A Method for Fatigue-Based Topology Optimization

Julian Norato
Engineering Supervisor, Structural Optimization
Optimization & Advanced Analytics, Caterpillar Inc.
1901 S. First St., Champaign, IL 61820
Norato_Julian_A@cat.com

Chau Le
Institute of Mechanics and Environmental Engineering
264 Đội Cấn, Ba Đình
Hanoi, Vietnam
lehoaichau@gmail.com

ABSTRACT

Durability is an important requirement in mechanical components, and consequently high cycle fatigue is a significant failure mode that must be taken into account in their design. Most of the existing topology optimization methods for structural design use a global structural response as an objective or a constraint, such as compliance or natural frequencies. Other structural criteria such as displacements are local, but are usually confined to one or a few locations in the structure. More recently, several research groups have developed methodologies that are able to incorporate stress constraints, where the constraint is applied in large portions or all of the structure. These methods are important predecessors of the work presented here, in that they: a) introduce ways to enforce local constraints in the entire design space; b) address the problem of stress singularity (which is also relevant in this work since in the proposed method fatigue is a function of the stresses); and c) highlight the importance of using consistent sensitivities due to the high nonlinearity of the problem. Specifically, the method herein proposed is a continuation of the work in [1], which has been used with success at Caterpillar for large scale stress-based topology optimization problems.

In this paper we develop a method for topology optimization of continua with regards to high cycle fatigue. The fatigue is calculated using a signed von Mises stress (cf. for example, [2]). Although signed von Mises fatigue does not correlate as well to experimental data as other fatigue algorithms that use principal stresses (or strains) and that track the plane of maximum damage, it greatly simplifies the sensitivity analysis. Stress ranges at any location are counted using the algorithm in [3]. The damage for stress ranges of different magnitude is accumulated linearly via Miner's rule. The Morrow correction is used to account for the effect of mean stresses. In order to approximate the maximum damage in the structure, a *p*-norm is employed. We show that an adequate scaling of this norm is critical for a convergent behavior of the optimization algorithm. Consistent sensitivities are obtained via the adjoint method. The Solid Isotropic Material Penalization is used for the topology optimization. We show examples that demonstrate the methodology, including an industrial-size example that demonstrates the efficiency of the proposed method.

[1] Le, C., Norato, J., Bruns, T., Ha, C., & Tortorelli, D. (2010). Stress-based topology optimization for continua. Structural and Multidisciplinary Optimization, 41(4), 605-620.
[2] Dowling, N. E. (1993). Mechanical behavior of materials: engineering methods for deformation, fracture, and fatigue (pp. 357-548). Englewood Cliffs, NJ: prentice Hall.
[3] ASTM E 1049-85. (Reapproved 2005). Standard practices for cycle counting in fatigue analysis. ASTM International.