# Multibody based topology optimization including manufacturing constraints

Karim Asrih[1], Francesco Cosco[1, 2], Frank Naets[1, 2] and Wim Desmet[1, 2]

[1] *PMA, KU Leuven, {karim.asrih, francesco.cosco, frank.naets, wim.desmet} @kuleuven.be*
[2] *member of Flanders Make*

Over the past decades topology optimization has gained large interest in structural design since it allows fast development of optimized complex geometries. These designs will often lead to superior properties compared to classical human design. [1]

One of the main advantages of the topology optimization with respect to size or shape optimization is the freedom of the optimizer to generate arbitrary topologies within a design domain. However a disadvantage of this design freedom is the possibility of obtaining components which are infeasible to manufacture using classical (low-cost) manufacturing processes. To overcome this difficulty we propose to include manufacturing constraints in the optimization process. Specifically we optimize components with the addition of extrusion constraints, as extrusion offers a particularly cost-effective production scheme.

Although topology optimization was originally developed to optimize single components rather than full system assemblies, several methods [2-5] have been proposed to account for the dynamic behaviour of multibody systems. For instance Kang [4] proposed to use a weakly coupled approach, referred to as the method of Equivalent Static Loads (ESL). This approach transforms the dynamic loads obtained from the multibody simulation into a static optimization problem consisting of multiple load cases for a single body. In this weakly coupled approach the optimizer does not explicitly take the multibody interaction into account, but only re-evaluates the component loads from the multibody model after an full optimization on the component.

For describing the multibody dynamics, we exploit the Dual Flexibility (DF) formulation [6] in this work. As a result of its simple description for the dynamic equations of motion (linear equations of motion with quadratic constraint equations), this approach leads to low computational loads and thus allows a fast evaluation of the dynamic multibody simulation. This formulation is then exploited to extract the ESL for a component topology optimization including the extrusion constraints.

The proposed weakly coupled multibody based optimization with extrusion constraints is validated numerically. In particular we look at a design problem which concerns the optimization of the weight of a robot arm. This application is interesting since the flexibility of the whole system is considered. The examples are meshed with 3D elements to demonstrate the general applicability of the method for problems with a high number of degrees of freedom.

**Acknowledgements**

The Research Fund KU Leuven is gratefully acknowledged for its support. The research of K. Asrih is funded by a grant from the Flanders Innovation & Entrepreneurship Agency. The research of F. Naets is funded by a grant from the Research Foundation – Flanders (FWO).

## References

[1] Bendsøe, M. P., & Sigmund, O. (2004). Topology optimization by distribution of isotropic material. In Topology Optimization (pp. 1-69). Springer, Berlin, Heidelberg.

[2] Bruns, T., & Tortorelli, D. (1995). Computer-aided optimal design of flexible mechanisms. In Proceedings of the Twelfth Conference of the Irish Manufacturing Committee, IMC12, Competitive Manufacturing, University College Cork, Ireland.

[3] Oral, S., & Ider, S. K. (1997). Optimum design of high-speed flexible robotic arms with dynamic behaviour constraints. Computers & structures, 65(2), 255-259.

[4] Kang, B. S., Choi, W. S., & Park, G. J. (2001). Structural optimization under equivalent static loads transformed from dynamic loads based on displacement. Computers & Structures, 79(2), 145-154.

[5] Tromme, E., Sonneville, V., Guest, J. K., & Brüls, O. (2018). System-wise equivalent static loads for the design of flexible mechanisms. Computer Methods in Applied Mechanics and Engineering, 329, 312-331.

[6] Vermaut, M., Naets, F., & Desmet, W. (2016). The Dual Flexibility (DF) formulation: a novel flexible multibody formulation resulting in quadratic system equations.