Optimization techniques with SIMULIA Tosca

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Optimization with SIMULIA Tosca

Introduction
A rough Classification into two Groups of Optimization Methods

Both groups have their strengths → The feasible method depends on the given optimization task
Parametric vs. non-parametric optimization

- **Isight**
  - Size, shape and location of the cutout is unknown and it is constrained by parameters

- **Tosca**
  - Size, shape and location of the cutout is unknown, and thus, non-parametric optimization
SIMULIA Tosca product line

- **Tosca Structure.topology**: Find the design with maximum stiffness or minimum weight
- **Tosca Structure.shape**: Reduce local stresses and increase durability
- **Tosca Structure.bead**: Increase stiffness or eigenfrequency of sheet metal structures
- **Tosca Structure.sizing**: Best static and dynamic behavior of sheet metal components
- **Tosca Fluid.topology**: Topology optimization of channel flow to reduce pressure drop

Images courtesy of AUDI AG
Images courtesy of Ford Werke AG
Topology Optimization

SIMULIA Tosca Structure.topology
**Topology optimization approach**

- **Process**
  - Change density of elements within design space considering:
    - **Objective function**
      - Minimize/maximize quantity
    - **Constraints**
      - Physical bounds
    - **DV constraints**
      - Manufacturing, symmetry

- **Result**
  - Optimal material distribution for given optimization problem

  - **Design space model**
  - **Result**
    - Low density elements (voids)
    - Intermediate density elements
    - Full density elements (solids)
    - Relative material density
    - Optimization max. stiffness
    - Design proposal
Results transfer and generation of new CAD model

- Export smoothed surface model in CAD-readable format (STL or IGS)
- Generate slices from smoothed results and export as IGS splines to be imported in CAD systems for the generation of new CAD design
- Reduction of the facets possible
- Guidelines for efficient CAD reconstruction using CATIA native functionalities
Topology optimization of a transverse link at AUDI

Redesign

Existing design

Cutting splines

Design space model

Topology optimization

Courtesy of AUDI AG
Comparison
Existing design – new design

Result
- Speed-up of the development process
- 45% stress reduction, 10% weight reduction
- The 1st prototype passed all mechanical tests!

(Image ATZ MTZ extra)
Optimization and Additive Manufacturing

- TOSCA is a powerful topology optimization tool for producing design concepts that often can’t be manufactured using traditional techniques.
- Those designs are driven by the **functional requirements** of the part.
- Additive Manufacturing makes topology optimization results **accessible** for production.

- Restrictions on the maximum allowed stress
- Restrictions on the maximum bolt tension force
- Optimization for maximum stiffness
- All stress and bolt tension constraints fulfilled
- Final weight 210g → 30% weight reduction compared to an existing design
Shape Optimization

SIMULIA Tosca Structure.shape
**SIMULIA Tosca Structure.shape**

**Functionality**

- **Shape optimization by homogenization of the stresses**
- **Controller algorithm update rule:**
  - Node stress > reference value → Growth in order to reduce stress
  - Node stress < reference value → Shrinkage in order to increase stress
  - Result: homogeneous stress distribution to the level of the reference value
  - Very fast convergence

**Homogeneous stress distribution results in a minimization of the stress peaks in the design area but can also result in a further mass reduction at a later product development stage.**
SIMULIA Tosca Structure.shape

Non-parametric approach

- All optimization definitions directly on the FEA mesh
- Node group of surface nodes (design nodes)
  - Node position can be modified
  - Optimization displacement is calculated during optimization
  - No shape basis vectors and/or morphing required
- Design variables are the displacement values of the design nodes
  - Positive: node “grows” out of the structure
  - Negative: node “shrinks” into the structure
Some Possible Objectives

- **Finite element solver result:**
  - Different stress criteria
  - Nodal strain density
  - Nodal plastic strains
  - Different strain criteria
  - Nodal contact pressure
  - Maximizing the first natural frequency

- **Fatigue results:**
  - Damage
  - Safety Factor

- Generally: stress or strain related responses
New sensitivity based algorithm

General shape optimization

- Free choice of design responses (DRESP) in objective function and constraint
- Optimize for stresses outside the design area (DV)
- New implementation of manufacturing constraint
- To be released
Optimization of thermo-mechanically loaded components

Load History/Workflow for
sequentially coupled transient nonlinear Analysis + Fatigue

1.) THERMAL ANALYSIS
   Transient Temperature Field e.g. from CFD simulation

2.) STRUCTURAL ANALYSIS
   Step 1: Assembly (Press Fits)
   Step 2: Bolt Forces
   Step 3: Temperature Loading: Heat Up
   Step 4: Temperature Loading: Cool Down
   Step 5: Temperature Loading: Heat Up
   Step 6: Temperature Loading: Cool Down
   Step 7: Temperature Loading: Heat Up
   Step 8: Temperature Loading: Cool Down

3.) Fatigue Analysis (FE-Safe, Inhouse Codes)

Nonlinearities:
- material plasticity
- contact

FE Analysis
Compressive Stress
Plastic Strain
Tensile Stress

Cycles to Failure
@ Rated Power
After Cool Down

Life span prediction (material dependent): Smith Watson Toper, Manson Coffin Morrow, energy-based, ...
Shape optimization results of submodel

Safety factor increase: +40%; +10%; +43%
Optimization strategy for exhaust manifold

Optimization based directly on the equivalent plastic strain (PEEQ)

- Goal is fatigue life improvement, no target for weight reduction

<table>
<thead>
<tr>
<th>Initial design</th>
<th>Surface change</th>
<th>Optimized design</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.61%</td>
<td>0.49%</td>
<td>0.54%</td>
</tr>
<tr>
<td>0.99%</td>
<td>0.99%</td>
<td>0.88%</td>
</tr>
<tr>
<td>1.43%</td>
<td>1.43%</td>
<td>1.14%</td>
</tr>
</tbody>
</table>
Optimization strategy 4 – Multilevel shape optimization

Stage 1: User-defined parametric modification of the wall thickness in low-stressed areas for changing the stiffness and thermal expansion behavior with the morphing module of TOSCA

Simultaneous increase of the fatigue life in critical areas and weight reduction

Stage 2: Standard shape optimization based on the result from Stage 1 for further increase of the fatigue life
SIMULIA Tosca Structure.morph: Manifold-Example
Automated generation of the best morphing combinations using Isight

- Priorizing design/tracking areas
- Calculation of surrogate models
- Performing an evolutionary based optimization
- Evaluation of the best designs
Sizing Optimization

SIMULIA Tosca Structure.sizing
SIMULIA Tosca Structure.sizing

**Thickness as design variables**

- Elemental thickness of shell elements as design variables
- Define lower and upper bounds on the thicknesses
- The thicknesses of the most typical shell element types are supported as design variables

**Two optimization approaches**

- Shell element thicknesses can be optimized
  - clustered
    - Combine shell thicknesses to combined design variables via element and property groups
  - individually
    - The shell thickness of each element is a design variable
    - Handle several millions of design variables
Free thickness optimization of a car door

Evolution of the thickness distribution

Areas with maximum thickness

Areas with minimum thickness
Optimization results

Second clustered sizing run

Absolute thickness distribution
Evolution of the thickness change

10% weight reduction while fulfilling all the stiffness and eigenfrequency constraints

Minimization of the total volume

Convergence plots: Normalized stiffness, eigenfrequencies and total volume over the iterations
Sizing Optimization of Circular Beams

- All commands are exactly the same as those for sizing of shells
- Support for beam TYPE=B31 and SECTION=CIRC

Radius is design variable

To be released

Initial

Optimized

Stiffness measure ($=P \cdot u$)

Original design

Max displ: 4.5

Optimized design

Max displ: 1.2

398% higher stiffness for same mass
SIMULIA Tosca Structure.bead

Calculate an optimal bead layout to improve bending stiffness or vibration behavior for sheet metal components
Optimization of beads using Tosca Structure.bead

- Automatic determination of location and orientation of beads for an increase of the moment of inertia
- Fast and stable optimization algorithms using special optimality criterion based on the bending stress
- Solution is independent from mesh
- Support of static or modal analysis
- Fast convergence using a controller based algorithm
- More sophisticated sensitivity based algorithm
- Good transfer and easy interpretation of results due to low scattering

Source: Oehler, „Steife Blech- und Kunststoffkonstruktion“
Preprocessing bead optimization

- Static or modal analysis
- Shell or plate elements must be present
  - All nodes at shell / plate elements may be used as design nodes
  - The optimization displacement direction can be inverted using a SCALE parameter

Simply supported plate optimized with respect to a static force
Simply supported plate optimized with respect to 1st eigenfrequency
Tosca Structure Workflow
Integration of SIMULIA Tosca Structure in the existing CAE environment

- **CAE preprocessing**
  - Abaqus/CAE
  - ANSA
  - Hypermesh
  - MEDINA
  - Patran
  - ...
  - Generation of CAE model with group information

- **Interactive setup**
  - SIMULIA Tosca Structure
  - Abaqus
  - MSC.Nastran
  - Ansys

- **CAE postprocessing**
  - Abaqus/Viewer
  - mETA
  - Hypermesh
  - MEDINA
  - Patran
  - ...
  - Evaluation of CAE and optimization results

- **Manufacturing**
Tosca Structure Optimization User Interfaces

Optimization Module in Abaqus/CAE

Tosca ANSA environment (TAe)

Tosca within ANSA

Tosca Extension for ANSYS Workbench

Tosca Structure.gui
Fluid Optimization

SIMULIA Tosca Fluid
OC-based topology optimization

Sedimentation method

- The optimality criterion is to avoid flow recirculation
- An achieved consequence is (for many technical flows) a reduction of pressure drop
- Redesign rule: elimination of local backflow and recirculation by “blocking out” of backflow areas
- Provides an “optimization” approach by means of “improvement”
- Physics: Internal steady single-phase duct flow with low compressibility
Topology optimization with Tosca Fluid: Step by step

- Define the design space (e.g. CAD)
- Meshing “as usual”
- Define boundary conditions
- Run the optimization
Topology optimization with Tosca Fluid: Step by step

- **Outflow 1**
- **Outflow 2**
- **Inflow**
- **Free flow**
- **Transition area (defining new channel shape)**
- **Prevented flow**
- **Optimized channel shape**

Design space
Automotive HVAC flow splitter manifold

**CFD model and design space**

Dimensions = 0.2 m x 0.14 m x 0.12 m

Boundary Conditions:
- Inflow = INLET
- Outflow = OUTLET

Fluid AIR
- Isothermal
- Turbulent (Std k-e)
- Stationary

$ h = 1.81 \cdot 10^{-5} \text{ kg/(m}\cdot\text{s})$

$ r = 1.205 \text{ kg/m}^3$

Air, $w_{in} = 5 \text{ m/s}$

**Optimized design**

Optimized Design Proposal

Design Space
Automotive HVAC flow splitter manifold

Optimized design proposal (new design)

Relative mean total pressure drop

Design space | Existing design | New design

Δp ↓ 26.1%
Innovative Powerful Simulation Technology

**Abaqus 6.14**
- FEA Multiphysics Simulation

**Isight 5.9**
- Process Integration & Design Optimization

**Tosca 8.1 & 2.4**
- Non-parametric Optimization For Fluids and Structures

**fe-safe 6.5**
- Durability & Fatigue

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