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Simplified fatigue resistance in mechanical engineering using topology optimization

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ABSTRACT

Topology optimization is formulated as an optimal distribution of a given amount of material within a design domain [1]. Since the seminal work by Bendsøe and Kikuchi [2], developments of topology optimization have been based mostly on compliance type formulation. Today, aeronautical and mechanical industries consider topology optimization as a practical design tool. In these industrial applications, compliance based topology optimization cannot fully satisfy industrial needs. One needs to consider also the strength instead of stiffness of the structures as well as various manufacturing constraints. In particular, considering maximum strength instead of maximum stiffness allows considering fatigue resistance of mechanical components which is essential in aeronautical and mechanical applications.

Compliance based problems have shown some interesting results in many problems. This formulation is quiet well mastered, see for instance [7] for a review. However it well known that maximum strength problems can lead to different solution when considering maximum stiffness problems, see for example [8]. Some issues can also be pointed out. Stress based topology optimization problems are subject to the so-called singularity phenomenon which could lead to non-convergence issues. This can be overcome by relaxation techniques, the so called *ε-relaxation* [6] or the so called *qp-relaxation* [3]. Furthermore, it has been shown that stress based topology optimization lead to large scale problems when we want to consider the local behavior of the stresses. This approach, called the *local stress approach*, initiated by Duysinx and Bendsøe introduced in [4], leads to many computational efforts which is not suited for industrial applications. *A global stress approach* using aggregation techniques has been proposed to solve this difficulty. This leads to reduced computational time effort but it may lose the local peak value of the stresses. New structural approximations have also been proposed [5] to solve in an efficient way the stress based topology optimization problem.

Stress based topology optimization is well suited to consider fatigue of mechanical components. Taking into account life of a structure in an optimization process is rather rarely considered in topology optimization. In Ref [9] fatigue restriction is tackled by replacing the stress constraints by damage constraints.

Our study continues along the work done so far with stress based topology optimization problems and extends the results in hand by taking into account fatigue criteria in the optimization process. In this work, we adopt the mechanical design approach of machine elements based on the SN diagram. Fatigue life is predicted on the basis of the alternating and mean stress components. The two stress components are bounded by Goodman, Gerber or Soderberg lines. The work describes the problem design problem formulation, the analysis implementation and the sensitivity analysis approach.

The developments are validated on academic benchmarks and the original character of fatigue stress is put into evidence.

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