Topological Optimal Design and Experimental Validation of a Milled Liquid Cold Plate

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This paper details the design of a liquid cold plate by topology optimization. The topology optimization procedure minimizes for a uniform surface temperature. The design is constrained by its assembly with screws, the need for structural integrity and the manufacturing process, CNC milling. The resulting cold plate is used as a replacement for a cold plate with a serpentine cooling channel. Both cold plates are experimentally tested in a setup which represents a general industrial use case. These experiments demonstrate that the average thermal resistance between the coolant and the heat sources can effectively be lowered by more than a factor of 2 by the application of topology optimization.

I. ....Introduction

THE cooling of machine components is a recurring problem in industry. One reason for this is that, very often, the operating temperature of these components is inversely proportional to its lifetime. Therefore, active cooling is applied to the components in an attempt to keep the maximal temperature below a certain limit temperature. Examples of such components range from lasers to engines and power electronics. Also products may require cooling during production. This is the case for instance for casting. By applying active cooling during casting, the cycle time is reduced with an increased productivity as a result. However, inefficient or non-uniform cooling can result in a reduced product quality. The goal of this paper is to explore the benefit of new cooling solutions enabled by topology optimization in an industrial setting.

This paper focuses on a generic liquid cold plate. A liquid cold plate is essentially a heat sink through which a liquid coolant flows. A number of discrete heating elements, mounted to the cold plate, serve as heat sources. The common design for such a generic cold plate is a CNC-milled metal plate with one serpentine channel which runs over all heating elements. In this work, a new design for the CNC-milled cold plate is generated using topology optimization. The goal function is a uniform surface temperature, thus considering both flow and heat transfer. Thereby, all necessary constraints are taken into account: assembly constraints (screws), manufacturing constraints, structural integrity and a limited pressure drop.

The new design is manufactured and tested against the original design on a dedicated test setup. The test setup determines has a range of operating conditions. The optimal design is created based on the worst case conditions (lowest mass flow etc.). Therefore, the robustness of the design with respect to variations in the operational conditions is also subject of the experimental validation.

Subsequently, the cold plate with a serpentine cooling channel and relevant design specifications, the design of a new cold plate using topology optimization and the experimental validation are discussed briefly.

II. ... Cold Plate with Serpentine Cooling Channel and Design Specifications

Nearly all designs of liquid cold plate are constructed from multiple equal-sized parallel channels or a serpentine cooling channel. In this case, the reference design is with the serpentine channel, pictured in Figure 1a. It is clear from this figure that the serpentine channel structure is projected onto the surface temperature for the given operating conditions. Moreover, in fig. 1b a cross-section of the coldplate is shown, which demonstrates the heating of the coolant along the channel. Clearly, depending on the operating conditions, this can greatly aggravate the effective cooling of the heaters near the end of the cooling channel.

In the test setup, a number of discrete heating elements is attached to the cold plate. These heating elements are cooled by glycol running through the cold plate. The temperatures of the heaters are measured and serve as the benchmark for the topologically optimized design. Since the cold plate is milled, a thermally isolating plastic cover is mounted to the back of the to close off the channels. These design specifications translate into boundary conditions and constraints for the optimal design detailed in the next section.

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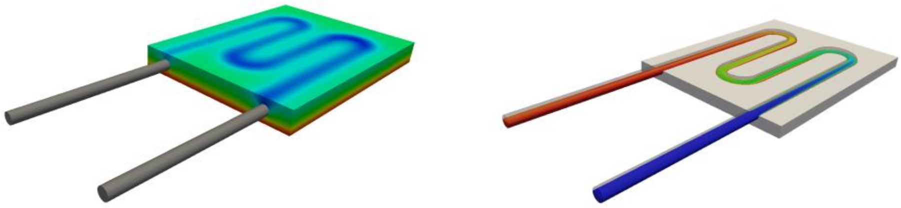

Figure 1. Thermal view of the liquid cold plate, revealing the serpentine cooling channel.

III..... Topology optimization of a Liquid Cold Plate

A new, optimal design of the liquid cold plate is generated using topology optimization with the density approach. This requires the solution of the Navier-Stokes equations, including the energy equation, in both forward and adjoint formulation. Because the flow in the heat sink is laminar, no turbulence modeling is required. The pressure drop from inlet to outlet is set equal to the pressure drop of the original cold plate. The goal function is a uniform surface temperature of the contact area between the heaters and the cold plate:

$$\min J(\varphi,\varepsilon) = \int_{\Omega_h} (T(\vec{x}) - T_{ref})^2 d\vec{x}$$

where J is the goal function, φ the state, ε the design variable (1 = fluid phase, 0 = solid phase), Ω_h interface between cold plate and heaters, T the temperature, T_{ref} the reference temperature and $\vec{x}$ the coordinate vector. The resulting optimization problem is similar to in [1] and will not be repeated here.

In order to ensure the manufacturability and the usability of the resulting design, the following additional constraints are imposed:

- Assembly screws: the heaters are mounted on the cold plate with screws. All cells within a radius of these screws are constrained to stay solid (ε = 0).
- Structural integrity: the rim of the plate as well as the bottom of the plate (where the heaters are attached) is constrained to the solid phase (ε = 0). This is a rough way of asserting structural integrity. However, these conditions were extracted from the original design with the serpentine cooling channel and thus mainly limit the freedom of the topology optimization. Refining this constraint is a future task.
- Manufacturability: channels that are cut out in the plate all have the same depth (equal to the height of the plate minus the height of the fixed bottom imposed in the previous constraint). This ensures that channels can be cut out and that no hollow structures are formed.

The final design consists of a network of cooling channels which ensures maximal local cooling and minimal overall pressure drop.

IV. ....Experimental Validation

The experimental validation is ongoing, and will test the liquid cold plate designed in this work versus the original cold plate with serpentine cooling channel. The results will be presented at the conference. Based on the simulations, it is expected that the average thermal resistance between heaters and fluid will lower by a factor 2.

V. ....Conclusion

In this work, a liquid cold plate was designed by topology optimization and will soon be experimentally validated. The liquid cold plate was optimized towards a uniform temperature of the attached discrete heating elements. The design is constrained by its assembly with screws, the need for structural integrity and the manufacturing process, CNC milling. The final design consists of a network of cooling channels which ensures maximal local cooling and minimal overall pressure drop.

The experimental validation is ongoing, and will test the liquid cold plate designed in this work versus the original cold plate with serpentine cooling channel. Based on the simulations, it is expected that the average thermal resistance between heaters and fluid will lower by a factor 2.

References

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