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Christian Karcher and Ali Karno

Convective heat transfer around microstructured bodies

Introduction and motivation

High-performance thermocouples must respond as quickly as possible to temperature changes in order to effectively control engineering processes and also increase their efficiency. However, simply reducing the sensor mass to obtain a lower characteristic time constant could possibly result in material failure. An innovative method to achieve shorter response times is to diminish the characteristic length L_C [1] of the thermocouple. This length is defined by $L_C = V/A$, where V and A are the volume and the heat exchange area of the sensor, respectively. Thus, at fixed mass or volume, A must be increased. This can be done by surface modification such as microstructuring. We present both an analytical model and numerical simulations to prove this method.

Analytical model

To study the transient heat transfer between a solid body and a surrounding moving fluid we apply the lumped capacitance method (LCM) [1]. With this method, temperature gradients within the body are neglected. Usually, this assumption is valid for small Biot numbers $Bi = \alpha L_C/\lambda$, where α denotes the convective heat transfer coefficient and λ is the heat conductivity of the body. The transient mean temperature T(t) of the body is governed by the exponential behavior $T(t) – T_F = (T_0 – T_F) \exp [t/t_c]$, where T_F is the fluid temperature, T_0 is the initial temperature of the body, and t_c is the characteristic time constant of the body. This time constant is given by $t_c = \rho c L_C/\alpha$, where ρ and c denote the density and the heat capacity of the body, respectively. Moreover, the correlations for laminar convective heat transfer [2], [3] show that α also depends on L_C according to the relation $\alpha \propto L_C^{-1/2}$. Thus, we obtain the central result $t_c \propto L_C^{3/2}$.

Numerical simulations

We perform numerical simulations using the commercial code FLUENT 6.3. We restrict the simulations to two-dimensional flow around a microstructured cylindrical body. We fix the Reynolds number $Re = UD/\upsilon$ at the value Re = 6000, indicating laminar flow. Here, U is the free stream velocity, D the diameter of the cylinder, and υ is the kinematic viscosity of the fluid. The fluid temperature is fixed at T_F = 70°C. As an initial condition, we fix the temperature of the body at T_0 = 20°C. Thus, we study how the body is heated up by the flow. The figure below shows the velocity vectors of the flow around the non-modified body (left) and a microstructured body (right). In this case the microstructure consists of 40 tracks of width 100µm and depth 50µm. Our simulation shows that the microstructured body responds about 11% faster than the non-modified body. This result is in excellent agreement with the predictions of the analytical model using LCM. Further numerical studies show that an optimization is achieved when the microstructure consists of about 120 tracks of width 40µm and d epth 20µm.

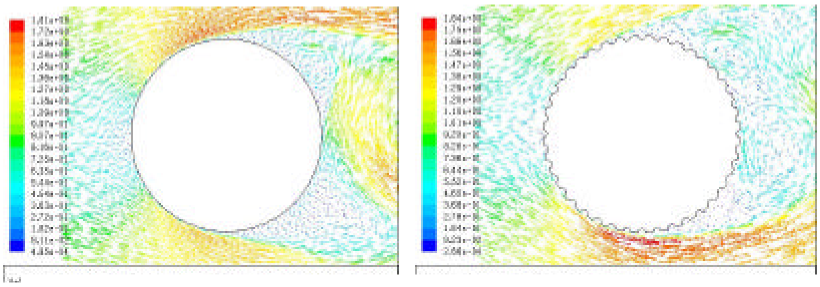

Fig. 1: Velocity vectors of the flow around a cylinder with smooth surface (left) and microstuctured surface (right). The flow is from left to right.

References:

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