Keynote Lecture's Extended Abstracts

Optimization methods for the development of crash structures.

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Prof. Dr.-Ing. Axel Schumacher, Chair for Optimization of Mechanical Structures
University of Wuppertal

Abstract

By using mathematical optimization methods, new structural designs are generated. Especially the topology optimization generate also new concepts. The topology optimization method are efficient in the field of structural design, taking into account linear structural properties and linear static loading conditions. E.g. the homogenization method introduced by M. Bendsøe and N. Kikuchi in 1988 (Comput. Methods Appl. Mech. Eng. 71:197–224) minimizes the mean compliance considering a mass constraint. Therefore, they divide the design space into small voxel and decide based on an analytical sensitivity for every voxel, is there material or not. After this optimization, the engineer has a good proposal and the possibility for the interpretation and the generation of a CAD model.

The consideration of the mean compliance is much too simple for the optimization of crash-loaded structures. When crash load cases have to be considered, the special characteristics of the highly non-linear dynamic crash problems have to be taken into account. Large deformations and rigid body displacements occur during a crash incident. The used material laws are mostly nonlinear because the kinetic energy is absorbed by plastic deformation. For the correct prediction of the material behavior, strain rate dependencies and complex failure criterions have to be considered. The majority of the forces is transmitted via contact. In additional to that, the crash simulation is much more complicate as the linear simulation of structures:

- non-smooth structural behavior
- not enough material data
- important scatterings of the material data
- mesh-dependent results
- physical bifurcations

- simulation bifurcations
- input deck optimized for a special design point

In the topology optimization we deal with all these problems. We have requirements like:

- Consideration of special acceleration values like the HIC value
- Energy absorption,
- Special force levels,
- Smooth force-displacement curve,
- Smooth acceleration-time curve,
- Special force paths for special loadcases.
- High stiffness of special parts, e.g. parts in a main force paths in the passenger area
- Low stiffness of special parts, e.g. at positions of the head contact of a pedestrian,
- Special safety criteria, e.g. no leakage of the petrol system.

One of the first works in the area of topology optimization for crashworthiness was the work of R.R. Mayer, N. Kikuchi and R.A. Scott in 1996 (Int. J. Numer. Methods Eng. 39:1383–1403). Their optimization method is based on the voxel method and an optimality criterion is used to maximize the energy absorption at specific weighted times. A resizing algorithm is utilized for the alteration of the design variables and a threshold algorithm is used to delete finite elements from the structure.

In the "Hybrid Cellular Automaton (HCA)" method of N.M. Patel et al. published in 2009 (J. Mech. Des. 131:061013.1–061013.12) an optimality criterion is used which is based on a homogenous distribution of the inner energy density. The design space is divided into cells in which the finite elements have an artificial density. These artificial densities have influence on the mechanical properties of the finite elements and are used as design variables for the optimization. The inner energy density distribution is homogenized with a material distribution rule, which changes the design variables. Neighbourhood relationships can be taken into account by the "Cellular Automaton Lattice". Displacement, mass and force constraints can be used in the optimization.

The "Equivalent Static Loads Method (ESLM)" of G.J. Park published in 2011 (Struct. Multidisc. Optim. 43:319–337) uses a nonlinear dynamic analysis domain and a linear static optimization domain. An iteration of this optimization method consists of a nonlinear dynamic simulationand a linear static optimization. Equivalent static loads are calculated for discrete times of the nonlinear dynamic simulation. They are calculated such, that they cause the same displacement field in the initial design of the linear static optimization as the structure has in the non-linear dynamic simulation at the specific time. The linear static optimization is performed with a multiple loading condition using the equivalent static loads. Due to the nonlinearities, other structural responses like strains and stresses are not identical in the analysis and the optimization domain.

The "Graph and heuristic based topology optimization (GHT)" of C. Ortmann and A. Schumacher published in 2013 (Struct. Multidisc. Optim. 47:839–854) was developed because of the limitations of the voxel-based methods. The approach combines topology, shape and sizing optimization and use established finite element shell models for the crash simulation. The optimization task is divided into an outer optimization loop which performs the topology optimization and an inner optimization loop which performs the shape and sizing optimization (Figure 1).

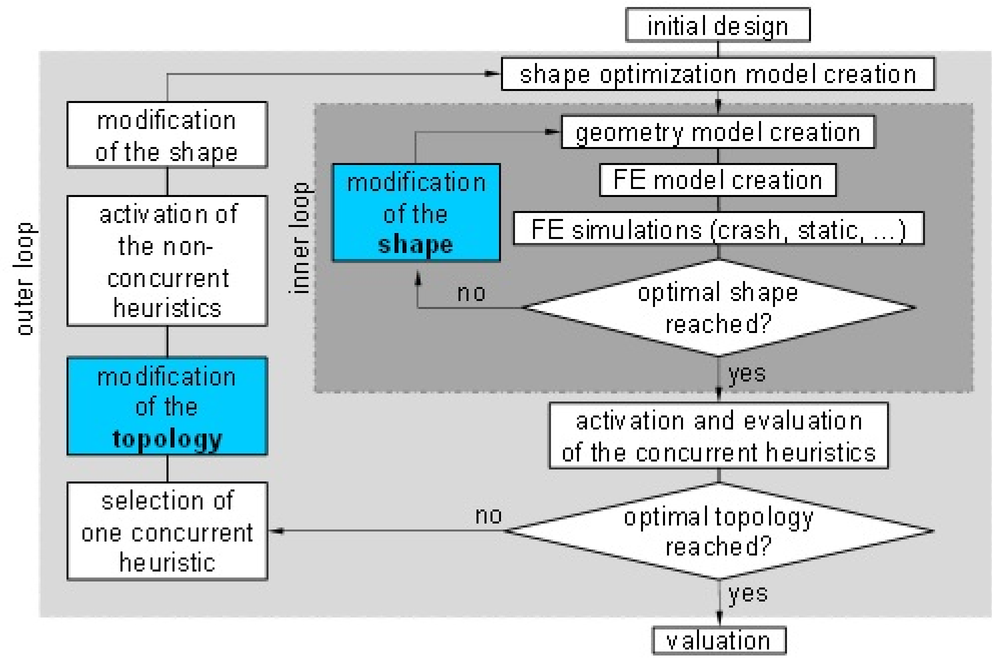

Figure 1: Optimization scheme of the graph and heuristic based topology optimization (GHT)

The inner loop is carried out with mathematical optimization algorithms while the outer loop uses in addition to mathematic tools heuristics (rules), which are derived from expert knowledge. E.g.:

- delete unnecessary walls,
- support fast deforming walls in order to avoid buckling,
- remove small chambers to simplify structures,
- balance energy density,

- use deformation space,
- smooth structure to simplify structures.

The basis for the modification of the geometry by the optimization software and for the automatic creation of input decks for the crash simulation is a flexible description of the geometry using mathematical graphs. The first approach is the optimization of profile cross-section of the structure abstracted by a planar graph, which reduces the geometric optimization problem to the second dimension, although the structure itself and all performed simulations are three dimensional.

Application examples

The shown application examples are optimized with the GHT. The first example is an academic application (figure 2): A simple frame structure clamped on the left side. A sphere with a mass of 1.757 kg hit the structure with an initial vertical velocity of 6.25 m/s. Two optimization tasks are considered:

1. minimize the maximum intrusion with a constraint of the mass ≤ 0.027 kg
2. minimize the maximum acceleration with a constraint of the intrusion ≤ 49 mm

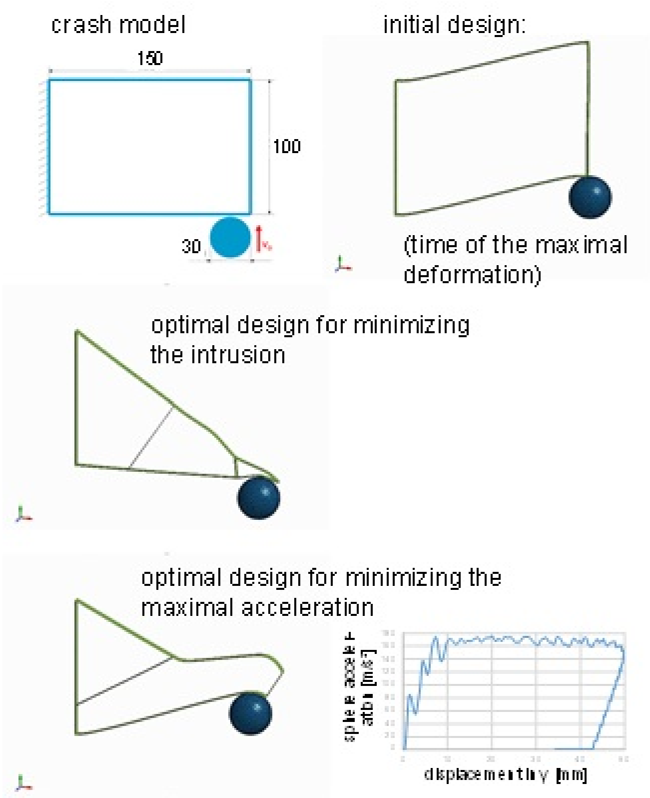

Figure 2: Topology optimization of a frame.

The second example is submodel of an automotive rocker again a pole (Figure 3). The optimization tasks is to find the optimal topology and shape of the cross section of the rocker profile. The goal is the minimization of the maximal force at a moved rigid wall, so that some stiffness constraints and the manufacturing constraints are fulfilled.

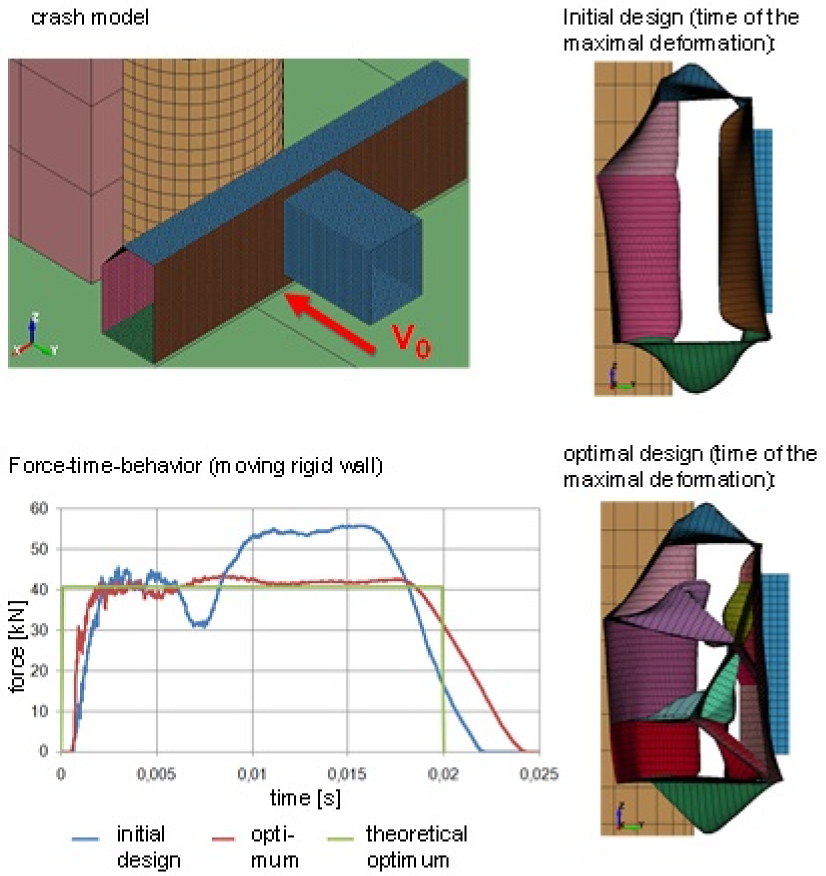

Figure 3: Topology optimization of a rocker.

Especially the force-time curve and the acceleration-time curve of the optimal results are impressively, because there are nearby the theoretical optimum (constant level during the crash time).

Note: This abstract text is similar to the text in the automotive safety Companion:
https://www.carhs.de/de/companion-poster/product/automotive-caecompanion-20212022-digital-pdf.html