Combining Optimal Control and Shape Optimization for an Adaptive Engineering Structure with Parameterized Reduced Order Finite Element Models

B. Fröhlich[1], J. Wagner[2], M. Böhm[2], O. Sawodny[2] and P. Eberhard[1]

[1] Institute of Engineering and Computational Mechanics
University of Stuttgart
Pfaffenwaldring 9, 70569 Stuttgart, Germany
[benjamin.froehlich,peter.eberhard]@itm.uni-stuttgart.de

[2] Institute for System Dynamics
University of Stuttgart
Waldburgstraße 17/19, 70563 Stuttgart, Germany
[julia.wagner,michael.boehm,oliver.sawodny]@isys.uni-stuttgart.de

ABSTRACT

Adaptive engineering structures combine classical engineering structures with actuators, sensors and a corresponding control concept. This allows to adapt the structure, for example to manipulate displacements or stresses, and therewith, to improve the load carrying behavior. In this context, taking the adaptivity into account during the design procedure seems advantageous. Therefore, we propose an integrated procedure, which combines the structural design and the control strategy design in one routine.

Complex engineering structures are often modelled with the finite element method leading to a high dimensional system of ordinary differential equations (ODEs) if a fine spatial discretization is employed. This renders dynamic simulations time-consuming, especially in the context of optimization, due to the necessary simulation reruns. However, a transient analysis is essential for the dynamic control design.

To overcome this problem, a novel approach for efficient reduced order modeling, control, and shape optimization is applied. In a first step, the approach requires to parameterize the shape of the engineering structure. Then, geometrically parameterized finite elements as presented in [1] are used for discretization to derive a parameterized system of ODEs that govern the dynamics. Parametric model order reduction by interpolatory projection methods is applied to derive a parameterized reduced order model which can be used in subsequent design or optimization procedures.

The approach shows two major advantages. First, the parameterized reduced order model is of much lower dimension compared to the full order model, decreasing the numerical effort for dynamic simulations drastically. Second, the parameterized reduced order system matrices are available analytically. This allows a differentiation of the system matrices with respect to the design parameters and, therefore, an efficient sensitivity analysis during an optimization.

The design procedure is illustrated for an exemplary optimization of an adaptive engineering structure, which reduces displacements due to a moving external load by applying a control force at a support of the structure, compare [2]. It is the objective of the optimization example to determine both an optimal shape and an optimal control input such that the actuation energy is minimized. Here, the optimal feed forward control problem is solved in an underlying optimization of the overall shape optimization.

REFERENCES

[1] Fröhlich, B.; Gade, J.; Geiger, F.; Bischoff, M. and Eberhard, P.: Geometric Element Parameterization and Parametric Model Order Reduction in Finite Element Based Shape Optimization. Computational Mechanics, 2018. doi:10.1007/s00466-018-1626-1.

[2] Sobek, W.; Teuffel, P.; Weilandt, A. and Lemaitre, C.: Adaptive and Lightweight. In Proceedings of the International Conference on Adaptable Building Structures, Eindhoven, Netherlands, 2006.