Session H2.5

OVERVIEW ON OPTIMIZATION METHODS

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ABSTRACT - Structural optimization plays an important role in industrial application. A variety of optimization methods for the improvement of structural components exist. Each of these methods has its advantages and drawbacks. The choice of the right optimization method dependents on different conditions: The problem size, type of objectives and constraints, number of design variables and much more. Not only the suitable optimization strategy has to be selected but in many cases, the parameterization of the inputs is also an important issue.
The presentation will give an overview of a variety of types of parametric and non-parametric optimization methods and their use on different applications. It will be pointed out how ANSA is supporting the optimization workflow for preprocessing and parameterization of models used for optimization. Not only the preprocessing itself but also the automation of these steps is very important for an optimization procedure, where manual interaction has to be avoided.

TECHNICAL PAPER -

1. INTRODUCTION

Optimization is more and more used for different types of application. One can distinguish a variety of optimization methods:

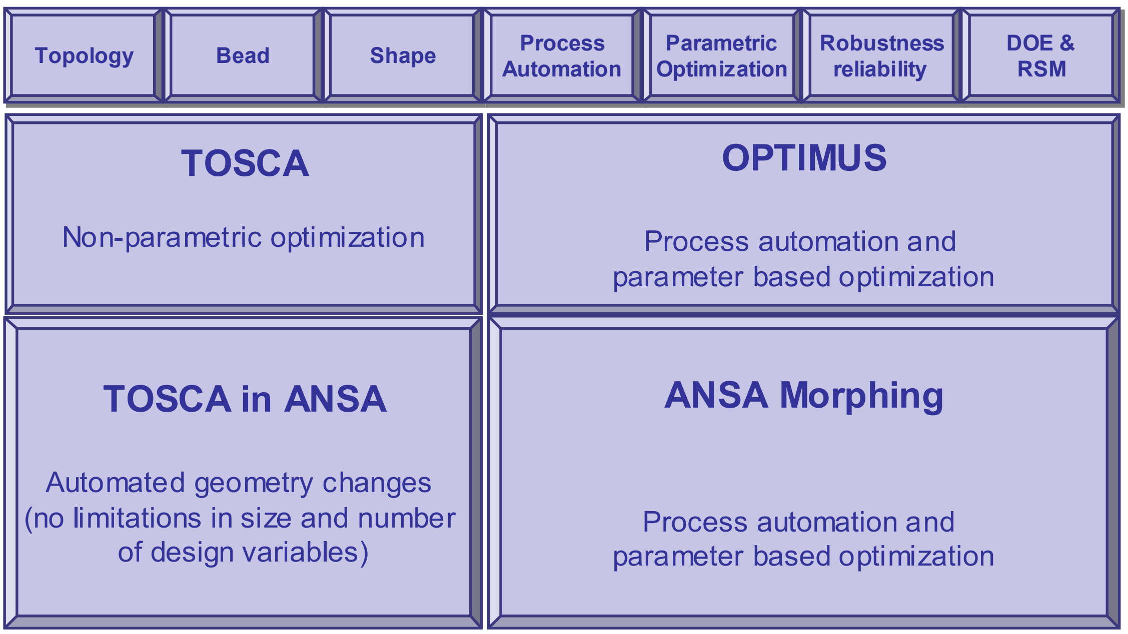

Fig. 1: Different types of structural optimization

The different optimization approaches are differing in the type and definition of design variables, the type and number of objectives and constraints, the type of responses that are considered for the optimization procedure and additional restrictions.

SELECTION OF THE RIGHT METHOD

The user has to select the right method for his optimization problem. He is faced with a number of questions:

- What are the design variables?
- What is the number of design variables?
- Are there modifications of geometry or FE-mesh?
- Is there a relevant distribution of the input quantities?
- What are the objective function(s) and the restrictions?
- Which analyses have to be considered for the optimization?
- Which accuracy is required for the optimization?

Dependent on the requirements, the corresponding optimization strategy has to be selected.

2. OVERVIEW OF OPTIMIZATION METHODS

NON-PARAMETRIC TOPOLOGY OPTIMIZATION

Topology optimization is used for completely new design proposals in a very early phase of the product development process. Starting from the available design space and all existing loads and boundary conditions, a new design concept is found. Different objectives and constraints may be considered for the formulation of the optimization task. The new structure gives an indication of the optimal energy flow considering all loadcases that are applied to the structure.

Fig. 2: Topology optimization example

During the optimization process void areas are generated in the finite element structure. The result of topology optimization typically is a very rough surface representation that has to be smoothed and a new geometric model has to be generated for the transfer to a CAD environment. The TOSCA.smooth module in TOSCA is used to realize this step.

Topology optimization often generates designs that are optimal considering the mechanical point of view but are not manufacturable. TOSCA allows considering various manufacturing restrictions during the optimization procedure. Undercuts may be avoided for castings, various mesh independent symmetry conditions may be defined and the maximum or minimum thickness of trusses may be influenced.

NON-PARAMETRIC SHAPE OPTIMIZATION

In shape optimization, the coordinates of the surface nodes are regarded as design variables. TOSCA.shape is based on a non-parametric approach – a parametrization of the mesh or the underlying CAD geometry is not necessary. The design variables are defined via node groups in the finite element preprocessor. During the modification of the surface, powerful mesh smooth algorithms ensure a good mesh quality.

During shape optimization, local changes of the components surface lead to a homogeneous stress distribution on the components surface. The stress distribution is not the only design response for the optimization algorithm in TOSCA. If durability aspects have to be considered during multiaxial stress conditions, the design response may also be a damage distribution that is determined by a fatigue simulation. TOSCA has interfaces to commercial fatigue software tools like FALANCS, FEMFAT and MSC.Fatigue.

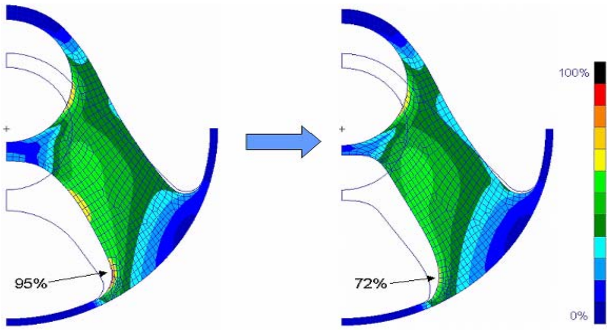

Fig. 2: Shape optimization example

NON-PARAMETRIC BEAD OPTIMIZATION

Beads are a widespread technology for reinforcing sheet metal structures. They can be applied without any noteworthy manufacturing efforts and without significant weight increase. The two main bead applications are to increase the stiffness for static loading conditions and to reduce the noise and vibrations for dynamic loadings.

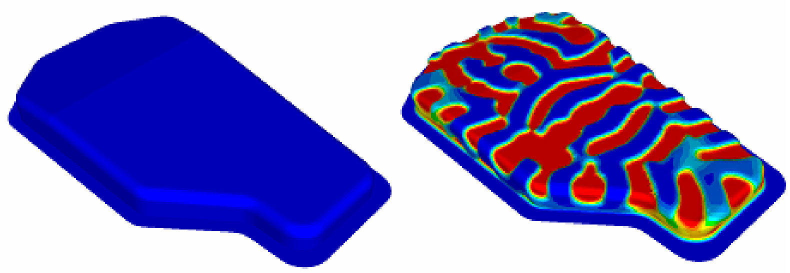

Fig. 3: Bead optimization example

Based upon the results of the finite element analysis, TOSCA determines the optimal bead location and bead orientation. The maximization of the moment of inertia leads to designs that have a maximum bending stiffness for the existent loading conditions.

PROCESS AUTOMATION

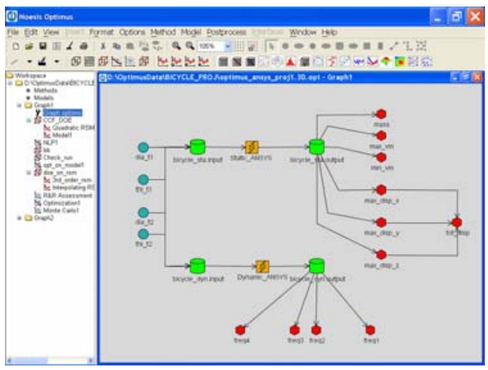

Fig. 4: Process Automation

This methodology guides the user in setting up the Sequence of Analysis functions that describe the complete simulation - much like setting up the test laboratory apparatus. For example, if the functional performance of the design depends on stresses, vibrations and acoustics the engineer will use stress, vibration and acoustic analysis programs to simulate the corresponding performance. This methodology enables the engineer to set up the Sequence of Analysis steps graphically through point and click operations. The analysis sequence specifies the flow of information from the design factors to the decision responses.

For example, in simulating the static and acoustic behavior of a motorcycle gearbox the engineer has to run a static simulation to calculate the behavior of the design under static loading. Then, calculating the eigenfrequencies and finally through coupling of the dynamic structural behavior to an acoustic simulation calculating the sound pressure level at a specified location over a specified frequency range.

Connections for each analysis to the required input files and the corresponding output files are drawn. The design variables are identified and connected to the input files. The performance variables that have to be extracted are identified and connected to the output files. Format independent mechanisms for executing the variable modification and extraction are available. The complete workflow results in a dependency graph which is a powerful formulation for conducting the simulations that will be needed during the design synthesis.

The graph formulation enables a few innovative mechanisms inside the software:

- Selective computation and investigation. If some simulation runs do not depend on a subset of the design variables, or some performance variables are temporarily not needed, the software automatically determines where simulation runs can be eliminated. If some performance variables do not depend on some design variables, this knowledge can be exploited in model construction and visualization.
- Distributed and parallel computation. The data distribution over the computation nodes and the interdependencies between the simulation runs is determined on the graph.

PARAMETRIC OPTIMIZATION

Parameter based optimization is always based on a parameterized input for the optimization system. The parameters may be of different types:

- Shell thicknesses and material properties
- Geometric entities like radii, lengths or spline supporting points
- Forces, Boundary conditions
- Any other parameter that may be accessed in the model.

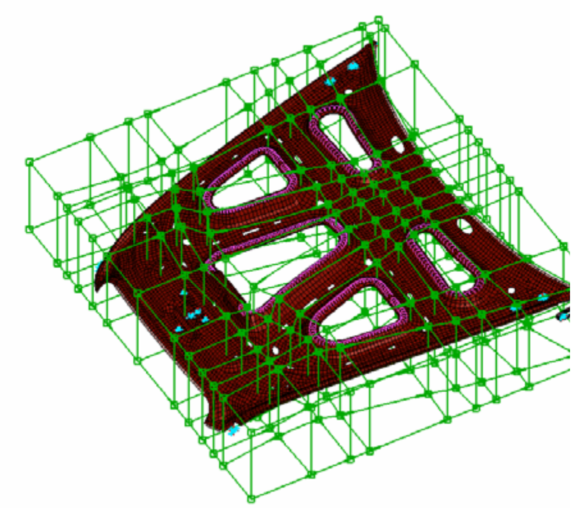

Fig. 5: Parametrization of a bonnet with ANSA Morphing

The variation of the design parameters is introduced into the simulation model by changing the parameterized model.

A very effective way to parameterize geometric entities in existing models is the use of ANSA morphing. The finite element mesh is parameterized by external morphing boxes. The parameters are applied on the control points of the morphing boxes. The movement of the control points is then applied to the underlying finite element mesh. For large geometric changes, one has to ensure the mesh quality during modification. As the mesh topology remains unchanged during the morphing procedure, elements may get distorted. If areas of high distortion are recognized during the morphing procedure, a mesh reconstruct may be applied on selected areas or the complete design in order to keep the needed mesh quality for simulation.

DESIGN OF EXPERIMENTS (DOE) and RESPONSE SURFACE MODELING (RSM)

DOE is a methodology that aims to maximize the amount of information obtained from experimentation while minimizing the amount of experiments [4]. DOE plans include two and three level full and partial factorials, adjustable factor level factorial, Plackett-Burman, Taguchi, Box-Behnken, and Composite designs. Each of the DOE plans listed above differs in the number of function evaluations required. Depending on the DOE plan selected, the degree of non-linearity of the subsequent RSM will vary. For instance, a three level full factorial DOE is sufficient in order to fit a second order Taylor polynomial model, while a Taguchi DOE will only produce sufficient data for a linear model. Figure 3 demonstrates the points of the design to be evaluated in a three level full factorial design for three design parameters. The corners of the (hyper-) cube represent the low and high values each factor is allowed to take.

There are a number of Response Surface Models that can be selected to fit the data generated from the DOE [5, 6]. The model shown is an RSM in five design variables. The representative types of RSMs available are polynomial type RSMs the order depending on the DOE type, with and without stochastic correction terms. The general form of the RSM is:

$$RSM(\mathbf{x}) = \sum_{i=1}^{n} a_i * F_i(\mathbf{x}) + Z(\mathbf{x})$$

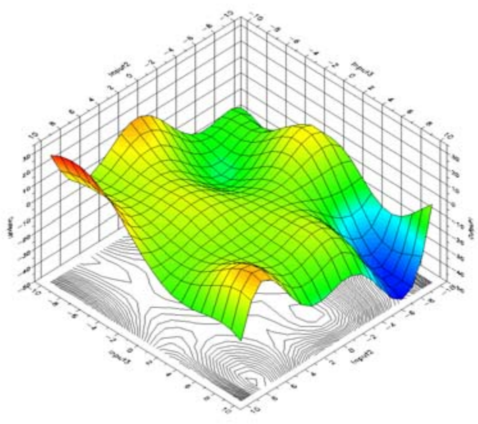

Fig. 6: Stochastic interpolation RSM

where i represents the number of approximating functions, a_i are the coefficients to be determined through Least Squares, $F_i(\mathbf{x})$ are the polynomial -or any user defined- mathematical functions. In the case of pure Taylor Polynomials the $Z(\mathbf{x})$ is set to zero.

A second type of RSMs are based on Stochastic Interpolation. In that case $F_i(\mathbf{x})$ is considered to be a constant. In computer experiments, observations are made on a response function by running the analysis sequence.

Some of the immediate benefits from a DOE/RSM approach are:

- All the models can be used as surrogates to the actual analysis sequence, replacing the computational costly simulation models
- The RSMs allow the engineer to interactively explore the design space prior to applying numerical optimization
- The most dominant design variables are detected, and their influence on the design outputs is quantified
- Correlation among the design outputs is revealed, such that conflicting optimization targets are detected in an early stage

ROBUSTNESS AND RELIABILITY

The optimal designs that are found by the use of optimization technologies are often found on the boundary of the design space meaning that one of the constraints is active. As soon as variability of the input parameters has to be taken into consideration, the scattering output data may lead to infeasible design in the failure domain. So the optimum point should be displaced in order to fulfill all constraints under consideration of scattering input data. The use of probabilistic design approaches helps to take these effects into account during optimization.

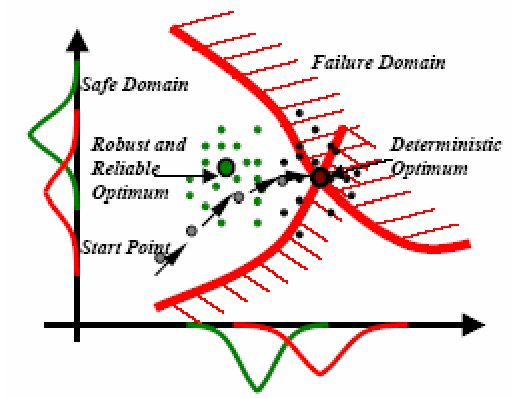

Fig. 6: Stochastic interpolation RSM

MULTIDISCIPLINARY OPTIMIZATION (MDO)

For every discipline to be considered in the MDO, the simulation workflow has to be automated in order to be executed multiple times. The automation must include the entire workflow from preprocessing over setup of the analysis to post-processing. The user has to assure that all relevant results for a design evaluation are extracted. Sometimes, objectives that seem very simple in the interactive evaluation of a design are very complicated to automate. For example the necessary space for the side-airbag between seat and door during a side-crash is more than just one value and this visual criterion has also to be defined to allow the optimization to rate the results.

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