Structural reliability based-design of mechanical components submitted to vibration-induced fatigue

Laboratory : Laboratoire de mécanique de Normandie (LMN), INSA Rouen

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With the emergence of rapid prototyping and the production of metallic components, it becomes interesting to study the potential of optimization methods in design, especially when mechanical components are subjected to vibrations that can impact their fatigue life.

Many methods exist in the literature, such as the topology optimization developed in the 90s by Bendsøe and Kikuchi [1]. It allows to find the optimal distribution of the material by "removing" the unstressed part (figure 1). Since several works related to theories and techniques have been proposed to make topology optimization more efficient and practical for industrial applications [2-6]. However, some optimal topological configurations seem to be difficult to achieve by traditional manufacturing.

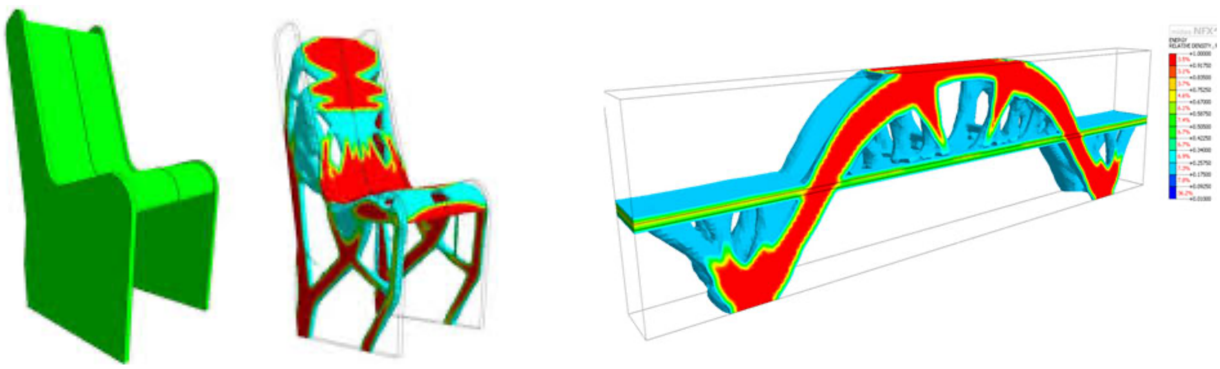

Figure 1 : Topology optimisation exemples applied on a chair (left) and a bridge (right) (http://www.midasnfx.com/)

Optimization techniques provide a final geometry that meets both mechanical and design performance requirements. Mechanical performance varies according to expectations and can therefore focus on strength, stiffness, weight, natural frequency or service life. However, topology optimization is based on a deterministic approach that does not take into account the input parameter variability and uncertainties related to loads and material properties. Thus, several optimization alternatives have been developed to consider uncertainties in the design optimization procedure, while respecting safety requirements. These include Reliability-Based Design Optimization (RBDO) or Reliability-Based Topology Optimization (RBTO).

The RBDO [7-10] consists in finding the best design with optimal cost and safety assurance, based on the theory of structural reliability. The integration of reliability concepts in topology optimization has led to the development of RTBO [11,12]. It is considered as the most rigorous approach for topology optimization because it considers the random nature of load fluctuations, material properties and geometrical dimensions and allows the propagation of uncertainties in mechanical performance (stresses, displacements, fatigue damage, etc.). At present, several works are focused on the development of efficient formulations of the RBTO but the formulation considering the fatigue lifetime remains challenging. These approaches are successfully used for the design of automotive [5] and aerospace [6] components for stiffness and strength, and several methods are proposed to take into account buckling stresses [4], natural frequency stresses [14,15].

The research work of the Normandy Mechanics Laboratory has been focusing on these methods for several years. Indeed, it has a strong expertise in the uncertainty propagation in mechanical and multi-physical models, design based on reliability and optimization of maintenance, topology and multi-criteria design, experimental fatigue, random vibration, etc... In addition, the LMN has vibration fatigue installations to experimentally validate the results obtained numerically.

The main objective of the proposed thesis work is to develop an efficient procedure to obtain a good design of a component subjected to vibration-induced fatigue. This objective remains a challenge because the best design in terms of natural frequencies must also have a good performance in terms of fatigue durability over a large number of cycles (yield stress constraint).

Several strategies based on a good literature review will be studied in order to improve this procedure. An experimental validation with fatigue tests of optimal parts is envisaged. The important tasks of this thesis project are the following:

- Development of the topology optimization under static and eigenfrequency constraints.
- Integration of fatigue damage constraint in deterministic topology optimization.
- Experimental validation of optimal topologies.
- Integration of the reliability requirement in the topology optimization under fatigue damage constraint.

Background requirement:

- Engineering school or Master in Mechanical or Applied Mathematics solid background in mathematics and solid mechanics, Finite element method, probability theory, and probabilistic approaches.

- Experience in numerical simulation on dedicated software (for example ANSYS, COMSOL, NASTRAN, etc.)
- Good programming experience, Matlab, Python, or C ++.
- Good communication in English (read and write)
- Ability to work independently and integrate the laboratory research team.

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