Title

Optimizing the internal structure of high-performance composite tubes with semidefinite programming

Abstract

The development of high-performance carbon fibers has enabled the production of thin-walled structural elements with unprecedented stiffness-to-weight performance. However, the extreme slenderness and anisotropy of these structures make them prone to wall instabilities, manifesting in low frequencies of natural vibrations and increased displacements under dynamic loadings. So far, these limitations have been overcome by increasing wall thicknesses (which increases structural weight) or by using manually-placed foam infills (which is labor-intensive and involves high processing time).

The purpose of this talk is to explain how to automate and rationalize the whole procedure using the techniques of topology optimization and semidefinite programming. To this goal, we discretize the interior of the component with a truss ground structure and determine its cross-section areas to achieve minimum-weight stiffening, such that the whole structure satisfies constraints on the fundamental vibration frequency and displacements during manufacturing and operational loads. Here, the essential step is the transformation of each constraint into a linear matrix inequality, so that the resulting formulation—minimization of a linear objective function over the intersection of an affine space with the cone of positive-semidefinite matrices—can be solved to global optimality with modern interior-point algorithms.

The optimization output is then decomposed into separate modules that are automatically exported for production using additive manufacturing based on conventional 3D printers and an ABS (acrylonitrile butadiene styrene) polymer. The modules are assembled on a steel mandrel to provide the support for subsequent production of wound carbon fiber-reinforced composite shell.

The feasibility of the whole approach is demonstrated by validating computationally predicted vibration eigenfrequencies and vibration mode against experimental data; the error does not exceed 10%. Altogether, this shows that the mechanical performance of the lightweight composite components can be substantially improved with optimized 3D-printed internal structure, even though the elastic properties of the ABS polymer reach only 1% of those of carbon fibers.

These results are a joint work between the Czech Technical University in Prague and the CompoTech company based in Sušice.