Cell flow problems using OpenFOAM

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Abstract Proton-Exchange Membrane Fuel Cells (PEMFC) are systems that directly convert chemicals into electricity by means of an electro-chemical reaction between hydrogen and oxygen. Following the concerns related to climate change and the search for cleaner, safer and more efficient power sources, Hydrogen PEMFC are a promising option. Indeed, PEMFC have the silent operation, high reliability, low working temperature and they only produce water as waste.

Nevertheless, to rival the Internal Combustion Engine (ICE), PEMFC shall decrease their manufacturing cost, increase their lifetime and their efficiency as well as improve the thermal management, among others. To carry on this challenge, our research project aims at using manufacturing bipolar plates made of coated steel plates, and to proposing innovative designs of the gas channel network using Topology Optimization techniques, while accounting for the manufacturing restrictions of steel forming process.

This work defines the channel network layout of the Fuel Cell using Fluid Flow Topology Optimization (FFTO) subject to design constraints. To achieve this goal, a simulation environment has been developed to couple OpenFOAM (to simulate the fluid flow) with mathematical programming Optimization Algorithms.

The mathematical framework considers the flow simulation using the Incompressible Navier Stokes equations in steady-state condition. These equations are combined with Darcy's law by means of the Brinkman penalization, which results in a density-based method to perform the topology optimization.

At first, we revisit the minimization problem of the dissipated power subject to a volume constraint to validate our in-house coupling framework between OpenFOAM and the Optimization Algorithms. The sensitivity analysis of the fluid flow equation is provided by OpenFOAM [1], while the optimization is performed using an MMA[2] version in MATLAB. In our implementation, we explicitly consider a volume constraint. Our optimization framework is validated by comparing the results with the vastly 2D benchmark applications available in literature.

Secondly, we consider the implementation of manufacturing constraints into the optimization problem in order to account, in a simplified way, for the sheet metal forming technology. In a first step, we consider maximum size [3] and minimum gap [4], that are able to reflect the practical and industrial manufacturing restrictions.

Thirdly, the well know minimum size filter [5] is added and tested in the developed optimization framework and the results are discussed in the case of the Incompressible Navier Stokes flow.

Finally, a novel interpolation law for the inverse porosity parameter is implemented. Its impact on optimized results is assessed and compared with the traditional approach used in fluid flow topology optimization.

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