Book of Abstracts

Poster Session
GAMM Juniors' Summer School 2021
Shape and Topology Optimization

Graz/Online, July 26-30, 2021

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TU Graz

GAMM Juniors

HELMUT SCHMIDT UNIVERSITÄT
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Topology Optimization of an Acoustic Diode

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An electric diode is a device that only allows current to flow in one direction. Similarly, a device that only allow acoustic waves to propagate in one direction is generally called an acoustic diode. By using material distribution-based topology optimization, we aim to design a passive acoustic device that only allow acoustic waves to propagate in one direction. Helmholtz equation is used to model the time-harmonic linear wave propagation inside an axi-symmetric problem setup and Dirichlet to Neumann boundary conditions are used to simulate non-reflecting absorbing boundaries at the left and right, respectively.

Our objective is to place the solid material inside the design domain such that for all incoming planar waves, it maximizes the propagation of acoustic waves from left to right and minimizes their transmission from right to left. In this way, we obtain a design that only allows acoustic waves to propagate from left to right for incoming planar waves. A gradient based optimization algorithm, method of moving assymptotes (MMA) is used to solve the optimization problem. A combination of non-linear filtering and penalization method is used to obtain a black and white design.

For numerical experiments, we choose a frequency range of 8–9 KHz. The results shows that for incoming planar waves the optimized design allows 99.8% of acoustic power to be transmitted to the left. However, less than 0.3% of acoustic power is transmitted in the reverse direction, that is, from right to left.

Multi-material topology optimization of rotating electrical machine with a density-based method

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Topology optimization (TO) has been extensively studied in the past decades especially in mechanical engineering. Among different techniques, density-based methods have become very popular. In electrical engineering, TO has been applied essentially to linear actuators [1] or machines rotors [2][3], but few works such as [4] deal with the coil repartition within the stator of rotating machines.

In this study, we investigate a density-based topology optimization method, which aims to maximize the average torque of a rotating electrical machine from random or uniform initial material repartition. Material properties such as magnetic permeability or current density are interpolated on densities between each material to obtain a differentiable optimization problem, using SIMP or RAMP [5] for example. A custom magnetostatic finite element solver was implemented on MATLAB®. It takes into account the non-linearity of magnetic materials with Newton-Raphson method. The optimization algorithm relies on sensitivities obtained by the adjoint variable method (AVM) [6]. The methodology was performed for two test cases :

- optimization of iron/air repartition within the rotor of a synchronous reluctant machine (SRM)
- optimization of coils/iron/air repartition within the stator of a one phase permanent magnet synchronous machine (PMSM).

In the air/iron case, a filtering technique inspired by ESO [7] is applied: iron which carries few magnetic flux is removed. No filtering was applied in the multi-material case, but a normalization of the gradient was investigated.

As a result, we obtain flux barriers [8] for the optimized SRM rotor, which correspond to industrial designs. However, some convergence issues happened, especially for multi-material optimization. The gradient normalization helps preventing this phenomenom but leads to surprising assymetric designs, which need further investigations. It is also necessary to improve the robustness of the method especially for high current density, in order to optimize both the rotor and the stator. Multiphysics considerations will be taken into account in future work.

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Optimization on diffeological spaces

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On this poster, we present optimization techniques on diffeological spaces. Diffeological spaces firstly introduced by J.M. Souriau in the 1980s are a natural generalization of smooth manifolds. In order to generalize optimization methods known from manifolds to diffeological spaces, we define various objects like a diffeological tangent space, a diffeological Riemannian space as well as a diffeological gradient. In addition we give the definition of a diffeological retraction. These objects are necessary for formulating the steepest descent method on diffeological spaces. We present this method and apply it on an example.

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A novel $W^{1,\infty}$-method for shape optimisation with Lipschitz domains

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In this poster we discuss a novel method for the implementation of shape optimisation with Lipschitz domains. We are concerned with finding a minimising direction in the $W^{1,\infty}$-topology. The idea of this approach is demonstrated with n-dimensional star-shaped domains which are represented as functions on the $(n-1)$-sphere. In this setting we provide the specific form of the shape derivative and are able to prove the existence of solutions to the underlying shape optimisation problem. In particular, we show the existence of a direction of steepest descent in the $W^{1,\infty}$-topology. We give several numerical experiments illustrating that our approach seems to be superior over existing Hilbert space methods, in particular in developing optimal shapes with corners.

Three-Dimensional Topology Optimization of a Cableway Pylon

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Topology optimization is an effective numerical tool to design high-performance, efficient and economical lightweight structures. The objectives of this work are twofold: The development of a open-source large-scale three-dimensional topology optimization framework for further research and its validation on large-scale engineering example of a cableway pylon [1].

Building upon previous work [2, 3, 4, 5, 6] a topology optimization tool was created in the open-source Kratos Multiphyics using C++ with Python interfacing [7]. The implementation and extensions of the code include sensitivity and density filtering as well as the update of the interface between Pyton and C++. The topology optimization was validated with an established benchmark code [8] using the MBB beam.

A cableway pylon is modeled and load cases and boundary conditions are developed supported by data from an industry partner based on an existing structure. The cableway pylon was optimized with different optimization algorithms and algorithm settings. The results were compared and evaluated. The plausibility of the resulting frame-like design agrees with the loading conditions and model characteristics.

Based on this code and using the experience with an in-house two-dimensional topology optimization code, the authors are currently extending the code to the three-dimensional topology optimization of compliant mechanisms. This requires extensions to stress constraints and non-linear analysis.

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A Hilbert space framework for sensitivity filtering and vertex-assigned morphing of optimal shape

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A common problem in structural optimization is the formation of checkerboard patterns due to numerical instabilities. One way to mitigate the issue is to consider regularization techniques such as the application of a smoothing filter during the optimization process. This approach leads to what is now called sensitivity filtering, which has become a popular method in the engineering community because of the easy implementation and satisfying results, especially for large-scale optimization problems. However, the method suffers from a lack of mathematical foundation and theoretical justification [1].

In an attempt to merge sensitivity filtering into the standard optimization technology, a framework for sensitivity filtering in conjunction with mesh-free methods and node-based optimization was developed in [2]. The resulting method is referred to as vertex morphing. Intermediate design iterations of the method exhibit certain desirable properties such as the attenuation of high-frequency modes and preservation of tiny details in the initial design, depending on the choice of filter radius. Since they can be seen as valid design choices, the method is usually stopped before convergence.

In this contribution, we provide a mathematical foundation for the vertex morphing method and establish a connection with known regularization techniques. We consider design variables as fields defined on some domain $D \subseteq \mathbb{R}^d$ that can be written as

$$q(x) = \int_D k(x,y)p(y)\,dy, \quad x \in D,$$

where $k \in L^2(D \times D)$ is an integral kernel and $p \in L^2(D)$ is the control variable. With this formulation, the so-called filtering rules, which form the basis for the design update rules, can be derived rigorously. To analyze the behavior of the method, we regard the linear least squares problem and show that the intermediate results correspond to some regularized solution to the problem. A comparison between the vertex morphing method and other regularization techniques is made for the linear least squares problem and the compliance minimization of a thin shell structure.

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Piezoelectric BC Modeling for Electrode Shapes with OED

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The piezoelectric effect is an interaction of mechanical and electrical states within a smart material. Excitation and grounding of a piezoceramic disk is done via conductive material on top and bottom commonly via electrodes. The position and size of the electrodes has a decisive influence on the information that can be obtained from the PDE system. One task with great influence is the solution of the inverse problem, in which the material parameters are to be determined with the help of measured and simulated electrical impedances. The uncertainty in the material parameters is to be minimized and the best possible experiment w.r.t. the electrodes is to be found. Here, the technique of optimal experimental design (OED) is used. The introduced design variable is a space-dependent function that determines the electrode configuration by choosing boundary conditions (BCs). The design variable switches between Neumann BC and a kind of Dirichlet BC leading to Robin BCs whereby a dominating Dirichlet part represents excitation of an electrode. The implementation is realized with Finite Elements in FEniCS.

Viscous energy dissipation reduction by optimization of multiple shapes

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Shape optimization has been an active field of research for the past decades and is used especially in engineering. On this poster, we consider a shape optimization model with multiple shapes, i.e., we consider more than one shape to be optimized. We assume that the optimization variable is a vector $u = (u_1, \ldots, u_N)$ of non-intersecting shapes contained in a bounded domain $D \subset \mathbb{R}^d$. We note that D depends on u, i.e., $D = D(u)$. On this poster, a shape optimization of a two-dimensional fluid-mechanical problem is considered. We minimize the viscous energy dissipation in the fluid domain D, more precisely

$$\min_u \int_{D(u)} \frac{1}{2} \nabla y : \nabla y \, \mathrm{d}x$$

subject to the equations describing Stokes flow

$$\begin{aligned} -\Delta y + \nabla p &= f \quad \text{in } D(u) \\ \nabla \cdot y &= 0 \quad \text{in } D(u) \end{aligned}$$

with appropriate boundary conditions, where $y \in \mathbb{R}^2$ describes the fluid velocity, $p \in \mathbb{R}$ the pressure, and $f \in \mathbb{R}^2$ a given source term. In order to solve the minimization problem, we use an optimization approach based on the Steklov-Poincaré metric, where the so-called weak form of the shape derivative can be used. The algorithm and implementation details are presented, and numerical results are discussed for the optimization of multiple shapes in the fluid domain.

Modular-topology optimization with Wang tilings: a Free-Material Optimization-based heuristics

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Modular cellular structures, assembled from a limited number of distinct building blocks called modules, allow balancing the computational efficiency of a periodic unit cell with the structural performance of a non-uniform, point-varying design. A well-architected set of modules provokes structural reconfigurability and component reusability.

To this goal, we define each module by its interfaces rather than by the module type alone. This formalism, called Wang tilings in mathematical logic, creates a convenient way to control the number of module interface types and the modules.

The optimal design of modular structures is inherently a bilevel optimization problem: (i) finding optimal distribution of the modules and (ii) their optimal topology. For truss modules optimized for a minimum compliance criterion, this bilevel problem is combinatorial-convex and can be tackled fairly efficiently by a combination of metaheuristics with mathematical programming, see our prior results in [1]. However, this procedure does not translate well to continuum topology optimization: the underlying problem is no longer convex, hindering a direct comparison of assembly plans.

In this contribution, we propose a heuristic solution to the emergent bilevel problem. First, we solve a free-material optimization problem on the assembly scale to determine (locally-)optimal distribution of material stiffnesses in the space of modular interfaces. Then, we cluster these matrices based on the Frobenius norm by using a custom-developed greedy agglomerative clustering algorithm. Combinations of the interface types then define individual module types and their arrangement in the design domain. Finally, topologies of modules result from standard topology optimization with embedded modularity.

We illustrate our results on several classical problems in topology optimization, including minimum compliance optimization and compliant mechanisms design, all with possibly reusable modules. These illustrations also outline additional merits of our approach: automatic connectivity of compatible module types, arbitrary but predefined number of module interfaces, and superior performance compared to the periodic unit cell.

The authors acknowledge the financial support of the Czech Science Foundation project no. 19-26143X.

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