Modeling Fluid-Structure Interaction in a Pressure-Controlled Current-Limiting Valve

L. Fromme, N. Mügge, M. Petry, A. Waschke
Department of Engineering Sciences and Mathematics, University of Applied Sciences Bielefeld, Bielefeld, Germany

FH Bielefeld
University of Applied Sciences

CFD has become well-established as an engineering tool in CAE. However, there are still challenges to face, like physical singularities. One of those phenomena is the closing operation of a valve (e.g. current-limiting valves as shown in fig. 1).

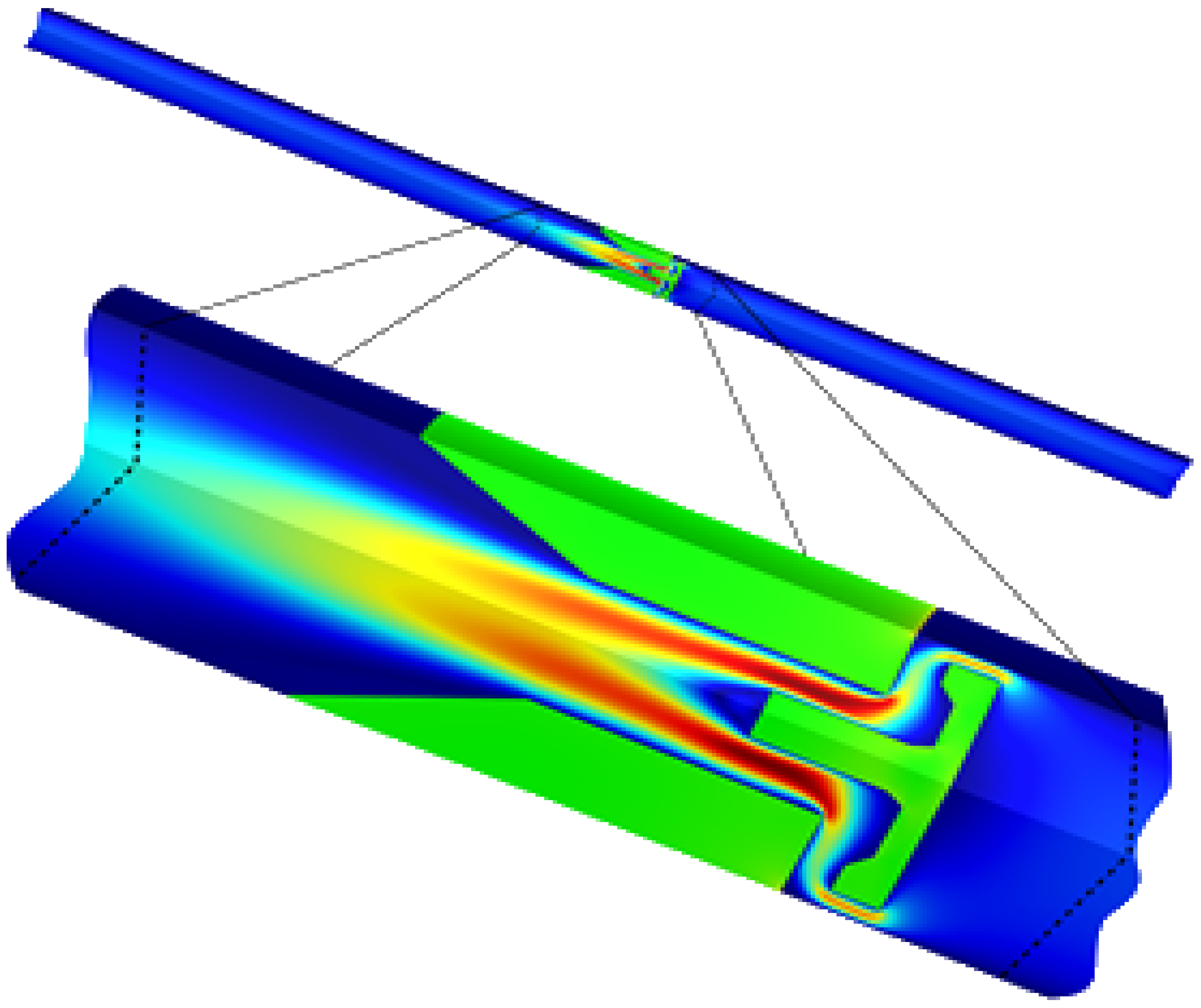

Figure 1: Flow through a current-limiting valve

Current-limiting valves are used as a measure of safety. They are released in case of a high decrease in pressure, e.g. burst pipe or leaks. However, the singularity persists in the entire closure of the valve due to numerical issues. To solve this challenge, the CAE-Software COMSOL Multiphysics® is used. Fig. 2 shows the boundary conditions of the valve model. On the right-hand side a pressure inlet is defined with a time-dependent condition. On the left-hand side there is a pressure outlet with ambient conditions. An axial symmetry is used and the symmetric axis is colored green.

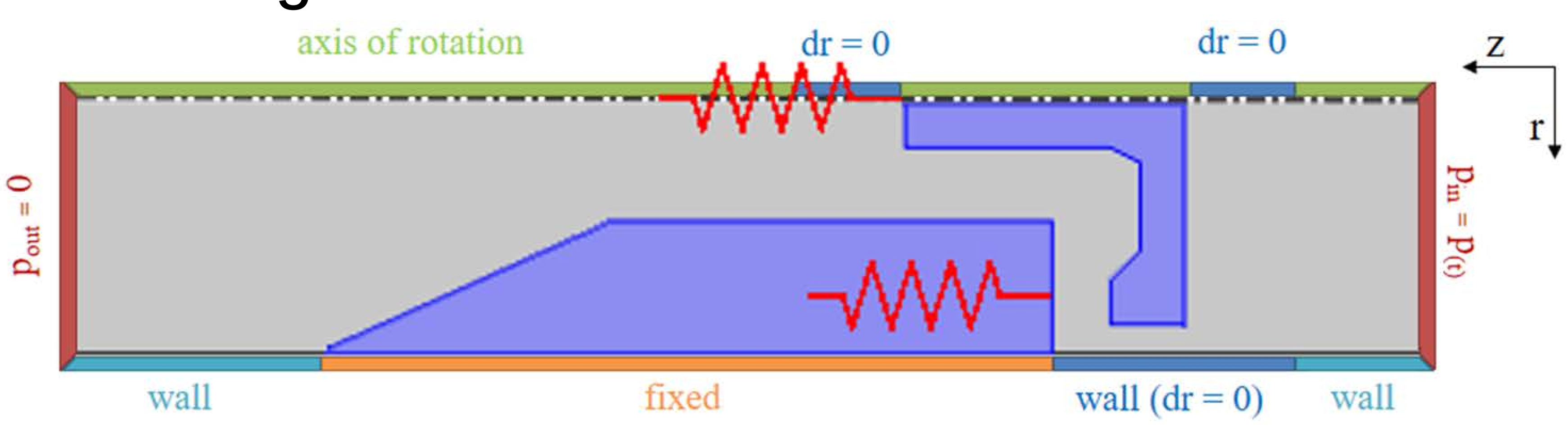

Figure 2: Boundary conditions of the valve model

A structured mesh inside the closing gap is required, as shown in fig. 3, to achieve a uniform deformation during the closing process.

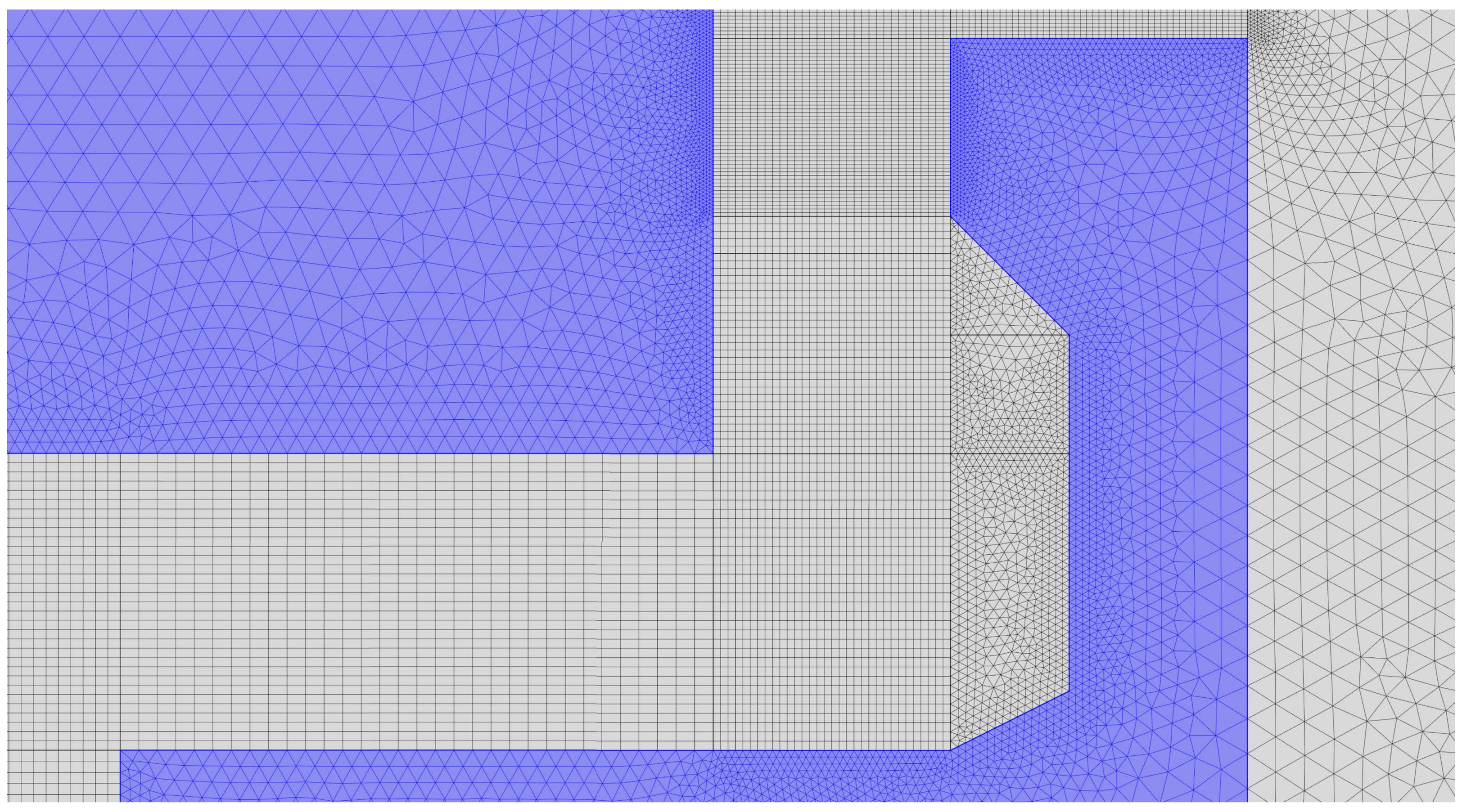

Figure 3: Mesh construction inside the closing gap

The coupling between the fluid and the solid is described by the equation below. The solids deformation $\vec{u}_s$ can be calculated under consideration of the volume forces $\vec{F}_V$and the solids stress tensor $\hat{\sigma}_s$. Whereas, at the interface, the fluids stress tensor is transferred to the solid.

$$\rho_s \partial_t^2 \vec{u}_s - \vec{\nabla} \cdot \hat{\sigma}_s = \vec{F}_V$$

To avoid a full closure, the solid contact of the valve is modeled with an additional spring. To reduce the mass flow through the remained gap, the viscosity inside the closing gap is increased as a function of the clearance by using a second fluid domain. The resulting mass flow as well as the inlet pressure condition are shown in fig. 5. The mass flow is delayed in comparison to the pressure. In the closed state, the mass flow remains at $4.77 \cdot 10^{-5} \frac{kg}{s}$.

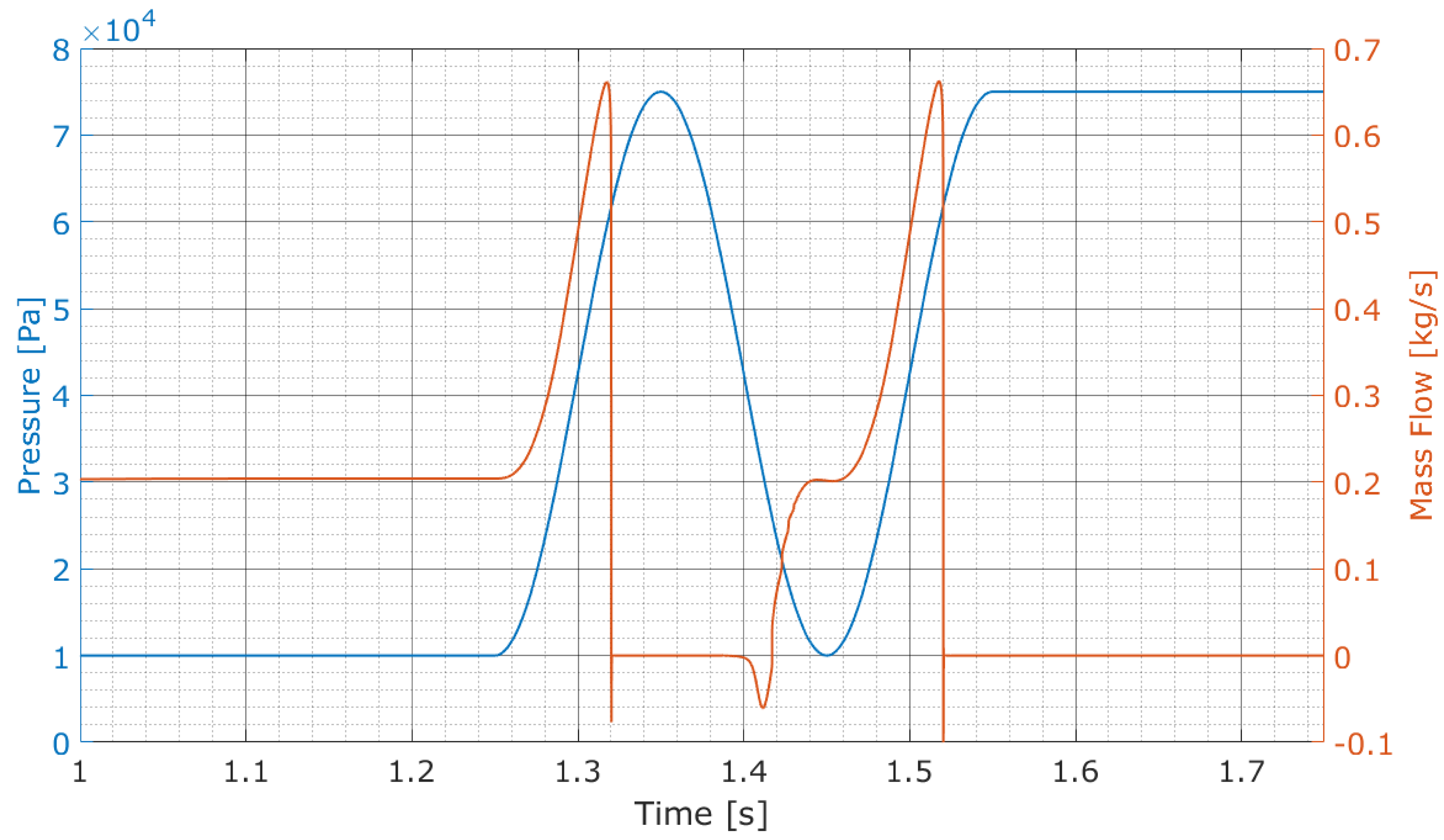

Figure 4: Mass flow (red) and inlet pressure condition (blue) as a function of time

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