INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 99 MUNICH, AUGUST 24-26, 1999

MULTIDISCIPLINARY SHAPE AND TOPOLOGY OPTIMIZATION AND ITS INTEGRATION IN THE PRODUCT DESIGN PROCESS FOR THE EFFECTIVE DEVELOPMENT OF COMPETITIVE PRODUCTS

O. Müller, A. Albers, B. Ilzhöfer, P. Häußler

Keywords: optimization, simulation, FEM, product development tools

1 Introduction

The step beyond the pure simulation of the behaviour of structures is to optimize their response in advance of the physical production and to fit it to the specific needs and requirements. Therefore almost all FEM codes have integrated at least basic optimization capabilities to support the analyst.

The currently implemented approaches are good for optimizations based on certain analysis types. The paper starts with a short overview of optimization approaches. Further sections are concerned with recent work done at the Institute of Machine Design and Automotive Engineering based on the shape and topology optimization software CAOSS (Computer Aided Optimization System Sauter). This includes the coupling of the proprietary nonparametric approach with classical mathematical optimization approaches as well as the generalization to allow the analysis of entire systems.

2 Structural Optimization

In new procedures like the Simultaneous Engineering, the calculation engineer is already integrated into the concept phase of the product development process. Efficient methods of working require powerful optimization algorithms to be provided in addition to the discrete methods (FEM/ BEM) proved worth while to support the calculation engineer in the draft and design phase. Almost all FEM codes have integrated sizing and shape optimization capabilities to support the calculation and design analyst.

Both for sizing and shape optimization a first design proposal, which is used as the start design, exists. The objective of general structural optimization methods is to compute even this first design proposal. For topology optimization the designer creates only the design space, which includes the future component. Subsequently the functionally required boundary conditions are applied. The efforts for the modeling and preparation are extremely low. The optimum structural shape with the appropriate topology is calculated utilizing a FEM program and issued as design proposal which might be refined by the designer. Unfortunately the available optimization codes allow only static or simple modal analysis for the topology optimization.

For shape and topology optimization which both require a large number of design variables considerable problems are encountered with the mathematical programming methods. This is due to the computation of sensitivities needed for the mathematical treatment of the optimization problem. For the application of these methods the sensitivity calculation is the bottleneck. For the application of real world structures model simplifications are required.

3 The Optimization System

At the Institute of Machine Design from the University of Karlsruhe, new optimization criteria and control strategies for sizing, shape and topology optimization were found in 1991, which allow the efficient optimization of even large real world structures, e.g. car bodies ([1]).

The theoretical background of CAOSS (which is behind MSC/CONSTRUCT) is based on mechanical principles describing stress and strain distributions and their homogenization. The resulting optimality criteria are combined with control algorithms. The method does not need sensitivity information and therefore avoids the above shown computational limitation. Based on these new strategies together with the software company FE-DESIGN the computer program CAOSS was developed ([2], [3], [4]).

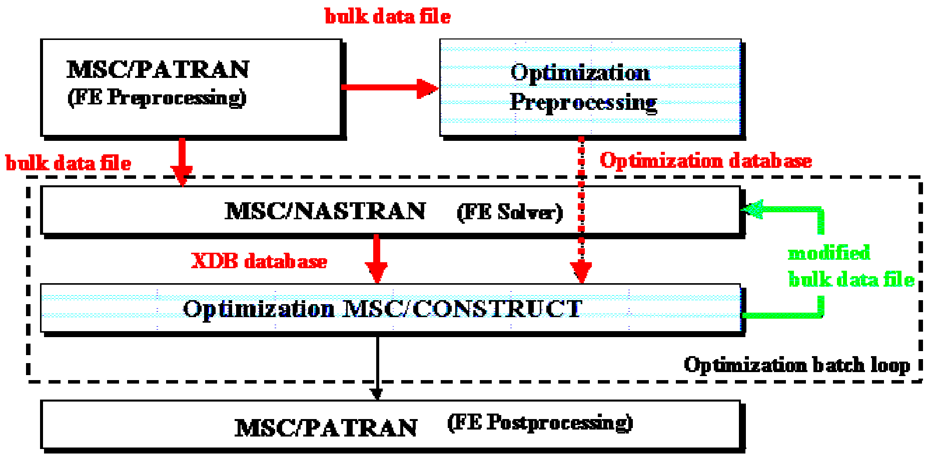

Figure 1. Data Flow during the Optimization

The software includes the optimization types sizing, shape and topology. It allows real world optimizations without model simplification and is coupled with the robust standard FEM solver MSC/NASTRAN (see Figure 1). The program was awarded in 1994 from the European Commission with the European Academic Software Award to be the best program in the field of mechanics.

4 Recent Approaches

4.1 Coupling of Optimization Approaches

An optimization model is required for an optimization in the same way as an analysis model is required for a finite element analysis. For shape optimization it also covers the statement of allowable shape changes. In the MSC/NASTRAN SOL200 these shape changes are expressed by so called shape basis vectors ([5]). The numerical optimization algorithm than determines the best linear combination of these shape basis vectors. To set up a SOL200 optimization model one major task is to derive shape basis vectors, which have sufficient influence on the optimization objective and constraints ([6]). Because the creation and definition of the shape basis vectors must be made manually, it is time consuming and costly especially for 3D structures.

Other optimization approaches are the optimality criteria procedures like the ones implemented in CAOSS. They often have the advantage to generate the new shape without the necessity of shape vectors. Their disadvantage is their lack of handling arbitrary object functions and constraints. Therefore the idea within HIPOP (High Performance Optimization) project was to use an optimality criteria for the generation of shape basis vectors and to use the mathematical optimization approach of the SOL200 to fulfill arbitrary objectives and constraint functions.

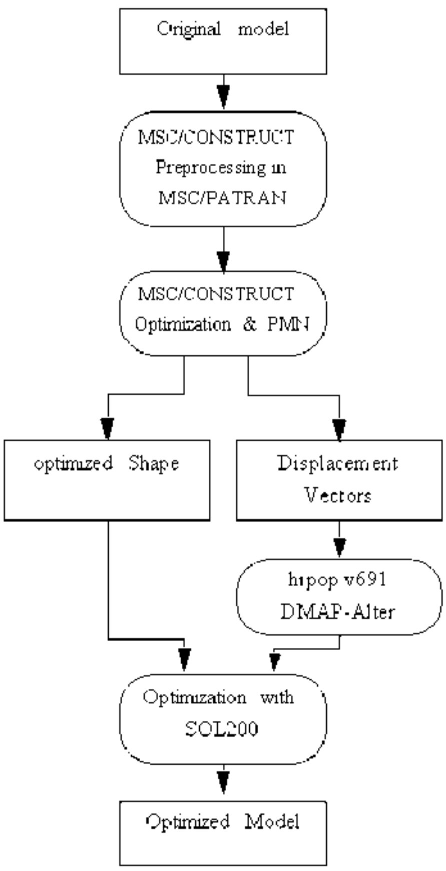

Figure 2. Coupled CAOSS and SOL200 shape optmization

This idea was realized as shown in Figure 2 ([7], [8]). The optimization preprocessing was made within MSC/PATRAN. Using the CAOSS GUI within MSC/PATRAN the modifiable design nodes were defined and the optimization control file was generated. The optimization control file includes e.g. the definition of the objective function, the constraints as well as optional restrictions. Then the nonparametric shape optimization with CAOSS was started. This resulted in an optimum shape and a corresponding displacement vector, which describes the change from the original shape to the optimum shape of CAOSS. With the hipop.v691 DMAP alter a modal analysis was run providing eigenforms which were then considered to be further shape basis vectors. The above mentioned displacement vector from the CAOSS run and these eigenform shape vectors were the parameters for the SOL200 optimization which was finally started.

This approach of coupling the easy and efficient modeling and optimization using CAOSS with the robust and general shape optimization capabilities of the SOL200 was verified with a crank shaft model.

The left plot in Figure 3 shows the displacements through the shape optimization with CAOSS based on the start model. The objective of this optimization was the reduction of the stress levels of the design nodes and therefore the homogenization of these stresses. It led to a new shape of the crank shaft which formed the input model for a MSC/NASTRAN modal analysis for a couple of eigenfrequencies. The corresponding eigenmodes were than considered as further shape basis vectors for the following SOL200 shape optimization which included constraints on the eigenfrequencies.

Comparing the plots of Figure 3 one may see that the shape optimization using CAOSS led to a design which was already very close to the optimum design found by the following SOL200 shape optimization. SOL200 then found only minor shape changes.

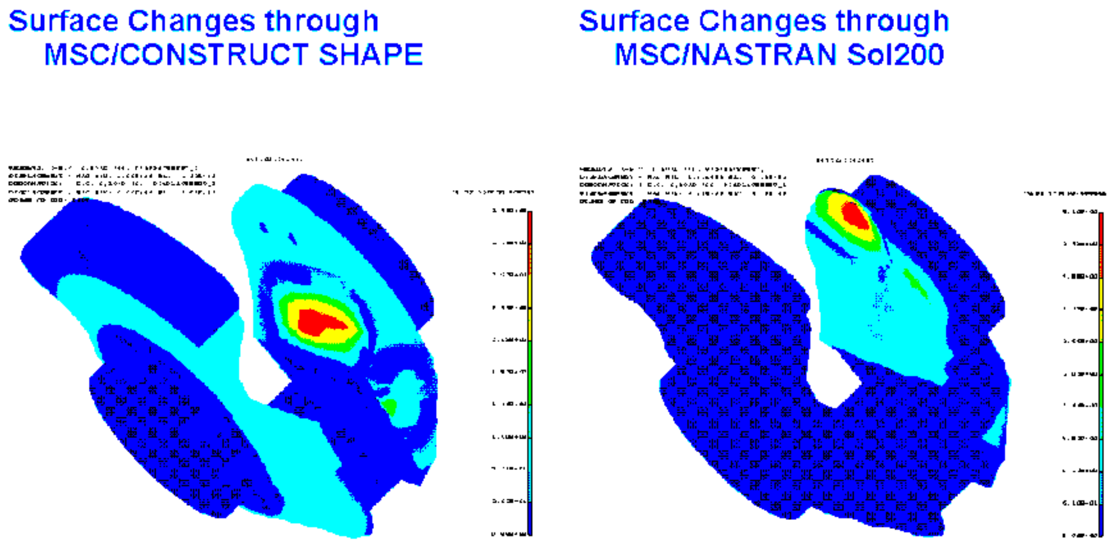

Figure 3. Surface Changes through the Preoptimization with CAOSS (left) and through the following SOL200 Optimization (right). Courtesy of BMW AG, Munich.

Besides cutting the preprocessing time from 2 weeks to 5 hours the use of CAOSS led also to a reduction of the computing time for the SOL200 run by a factor of 10. This is due to the fact that running the SOL200 shape optimization based on a good start design reduces the number of required iterations.

The shape optimization using CAOSS and the SOL200 therefore shows the following benefits:

– The generation of shape basis vectors could be performed automatically.

– This process is fully embedded in MSC/PATRAN and easy-to-use.

– The combination of this software resulted in tremendous time savings without losing generality.

4.2 Use of Multibody Software to consider System Behaviour

Recently software companies developing multibody software (e.g. ADAMS) provide interfaces to widely used FEM software like MSC/NASTRAN and ANSYS. These coupling allows the consideration of complex flexible parts in the models. As a result, the entire mechanical system behaviour can be analyzed. Component changes and it's influence and interaction with other parts can be studied. These interfaces also allow the user to derive component loads and boundary conditions directly from the multibody system (see Figure 4).

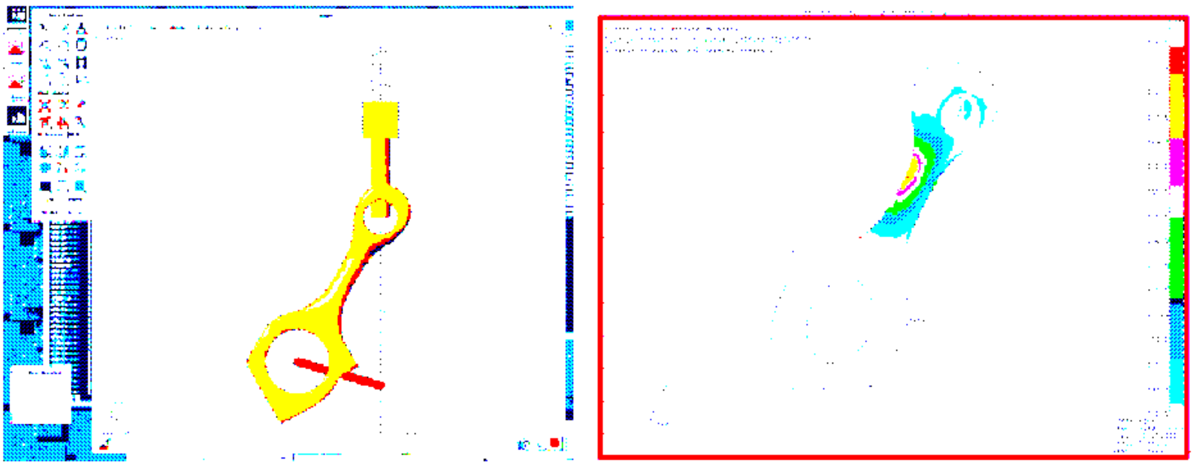

Figure 4. Conrod Loads derived from a Multibody System

These features are used to create an intelligent optimization loop considering automatically the system behaviour changes due to component modifications. This approach was implemented at the Institute of Machine Design. Therefore it was necessary to realize all necessary interfacing with batch routines. Otherwise it would not have been possible to run automated loops. The optimization loop as shown in Figure 1 has been improved through the modules to integrate the multibody software. The enhanced data flow is shown in Figure 5.

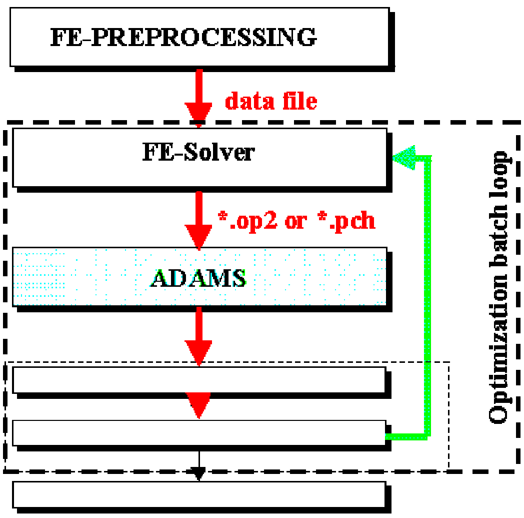

Figure 5. Data Flow of the improved Optimization Loop

5 Conclusion

The institute research focus on the improvement of the efficiency of the whole optimization process. This includes the utilization of High Performance FE solvers as well as the coupling of existing optimization software to come to more general tools. Through the combination of multibody simulation systems and optimization tools the full consideration of system behaviour is possible during the optimization process.

References

[1] Mulfinger, F. ; Müller, O.; Sauter, J.: "Neue Entwicklungen im Bereich der Gestalt- und Topologieoptimierung", Proceedings of the ANSYS-Users' Meeting, Arolsen 1992

[2] Kasper, K.; Friedrich, M.; Sauter, J.; Albers, A.: "Parameterfreie Formoptimierung von Bauteilen, Erfahrungen im industriellen Einsatz", Infografik, 2/1994

[3] Sauter, J.; Müller, O.; Allinger, P. ; Brandel, B.: "Optimierung von Bauteilen mit CAOSS und VECFEM/S", Proceedings of the ODIN-Symposium in Karlsruhe, Karlsruhe 1994, pp 57-89

[4] Allinger, P.; Bakhtiary, N.; Friedrich, M.; Müller, O.; Mulfinger, F.; Puchinger, M.; Sauter, J.: "A New Approach for Sizing, Shape and Topology Optimization", Paper-No. 960814, SAE Congress, Detroit 1996

[5] Moore, G.J.: MSC/NASTRAN Design Sensitivity and Optimization, User’s Guide, Version 68, 1994

[6] Raasch, I.; Irrgang, A.: Shape Optimization with MSC/NASTRAN; MSC/NASTRAN European Users' Conference, Rome, 1988

[7] Müller, O.: "MSC/CONSTRUCT - Topology and Shape Optimization of Large Real World Structures using the distributed parallel MSC/NASTRAN", MSC Users’ Conferences, Paris and Birmingham, June 16-18, 1998

[8] Raasch, I.; Bella, D.F.; Müller, O.: "Weitere Fortschritte in der Topologie und Formoptimierung unter Verwendung von MSC/NASTRAN als Analysepaket", VDI-Conference ‘Numerical Analysis and Simulation in Vehicle Engineering’ in Würzburg, September 24-25, 1998, pp 629-639

Ottmar Müller
University of Karlsruhe
Institute of Machine Design and Automotive Engineering
Kaiserstraße 12
76128 Karlsruhe
Phone: +49-721-608-6495
Fax: +49-721-608-6051
Email: ottmar.mueller@mach.uni-karlsruhe.de