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Ground structure based linkage mechanism topology optimization: new formulation and applications including automobile steering system design)

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1. Abstract

Compared with great success of the topology optimization method in structural problems [1], the progress in linkage mechanism is rather slow. There were several interesting and important related research works [2-8], but the intrinsic difficulties in mechanism synthesis, such as required highly-nonlinear analysis and the difficulty to impose the discrete degree-of-freedom (DOF) condition with continuous design variables, still hinder the gradient-based topology optimization from being used to solve realistic linkage synthesis problems. In particular, no existing method has been attempted for the synthesis of a steering linkage system of an automobile, which is not only practically important for automobile industry but also academically interesting in the topology optimization community. In this work, we first investigate carefully the intrinsic difficulties appearing in the application of the topology optimization in linkage mechanism synthesis, propose a formulation to overcome them and use it for the synthesis of a steering linkage mechanism of an automobile. In the present study, we only consider a continuous variable, gradient-based topology optimization approach because the computation with integer variable based topology optimization is formidable.

For the topology optimization method of linkage mechanisms, we employ the ground structure model with non-linear bar elements and zero-length springs. Kinematic chains connected by revolute joints with somewhat arbitrarily-located ground joints can be simulated by this model. It is known that especially the correct imposition of the propoer DOF (1 in case of a four-bar linkage) remains difficult to handle within the toplogy optimization setting where a gradient-based optimizer is to be employed [2-6]. Definitely the desired motion or function should be realized by an opitmized mechanism but it cannot be used if its DOF is redudnant or deficient. As a means to DOF problem, we propose to use the energy transmittance efficiency function as an objective function while the required motion or function is stated as constraints. This objective function was used in similar problems, but it has never been used for the synthesis of rigid-body mechanisms. The function physically represents the combined effect of flexibility and stiffness simultaneously. Therefore, it can be possible to find a mechanism system having the correct DOF if artificial external loads are properly applied. Without the proposed approach, it will be very difficult to control the DOF issue without many trials and errors in selecting the objective functions. The effectiveness of the proposed formulation using the energy transmittance function is first verified with Grashof-type 4-bar linkage synthesis problems. Then the synthesis of a steering mechanism of an automobile, a problem that has not been solved by earlier topology-optimization based approaches, was considered. In dealing with the steering mechanism design, the Ackermann condition representing an ideal steering system should be satisfied. Even with a relatively low-resolution ground structure, the present approach has yielded a steering system which apparently performs better than the nominal steering system.

2. Keywords: Topology Optimization, Rigid-body Mechanism, Automobile Steering, Nonlinear FE

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