Institut für Technische Logistik

SIMULATION POTENTALITIES FOR A RECIPROCATING COMPRESSOR

Christian LANDSCHÜTZER[1],

Andreas WOLFSCHLUCKNER[2]

[1,2,]TU Graz, Institute of Logistics Engineering, Graz Austria

E-mail: *landschuetzer@tugraz.at*

Tel +43 (316) 873 7325
Fax +43 (316) 873 107325

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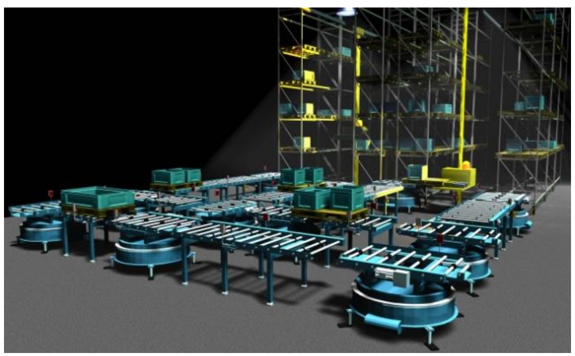
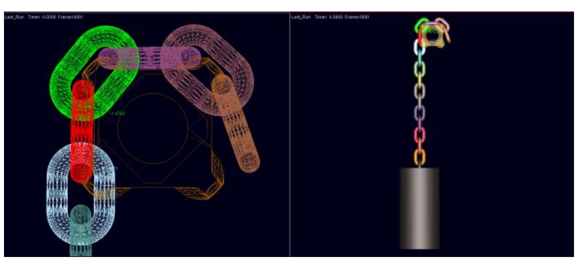
Overview

Topics

- Institute of Logistics Engineering
- Simulation for engineers
- SIMULATION POTENTALITIES FOR A RECIPROCATING COMPRESSOR
  - Thermal Analysis
  - Vibrational Analysis
  - Structural Analysis
  - Summary

Fields of Expertise - Portfolio





Machine Design

- CAD and CAE
- Prototype design, Field Tests

Automation

- Identification and Communication Technologies
- Control and Drive Design

Planning

- Modelling and Abstratcion
- material flow calculation and simulation

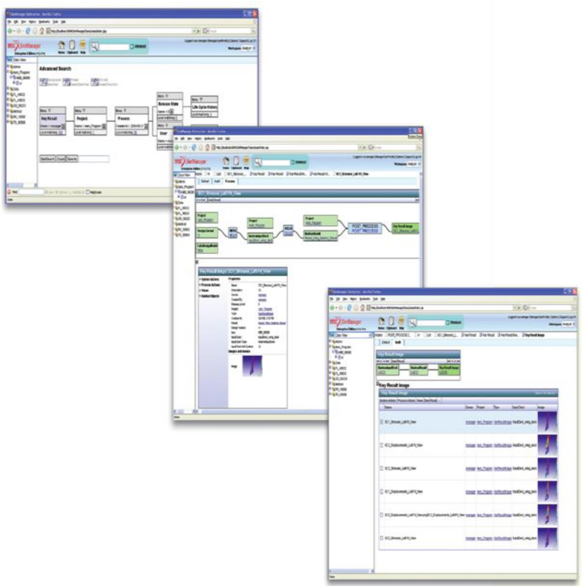
Research

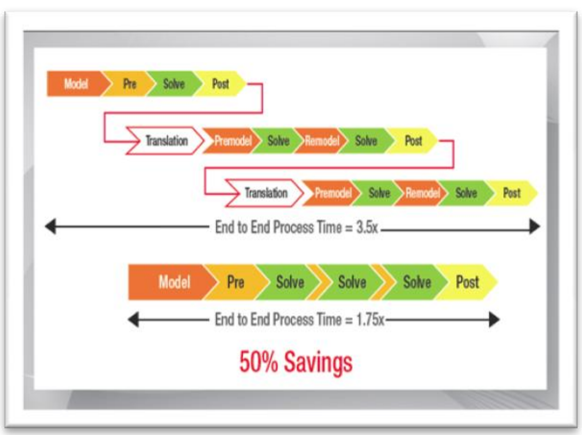
- Optimization of Machine Elements (from MH Equipm.)
- Material Handling Machinery
- Smart Carriers (AGV), Sorting Machinery

Teaching

- CAD and CAE for > 300 Stud.
- Spec. courses in machine design, Material Flow Syst.

Simulation for Engineers





The Challenge: SIM within the design process

simulating what: (VDI 2209)

- Geometric Analysis
- Static, Dynamic Analysis
- Structural Anaylsis
- Etc.,… (Hydraulics, Thermics, Fluids, Electricity)

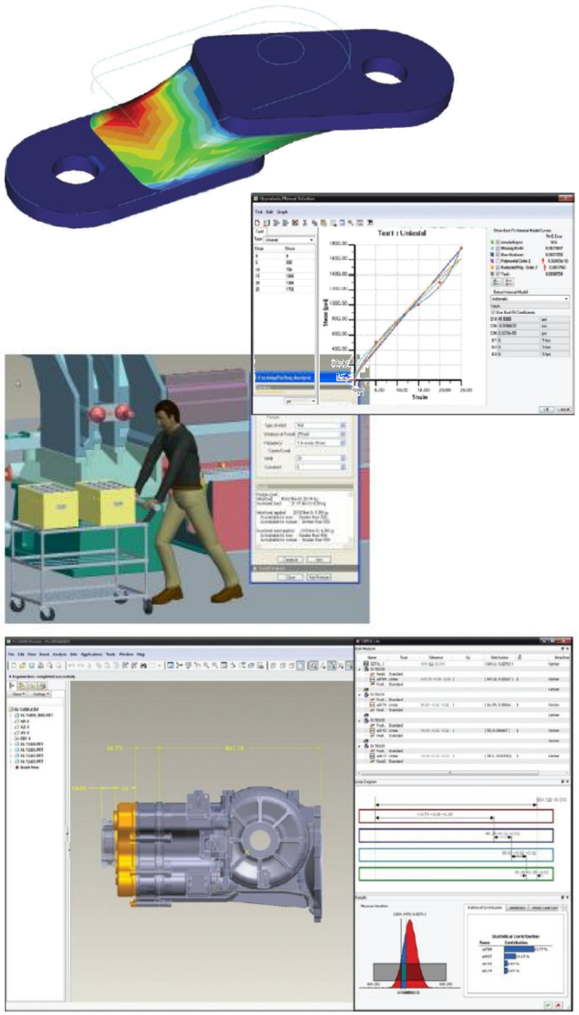
Challenges:

- various SW-Products within various phys. Domains
- various stages of detail and accuracy
- Sometimes unspecific Tasks within Submodelling

Trends

- Knowledge Based Engineering
- Managed Simulation
  - Templates from Experts for „Engineers“ with trusted quality – high efficency

Simulation for Engineers



Simulation within CAD (Source: PTC)

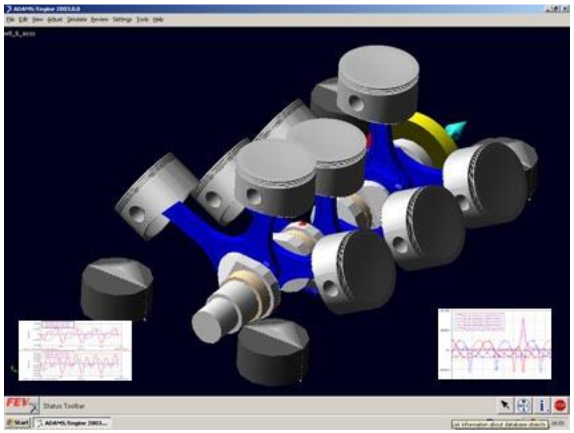
Costly and laborious prototyping hinders a design team, resulting in compromised schedules and budgets.

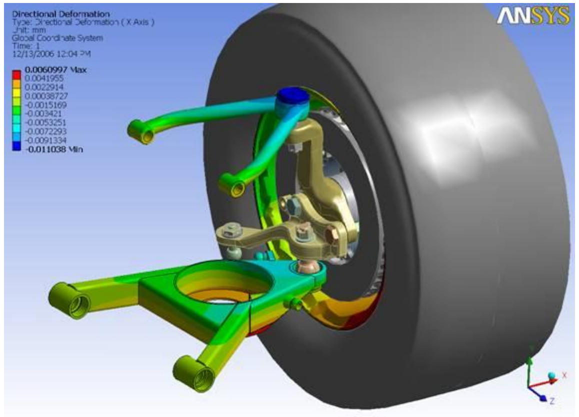
- Obtain real-world performance data by directly applying conditions to design geometry without requiring data translation
- Fast, automatic solution convergence, mapped precisely to underlying CAD geometry; 3rd party solver output
- Increase innovation by simultaneously designing and simulating results of design variations
- Decreases development costs

Handicaps

- No special Simulation Techniques, not open configurable, hidden theory,…

Simulation for Engineers





Defintion of basic skills for eng. in „Mech.Sim“

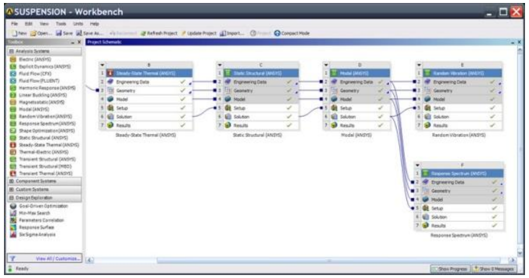
Engineering and Mechanics basics from University, Courses and self training

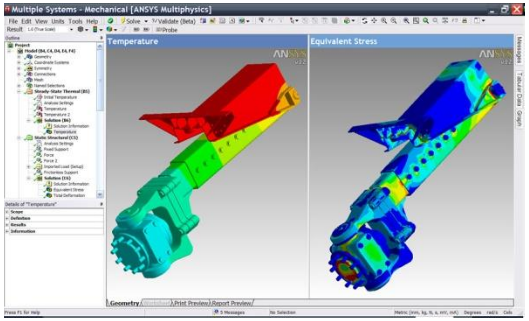
- Don‘t often correspond
- Theory must meet praxis
- Not every engineer must be able to programm a FEM and MBD System
- Every engineer should have basic knowledge of general methodolgy behind the Software
- → Gap between user and SW developing engineer

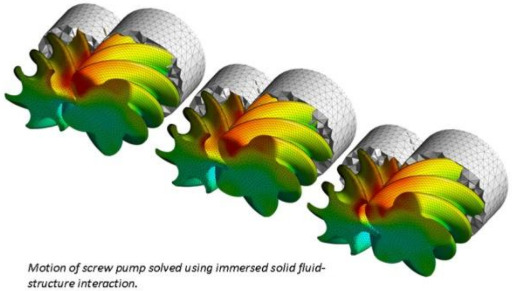
From practical experience

- General problem understanding (many examples)
- Field experience in measuring
- Interpretation KnowHow

Simulation for Engineers
basic skills for engineers – qual. criteria







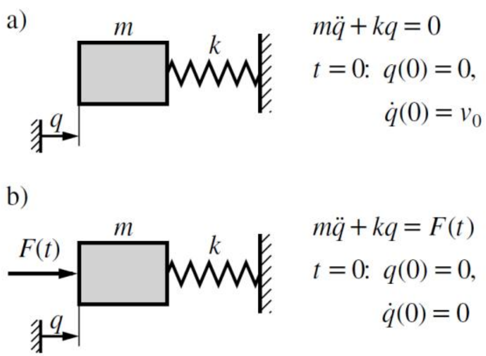
Motion of screw pump solved using immersed solid fluid-structure interaction.

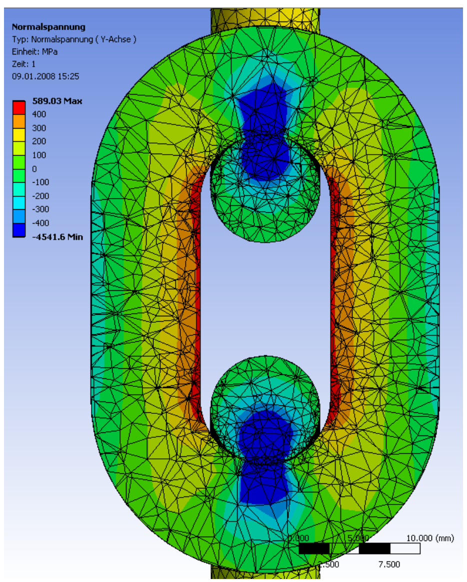
Main Programm Functions

- **Possibilities**
  - Calculation Intensity (elements vs. calc. time)
  - Interfaces
- **SW concept**
  - Submodels, automated Sim, parameter handling
  - Libraries with tailored objects
  - user-written subroutines and „equations“
  - Simulatorcoupling
- **Assignments in connection with similar SW**
- **Postprocessing of result**
  - Data export (formats), visualization
  - Code-Export
  - Simulation Content Management

Simulation for Engineers
basic skills for engineers – qual. criteria

Modeling – theory behind describing functions





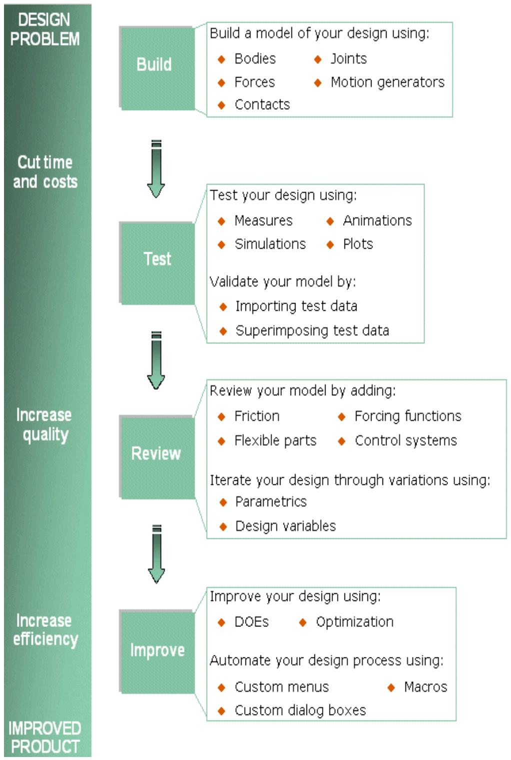
Basic understanding of equations behind library objects
(linear or nonlinear behaviour,…)

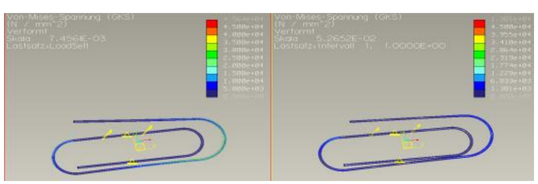
Influence of parameters in equations
(small masses and high rigidities → numerical problems)

Types of Elements
(i.e. rigid – flex – contact)

Knowledge behind abstract PreProcessing like meshing and contact formulation

Simulation for Engineers
basic skills for engineers – qual. criteria





modeling

Modelling – replacing reality

- Basic knowledge of real objects behaviour (anticipated motion and deforamtion)
- Influence of constraints-types
- inductive or deductive modeling
- Adequate stage of abstraction maximum modeling vs. Required modelling for selected results
- Synthesis of validated submodels

Materails and geometry

- Detecting nonlinearities (geometric, material) and valuation
- Chossing adequate CAD formats for forwarded import/export and change management

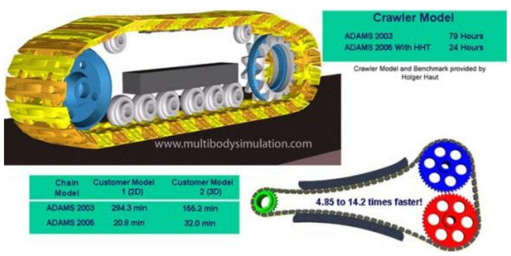
Coupling between various physical domains (mechanical, elctric., hydraul., control,…)

Simulation for Engineers
basic skills for engineers – qual. criteria

Mehrschritt

- BDF:
  - 1. Ordnung: $x_{i+1} = x_i + \dot{x}_{i+1} \cdot \Delta t$ *wie Euler implizit*
  - 2. Ordnung: $x_{i+1} = \frac{4}{3} x_i - \frac{1}{3} x_{i-1} + \frac{2}{3} \dot{x}_{i+1} \cdot \Delta t$ *häufig ve*
    Parabelapproximation
  - 3. Ordnung: $x_{i+1} = \frac{18}{11} x_i - \frac{9}{11} x_{i-1} - \frac{29}{11} x_{i-2} + \frac{6}{11} \dot{x}_{i+1} \cdot \Delta t$
- Gear (GSTIFF in ADAMS):
  - 1. Ordnung: $x_{i+1} = \alpha_i x_i - \beta_0 \dot{x}_{i+1} \cdot \Delta t$
  - k-te Ordnung: $x_{i+1} = \sum_{n=1}^{k} \alpha_i x_{i-n+1} - \beta_0 \dot{x}_{i+1} \cdot \Delta t$

$$x_{n+1} = N_f(x_n) = x_n - \frac{f(x_n)}{f'(x_n)}$$



Solving

Underlying methods
solving of DAEs with numeric integration formulation by use of i.e. euler methods

Differences between solvers
stability and errors of solvers for different systems (stiff – nonstiff)

Solver Parameters

- Step size (directly proportional with frequencies)
  event based step size adoption
- Accuracy and errors
- Degrees of solver polynoms and index reduction methods

Detection of solver time consumtive processes
(small masses and high stiffness)

Interaction of solver and hardware

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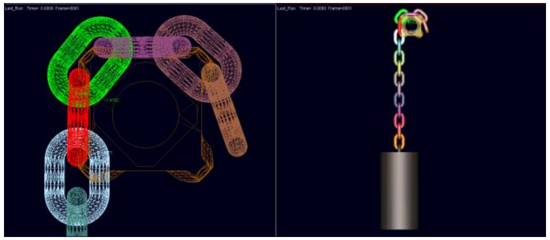
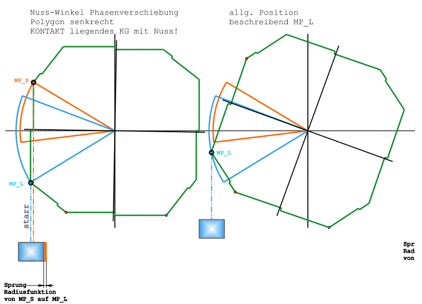




Es ist dann der Hubweg (in Analogie zu Abb. 5-18):

$$y_k = \begin{cases} r_4 \sin(\rho_L) + r_4 \sin(\psi_k - \rho_L) & 0 \le \psi_k \le \beta \\ r_4 \sin(\rho_L) + r_4 \sin(\beta - \rho_L) + \\ \quad + r_5 \sin(\rho_S) + r_5 \sin(\psi_k - \beta - \rho_S) & \beta \le \psi_k \le \alpha \end{cases} \quad (5\text{-}13)$$

Der Hubweg nach der Drehung um eine Periodizität ist ein Vielfaches der Teilung t_k für die auch gelten muss, wenn eine reale Einbaulage vorliegt (p_n* s. Glg. 5-2 und 5-3):

$$t_k = p_{n*} = r_4 \sin(\rho_L) + r_4 \sin(\psi_k - \rho_L) + r_5 \sin(\rho_S) + r_5 \sin\left(\frac{\pi}{2} - \beta - \rho_S\right) \quad (5\text{-}14)$$

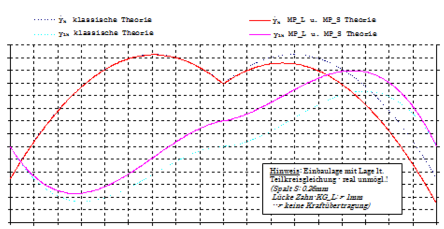
Die Hubgeschwindigkeit beträgt dann:

$$\dot{y}_k = \begin{cases} r_4 \cos(\psi_k - \rho_L) & 0 \le \psi_k \le \beta \\ r_5 \sin(\psi_k - \beta - \rho_S) & \beta \le \psi_k \le \alpha \end{cases} \quad (5\text{-}15)$$

Und die Wegerregungsfunktion lautet mit der Taschenzahl e:

$$y_{1k} = y_k - \frac{e\, p_{n*}}{2\pi} \psi_k \quad (5\text{-}16)$$

Damit zeigen sich folgende Unterschiede im Geschwindigkeits- und Wegverlauf:



Result

Validation

- Measurement of relevant quantities (elongation, acceleration) of subsytems or overall
- Analytical Methods (mechanics of materials, dynamics)
- System behavior under extrem conditions (theor. Considerations)

Actual vs. Permissible quantities

- FEM-structural: yield stress is not enough! (compare local stresses vs. overall stresses)
- FEM-structural : fatigue methods
- dynamics: interpretation of accelerations causing motion or noise…
- FFT (instead of time based signals)
- Animation

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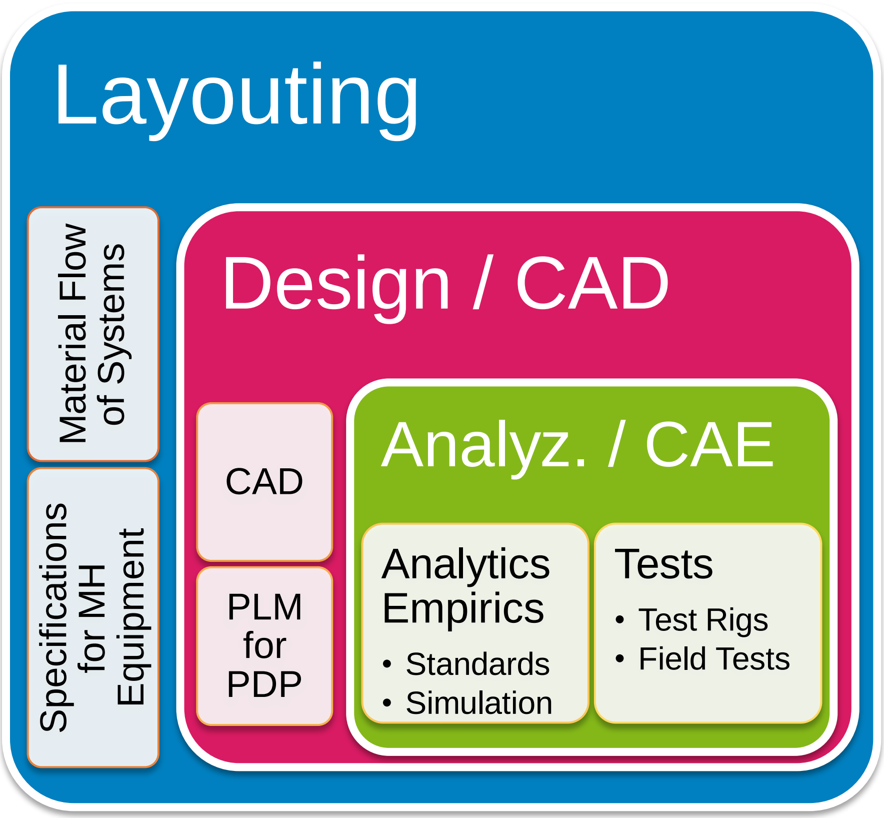
Simulation for Engineers



Flashlights for Simulation

„Risk of simulating“ due to SW functionalities

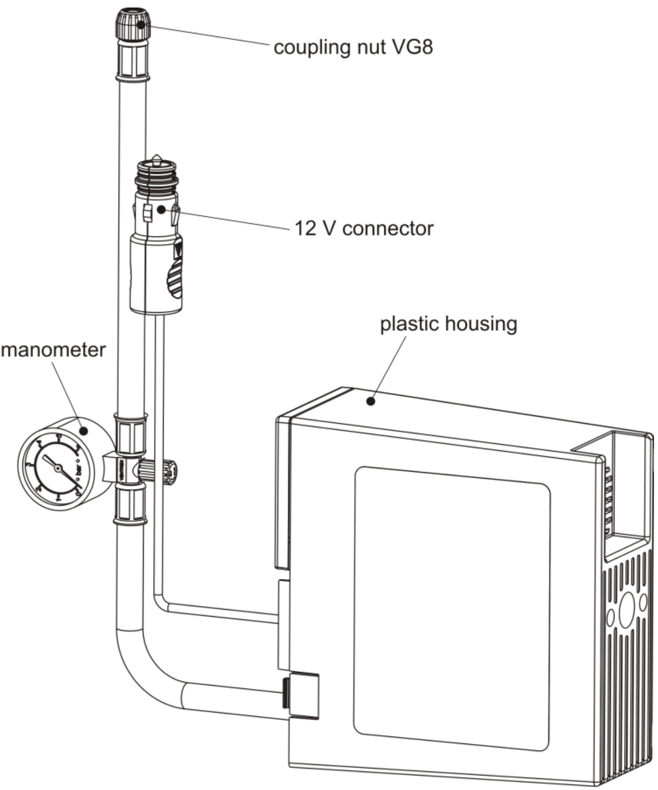
Specalists SW

- When CAD embedded not powerful enough, detailed problems (contacts, high dynamics, interaction, controlled systems…)

Main Aims of Simulation

- Studies and Influences of Parameters
- DOE, Sensitivity Analysis, 6-σ
- Dimensioning new designs
- Proofs and Analyzation of already working machinery
- Visualization and insights in design
- Cost efficiency

SIMULATION POTENTALITIES FOR A RECIPROCATING COMPRESSOR



Using the example of a piston compressor for tire repair systems, shown which problems can be addressed through simulation, as well as the limits for an effective application of numerical methods.

Motivation for simulation

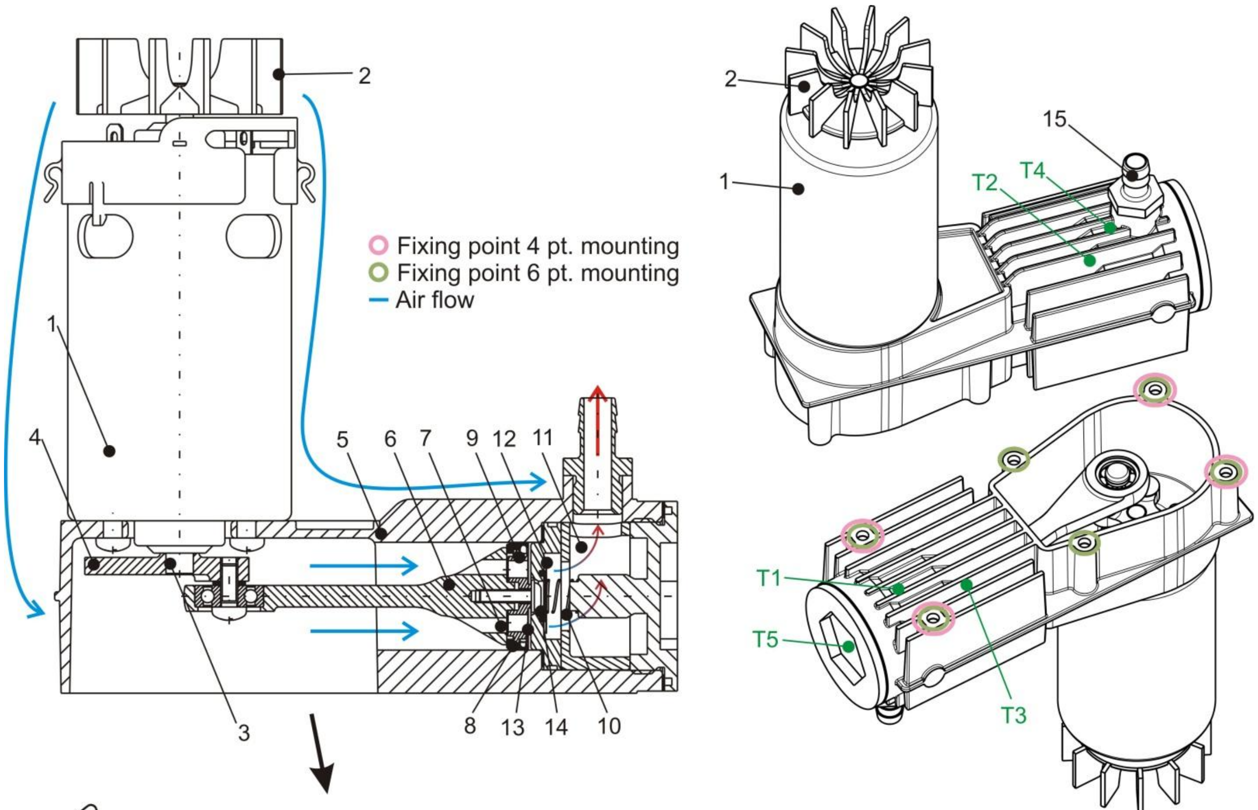
- find cost-detailed solutions
- avoidance of oversized designs
- avoidance of expensive field tests

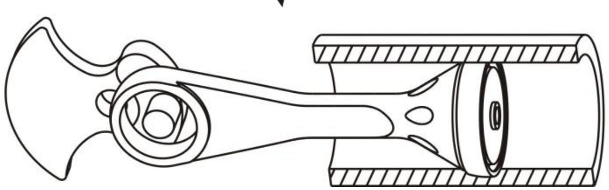
Three fields of interest are discussed:

- Analysis of the thermal compressor behavior (FEM)
- Natural frequency and operational vibration analysis (FEM)
- Mechanical analysis of compressor components (MKS/FEM)

DESIGN FEATURES

Reciprocating compressor for tire repair systems





Idealized geometry
(dynamic FEM-model)

1 Engine
2 Fan
3 Engine shaft
4 Crank
5 Cylinder housing
6 Piston rod
7 Intake
8 Piston
9 Piston holder
10 Spring
11 Plenum chamber
12 Valve plate - outlet
13 Valve plate - inlet
14 Outlet valve
15 Inlet valve

T1...T5 Temp. Sensors

Key data:
Stroke: 22mm
Bore: 25mm
Connection voltage: 12V

THERMAL BEHAVIOUR OF COMPRESSOR

Expected simulation results:

- temperature distribution on the surface
- design improvements (e.g. location and number of cooling fins)
- comparison of different compressor designs

Model building

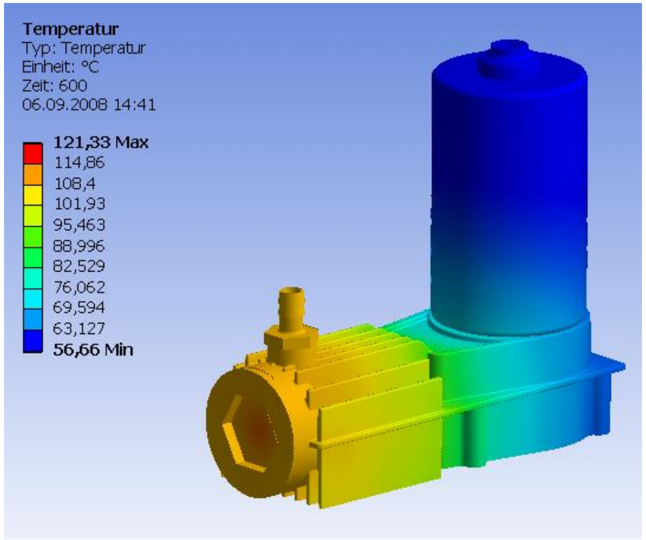
- SW: Ansys Workbench
  - Interface to most popular CAD programs
  - Solution of linear and nonlinear problems
  - modern GUI and improved algorithms for meshing and contact determination

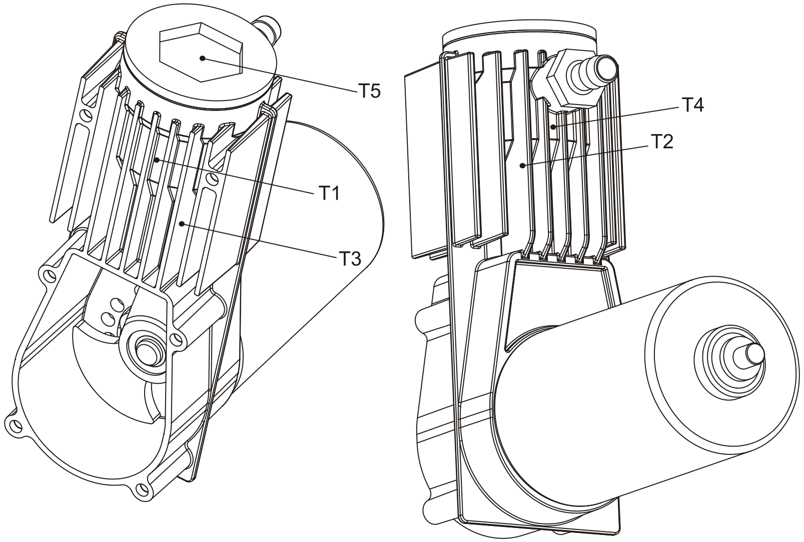
- Data Collection
  - real compressor test runs
  - engineering data reference books
- Geometrie
  - Original CAD geometrie (except some simplifications
- Thermal loads
  - difference between total power consumption and the thermal output dissipated by compressed air
- Boundary conditions
  - Convective dissipation of heat
  - Heat emission by radiation

THERMAL BEHAVIOUR OF COMPRESSOR

Results

- graphical representation of the temperature distribution on the surface of the compressor.





Validation

- Comparison temperatures simulation/measures

	Measured values [°C]	Results from simulation [°C]	Discrepancy [%]
T1	109,5	108,4	1,0
T2	103,0	105,5	2,4
T3	110,9	107,0	3,5
T4	109,2	108,8	0,4
T5	119,0	113,6	4,5

THERMAL BEHAVIOUR OF COMPRESSOR

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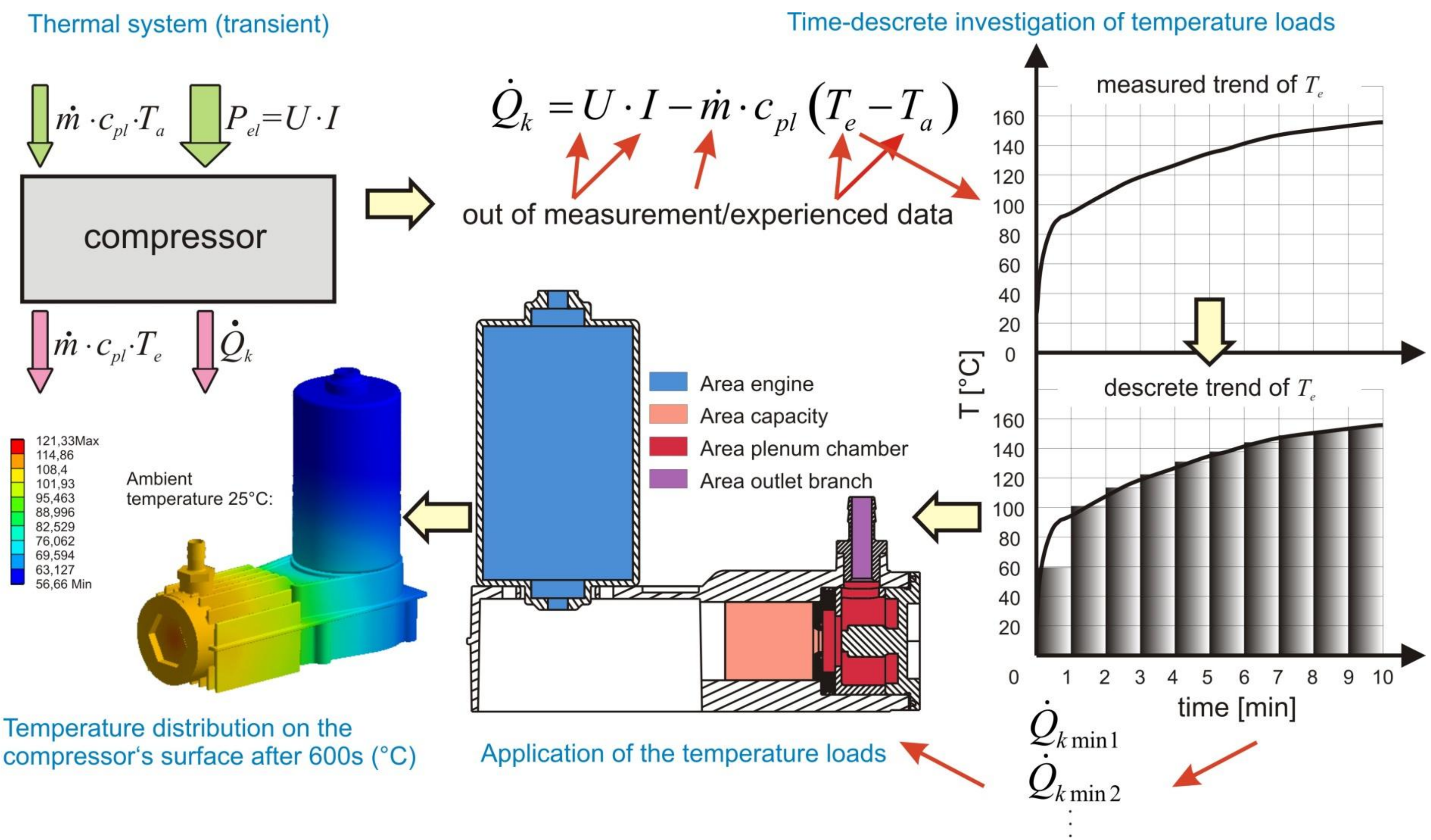
Thermal Simulation Model



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VIBRATION CHARACTERISTICS

Expected simulation results:

- insights into the deformational and kinesic behavior of the compressor
- orders of magnitude of the vibration caused deformation
- the direction for design improvements should be shown by the analyze result

Two analyses are made:

- Modal analysis to identify the natural frequencies
- Analysis of operational vibrations

Model building

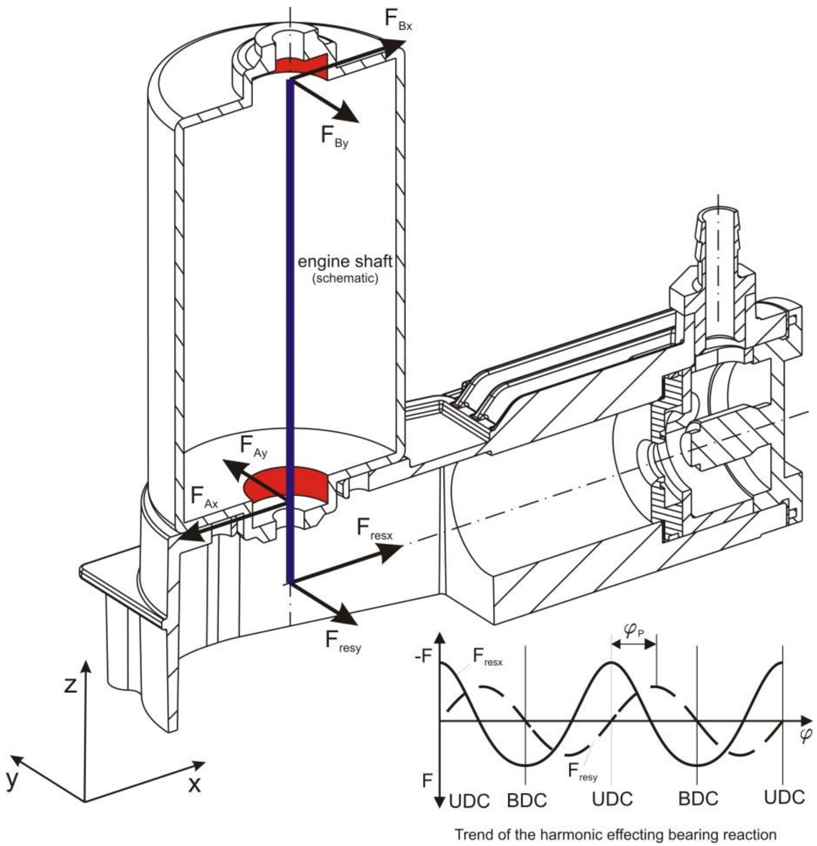
- SW: Ansys Workbench
- Geometrie
  - Original CAD geometrie (except some simplifications)
- Boundary conditions
  - Comparison of different mounting options
- Loads (only for operational vibrations)
  - caused by the mass forces of the crank mechanism
  - Mass forces have harmonic character
  - Bearing forces are applied for every coordinate axis
  - Phase shift of 90° between x- and y-direction

VIBRATION CHARACTERISTICS

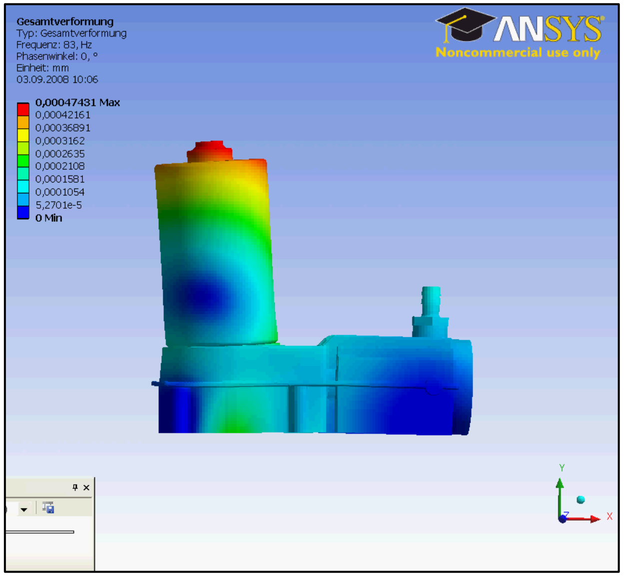
Loads and Results of the Simulation Model

	natural frequency	vibration characteristics
4 pt. mounting	1333Hz	Pivoting of the electric motor about the cylinder axis
6 pt. mounting	1858Hz	Pivoting of the electric motor about the cylinder axis

Natural frequencies – modal analysis



Bearing reaction - operational vibration analysis



Deformations - operational vibration analysis (83Hz)

MECHANICAL BEHAVIOR

Expected simulation results:

- Stress in the compressor components (connecting rod with piston)
- Component deformations

Model building

- SW: RecurDyn
  - Dynamic FEM-Simulation to represent the compressor realistically
  - Recursive computation of multibody dynamics
  - Multibody dynamics with flexible bodies
  - This means large displacements, nonlinear FEM Analysis and a detailed simulation of contacts

- Geometrie
  - Rigid bodies (cylinder, crankshaft)
    - Neutral data created from CAD are imported to RecurDyn
  - Flexible bodies (connection rod, piston)
    - Ports produced from the parts in Pro / Engineer neutral geometry data and saved as IGES solids.
    - Now a FE mesh of the components is created. For this, the IGES data imported into the program Ansys (classic version). There the parts are meshed and the generated mesh is exported using CDB files.
    - At least the FE meshes are read into RecurDyn and flexible bodies are generated.

MECHANICAL BEHAVIOR

- Configuration of the model

  The following joints and contacts need to be defined between the bodies:
  - Rotary joint between the environment and crankshaft.
  - Rotary joint between the crank pin and the large connecting rod eye. A connection between a rigid and a flexible body has to be created. This is done by use of a so-called FDR (Force Distributing Rigid) element, which divides the point force to surface element nodes of the connecting rod by rigid connections.
  - Contacts between connecting rod and piston and between piston and cylinder surface to ensure that the piston is centered in the cylinder and can run.

- Loads and boundary conditions
  - mechanism is set to a constant angular rate
  - the gas force is applied to the piston (the gas force is a function of the crank angle)

Results

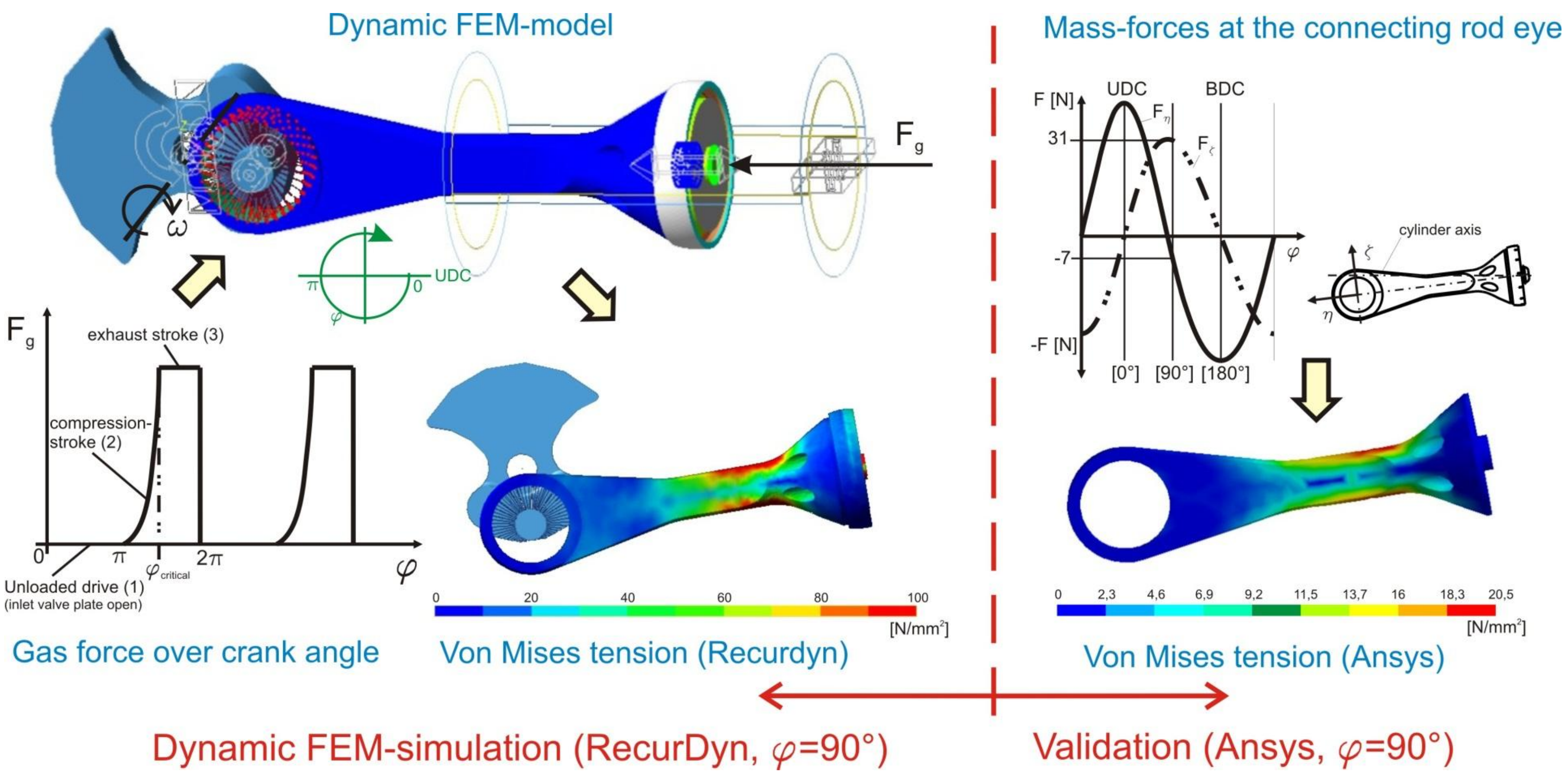
- stresses and deformations during one revolution of the crankshaft
- The visualization of the results is an animated presentation

Validation

- By Comparison with the results of a quasi-static stress analysis carried out of the connecting rod

MECHANICAL BEHAVIOR

Mechanical Simulation Model



EVALUATION OF MODELS AND OUTLOOK

Thermal- and vibration analysis

- valuable insights for further compressor designs and other improvements
- usable for a broad community of users

Mechanical analysis (dynamic FEM)

- several improvements are necessary
  - GUI and interfaces for CAD
  - Users must have good knowledge of software fundamentals and basic theory

	Modeling effort	Computing time	Software	Adjustment for geometry optimization processes	Model flexibility on new load and boundary conditions	Validation	Applicability of validated Simulation Model	Benefit/ Effort
Thermal FEM-Model	Low/ Interface to CAD, GUI	Low / 10min, Core2 Duo	Ansys WB. V11	Excellent Very good Interface to CAD	Excellent	Successful/ Temperature measurements	Thermal optimization of the compressor	Good
Model for the analysis of vibrations	Low/ Interface to CAD, GUI	Low/ 20min, Core2 Duo	Ansys WB. V11	Excellent Very good Interface to CAD	Excellent	Successful/ Qualitative comparison	Minimize vibration caused stress	Excellent
Structural dynamic FEM-Model	High/ Laborious contact def.	Very High/ 10h, Core2 Duo	RecurDyn V6.3 Ansys WB. V11 Pro/Mechanica	Difficult Rebuilding of the model is needed	Good	Not Successful/ Static FEM analysis →	No re-use possible	Unsatisfactory

Qualitative assessment of the simulation models