Approximation of Gradients in Topology Optimization of Flexible Multibody Systems

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ABSTRACT

Flexible multibody systems are used to model machines which undergo large nonlinear rigid body motions and in addition undesired linear elastic deformations. The performance of these systems can be enhanced by adapting the structural design to the dynamical loads, using for instance, topology optimization, see [1]. Thereby, a challenging task is the gradients calculation of the objective function with respect to the design variables, because the number of design variables in a topology optimization is normally very high. In this work, the approximation of gradients in the topology optimization of flexible multibody systems which are modeled with the floating frame of reference formulation is addressed. Commonly, the gradients are approximated using the equivalent static load method, see [2]. In this approximation, time dependent dynamic loads on the flexible bodies are considered in the optimization only at selected time points. Moreover, these loads are assumed to be design and time independent, which greatly simplifies the calculation of gradients. For the case of compliance minimization, the objective function $c$ and its gradients with respect to the $i$-th design variable $x_i$ are given by

$$c = \mathbf{u}^T \mathbf{K} \mathbf{u}, \quad \frac{dc}{dx_i} = -\mathbf{u}^T \frac{\partial \mathbf{K}}{\partial x_i} \mathbf{u}, \quad i = 1, \ldots, n$$

where $\mathbf{u}$ is the vector of nodal displacements, $\mathbf{K}$ is the global stiffness matrix and $x_i$ is the number of design variables. In flexible multibody systems, the dependence of loads on the design variables is not always negligible, thus this might result in unsatisfying optimization outcome. Alternatively, it is possible to calculate the exact gradients of the objective function in a flexible multibody system using the adjoint variable method, see [3]. In this approach, all the dependencies on the design variables are considered, and hence, the optimization is able to solve the minimum compliance problem even when the loads are highly design-dependent.

In this research, the first approach is used and extended to account for the dependency of inertial forces in flexible bodies on the design variables. The accelerations are still assumed to be design-independent. Including these dependencies in the computation of gradients gives

$$\frac{dc}{dx_i} = -\mathbf{u}^T \frac{\partial \mathbf{K}}{\partial x_i} \mathbf{u} + 2 \mathbf{u}_i^T m_i \mathbf{a}_i, \quad i = 1, \ldots, n$$

in which $\mathbf{u}$, $\mathbf{u}_i$ and $\mathbf{a}_i$ are the mass, displacement and global acceleration of the $i$-th element, respectively. For demonstration purposes, the modified gradients in Eq.(2) are implemented in the optimization of a slider-crank mechanism. Using this example, it is shown that the gradient approximation in Eq.(2) does not impair the computational efficiency of the optimization, however, it improves the solution of the minimal compliance problem compared to the formulation in Eq.(1). The modified approximation is additionally compared with the example where the exact gradients are used.

References