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Foot controls made of plastic

- efficient solutions by combined analysis techniques -

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Abstract

In general the three different methods of calculation FEA, MBS and Optimization have independent approaches within the CAE-Process.
The limitations of this conventional process but also the chances of an interdisciplinary approach are shown on a brake-pedal-system of a car. This part is one of the most important safety-parts in a car.
Based on a kinematic analysis of the brake-pedal-system the optimized transfer of the pedal-force (pedal-displacement) to the resulting braking-force will be determined.
The implementation of the FE-model into the MBS-model builds up a closed optimization loop in terms of a comparing the results of the different models.
The kinematic analysis of the FE-implemented MBS-model defines the constraints for the optimization of the pedal-bracket which is proceeded by the methods of the topology-analysis and the FEA.
The approach of this systematic process, which is following a closed control loop, shows a flexible method and meets the practical needs in the development process of this system.

Introduction

The essential job of the engineering sciences is both the mathematical and physical description of technical processes in order to get the opportunity of a determined design and optimization.
The methods used reach from systematical experiments and test on real parts up to the arithmetical design of virtual prototypes. Since the introduction of the different computer-aided techniques (CAx) they get a growing importance. Not only the accurate definition of the loads and the constraints is essential for the today's results of calculations but also the complete coverage of the surrounding system.

The different CAx-techniques lead from the analysis and simulation of multibody-systems (MBS) via the calculation of prototypes with the Finite-Element-Analysis (FEA) to the final design of parts. A new approach in the development of parts are optimization techniques (CAO) that determine an optimum of shape and topology of parts.

A characteristic and major problem in the context of this article is the separation of the different techniques. On the one hand the focus is set to the system level and on the other hand the goal is to optimize a single part.

A considerable improvement of the development-process by means of the essential job of the engineering sciences can be expected by integrating the different methods to a closed loop development. This process will be explained using the example of an automotive brake-pedal-system.

The brake-pedal-system has to fulfill one of the most important safety functions in the car. Due to this every single part in this system has a significant role to play. Referring to the ergonomics, functionality and the durability each component has to meet the strong corresponding requirements. This is also shown in the different specifications of the automotive industries.

1 Modeling of the Kinematics

The kinematical behavior of the brake-pedal-system is the starting point for the here shown development loop. The first step is to define the braking force on the wheel depending on the weight of the car and the specified stopping distance. The definition of the brake booster is done with respect to the brake force on the wheel and the pedal force which is brought into the system by the driver. There are two force-transmission steps in the system.
The geometrical transmission of the first step is built in the MBS model with a joint to connect the pedal to the bracket and a second joint to connect the pedal to the brake booster. The second transmission takes place in the brake booster which is the interface to the hydraulic part of the brake system. This interface is built as a force function which is depending on the displacement and the velocity of the brake pedal. This force function provides all necessary information of the hydraulic system.
For the first step the elasticities of the brake-pedal, the pedal-bracket, the joints and the car body are neglected. From this point of view the kinematic design of this system is a typical problem for ADAMS.

In this simplified model (all parts of the system are rigid) the result shows an ideal transmission of the foot force on the pedal to the braking force at the booster. See figure 1.

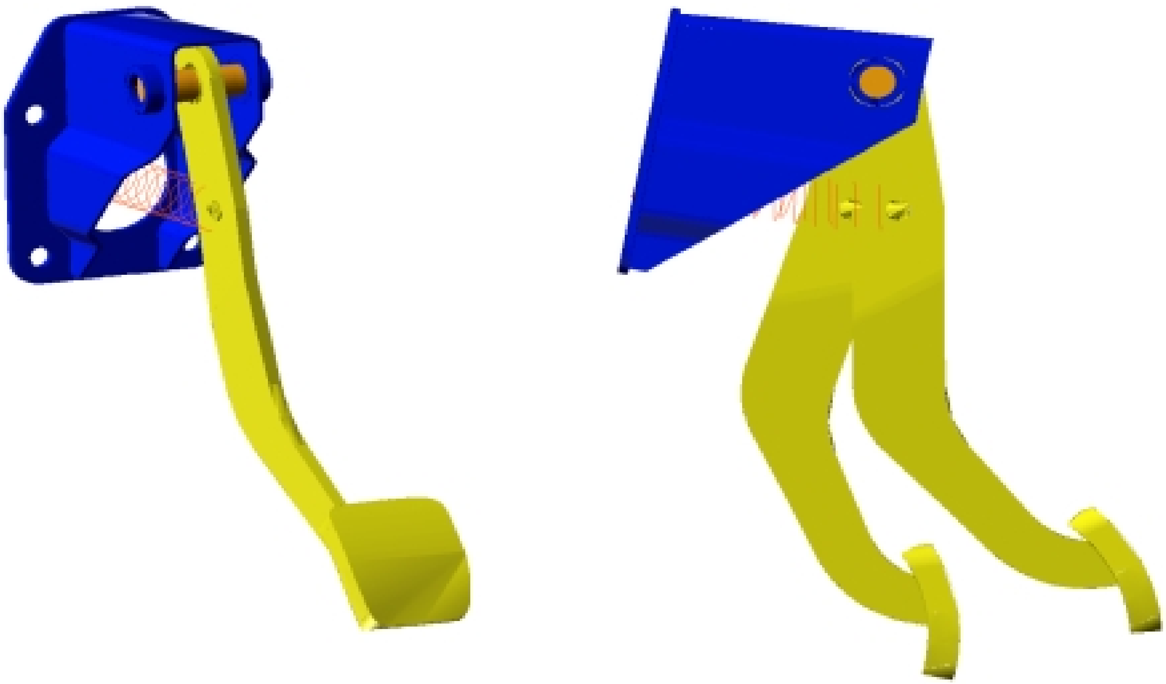

Figure 1: MBS model of a pedal system (ADAMS)

For general load conditions the model shows a good correlation with the reality, because the behavior of the booster is dominating the system. In the case of a more impulsive operation (e.g. an emergency brake situation) the meaning of the dynamical behavior of the parts and the system becomes more important.

The advantage of the classical MBS compared to the FEA is given by the fewer degrees of freedom (dof) which are necessary to describe the system. Referring to this the simulation-time of a MBS is very fast and the description of the kinematics is done easier.

2 Modeling of the parts

The strength of the MBS is clearly the simulation of connected moving parts whereas the FEA reflect on the single parts. Even if software-packages like Nastran or Abaqus have the capability to couple parts together for building groups or systems, this requires in general a great deal of time.
But the strength of the FEA comes out of the elastic description of a part where different loadcases and boundary conditions as well as geometric- and material-specific properties (see chart 1 and figure 2) are taken into account.

	Material		
	PA 66 GF 35	**Aluminium**	**Steel**
E-Modulus [MPa]	9000	70000	210000
Density [kg/m³]	$1{,}42 \times 10^3$	$2{,}7 \times 10^3$	$7{,}8 \times 10^3$
Poisson value	0,4	0,3	0,3

Chart 1: Material properties for the FE calculation

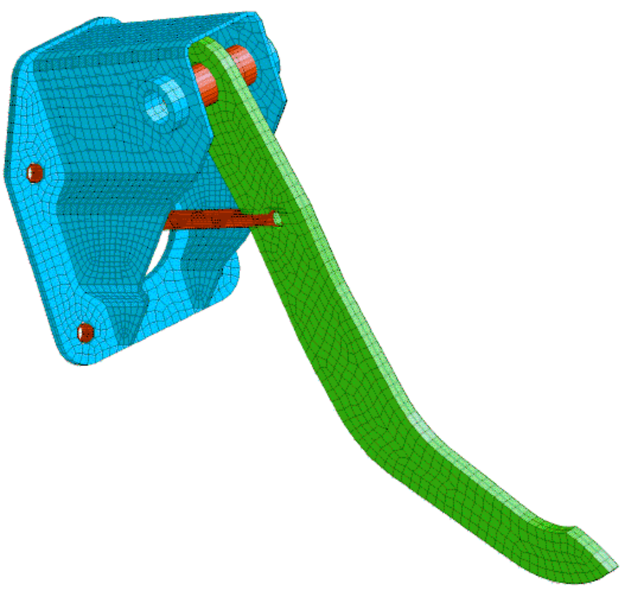

Figure 2: FE-model of the pedal and pedal-bracket

The pedal and the bracket show, especially under impact or impulse loads already their elastic behavior, while the brake booster doesn't show any stress. At this short moment the booster behaves like a rigid part. This behavior is shown in the model with a foot force of 1000 N and the pedal blocked in its initial position.

The deformations and von Mises stresses are given for the above shown model of a simplified pedalbracket which is made of PA66 GF35 (see figures 3 and 4). The resulting maxima depending on different materials are collected in the following chart 2. This loadcase shows a good approximation of the system-elasticity and additionally, it gives information about the expected durability of the parts.

Pedalforce 1000N	Material		
RT	**PA 66 GF 35**	**Aluminium**	**Steel**
σ_{max} [MPa]	329	344	336
u_{max} [mm]	9,76	2,87	2,13
C [N/mm]	102,46	348,43	469,48

Chart 2: Calculation results depending on material properties

Keeping these results within specific criteria it's possible to obtain a durable design, but it's not possible to learn whether the system does achieve the elasticity-targets. The efficiency of the system remains a question too.

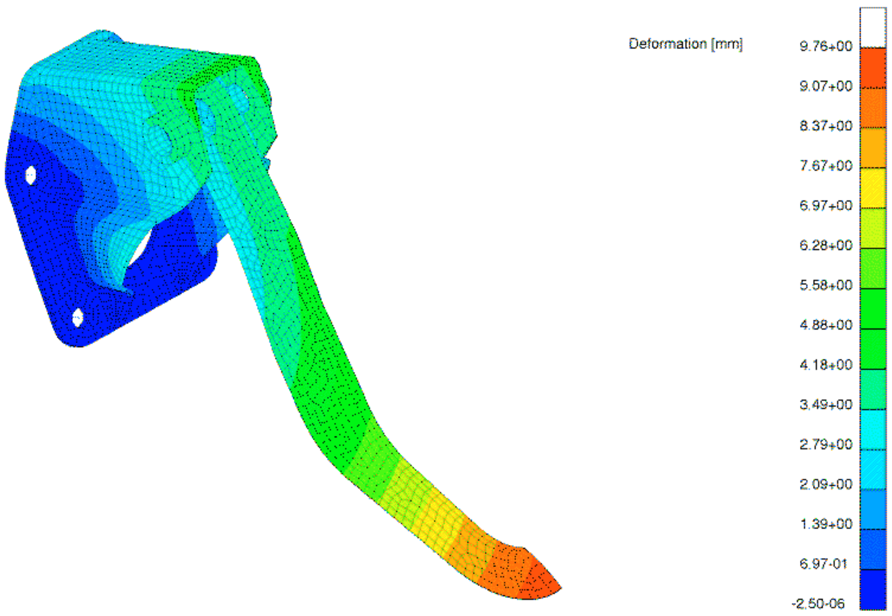

Figure 3: Deformation of the pedal-system (material: PA 66 GF 35)

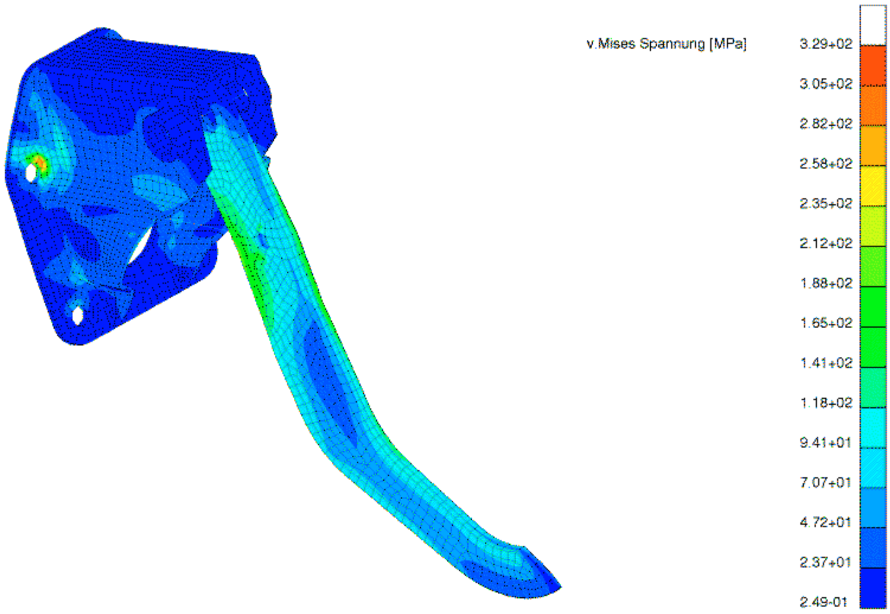

Figure 4: von Mises stress of the pedal-system (material: PA 66 GF 35)

3 Hybrid-Models coupling MBS and FEA

In the first two sections of this report the advantages and disadvantages of MBS and FEA are discussed. The strength of the one is the weakness of the other.
A real closed loop circle results of the implementation of >hybrid-models<. These models couple the elastic and model part properties from FEA into a system model as known from MBS. This way it's possible to combine both methods into one model, that handles the kinematic and elastic properties with sufficient accuracy (see figure 5).

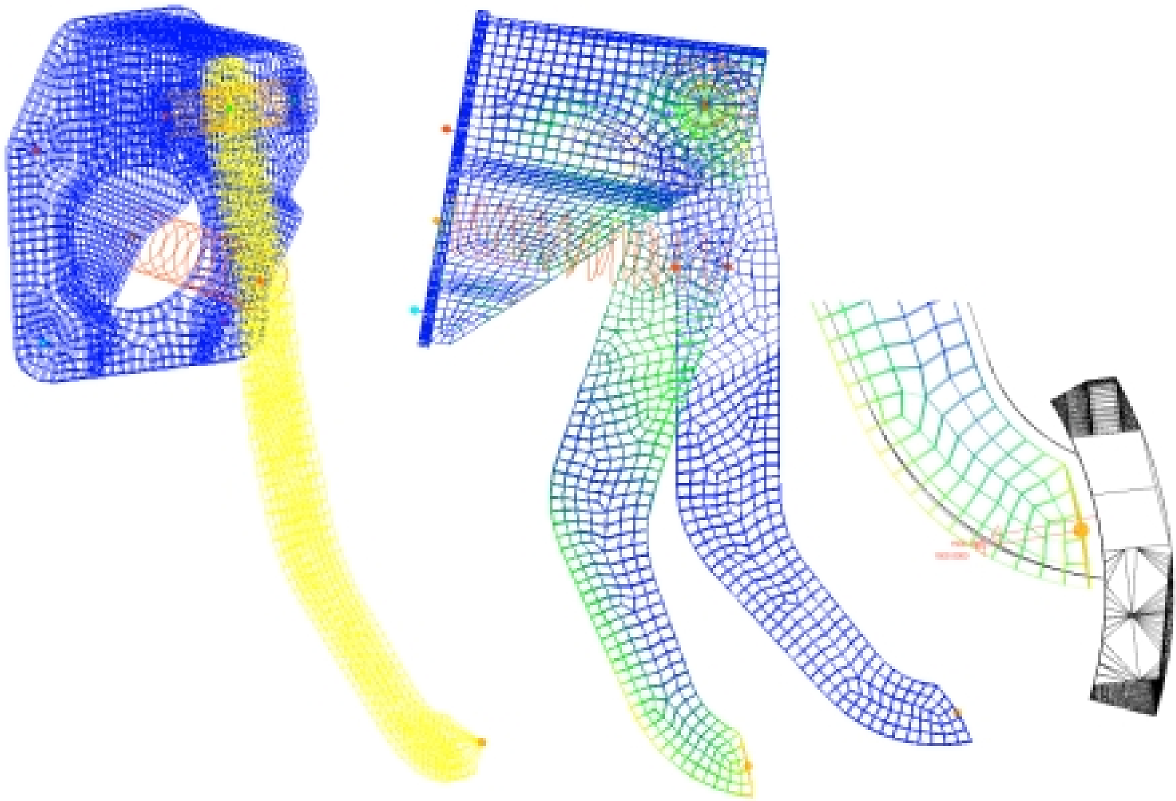

Figure 5: Hybrid model of the pedal-system (ADAMS/Flex)

A measure for the quality of the design is the comparison of the force transfer from the ideal (rigid) and the realistic (hybrid) model. Variation of material properties f. e. elasticity will deliver valuable information to define part-stiffness targets.
The influence of different part-elasticities to the system-behavior is shown in figure 6. The diagram is coming out of a quasi-static simulation where a force is applied to the pedal.

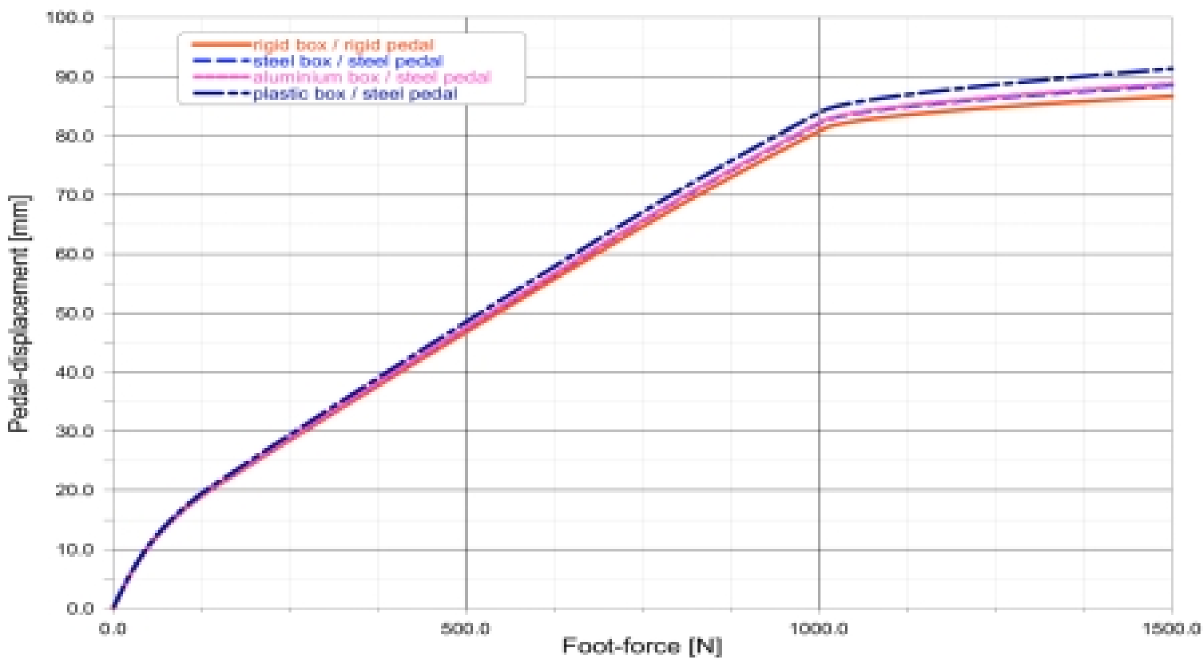

Figure 6: Pedal-displacement as function of pedal-force depending on materials

4 Optimization of the pedal-bracket

From experience the specifications defined by the automotive industry will lead to a durable but sometimes >soft< part with a low efficiency. The driver will recognize this by an indifferent force feedback from the pedal.
In this context the results achievable with the hybrid model are even more valuable for optimization of brake-pedal-systems. A further step is the topology optimization using MSC/Construct which will be discussed in the next paragraph.

4.1 Construct-Model

The topology optimization will not deliver a completed design. It will increase the understanding of important design features in terms of stiffness and material usage.
If the boundary conditions, loads and available packaging are defined, the optimization will return a design concept which can be translated into a part. Hence the optimizer must be used at the beginning of the design process.

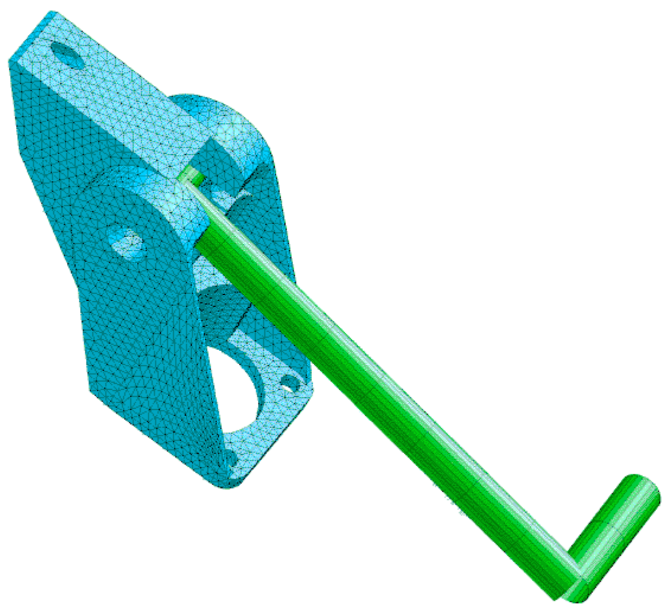

Figure 7: Design-space-model of the pedal-system as base for the topology optimization

The starting point of the iterative optimization, design-space model, is shown in figure 7. The goal is to optimize the stiffness of the bracket. The pedal is built with beam elements of a similar stiffness like the real pedal. Construct generates with the inclusion of this initial geometry, the different loadcases and the boundary conditions a automated order of simulations which is based on the FE-Code NASTRAN. The stiffness of single elements will be reduced in an iterative way. The goal is to identify areas which have minor contribution to the load distribution. These spaces can be left out in the final design. So the topology of the part is developed step by step, which converges to an optimum regarding the use of material and the efficiency of the part.

To have an general idea of this material reduction see the figures 8, 9 and 10. The spreading flow of the force from the pedal mounting point to the upper bolt point and to the bolt on the flange is clear to see. It is also possible to recognize in which areas the stiffness of the structure is essential. Particular the area from the upper bolt point to the flange and the left side are kept more or less completely in this optimization procedure.

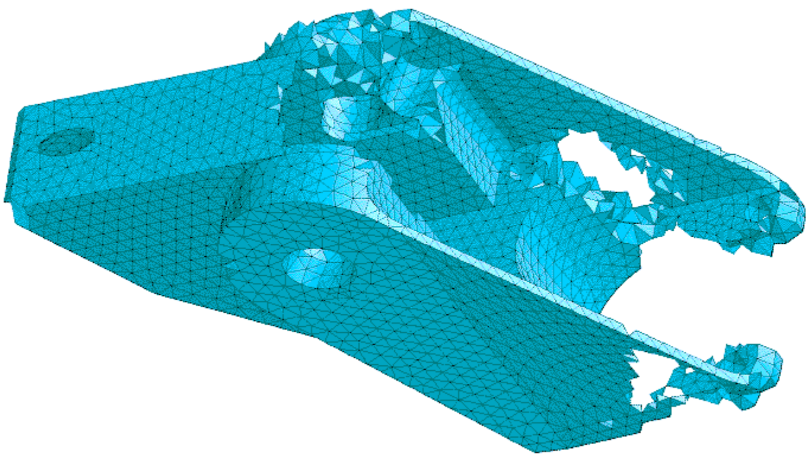

Figure 8: Reduction of material after 2. optimization iteration

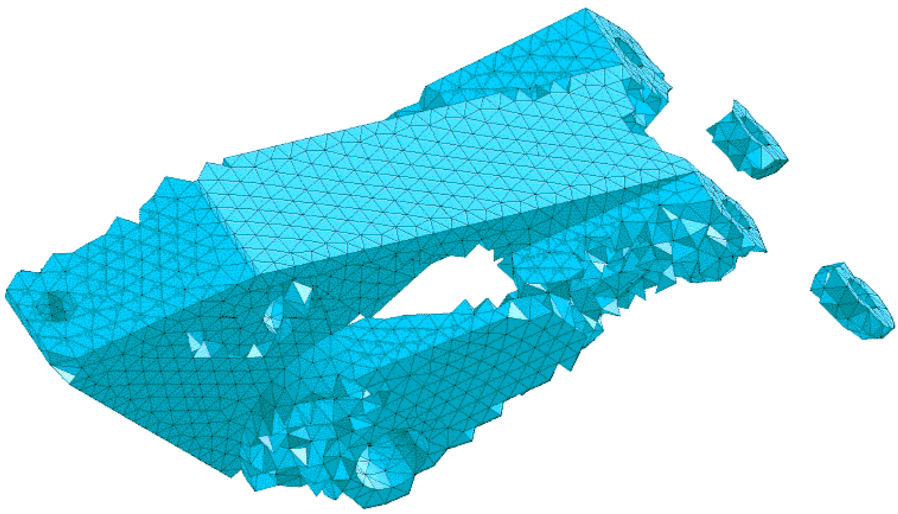

Figure 9: Reduction of material after 16. optimization iteration (top view)

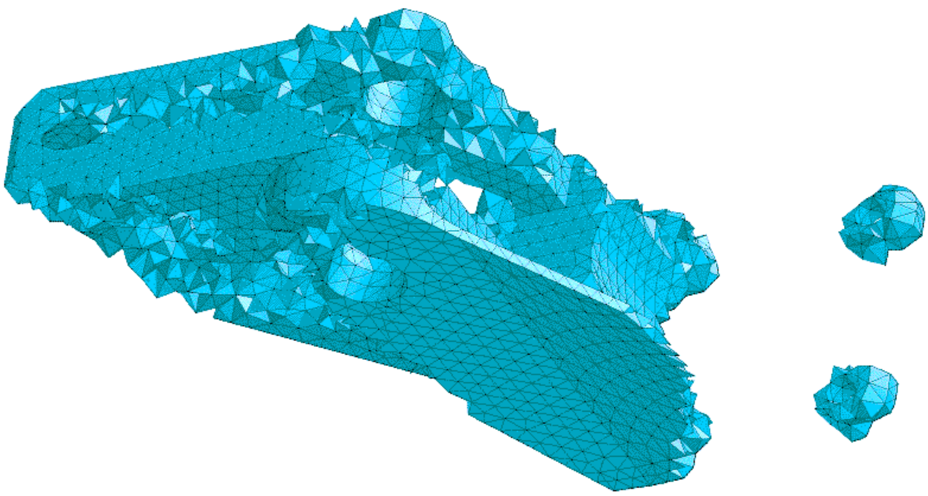

Figure 10: Reduction of material after 16. optimization iteration (bottom view)

4.2 Optimized Model

Based on the now available results a concept for the final design of the bracket has to be derived.
This new model takes into consideration both, the topological requirements coming out of the previous development and details that are added for functional reasons in the meantime.
The translation of the topology optimization result to the new design is shown in figure 11. The next step in the development circle is to calculate the new design under the same conditions (boundary conditions and loadcases) like the initial design (before optimization). Already the first calculation shows that the stiffness of the part is sufficient (see figure 12). Just in the area of the bolts it was necessary to adjust the curvature and thickness of some ribs as well as some radii for reducing the stress concentrations at this locations. The von Mises stress shown in figure 13 have a maximum value of 56 MPa under a load of 1000 N on the pedal. This can be expected as durable.
After this, the next step could be a shape- or thickness-optimization. But the results up to here are sufficient enough so that it isn’t necessary to do further optimizations in this way. The ongoing development and the process of the series tooling is done with the usual FE calculations.

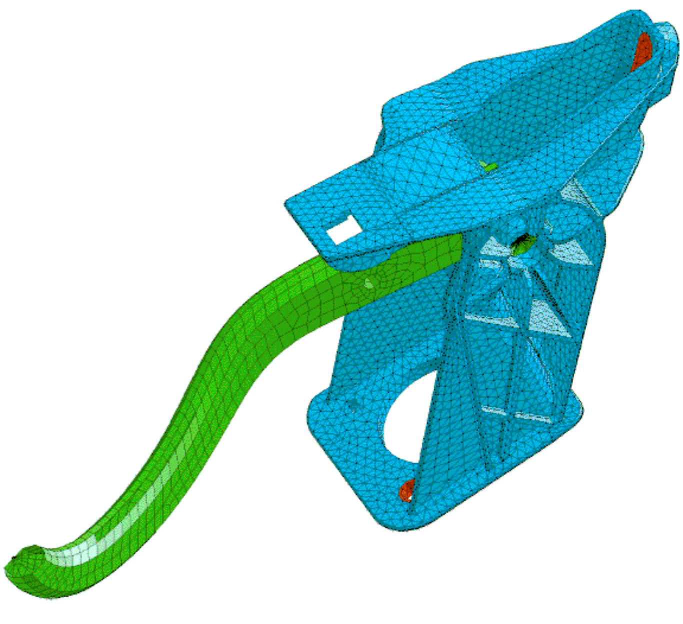

Figure 11: New designed model under consideration of the optimization

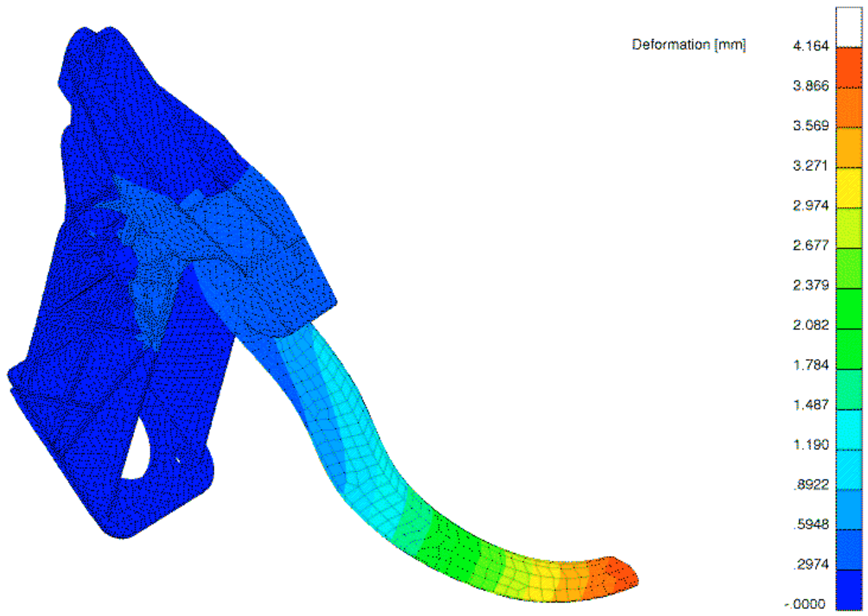

Figure 12: Deformation of the new designed pedal-system (material: PA 66 GF 35)

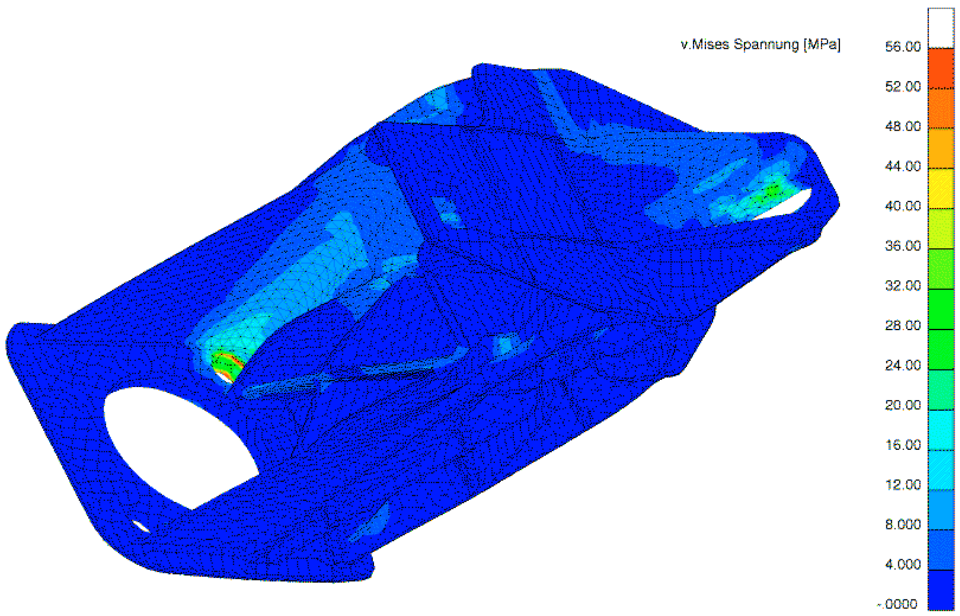

Figure 13: von Mises stress of the new designed pedal-system (material: PA 66 GF 35)

Tests by means of a comparison between the reported plastic bracket and some conventional brackets made of aluminium show that the plastic part has a significant higher stiffness value and consequently a better efficiency of the force transmission from the pedal to the brake booster.

5 Summary

The introduction of the CA-techniques to the engineering practice has lead to the development of different calculation methods. Each of the different methods has advantages but also disadvantages. The strength of one method is the weakness of the other and vice versa. The separation of the methods is caused by their respective approach but not in the required solution. Therefore it is a necessity to integrate the methods and built a overlapping approach.

Another improvement of this solution strategy comes out of a determined implementation of optimization methods for the topology, the shape or the distribution of rib thicknesses.

The consequent application of this interdisciplinary part- and system-design leads to efficient products which is shown on the development of a brake-pedal-bracket.

A future step is the implementation of the mechanics into the optimization loop. In this case the part is not only optimized for the final loadcase, but also for every kinematic motion-step in between. Furthermore this will lead to a response-surface-approach.