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DESIGN OF MECHANISM COMPONENTS USING TOPOLOGY OPTIMIZATION AND FLEXIBLE MULTIBODY SIMULATION

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ABSTRACT

This work addresses the topology optimization of structural components embedded in multibody systems with large amplitude motions. For example, in deployable space structures, piston engines, automotive suspensions, robots and high-speed machine-tools, the articulated components undergo large displacements and elastic deformations, and are subject to transient loads and nonlinear dynamic effects. The performance of such systems often depends on the mechanical design in a non-intuitive way.

Several researchers have addressed the optimization of the geometric parameters of mechanisms [1] and also of the connectivity of mechanisms made of rigid members [2,3]. In contrast, topology optimization techniques [4] are often based on continuum mechanics assumptions, and usually aim at optimizing the layout of an isolated structural component under the assumption of small displacements and small deflections. In order to apply topology optimization to mechanism components, one may consider that each structural component is isolated from the rest of the mechanism and use simplified quasi-static load cases to mimic the complex loadings in service, see, e.g. [5]. However, two main drawbacks are associated with this approach. Firstly, defining the equivalent load cases is a rather difficult task, which is often based on trials and errors and which requires some expertise. Secondly, topology optimization is often sensitive to loading conditions, especially for multiple load cases and stress constraints, so that the optimal character of the resulting design becomes questionable if the loading is approximative. For these reasons, in order to obtain better optimal layouts, this paper proposes an optimization procedure based on dynamic simulations of the full flexible multibody system.

For this purpose, the nonlinear finite element approach proposed in [6] is selected for the modelling and the simulation of the flexible multibody system. The present work is thus similar to the usual approach used in topology optimization in which the continuum domain is discretized into finite elements, see [4]. The nonlinear finite element formalism accounts for both large rigid-body motions and elastic deflections of the structural components. The design variables are classically density-like parameters associated to a power law interpolation of effective material properties for intermediate densities, also known as Simply Isotropic Material with Penalization (SIMP).

The nonlinear equations of motion are solved using a generalized-α time integration scheme [7], and the sensitivity analysis of mechanical responses is based on a direct differentiation method described

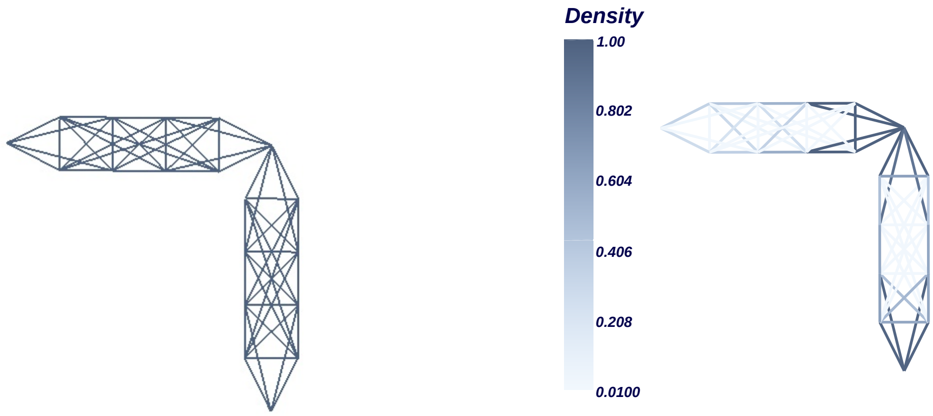

Figure 1: Robot arm with two truss linkages: initial structural universe and optimized layout.

in [8]. The efficient solution of the optimization problem relies on the sequential convex programming concept at the core of the CONLIN software [9].

In the present study, the method is applied to various types of mechanical systems. Firstly, planar mechanisms with truss structural components are considered, as illustrated in Figure 1. Each truss is represented by a structural universe of beams with a topology design variable attached to each one. Secondly, the discussion is extended to similar mechanisms with 3D motions. Finally, the topology optimization of spatial bodies represented by 3D finite element meshes is considered.

REFERENCES

[1] D. Bestle and P. Eberhard. “Analyzing and optimizing multibody systems”. *Mechanics of Structures and Machines*, Vol. **20**, 67-92, 1992.

[2] A. Kawamoto, M.P. Bendsøe and O. Sigmund. “Articulated mechanism design with a degree of freedom constraint”. *International Journal for Numerical Methods in Engineering*, Vol. **61**(9), 1520–1545, 2004.

[3] K. Sedlaczek and P. Eberhard. “Augmented Lagrangian Particle Swarm Optimization in Mechanism Design”. *Journal of System Design and Dynamics*, Vol. **1**(3), 410–421, 2007.

[4] M.P. Bendsøe and O. Sigmund. *Topology Optimization: Theory, Methods, and Applications*, Springer Verlag, Berlin, 2003.

[5] B.S. Kang and G.J. Park. “Optimization of flexible multibody dynamic systems using the equivalent static load method”. *AIAA Journal*, Vol. **43**(4), 846–852, 2005.

[6] M. Géradin and A. Cardona. *Flexible Multibody Dynamics: A Finite Element Approach*, John Wiley & Sons, New York, 2001.

[7] M. Arnold and O. Brüls. “Convergence of the generalized-α scheme for constrained mechanical systems”. *Multibody System Dynamics*, Vol. **18**(2), 185–202, 2007.

[8] O. Brüls and P. Eberhard. “Sensitivity analysis for dynamic mechanical systems with finite rotations”. *International Journal for Numerical Methods in Engineering*, in press.

[9] C. Fleury. “CONLIN: An efficient dual optimizer based on convex approximation concepts”. *Structural Optimization*, Vol. **1**(2), 81–89, 1989.