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Multi-Body-Dynamics

„Dynamics simulation of flexible tubes as combined application of finite elements and multibody systems“

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4th GACM Colloquium on Computational Mechanics
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- motivation
  - challenges to the MBS algorithm
  - software-trends
  - solver of the alaska/SimulationEngine
- dynamics simulation of flexible tubes
  - results
- conclusion and future development

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Institute of Mechatronics

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Organisation

- private non-profit institute, 20 employees
- no governmental basic funding → applied research

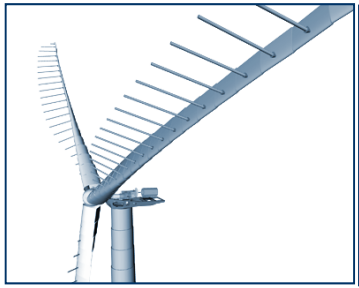
R&D

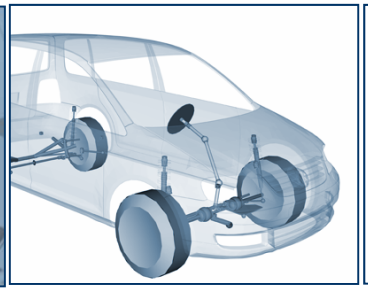
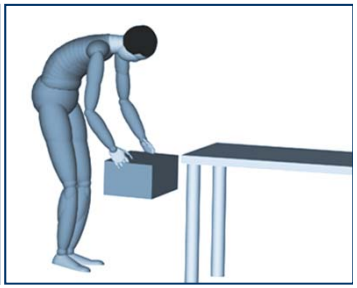
- simulation of dynamic systems, motions and the related forces
- emphasis on mechanical systems
- all topics related to the development of MBS simulation tools

Results

- general MBS-Tool alaska, modules like alaska/Wind
- special purpose tools, e.g. real time applications, MBS-FEM-coupling

Applications



Challenges to the MBS algorithm

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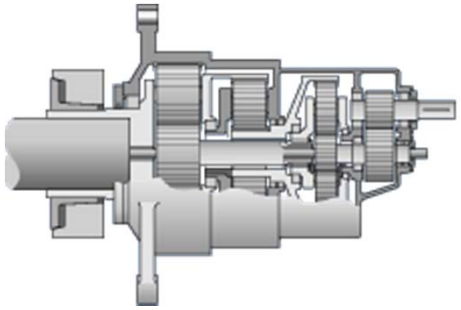
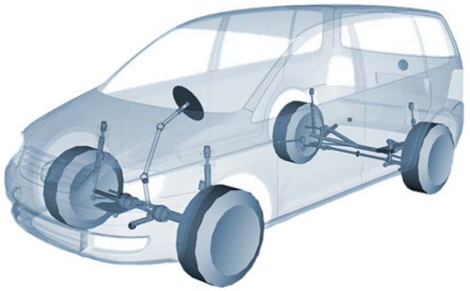
Examples



Wind turbine – Gearbox



Full car model as real time application?

Properties of the models

- flexible connections between the bodies instead of ideal joints
- increasing number of flexible bodies

Consequences

- minimum set of coordinates only little smaller than absolute coordinate set
- topology badly suited for the recursive O(n) algorithm
- mathematical properties more similar to FE-Model than to usual MBS

Questions

- performance of a solver approach similar to FEM?
- adequate implementation of such a solver for MBS?

Software-Trends

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Contrary trends to support

- increasing complexity of general tools – demand for „all-in-one“
- demands for „one-click-solution”

General MBS-software

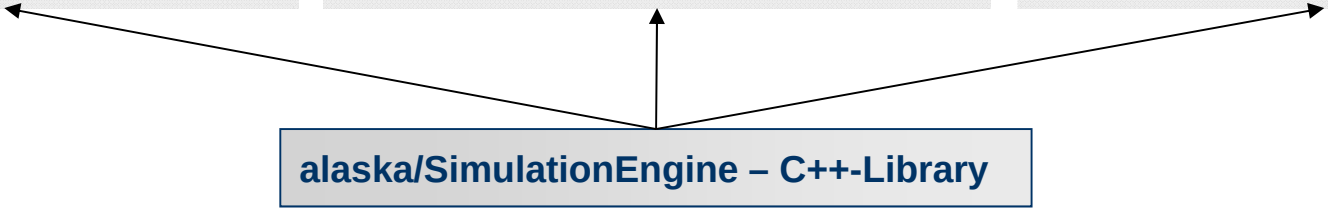
- general modelling
- general solver

Hidden general software

- separation between modelling and utilization – wind branch

Special purpose software

- integrated model
- adapted simulator



alaska/SimulationEngine – C++-Library

Library of modelling elements

- modelling by declaring instances of classes
- comprises
  - rigid and flexible bodies
  - forces, joints, motions, finite elements

Library of methods for the solution

- completely different from the available approach

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Equations of Motion

- Newton/Euler equations (balance of forces and torques)
- joints as stiff contacts, motions as stiff PD-elements
- description of the finite rotations, incremental rotations instead of parameters
- solve equations $f\left(x, \dot{x}, \ddot{x}, \varphi, \dot{\varphi}, \ddot{\varphi}\right) = 0$ by Newton's method
- emphasis on efficient evaluation of Jacobian matrix $\boldsymbol{J}$ (sparse) of f
- block sparse solver for the LES using the Schur complement
- minimum-degree algorithm for order reduction and minimum fill-in

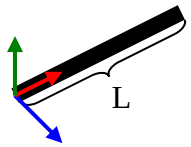
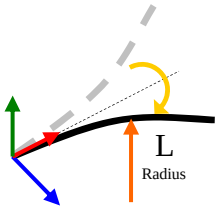
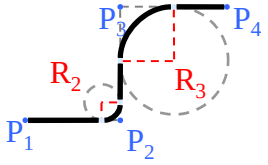
→ potential for parallelization

Integration scheme: generalized alpha (HHT, Newmark type)

- implicit, unconditionally stable → stable for large constant time steps
- second order accuracy
- user-controlled high frequency energy dissipation

Tasks and requirements on the simulation

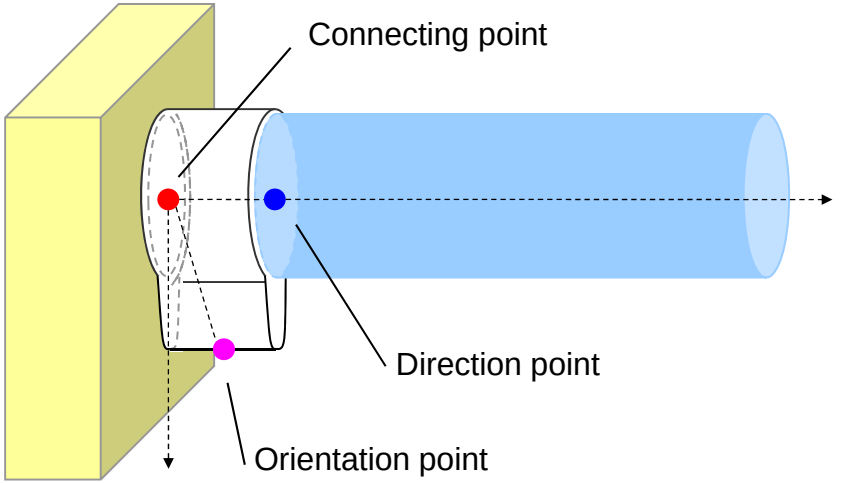
- computation of space requirements and material stress
- user definitions with few parameters
  - material properties of the tube (Young's modulus, shear modulus, discretisation)
  - geometry (length, inner/outer diameter, centerline)

straight	curved	user-defined
		
		

  - mounting points
  - excitations and additional constraints

Modelling

- model class: rotationally symmetric chain structure
- internal model description: large translations,
  large rotations,
  small strains (local)
- analysis type: quasistatic, dynamic (soon)



Elements (internals)

- nodes (rigid bodies)
- force coupled elements
  - used MBS elements: distancer, motions, rigid contact elements,
    joints (torsion-free boundaries, mounting constraints, …)
  - used finite elements: Timoshenko beam

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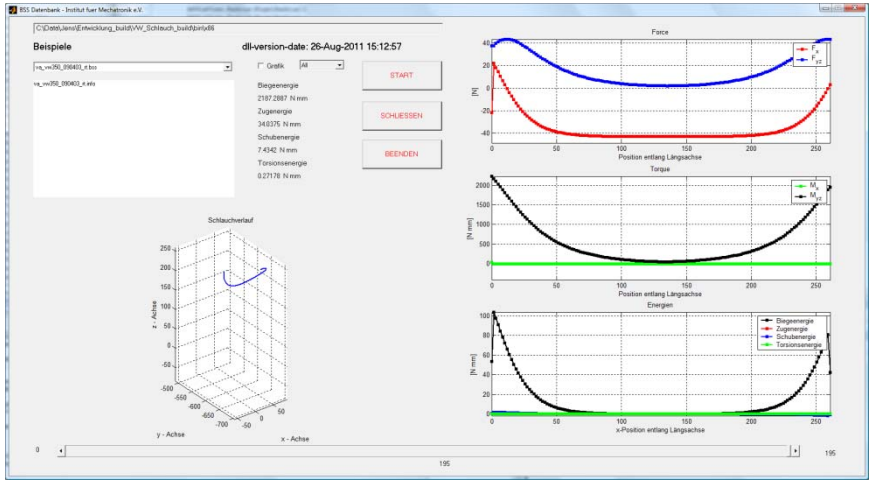
Simulation processes

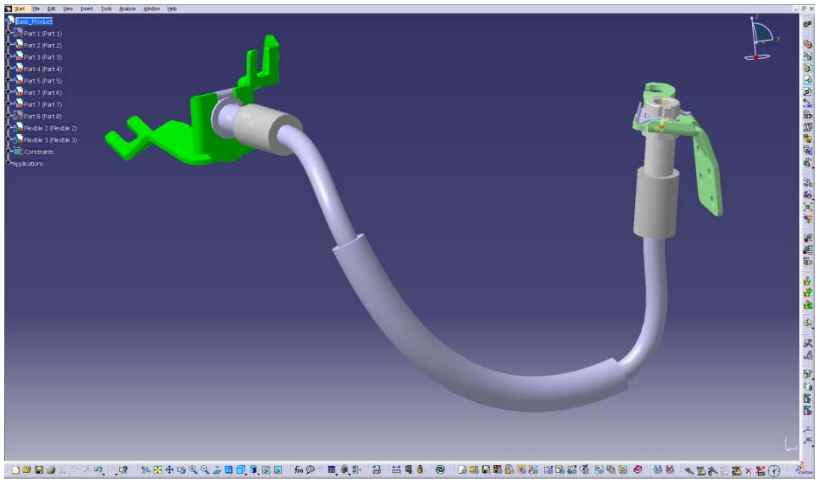
1. mounting process: compute curved tubes given by:
   - mounting points (boundary conditions)
   - additional built-in elements (distancer, eye, contact geometry)
   - achieve a certain configuration (no unique solution due to the nonlinearity)
   - → temporary active elements, variable order of constraint activation
2. excitation (movements of the endpoints and / or objects in space) given by:
   - measured data (laser scanning, tracking systems, …)
   - results from other simulation tools (engine dynamics, wheel motion, …)
   - input files or network interface (TCP/IP, UDP)

Utilizing and integration in other processes

- use in VR/AR systems
  → importance of real-time for all applications !
- integrated use (dll) by API‘s in other tools (e.g. Matlab, CATIA, Excel, …), basically all the tools with the ability to call external dll's



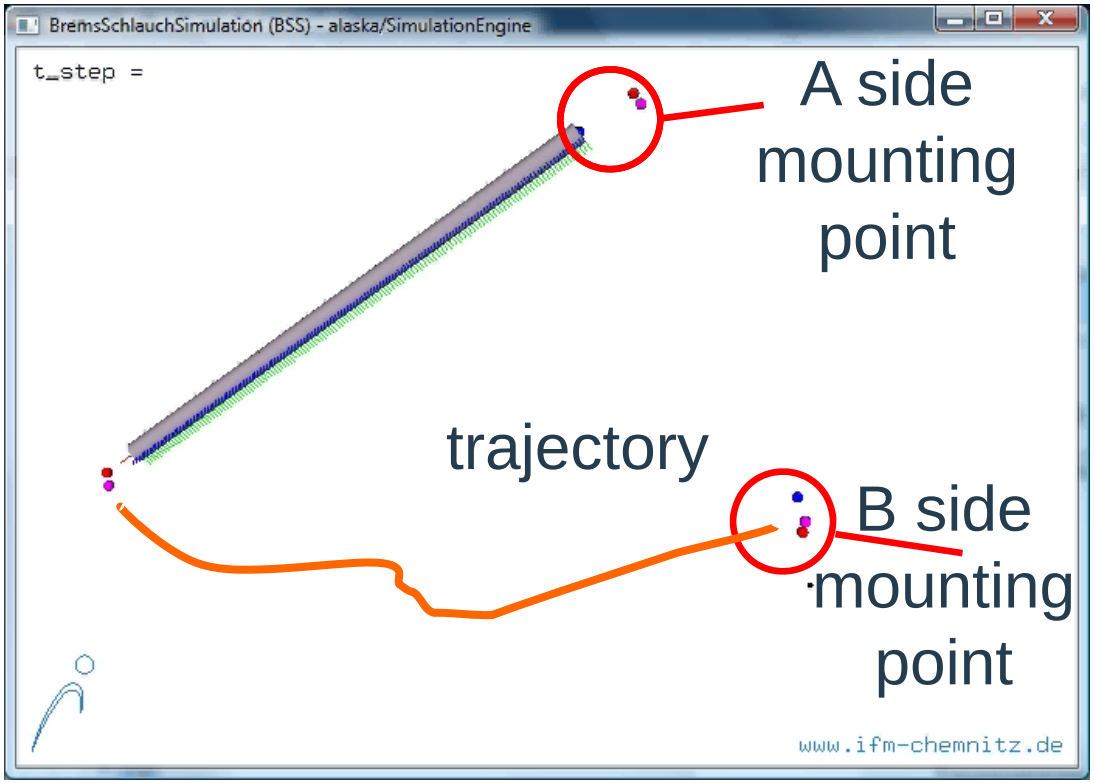
Matlab - GUI



CATIA V5

- stand-alone application (exe)
- optional use of graphics (batch-mode)

Mounting process of a tube and excitation at one end of the tube



reference tube: straight

nodes (bodies): 153

beam elements: 152

motion objects: 2

number of equations: 918

mounting steps: 180

excitation steps: 15

batch-mode:

time per simulation step: 8 ms

simulation time needed: 1.6 s

Results

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Observables

- effects of mounting points on the course and the stresses of the tube
- trajectory – discrete framed curve (position, orientation) → installation space
- derivatives (velocity, acceleration for dynamic analysis)
- force, torque, energy, stress, strain

Validation of results

- comparison with experimental measurements (laser measurement)
- comparison with theory (for simple and easy superimposed load cases)

Quality of results

- deviations from the theoretical and experimental results below 0.1‰

→ very good agreement

Conclusion

- expert know-how in modelling languages is not necessary
- tube simulation meets the needs of the user in relation to:
  - simple operation
  - modelling possibilities
- good performance by customized algorithms and mixed element types
- starting point for real-time simulations
- useful possibility to integrate the tube simulation into process chains like CATIA

Future development

- investigation of dynamic analysis
- discretisation with shell elements
- extension of the contact algorithms

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Thank you for your attention!

Questions ??

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- further information: www.ifm-chemnitz.de