8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Topology Optimization of Fluid Dynamics Devices

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Key Words: *Fluid Mechanics, Topology Optimization, Design Tool.*

ABSTRACT

Facing a design related problem often means to search among a set of possible options to find the one which meets certain requirements and satisfies one or more optimum criteria.

A typical design problem is the research of the optimal geometry of some device that has to accomplish a task (be it a structural one, or regarding heat and mass transfer etc.); it's clear that an optimization method able to explore the whole set of possible configurations with little or no limitation will approach better the real optimal design. When using topology optimization methods, very little *a priori* knowledge of the domain in which the physical phenomenon of concern takes place; though the great majority of these methods was developed (and applied) in the field of structural mechanics, their extension to other disciplines is very attractive.

In the fluid mechanics field, shape optimization methods (the control parameter is the boundary of the domain in which the flow takes place) are well-tested (see e.g. [1]. However, this kind of optimization requires to choose the domain topology *a priori*; moreover, the number of parameters controlling the boundary shape can't be excessively high in order to keep the setting of constraint condition on their reciprocal position to a reasonable level of simplicity. The feasible design set which is actually explored is therefore limited and it can be difficult to assure the mesh quality needed to obtain a valid result from the underlying numerical simulation. In this context, the design resulting from topology optimization can be used as a reasonably good starting point for the shape optimization step, whose purpose will be to refine an already well-performing design and which will probably require a reduced number of iterations to reach convergence.

The topology optimization algorithm used in this paper can be considered as an extension to fluid dynamics of the popular (in structural mechanics) *material distribution method* (see [2]); the absence or presence of fluid is related to the value assumed by a variable γ which control a penalty term directly proportional to the fluid velocity added to the momentum equation. This approach was firstly proposed by Borrvall and Petersson in [3] for Stokes (creeping) flow and succesively extended to (low Reynolds) Navier-Stokes flow in [4]. Each iteration of the optimization process requires the solution of a boundary conditions problem, followed by the sensitivity analysis of the objective function w.r.t. the control variable and by the updating of this variable by means of the MMA algorithm [5]. A constraint on the total amount of fluid

allowed in the domain is usually specified as a fraction of the frame domain volume. The mesh remains the same along the process; the drawback is that the interface between fluid (γ=1) and no-fluid (γ=0) won't be available as a parametric curve or surface; moreover, though the optimization process itself tends to penalize intermediate values of γ (which are of difficult physical inerpretation) a restricted area) a restricted number of cells/nodes located between the fluid region and the "solid" region assumes these values, resulting in a somehow blurred "wall region".

In the work here presented, the contour corresponding to an itermediate γ value (precisely γ=0.5) was extracted and post-processed in a semi-automatic way to obtain a parametric geometry definition apt to be used as the input for shape optimization; examples (a tee-joint, a single inlet- multiple outlet device) are presented aimed to show the complete process.

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