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A level set approach for the optimal design of flexible components in multibody systems

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During the development process, one of the designer goals is to find the optimal design of the product. An automatic procedure based on optimization methods would offer important advantages compared to trial-errors methods. Over the last 30 years, many efforts have been devoted to structural optimization. Nowadays, structural optimization has reached a certain level of maturity and is currently used for industrial applications, not only in optimal sizing, but also in shape and topology optimization.

Recently, structural optimization has been extended from a component level approach towards a system level approach, which means that a multibody system simulation is used to analyze the global response of the whole mechanical system. This evolution aims at better capturing the real loading conditions accounting for the component interactions and couplings in the system. As a result, the optimal design is much more accurate because the optimal structural design of the component can be very sensitive to the boundary and loading conditions. Moreover, as the component shape is changing during the optimization process, the mass repartition is also changing, thus modifying the interactions between the components and the loading conditions at each iteration.

Other authors focused on the structural optimization of components considering loading conditions coming from the multibody system dynamic analysis. Nevertheless most of these studies consider that the component is isolated from the rest of the mechanism and use quasi-static loads cases to mimic the complex dynamic loading [1, 2].

In our previous work [3, 4, 5], a more integrated approach has been proposed with an optimization loop directly based on the dynamic response of the flexible MBS [6]. The first study validated this approach by realizing the topology optimization of a robot arm composed of two truss linkages [3]. In Ref. [4], the "fully integrated" optimization problem of flexible components under dynamics loading conditions was investigated and was illustrated on the mass optimization of robot arms subject to trajectory tracking constraints. Sizing and shape optimization were performed. In these two studies, it has been shown that the MBS optimization is not a simple extension of structural optimization. The coupled problem between vibrations and interactions within the components generally results in complex design problems and convergence difficulties. The design problem is complicated and naive implementations lead to fragile and unstable results. In Ref. [5], the formulation of the MBS optimization problem was investigated because it had turned out that it is a key point to obtain convergence in a stable and robust way. The study was performed on the shape optimization of a connecting rod under cyclic dynamic loading.

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The present study continues along the investigation of optimization of flexible components included in MBS and extends the shape optimization presented in reference [5] to an intermediate level between shape and topology optimization thanks to the introduction of the level set method which is a numerical technique for tracking interfaces and shapes [7]. This approach combines the advantages of shape optimization with some possibilities of changing the topology. The advantages of topology optimization are that it allows getting the best topology for the structure and suggests innovative design since no initial shape of the component is required. However, the number of design variables is very large which leads to complex optimization problems. Furthermore, the optimal design can not be immediately manufactured. Shape optimization is not able to modify the component topology but can be useful after topology optimization to improve the current design and to introduce stress or manufacturing constraints which are difficult to deal with in topology optimization.

This extension allows optimizing any boundaries of the structure defined by a compound level set. With this approach, there is less mesh problems since a fixed mesh grid is considered. The elements inside the domain defined by the component geometry are full density while the elements outside are void. Concerning the elements intersected by the boundaries, an intermediate density defined by the SIMP law is used. Design variables are the parameters of basic geometric primitives described by a level set representation. The number of design variables remains small. The bottleneck is that with our level set approach, the topology is not completely defined by the optimization process. The process can suppress holes but can not create them. The considered application will be the optimization of a connecting rod (slider-crank mechanism) under cyclic dynamic loading.

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