Application of a new reduction method for contact problems

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  Dynamic Simulation of Jointed Structures

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Fatigue assessment based on simulation

• Prediction of the fatigue performance
  – Very important step during the development process
  – Physical tests need to be carried out
  – Reliable simulation results are essential for cutting costs

• Dynamic simulation is very demanding in terms of
  – Modeling
  – Computational effort
  – Amount of result data
  – Result evaluation
• Handling of joints is a challenging task
  – Nonlinearities are introduced by flange contact
  – These local nonlinearities have global influence
    • Stiffness
    • Load distribution
    • Energy dissipation
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How to handle joints?

- **Large effort when utilizing conventional simulation**
  - Direct FEM causes high computational effort
  - Modal approach leads to moderate accuracy

- **New method available**
  - Reduced order modeling based on FEM models
  - Contact consideration during MBS simulation
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Generic example: bolted cantilever

- **FEM structure**
  - Two solid substructures
  - Bolted connection
  - 2 000 elements and 3 000 nodes

- **Boundary and loading conditions**
  - Structure fixed with respect to ground
  - Bolt pretension
  - Force at free end of beam substructure
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How is the model order reduction done?

- The flexible structure is represented by mode shapes
  - Mode base according to Craig and Bampton is extended by JIMs

Constraint modes (CM)

\[
\tilde{\psi}_{CM} = \begin{bmatrix} \tilde{1}_{c,b} \\ \tilde{\psi}_{c,i} \end{bmatrix}
\]

Fixed boundary normal modes (FBNM)

\[
\tilde{\Phi}_{FBNM} = \begin{bmatrix} \tilde{0}_{n,b} \\ \tilde{\Phi}_{n,i} \end{bmatrix}
\]

Joint interface modes (JIM)

\[
\tilde{\psi}_{JIM} = \begin{bmatrix} \tilde{0}_{JIM,b} \\ \tilde{\psi}_{JIM,i} \end{bmatrix}
\]

\[
\bar{x} = \begin{bmatrix} \tilde{1}_{c,b} & \tilde{0}_{n,b} & \tilde{0}_{JIM,b} \\ \tilde{\psi}_{c,i} & \tilde{\Phi}_{n,i} & \tilde{\psi}_{JIM,i} \end{bmatrix} \begin{bmatrix} \tilde{1} \\ \tilde{\psi} \end{bmatrix}_{\text{extended}}
\]
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Simulation process for fatigue assessment

Flexible Structure using **MSC Nastran** and [MAMBA](#)

MBS Simulation using **MSC Adams** and [MAMBA](#)

Fatigue assessment using [FEMFAT](#)

Flexible Structure

- Modal Coordinates
  - $q_1$
  - $q_2$
  - $q_n$

Modal Stresses

- $\sigma_1$
- $\sigma_2$
- $\sigma_n$

Channel 1

- $\sigma_1$
- $q_1$

Channel 2

- $\sigma_2$
- $q_2$

Channel n

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Simulation process including bolt pretension

- **Bolt Pretension Characteristics**
  - Flexible structure is prepared for arbitrary pretension values
  - Influence of pretension is considered during the MBS simulation

**Flexible Structure** using **MSC Nastran** and **MAMBA**

**Bolt pretension using MAMBA Preprocessor**

**Pretensioned Structure** using **MSC Adams** and **MAMBA**

**MBS Simulation** using **MSC Adams** and **MAMBA**

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How is pretension considered?

• Bolt Pretension
  – Arbitrary shaft model, e.g. using CBEAM elements
  – Arbitrary bolt and nut model, e.g. using RBE3 elements

Bolt model characteristics
✓ 1 Shaft CBEAM elements
✓ 2 RBE3 elements which represent head and nut
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Good convergence with respect to number of JIMs

• Normal stresses due to pretension and applied load
  – Adams and MAMBA subroutine for contact
  – FEM reference solution
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How is friction considered?

- **Local Behavior**
  - Coulomb type friction relation
  - Parametrized by stiction stiffness and friction coefficient

**Force law characteristics**

1. Stiction stiffness
2. Stiffness discontinuities
3. Stiction limit depends on friction coefficient and current contact pressure
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How is the global influence of friction?

- **Global Behavior**
  - Characteristic hysteresis loop
  - Hysteresis shape is parameter and contact pressure (pretension) dependent

![Diagram of global relative movement of jointed structures](image)

**Hysteresis characteristics**
- 1 – 2 and 4 – 5
  - Stiction of jointed structures
- 2 – 3 and 5 – 6
  - Micro slip within joint
- 3 – 4 and 6 – 1
  - Macro slip within joint
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Friction in surface tangential direction

- Stick-Slip within joint in case of longitudinal deflection
  - Reaction force is significant for friction within joint
  - Plotting force vs. deflection shows characteristic hysteresis loop
  - Shape of hysteresis loop depends on pretension
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Industrial application: vehicle door slam

- Flexible MBS is particularly suitable for this task
  - Large displacement
  - Small elastic deformations
  - Highly dynamic test scenario

- Flexible MBS implies questions
  - Is it possible to consider contact?
  - How is energy dissipation considered?

As a result nonlinear FEM analysis is favored very often
• **Task description**
  – Fatigue assessment of a vehicle door
  – Consideration of contact to weather strip, within latch and within door structure itself
  – Revolving door slams into weather strip and latch (velocity of 2 m/s at latch)

• **Analysis**
  – MBS analysis with MSC Adams and MAMBA for joint contact consideration

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### Number of modes

- Constraint modes: 18
- Normal modes: 35
- Contact modes (JIM): 377
Vehicle door slam simulation result

- Vehicle door slam considering weather strip
- Latch forces are hidden
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Joint contact influences deformation

• Exemplary deformation shapes

Linear flexible Structure

Flexible Structure with MAMBA
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Joint contact influences spot weld damage

• Exemplary damage distribution

Linear flexible Structure

Flexible Structure with MAMBA

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Low computational effort

• Result evaluation can start within 1 hour

For comparison:
40h and 11 CPUs were necessary to obtain **nonlinear FEM solution**
• Fully dynamic MBS simulation with lap joint contact consideration

Door slam
BIW segment (200 sec. simulation)
BIW trailer coupling (600 sec. simulation)
MAMBA software package provides
- An extended order reduction method for FEM models
- Joint contact consideration in flexible MBS simulation

Realistic stress distribution
- Results of Adams utilizing MAMBA are comparable to nonlinear FEM analysis.
- Obtained stresses enable for improved fatigue assessment.

Significantly lowered computational effort
- Adams utilizing MAMBA is significantly faster than nonlinear FEM analysis.
- This enables dynamic simulation of complex structures (e.g. body in white structures) with joint contact consideration and many timesteps.
The future is ours to make.