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Multi-material optical mounts to mitigate thermal deformations – a topology optimization study

Joran van der Zwet[1], Can Ayas[1], Matthijs Langelaar[1]

[1]*Delft University of Technology, Mekelweg 2, 2628CD, Delft, The Netherlands*

J.M.vanderZwet-1@tudelft.nl

Abstract

Thermal effects are important to take into account when designing high-precision optical instruments for space, as thermal deformation can cause significant misalignment errors. These misalignments can be exacerbated by the temperature gradients induced when the spacecraft leaves or enters the shadow of the earth. Another important factor to consider is vibrations introduced during the launch as well as during operation [1], which translates into eigenfrequency requirements.

These design requirements are difficult for an engineer to satisfy, as their complex physics occlude the impact that specific design choices have on the resulting dynamic and thermo-elastic responses. Topology optimization (TO) is a powerful computational design tool that can aid in this process. It aims to find an optimal material distribution for a given design problem, with the main designer input being a design objective and constraints. TO is most commonly used to maximize the stiffness of a design, but has also been applied to numerous multiphysics cases, including thermo-elastic and dynamic design problems. Considering combinations of multiple materials in TO potentially offers advantages by expanding the design space, but also further complicates the optimization problem. The majority of TO studies have been performed for single-material cases, but an extension of TO to include multiple materials [2,3] holds the promise of reaching higher performance levels.

We study the benefits of multi-material topology optimization for the design of thermally stable optical mounts, by comparing multi-material designs with their single-material counterparts. The thermal stability requirement is translated to a constraint on a prespecified optical surface. This constraint is then combined with a mass minimization objective and an additional constraint on the minimum eigenfrequency. Considering multiple materials comes at the cost of additional complexity in both design and manufacturing, this should be offset by a significant performance increase of the design.

The considered optimization problem is highly nonconvex, so to reduce the influence of local optima the optimization formulation is applied to numerous different design problems, where each problem is also expanded to mitigate thermal aberrations induced by different thermal scenarios. To compare the resulting designs we investigate their respective objective values, as well as newly proposed measures of non-discreteness [4] adapted to multi-material TO. These measures are further expanded using density-based clustering detection [5], which ensures their value more accurately indicates a flaw in the optimized design.

The results show that when thermo-mechanical stability is harder to achieve, multi-material TO offers improved performance compared to single-material solutions. However, for less demanding cases undesired interface behaviour starts to influence the multi-material results, which causes single-material TO to outperform multi-material TO.

Topology optimization, Multi-material, Thermo-mechanical, Optical aberration, Eigenfrequency

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