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Topology optimisation for transient thermoelastic design

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Abstract

Transient thermal phenomena are observed in a wide range of applications, e.g. combustion processes, (additive) manufacturing, and during operation of precision tools and instrumentation. These temperature fluctuations introduce, often undesired, thermoelastic deformations, leading to thermal errors. As the requirements on next generation precision tools and instrumentation are becoming stricter, thermal errors are consuming increasingly bigger portions of the available error budget. Precision equipment is typically thermally conditioned to constrain these errors, either actively by introducing external cooling, or passively by carefully designing the instrument's geometry. Adequate thermal design can already be challenging for steady-state operating conditions. This challenge only increase when transient thermal behaviour becomes important.

In this work, we present an effective design methodology to design passively compensated thermoelastic structures in a transient setting. The methodology is based on topology optimisation [1], a method which is able to generate effective designs without needing an initial concept. Earlier works illustrated the potential of topology optimisation for the design of thermoelastic structures in steady-state conditions, e.g. by minimising thermoelastic compliance [2], designing thermally actuated compliant [3], and for the design of multicomponent optomechanical systems [4]. Although some earlier works have treated fundamental aspects of transient thermoelastic design, e.g. sensitivity analysis [5] or material design [6], we have developed a practical formulation to design passively compensated thermoelastic structures to minimise parasitic deflections in at points or surfaces of interest for both steady-state and transient operation conditions.

To illustrate the performance of the proposed methodology, we consider the thermoelastic design of optical devices as an example. First, we optimise two- and three-dimensional optical devices for their steady-state performance. The desired shape of the optical surface is expressed by Zernike polynomials and should remain undistorted when subjected to external thermal loading. The optimised designs passively compensate for the induced thermoelastic deformations, minimising the thermal errors observed at the optical surface. Secondly, we show the ability to design optical device considering transient operation conditions. Here, the complete transient thermoelastic analysis is considered during topology optimisations and the resulting designs strongly outperform the steady-state designs.

The proposed methodology enables automated design of optimized, passively compensating thermoelastic structures. Although the performance of the method was illustrated considering optomechanical design, the methodology is applicable to a wide range of design problems encountered in the design of next generation precision tools and instrumentation. As future research, we attempt to combine passively conditioned structures with simultaneous optimisation of actively conditioned components.

Topology optimisation, thermoelastic design, transient response, thermal error minimisation

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