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Optimization and Control of Nonsmooth and Complementarity-Based Systems: Theory and Numerics

Model-Based Control of Slab Shapes in Hot Rolling Processes

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Abstract: We consider hot rolling processes, which involve a metal solid body and several rolls that are utilized to deform the body in order to obtain a desired final shape. As we want to minimize unnecessary manufacturing costs arising for example from cutting scrap or energy consumption, we next formulate an optimal control problem where we use the trajectories of the rolls as control variables. In doing so we also have to take into account box- and slope-constraints for the trajectories since the operating space of the rolls is restricted and since the rolls cannot move arbitrary fast.

The motion and deformation of the solid body subject to external forces can be described through the basic equations of nonlinear continuum mechanics, which in the end leads to a nonlinear hyperbolic initial boundary value problem. To characterize the behavior of metals at high temperatures and high rates of deformation we use an elasto-viscoplastic material model based on a multiplicative split of the deformation gradient into elastic and plastic parts, which yields a system of highly nonlinear ODEs that is accompanied by a set of complementarity conditions. We furthermore assume that we can neglect the deformations of the rolls and therefore have to deal with unilateral frictional contact between an elasto-viscoplastic body and several rigid obstacles, which introduces additional complementarity conditions on the contact boundary. The associated weak form will then turn out to be an evolutionary quasi-variational inclusion, which we regularize by utilizing an Augmented Lagrangian method before solving the problem numerically.

As we want to apply gradient-based methods to solve the optimal control problem outlined above, we also have to compute the derivatives of cost function and constraints. This is done by applying the Direct Differentiation Method to obtain sensitivity information of the nonlinear equilibrium problem described in the previous paragraph. On that point we have to further regularize the underlying equations because of the non-differentiable transitions occurring in conjunction with elasto-viscoplasticity and frictional contact.