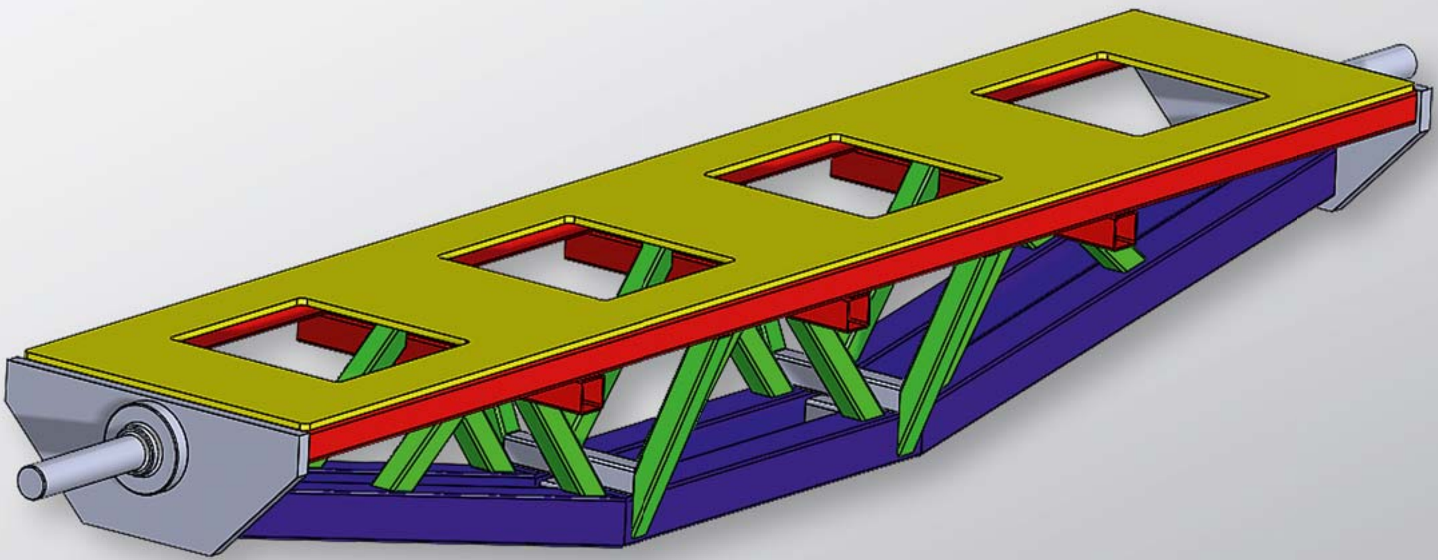

CASE STUDY // MECHANICAL ENGINEERING

MULTI-OBJECTIVE OPTIMIZATION OF THE WORK HOLDING DEVICE OF A MACHINE TOOL

The optimization of a work holding device regarding mass and deformation behavior was achieved with the help of a multi-objective optimization using optiSLang.

Task Description

The cover picture above shows the parametric CAD model of a work holding device with investigated geometric parameters of the upper (red), middle (green) and lower (blue) cross sections. The structure was represented by a parametric CAD model within ANSYS Workbench. The measure and thicknesses of the beams as well as the thickness of the upper plate were considered as geometrical parameters. Based on the CAD model, a finite element model was created by automatic meshing. Four lumped masses represented the work pieces while one external force was acting on one of the pieces to model the processing. Both shafts were modeled as fixed support. Three load cases were considered with the maximum deformation of the beam structure under 0°, 90° and 180° positions being calculated by the finite element model.

Minimizing the mass of the structure and the maximum deformation in all three load cases were the optimization tasks to be reached. The initial design had a mass of 207 kg and maximum deformations between 0,07 and 0,12 mm by using an aluminum plate and steel beams. With the help of a multi-objective optimization, first a suitable compromise between the optimization goals should be achieved. For this purpose, not only the beam cross sections should be modified but also different materials of the beam construction, namely aluminum ans steel, were investigated. Finally, the investigation should consider available standard beam measures out of a supplier catalogue in order to enable a cheaper production.

Design of Experiments (DoE) and Sensitivity Analysis

In a first step, the influence of the design parameters with respect to the mass and the deformations were analyzed. For this purpose eleven geometry parameters such as height, width and thickness of the upper, middle and lower beam cross sections as well as the thickness of the upper plate were varied within the defined boundaries. 200 parameter combinations were generated by the Advanced Latin Hypercube Sampling and evaluated by the finite element model for both types. From the 200 samples, only 10% failed as shown in Fig. 1 (see next page). The figure also illustrates that the failed designs occur if the height of the lower and upper cross section is too small. In such a situation, the external load could not be carried by the structure and the simulation model did not converge.

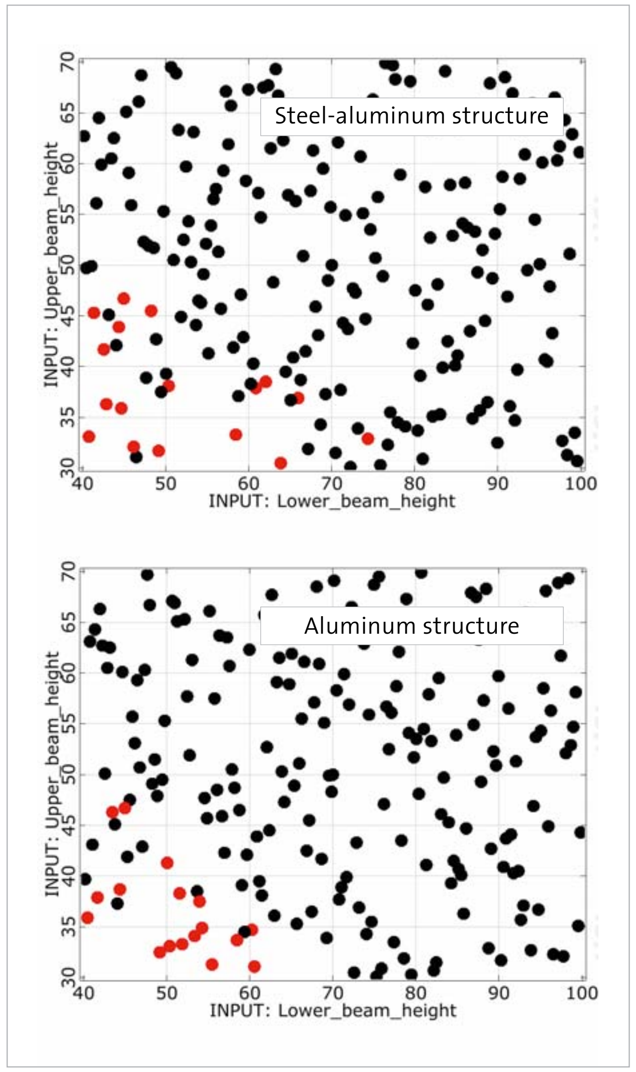

Fig. 1: 200 Latin Hypercube samples of sensitivity analysis with 10 % failed designs

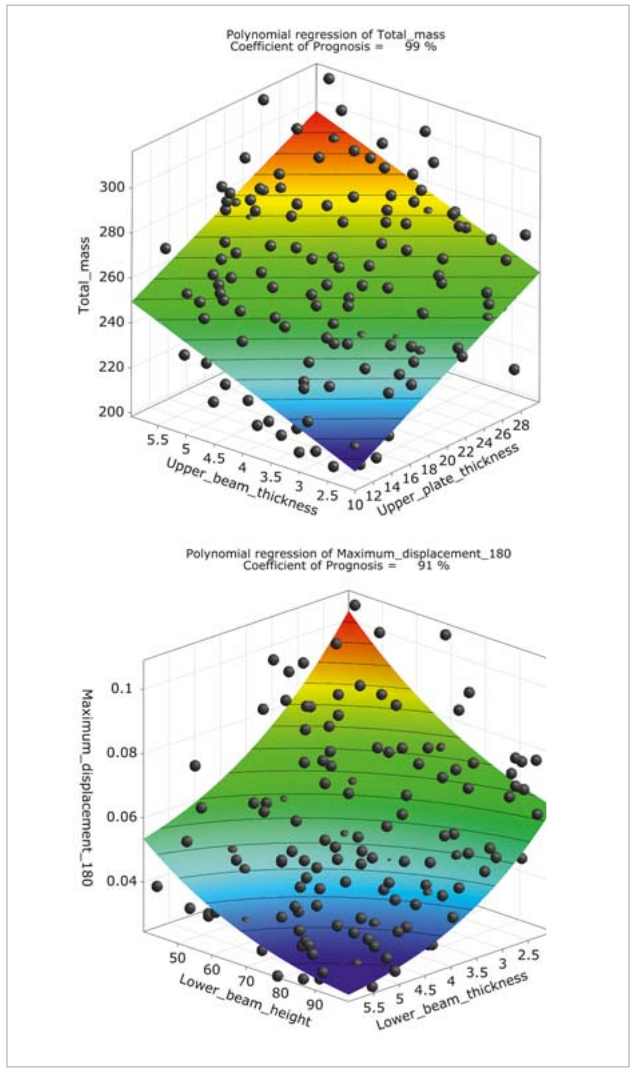

Fig. 2: Metamodels of Optimal Prognosis for the mass (top) and for the maximum deformation in 180°-position (bottom) for the steel-aluminum-structure

Thus, valid simulation results could be obtained in 90% of the design space. Using the Metamodel of Optimal Prognosis [Most 2011], the dependency of the mass and the deformations with respect to the variation of the eleven geometry parameters were quantified. The resulting optimal approximation models in the optimal subspace for the mass and one deformation value are exemplarily shown in Fig. 2. Meanwhile, the mass can be perfectly approximated with a linear polynomial model. The approximation quality quantified by the Coefficient of Prognosis with respect to the deformations is between 91% and 97%. The influence of the design parameters can be quantified sufficiently for each individual response value with the help of the MOP. In Fig. 3, the variance-based sensitivity indices with respect to the CoP are illustrated. The mass of both structure types is here mainly influenced by the thickness of the upper plate. However, the variation of the deformations can be mainly explained by the parameters of the lower beam cross sections. The influence of the distance between the lower beams is negligible, thus this parameter was kept constant in the following optimization.

Multi-Objective Optimization

In the next step, a good compromise between the different objectives was searched. For this purpose, the MOP was used as a solver surrogate within a multi-objective optimization. By using the evolutionary algorithm, the Pareto frontiers shown in Fig. 4 were obtained. The figure indicates that there is a clear conflict between mass and deformation but no conflict between the individual deformations. Furthermore, the figure clarifies that deformations less than 0.15 mm are not possible with the aluminum structure. Therefore, the steel-aluminum structure was preferred in the following analysis. Based on the identified Pareto-frontier, a maximum displacement of 0.1 mm was defined for all load cases.

Single-Objective Optimization

Using the results of the multi-objective optimization, a single-objective optimization was performed. As an optimizer, the Adaptive Response Surface Method [optiSLang 2016] was applied by minimizing the mass while the deformations of the three load cases were restricted to 0.1 mm. The convergence of the optimizer as well as the optimal design is shown in Fig. 5 (see next page). Compared to the initial design, a mass reduction of 10% and a reduction of the deformations in all three load cases of 17% were reached.

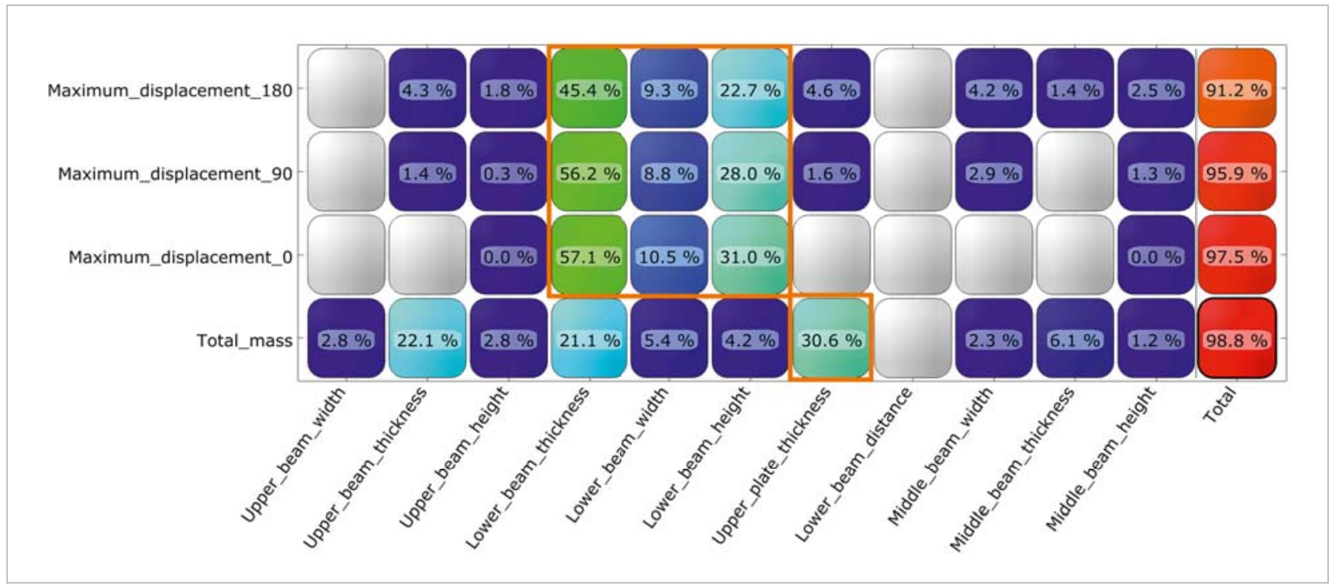

Fig. 3: MOP sensitivity indices of the design parameters with respect to the variation of the mass and deformations for the steel-aluminum-structure

However, the best parameter combination is probably too expensive for production, because the optimal designs are based on arbitrary values and might not be available from standard suppliers. Therefore, the design parameters were defined as discrete parameters to enable the usage of standard cross sections. According to catalogue values [Thyssen 2015], the upper and middle beam cross sections were defined as quadratic with possible values for width and height of 30, 40, 50, 60 and 70 mm. The available thickness values of these beam elements ranged between 2, 2.5, 3, 4 and 5 mm. For the lower profiles, cross section values of different width and height with 40, 50, 60, 80 or 100 mm were selected with thickness values of 2.5, 3, 4 or 5 mm. The optimization again was performed with the Adaptive Response Surface Method. The results are shown in Fig. 6 (see next page). Due to the lower flexibility in the optimization task, the mass was reduced only by 7%. Nevertheless, due to the usage of cheap standard beam cross sections, the production cost is much less compared to the optimal design of the previous optimization.

Summary

Based on a parametric geometry model the deformations of the work holding device were calculated by a finite element model. Since, a priori, weighting of the different objective function was not possible, a multi-objective optimization was performed first. Based on these results, a single objective optimization problem could be formulated by defining a maximum deformation constraint. Compared

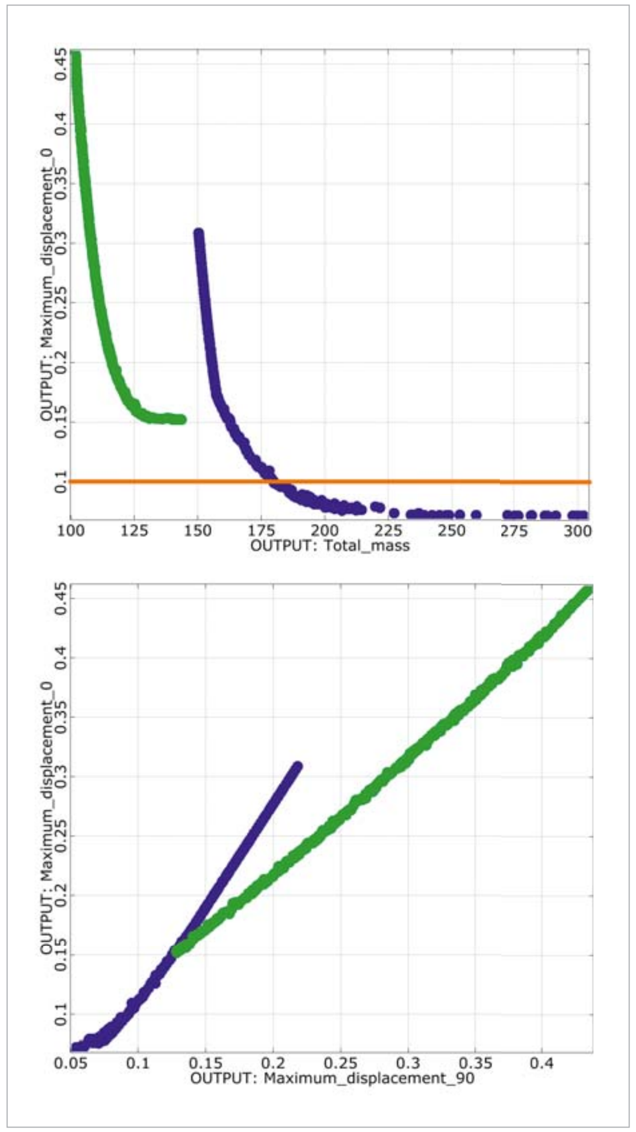

Fig. 4: Pareto-frontier of the multi-objective optimization: mass and deformation show a clear conflict (top), the individual deformations show no conflict (bottom) | green=aluminum / blue=steel

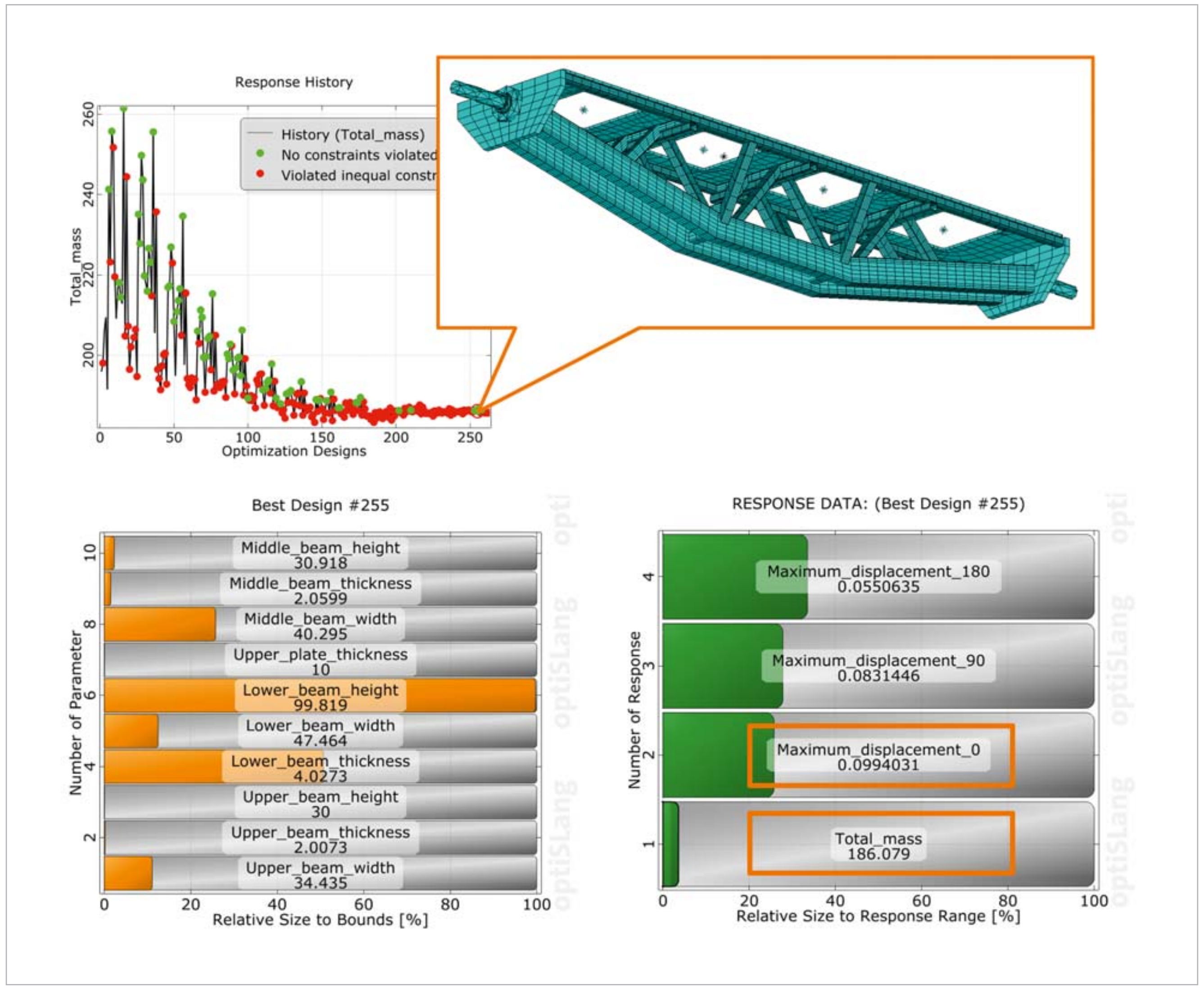

Fig. 5: Single-objective optimization with continuous design parameters – optimizer convergence and best design

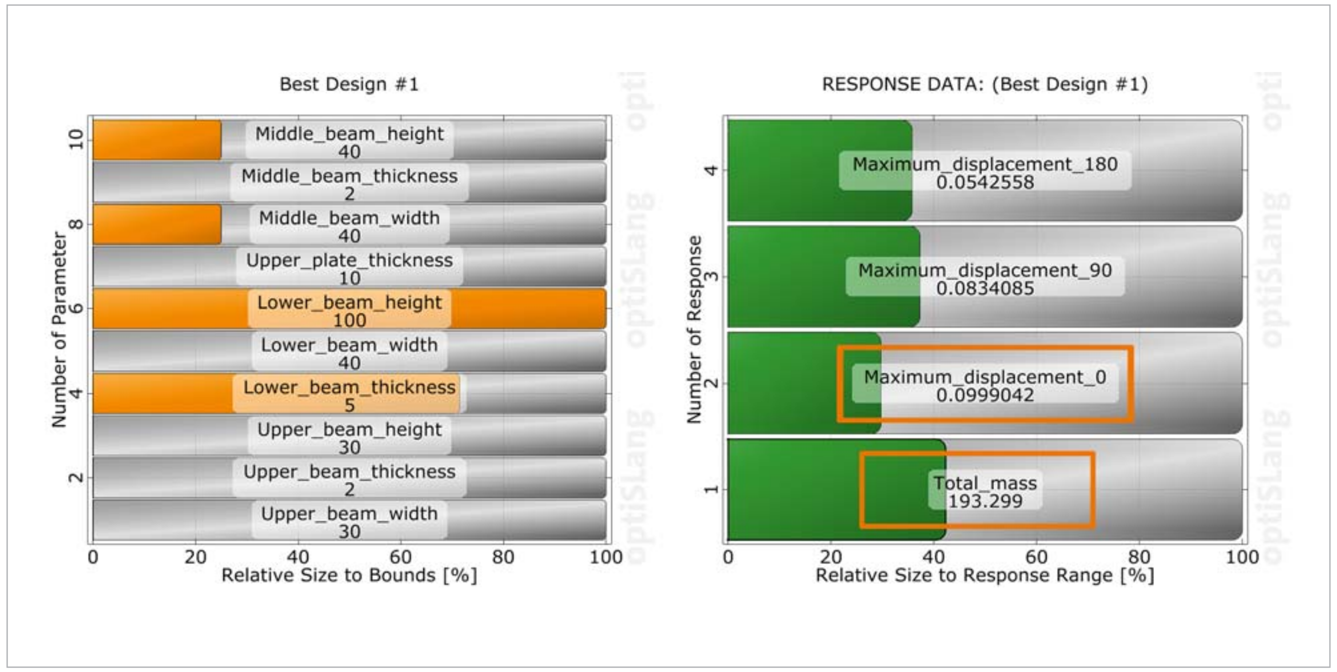

Fig. 6: Best design of the single-objective optimization using discrete design parameters

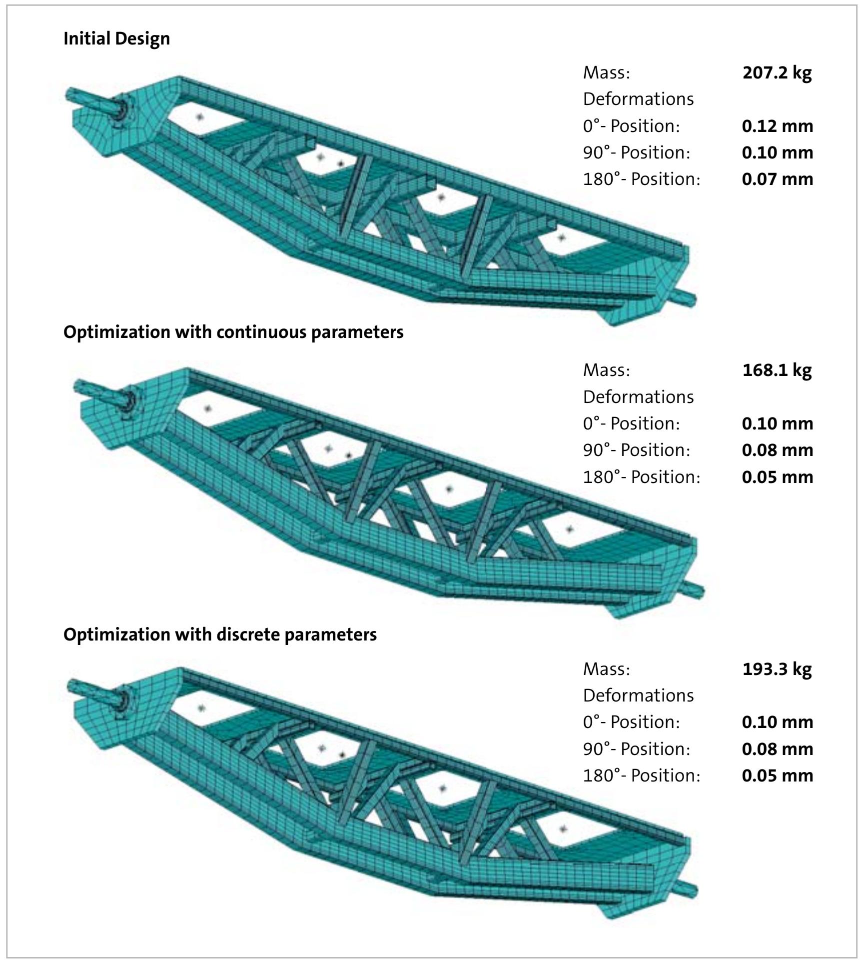

Fig. 7: Summary of the results of the two optimization steps

to the initial situation, the mass could be reduced by 10% and the maximum deformations by 17%. In order to allow a cheap production, the design parameters were finally formulated as discrete parameters considering the standard beam measures of a supplier catalogue. With this setup, the mass could be reduced by 7% and the deformation by 17%.

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