A stabilised fictitious domain method for Signorini-Stefan problems for laser cutting

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Many thermal ablation processes can be modelled using a unilateral Stefan formulation. The unilateral Stefan problem can be elegantly reformulated as a Signorini problem, such as the ones arising in contact mechanics [1]. Such a formulation introduces nonlinearities in the problem, but alleviates some of the modelling inaccuracies associated with applying Dirichlet conditions in a heuristic manner in regions where the material is assumed to melt.

One major challenge in the simulation of thermal ablation processes is that the moving domain boundary must be tracked through time, which can be cumbersome when using conforming finite element methods. Here, we propose to alleviate this problem by using a fictitious domain method based on CutFEM [2]. While our previous work on contact mechanics focused on a Lagrange multiplier approach to the Signorini problem [3,4], we develop a Nitsche formulation for the unilateral laser ablation problem, following the work proposed in [5,6]. An explicit time integration scheme associated with a fast marching method allows us to propagate the level-set used to describe the domain boundary. We will show that the quality of the interface thermal field, and in particular fluxes, is of key importance to the success of the approach, and we will discuss the regularisation approach that we have developed to address this issue.
Our implementation will be demonstrated on several applications ranging from micro-cavity manufacturing by pulse laser ablation to laser cutting.

REFERENCES

[1] Narimanyan, A. (2009). Unilateral conditions modelling the cut front during plasma cutting: FEM solution. Applied mathematical modelling, 33(1), 176-197.

[2] Burman, E., Claus, S., Hansbo, P., Larson, M. G., & Massing, A. (2014). CutFEM: discretizing geometry and partial differential equations. International Journal for Numerical Methods in Engineering.

[3] Claus, S., & Kerfriden, P. (2017). A stable and optimally convergent LaTIn-CutFEM algorithm for multiple unilateral contact problems. International Journal for Numerical Methods in Engineering.

[4] Burman, E., Hansbo, P., & Larson, M. (2016). Augmented Lagrangian finite element methods for contact problems. arXiv preprint arXiv:1609.03326.

[5] Burman, E., Hansbo, P., & Larson, M. G. (2017). The penalty-free Nitsche method and nonconforming finite elements for the Signorini problem. SIAM Journal on Numerical Analysis, 55(6), 2523-2539.

[6] Chouly, F., Fabre, M., Hild, P., Mlika, R., Pousin, J., & Renard, Y. (2016). An overview of recent results on Nitsche's method for contact problems. <hal-01403003>