Headquarter Research and Technology
Introduction and first experiences with optimization tools within the Pierburg DRIVE product development process

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Neuss, 20th of October 2010
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- Introduction
- Structure of simulation within R&D organization
- New product development process DRIVE and contribution of optimization tools
- Implementation approach
- First experiences
- Summary
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Rheinmetall AG
€ 3.4 bn Sales 19,750 Employees

Kolbenschmidt Pierburg AG
Leading automotive supplier of engine components and systems
Sales: € 1.5 billion
Employees: 10,300

Rheinmetall Defence
Leading European Defence company for ground forces technology
Sales: € 1.9 billion
Employees: 9,300

Fiscal year 2009
The six divisions

### Kolbenschmidt Pierburg AG

<table>
<thead>
<tr>
<th>KS Kolbenschmidt</th>
<th>KS Aluminium-Technologie</th>
<th>Pierburg</th>
<th>Pierburg Pump Technology</th>
<th>Motor Service</th>
<th>KS Gleitlager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales: € 466 m</td>
<td>Sales: € 119 m</td>
<td>Sales: € 392 m</td>
<td>Sales: € 293 m</td>
<td>Sales: € 185 m</td>
<td>Sales: € 126 m</td>
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<tr>
<td>Employees: 4,777</td>
<td>Employees: 931</td>
<td>Employees: 1,929</td>
<td>Employees: 1,240</td>
<td>Employees: 409</td>
<td>Employees: 994</td>
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<tr>
<td>Products:</td>
<td></td>
<td>Products:</td>
<td>Products:</td>
<td>Products:</td>
<td>Products:</td>
</tr>
<tr>
<td>- Passenger car</td>
<td></td>
<td>- Air Management</td>
<td>- Oil pumps</td>
<td>- Engine bearings</td>
<td>- Engine bearings</td>
</tr>
<tr>
<td>pistons</td>
<td></td>
<td>- Emission Control</td>
<td>- Water pumps</td>
<td>- Dry bearings</td>
<td>(Permaglide®)</td>
</tr>
<tr>
<td>- Commercial</td>
<td></td>
<td>- Actuators</td>
<td>- Vacuum pumps</td>
<td>- Continuous</td>
<td></td>
</tr>
<tr>
<td>vehicle pistons</td>
<td></td>
<td>- Solenoid Vales</td>
<td></td>
<td>casting</td>
<td></td>
</tr>
<tr>
<td>- Piston modules</td>
<td></td>
<td>- Commercial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Large-bore pistons</td>
<td></td>
<td>Diesel systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- MIR</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Corporate Functions

- Controlling + Finance
- Research + Technology
- IT
- Human Resources
- Corporate Development
- Corporate Communications
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- ML0, Member of Executive Board
- ML1, President / Senior Vice President
- ML2, Vice President / Director
- Crossdivisional Functions

CEO
A1

President
GB P

Senior Vice President
Fi / Co GB P

Member of the Executive Board / CFO
A2

Vice President
IT KSPG

Member of the Executive Board
A3

Vice President HR
Pierburg

Sales worldwide

Purchasing worldwide

Business Development

Business Excellence/CQ

Controlling

IT

HR

BU E

BU C

BU S / Plant Neuss

BU A / Plant Berlin

Region America

Plant Usti

Plant Pune

Plant Nettetal

Plant Abadiano

www.kspg.com

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New Pierburg product development process

- Evaluation
  - Project approval (G1)
  - Business evaluation team (PBS)
- Preparation of quotation
  - Quotation approval (G2)
- Application
  - Design approval (G3)
- Production planning
  - Investment approval (G4)
- Implementation
  - Tooing approval (G5)
- Pre-production
  - Production approval (G6)
- Series start-up
  - Team discharged (G7)

Sections
- Order Acquisition
- Product development
- Process development
- Validation
- Series

Process
- Feasibility study based on simulation and researches
- Sample: Simulation planning
- Product design review: Results simulation
- Update: Simulation planning
- Product design review: Update results simulation
- Final results simulation

Decision
- G1
- G2
- G3
- G4
- G5
- G6
- G7

Deliverables
- Actions
- Financial update
- Approval
- Project status

Customer
New Pierburg PDP: Goals

Objectives of the New PDP:
- Reduced development times
- Reduced costs
- Improved product reliability and quality

Major constituents:
- Controlled project status and defined approval of project phases
- Professional multi-project management and efficient resource management
- Simultaneous engineering
- Frontloading

Important contributions of simulation:
- Realization of frontloading by concepts analysis and feasibility studies
- Virtual prototype testing
- Simulation driven design optimization according to requirements
Strategic analysis results: Implementation of Optimization Tools

Possibilities for application in different project phases:

Order Acquisition

Product development

Process development

Validation

Series

Customer

- Topology- and Topography-Optimization
  - Optimized component shape in given design space
  - Shortening of development times
  - Reduction of material usage

- Shape- and Size-Optimization
  - Minimization of loading by model modification on component surface
  - Lifetime enhancement
  - Reduction of peak loads

Excellent tools to implement real Frontloading
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Implementation approach I

Selection process of optimization tools:

- Benchmark of topology optimization tools
  - One interesting “urgent” example case
  - 1 engineering solution
  - 2 optimization tools results

- Rating of the tools:
  - Input data/model
  - Results quality
  - Supplier performance
  - Usability
  - Costs

- Decision and purchasing
  - First licensing in September 2007
  - First enhancement in July 2008
  - Second enhancement in January 2009
  - Enhancement for next site planned for January 2011

<table>
<thead>
<tr>
<th></th>
<th>Original design</th>
<th>Optimized design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in kg</td>
<td>0.556</td>
<td>0.795 (+43 %)</td>
</tr>
<tr>
<td>Max. von-Mises stresses in N/mm²</td>
<td>179</td>
<td>39.86 (-78 %)</td>
</tr>
<tr>
<td>Max. strains in mm</td>
<td>0.658</td>
<td>0.317 (-52 %)</td>
</tr>
</tbody>
</table>
Implementation approach II

Adoption and rollout of optimization tools:

Training

- In house, on Pierburg products and examples
- First 2 CAE-engineers, HyperMesh and OptiStruct in October 2007 for structural mechanics
- HyperMesh and Morphing in November 2007 for structural mechanics
- Morphing/HyperStudy for all structural mechanics and CFD engineers in July and August 2008
- Next 2 CAE-engineers for OptiStruct in April 2009
- Periodic application-driven support days in 2009 and 2010 and advanced trainings in May and July 2010
- Simulation team internal projects and simulation internal free training time

Organizational implementation

- Integration in development processes and PDP DRIVE
- Promotion and management support
- Acquisition of internal customers
- Application to “rescue missions”

Internal presentations of CAO methods

- First examples and results with first success and achievements
- Capabilities and opportunities
- Vision and strategy
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Example I: Sealing Body I

Sealing body failure of an electrical turbo boost recirculation valve:

- Used in turbocharger applications in compressor bypass for surge prevention and mapping
- Operational forces due to armature displacements
- Failure of sealing body in early development phase
Example I: Sealing Body II

Optimized design by means of iterative ANSYS calculations:

- Changing shape of inner ribs and defining additional ribs
- Result
  - Reduction of maximum stresses to 70-85MPa
  - Increase of stiffness by 3.5% (initial design)
Example I: Sealing Body III

Definition of optimization objectives and constraints

- Maximization of stiffness together with 20% usage of design space

Effort for adoption of CAD model, Tetra mesh and definition of optimization objectives and constraints approx. 3 h

- Min size 0.6mm
- Max size 2.0mm

Given displacement

Symmetry constraints

Drawn direction

None-design space

Axial constraints
Example I: Sealing Body IV

Example: Sealing Body, result after 44 iterations, 24 h CPU-time, 2 processors
Example I: Sealing Body V

Transfer to new design and recalculation with ANSYS:

- **Result**
  - Reduction of maximum stresses to 65-80MPa
  - Increase of stiffness by 12%
    (compared to initial design)
Example I: Sealing Body VI

Summary of optimization results

<table>
<thead>
<tr>
<th>Variant</th>
<th>Von Mises in MPa</th>
<th>Remark</th>
<th>Stiffness in N/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Design</td>
<td>75 - 105</td>
<td>No Process-/Manufacturing issues</td>
<td>3180</td>
</tr>
<tr>
<td>1st Optimized Design</td>
<td>70 - 85</td>
<td>No Process-/Manufacturing issues</td>
<td>3294</td>
</tr>
<tr>
<td>2nd Optimized Design</td>
<td>65 - 80</td>
<td>No Process-/Manufacturing issues</td>
<td>3556</td>
</tr>
</tbody>
</table>

Considerable additional optimization by use of Altair OptiStruct
Example II: Coolant Inlet and Outlet I

Coolant flow optimization in Exhaust Gas Recirculation-System:

- EGR-Systems are used to reduce emissions (NO$_x$, HC, Particles, …)
- Hot exhaust gas has to be cooled
- Optimized coolant flow in cooling jacket to ensure efficient cooling and low pressure drop
Example II: Coolant Inlet and Outlet II

Optimization of rectangular inlet- and outlet geometries:

- Simplified generic geometry
- Definition of Morph-Volume in HyperMesh
- Definition of only 2 Shapes to ensure production process feasibility

\[ D = w_1 S_1 + w_2 S_2 \]
Example II: Coolant Inlet and Outlet III

Optimization with HyperStudy and ANSYS CFX:

- Objective: Minimize static pressure loss
- Run / re-run CFD
- Check results automatically
- Modify geometry automatically

Variation of $w_i$

ANSYS CFX

Analysis of results

HyperStudy

![Graph showing static pressure loss vs iteration]

Objective

- Static pressure loss in Pa

- Iteration

- 41.8 mbar

- 4.8 mbar

- 88.5 %

Courtesy of Altair Engineering
Example II: Coolant Inlet and Outlet IV

Optimization results:

- **Inlet**
  - Initial contour
  - Optimized contour

- **Outlet**
  - Initial contour
  - Optimized contour
Example II: Coolant Inlet and Outlet V

Summary of optimization results

<table>
<thead>
<tr>
<th>Inlet Design</th>
<th>Static pressure in mbar</th>
<th>Outlet Design</th>
<th>Static pressure in mbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Design</td>
<td>41.8</td>
<td>Initial Design</td>
<td>33.3</td>
</tr>
<tr>
<td>Optimized Design</td>
<td>4.8</td>
<td>Optimized Design</td>
<td>16</td>
</tr>
</tbody>
</table>

- 88.5%  - 52%

Considerable optimization by use of Altair HyperStudy and ANSYS CFX
Example III: Actuator Heat Shield I

**Plastic vacuum actuator needs heat shield:**

- Cheap design, sheet metal 1 mm thickness
- 1st natural frequency of heat shield should be above 450 Hz
Example III: Actuator Heat Shield II

**Initial design and first engineering judgement optimization:**

- Removing beads and two wings, additional cut-out and moved top fixing point
- Results
  - 1st natural frequency increased from 155.4 Hz to 350.7 Hz

Initial design: 155.4 Hz

1st optimized design: 350.7 Hz
Example III: Actuator Heat Shield III

Definition of topography (bead) optimization objectives and constraints

- **Objective**: Maximize 1st natural frequency
- **Constraints**:
  - Maximum height of beads should not exceed 1.5 – 1.6 mm
  - Draw angle should be between 50 – 70°
  - Areas around fixing points are none design space

**Effort for adoption of CAD model, Shell mesh and definition of optimization objectives and constraints approx. 4 h**

1st optimized design: 350.7 Hz used as new initial design
Example III: Actuator Heat Shield IV

Optimization with OptiStruct, result after 11 iterations, 12 min CPU-time, 1 processor

C:/Documents and Settings/ca33000/Desktop/OPT/FORD_ABSCHIRMLECH/file_ohne_sicken.fem
Result: C:/Documents and Settings/ca33000/Desktop/OPT/FORD_ABSCHIRMLECH/FILE_ohne_sicken.res
Loadcase 1: DESIGN [0]
Frame 1
Example III: Actuator Heat Shield V

Optimization results:

- Optistruct proposed bead pattern
- Transfer to new design and recalculation with ANSYS

2nd optimized design: 527 Hz
2nd optimized transferred design: 522 Hz
### Example III: Actuator Heat Shield VI

#### Summary of optimization results

<table>
<thead>
<tr>
<th>Variant</th>
<th>1st natural frequency in Hz</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Design</td>
<td>155.4</td>
<td>Requirements not met ( &gt; 450 Hz)</td>
</tr>
<tr>
<td>1st Optimized Design</td>
<td>350.7</td>
<td>Requirements not met ( &gt; 450 Hz)</td>
</tr>
<tr>
<td>2nd Optimized Design</td>
<td>522</td>
<td>Requirements met ( &gt; 450 Hz), no Process- / Manufacturing issues</td>
</tr>
</tbody>
</table>

- Considerable additional optimization by use of Altair OptiStruct

![Graph showing 1st natural frequency in Hz for Initial Design, 1st Optimized Design, and 2nd Optimized Design with increased values of +126% and +110% respectively.](image)
Example IV: Geometric Parameter for FSW design I

Friction Stir Welding of Aluminium EGR-Cooler: Welding zone geometry

- New welding technology introduced by Pierburg for aluminium pressure die cast parts.
- Analyze impact of simplified basic geometry on strength, stiffness and fatigue.

![Welding Line](image)

- End Point
- Welding Line
- Starting Point
Example IV: Geometric Parameter for FSW design II

CAE-supported DoE: Detection and assessment of influencing parameters

- 7 parameters have been chosen.
- For a full factorial analysis with 7 parameters and 2 steps: $2^7 = 128$ tests would have to be carried out.
- Therefore the first step has been a screening to detect the most influencing parameters.
Example IV: Geometric Parameter for FSW design III

CAE-supported DoE: Screening results

- 7 parameters have been chosen
- 3 parameters have high impact on 1st principal stress
Example IV: Geometric Parameter for FSW design IV

CAE-supported DoE: DoE on main effects including weld line position

- 4 parameters have finally been chosen (with additional parameter weld line position)
- Objective: Minimize equivalent Stress Intensity Factor within parameter range

Results:

- 3 parameters have high impact on equivalent stress intensity factor
- Lower top cover width has positive effect on life time of the welding line
- Because the lower width leads to lower displacements of the top cover
Example IV: Geometric Parameter for FSW design V

Geometry optimization with HyperStudy and ANSYS:

- Optimization with Adaptive Response Surface Method

- Optimization leads to maximum top cover thickness and maximum welding depth

- Equivalent stress intensity factor could be reduced by 50%

- Efficient parameter optimization by use of Altair HyperStudy

**Graph:**
- Welding depth
- Weld line position
- Equivalent Stress Intensity Factor
- Top cover thickness
- Gap width from 0.2 to 0.7 mm

**Comparison:**
- Initial vs. Optimized Equivalent stress intensity factor in MPa/mm$^{1/2}$
  - Initial: 289
  - Optimized: 143
  - Reduction: -50.5%
Implementation Experiences

Lessons learned:

Training

- Successful in house training, good advantage to learn on Pierburg products and examples.
- More training days, especially if HyperMesh training is needed, too.
- To start not with the whole group leads to potential concentration of operational tasks, but
- Risk of two or more groups of users with different level of experiences and knowledge.
- Periodic application-driven support days are very successful.
- To get additional simulation internal projects and simulation internal free training time has been very
difficult, especially during current financial crisis impacts.

Organizational implementation

- The formal integration in development processes and PDP DRIVE has been easy, the real usage of the
tool remains difficult, therefore additional promotion and management support is needed.
- Acquisition of internal customers is still difficult, except there is a need to rescue a project design.

Internal presentations of CAO methods

- Big need for internal presentation of first examples and results with first success and achievements.
- Design and Project Management need to know the capabilities and opportunities of CAO.
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The introduction of numerical optimization tools into the Pierburg DRIVE product development process has been successful:

- The tools are one of the most important drivers to realize “Frontloading” and to remain competitive on the market.
- Throughout the whole product range they could provide innovative and better solutions.
- Well trained experts and strong support of the management are needed until the tools are firmly established within the organization.
- The different methodologies, topology, topography, size optimization and DoE provided very promising results.

To gain full integration of the tools and to achieve full internal customer satisfaction:

- The vision and strategy for CAO tools has to be presented internally again and again.
- Convincing examples and impressive solutions are still needed.
- Still effort for CFD optimization has to be spent to obtain the full range of results here, too.
Thank you for your attention

KSPG AutoMotivePower

4th European HTC
Versailles October 28th – 29th, 2010
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