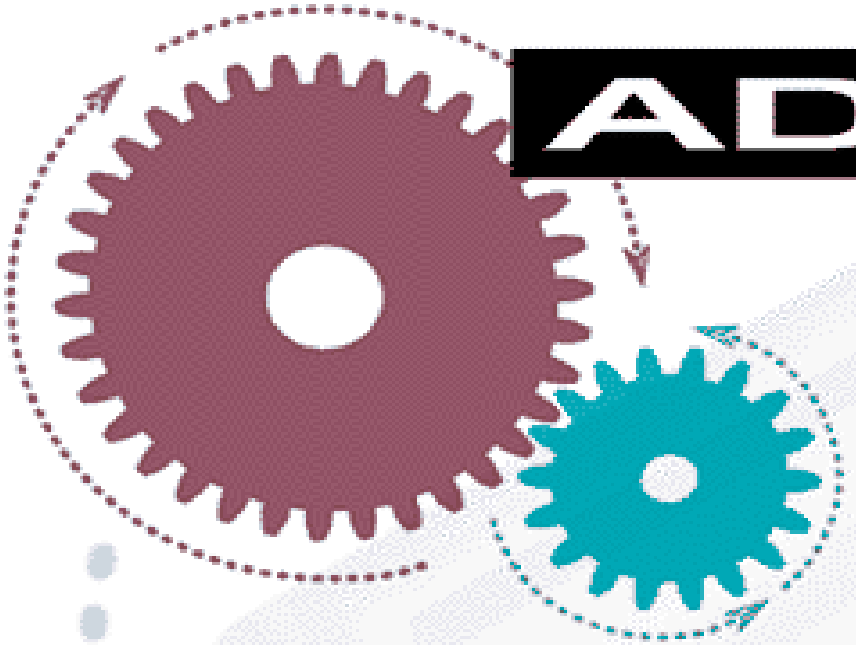

ADAMS User Conference Japan 2001

Mechanical Simulation in the Engine Development Process

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CAE in the Engine Development Process

- **Objectives**
  - Cost reduction
    - Less hardware prototypes
    - Limitations of measurements
  - Shorter development cycles
  - Increase in product quality
  - Support innovation

- **Application**
  - Analysis
    - Design studies based on physical input data
    - Problem solving based on validated detail models
  - Data exchange
    - Between design and test
    - Between OEM and supplier

- **CAE Software Requirements**
  - Open and extensible
  - Easy to use
  - Multiple levels of refinement
  - Modular

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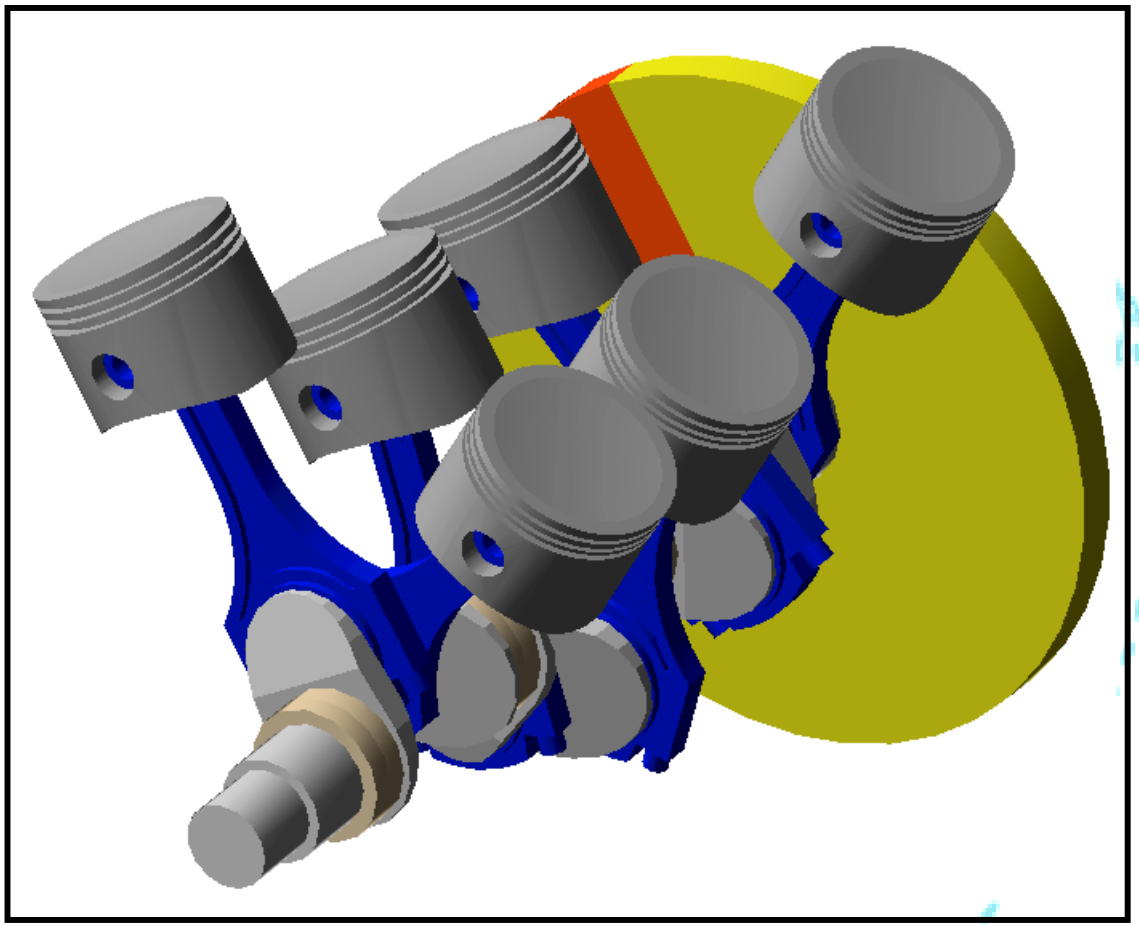
Application Example: Crank train

- **Topology**
  - 6 Cylinder
  - 4 Main bearings
  - 2 crank pins per throw
  - Intermediate webs
  - **Definition contained in template**
- **Data**
  - Subsystem: V-angle, stroke, bore,...
  - Components: Inertia, Stiffness,...
  - **Definition contained in database**



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Application Example: Crank Train

Free forces and moments

Engine Order	rotating force [N] lateral axes	oscillating force [N] lateral axes	rotating torque [N mm] lateral axes	oscillating torque [N mm] lateral axes	oscillating torque [N mm] rotation axis
1.0	0.0	0.0	2714756.70	0.0	0.0
2.0	0.0	0.0	-215022.04	0.0	0.0
3.0	0.0	0.0	0.0	0.0	507579.03
4.0	0.0	0.0	4381.60	0.0	0.0

Static and dynamic amplitudes and phases

Engine Order	rotating stat. amp. [kgmm] phase [deg] lateral axes	oscillating stat. amp. [kgmm] phase [deg] lateral axes	rotating dyn. amp. [kgmm²] phase [deg] lateral axes	oscillating dyn. amp. [kgmm²] phase [deg] lateral axes	oscillating dyn. amp. [kgmm²] phase [deg] rotation axis
1.0	0.0 0.0	0.0 0.0	2.750624e+004 180.0	0.0 0.0	0.0 0.0
2.0	0.0 0.0	0.0 0.0	-5.446572e+002 0.0	0.0 0.0	0.0 0.0
3.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	5.714279e+002 0 .0
4.0	0.0 0.0	0.0 0.0	2.774682 0.0	0.0 0.0	0.0 0.0

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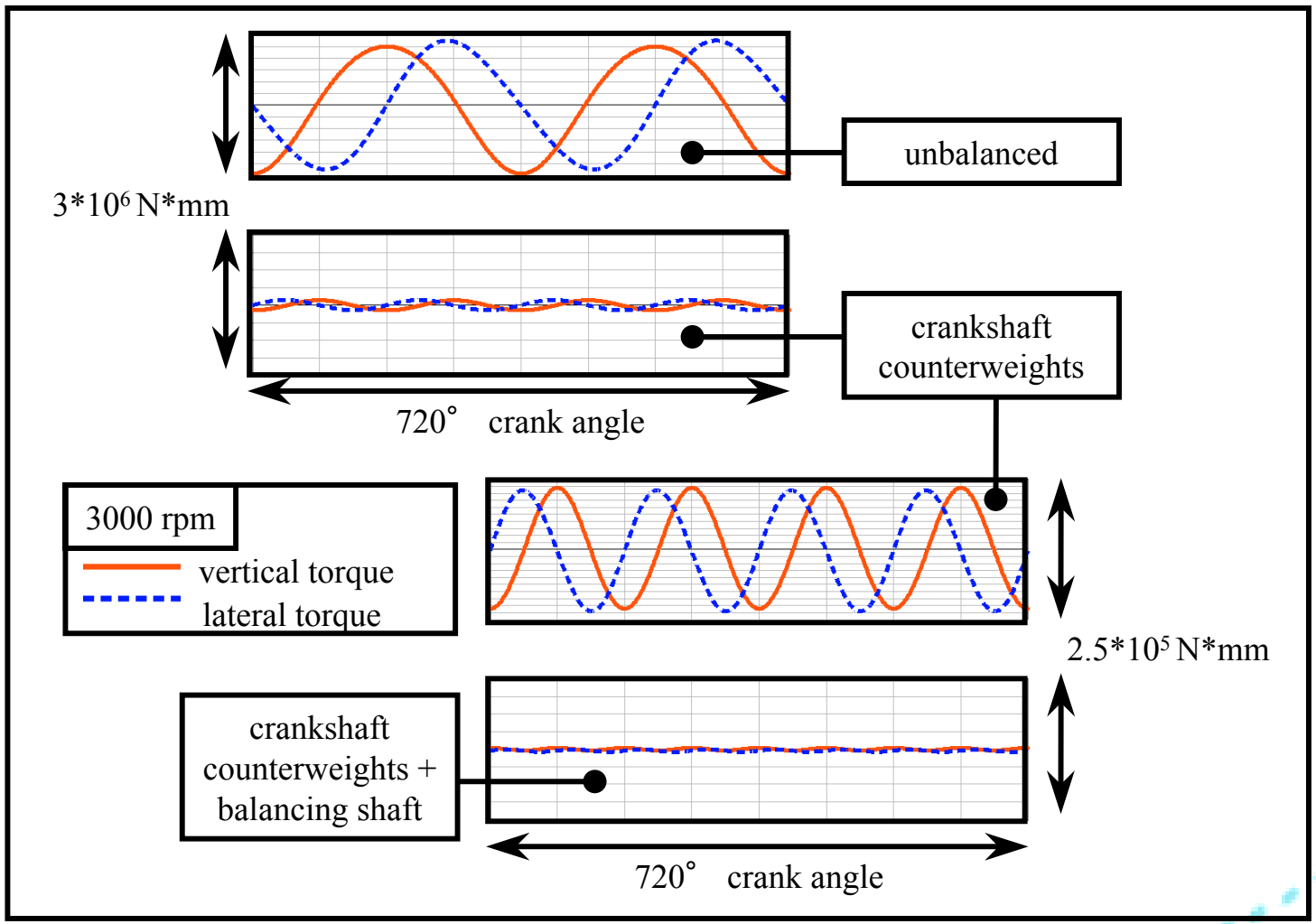
Application Example: Crank Train

Mass moments in the engine reference system



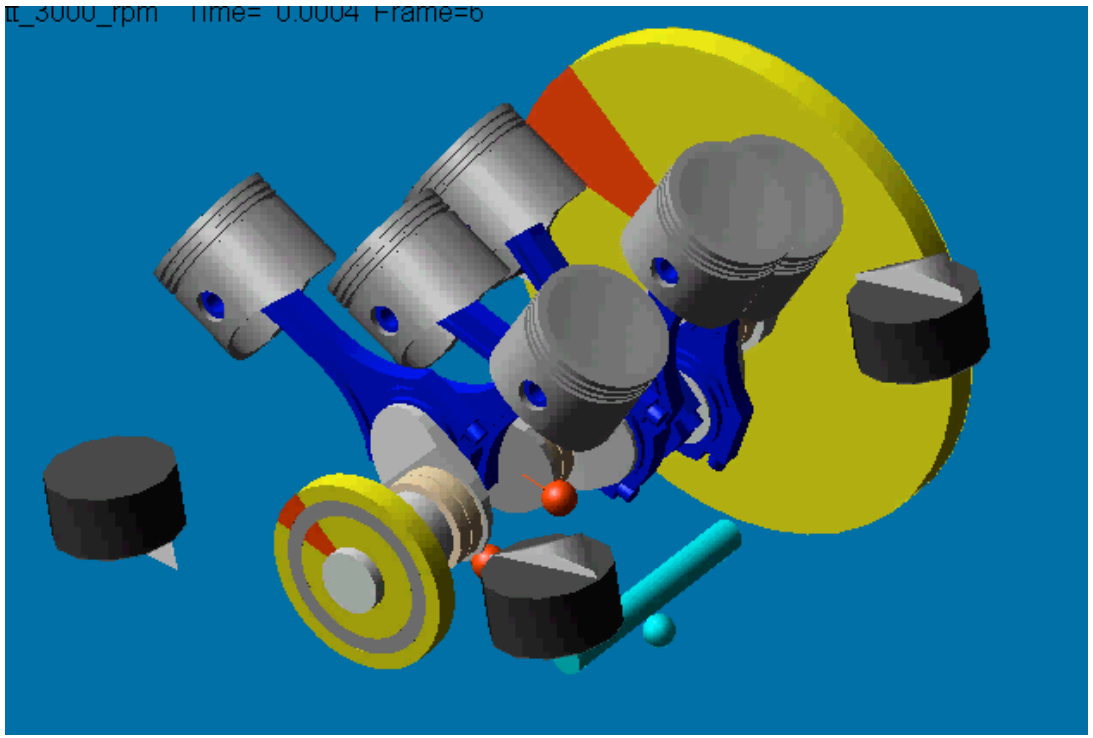
Application Example: Crank Train

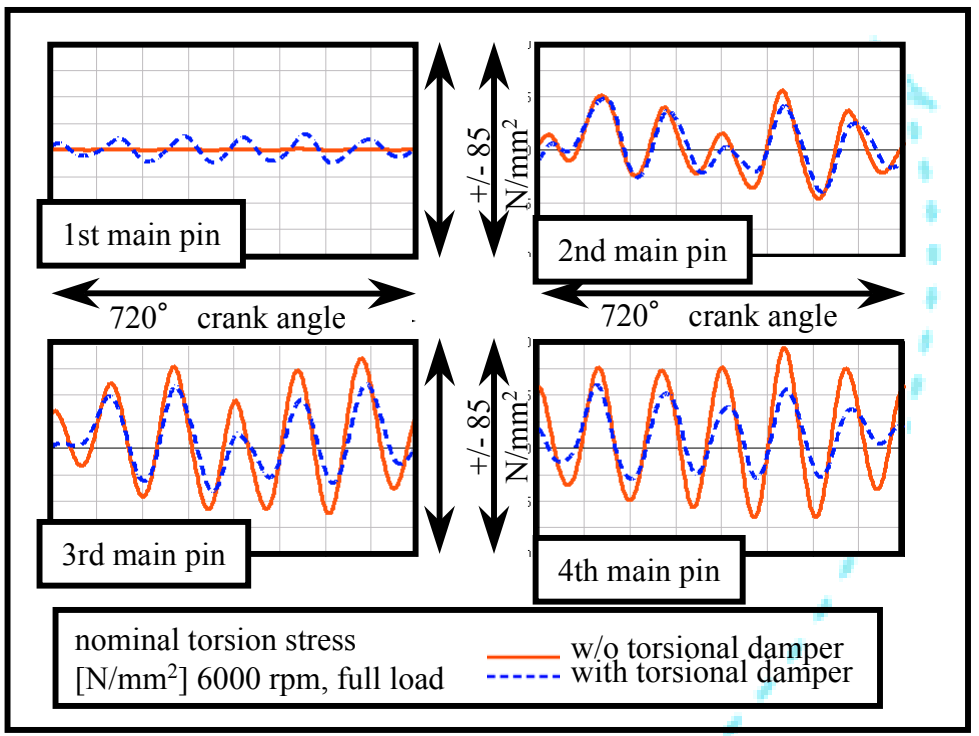
Model Refinement:

Torsional vibration damper

Simulation:

Influence of vibration damper on the nominal torsion stress





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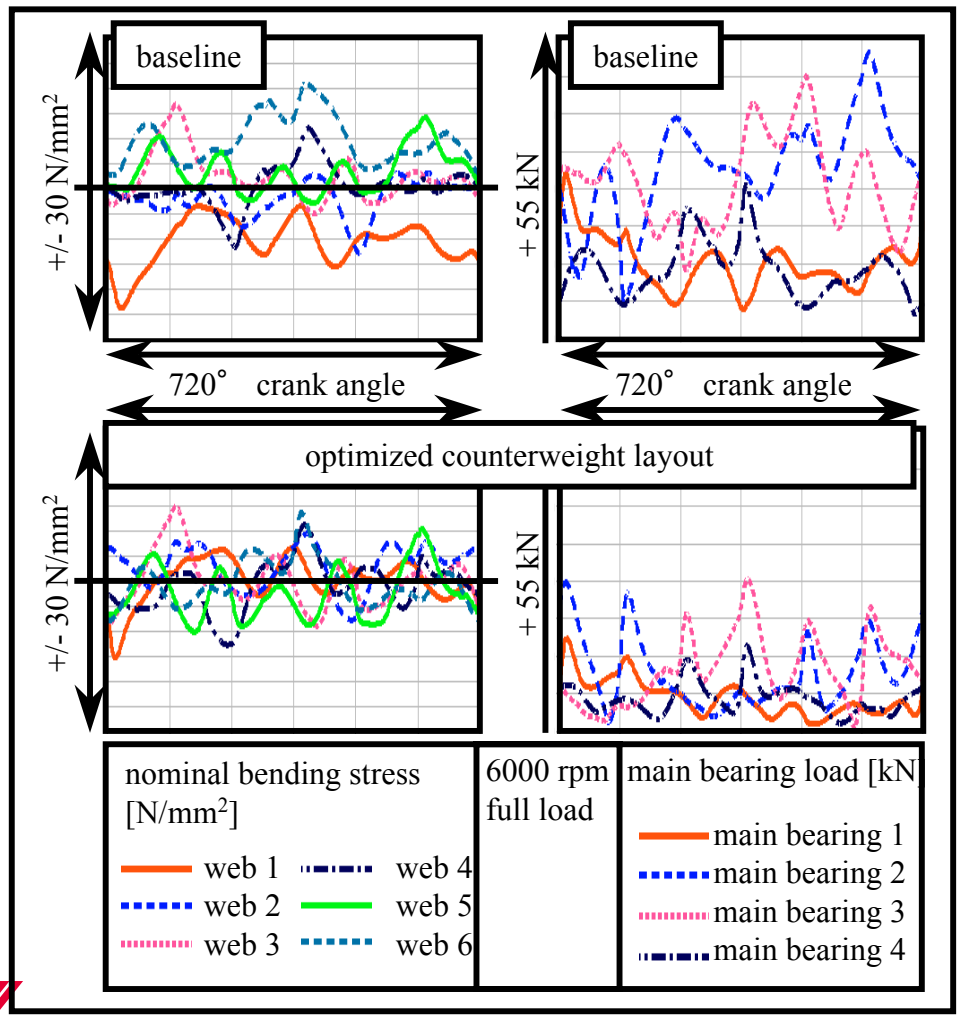
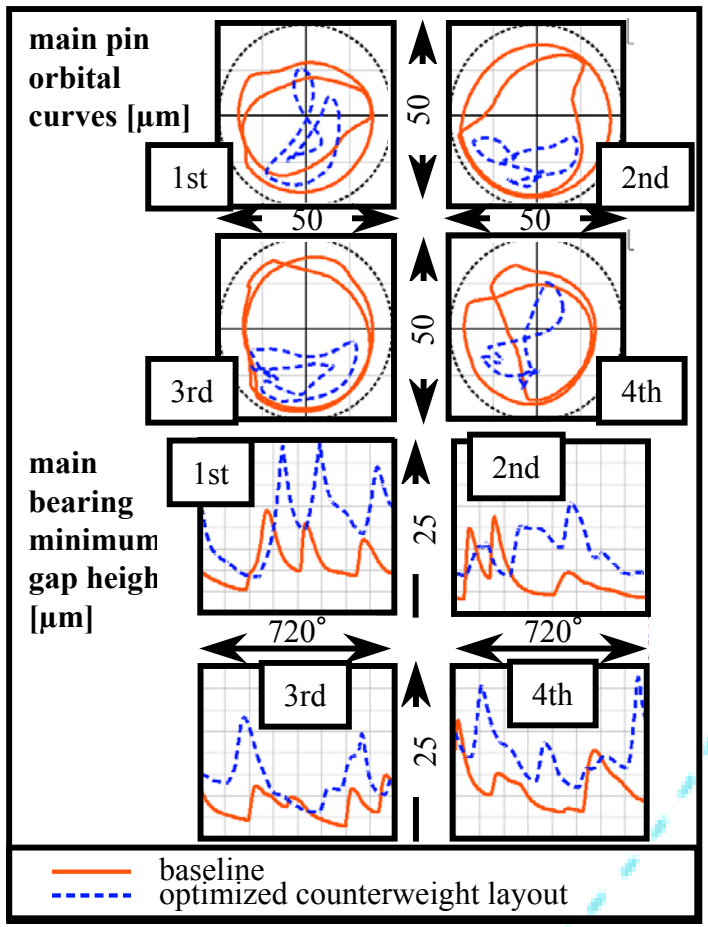
Application Example: Crank Train

Model Refinement:
Beam crank shaft, hydro-dynamic bearings

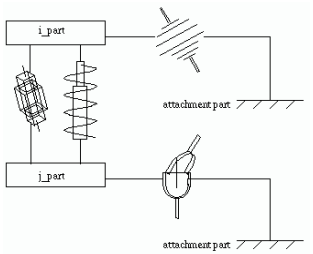
Simulation:
Internal balancing



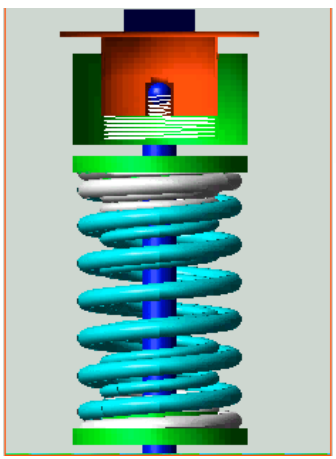


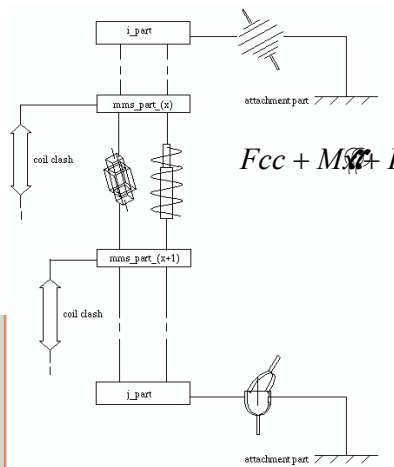
Application Example: Valve Train

- **Dual-Mass-Spring Approach**
  - Linear and non-linear stiffness
  - No internale dynamics
  - Sufficient if valve train is not primary focus
  - Very fast



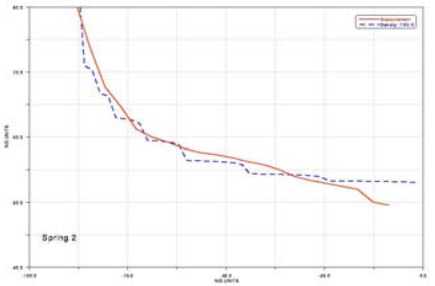
- **Multi-Mass-Spring Approach**
  - Based on physial data
  - Internal dynamic effects
  - Coil clash
  - Only longitudinal direction
  - High Accuracy
  - Relative CPU expensive



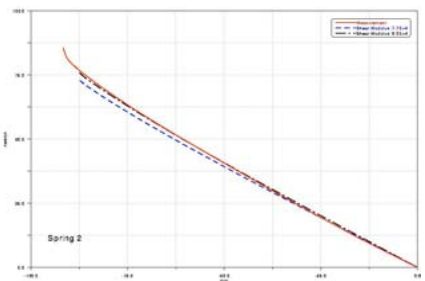


$$Fcc + M\ddot{x} + Kx = F$$

Eigen-Frequency vs Disp.



Force vs Disp.



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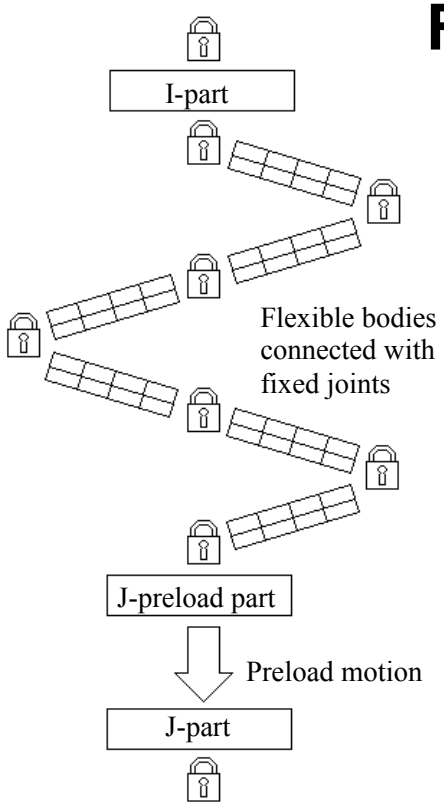
Mechanical Dynamics

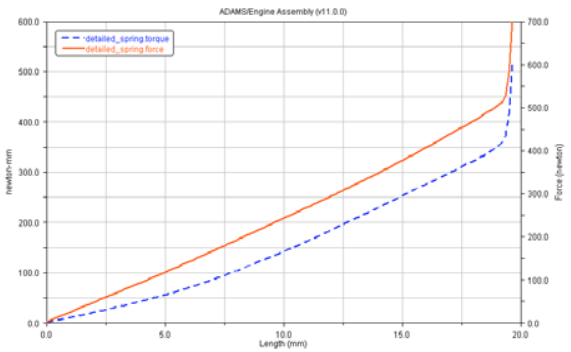
Application Example: Valve Train

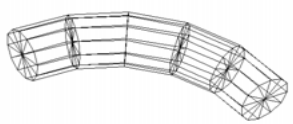
Flexible-Spring Approach

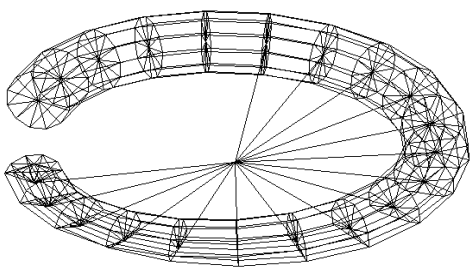


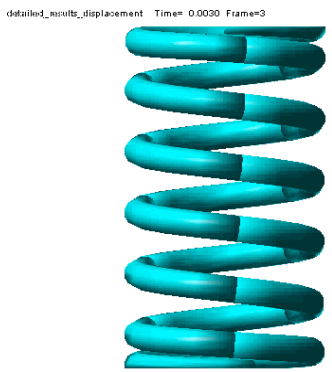
- **Detailed Model**
  - Flexible body with solid brick elements
  - Flexible bodies connected via fixed joints
  - Contact between flexible bodies
  - Requests at all joints

Force and Torque vs. Displacement









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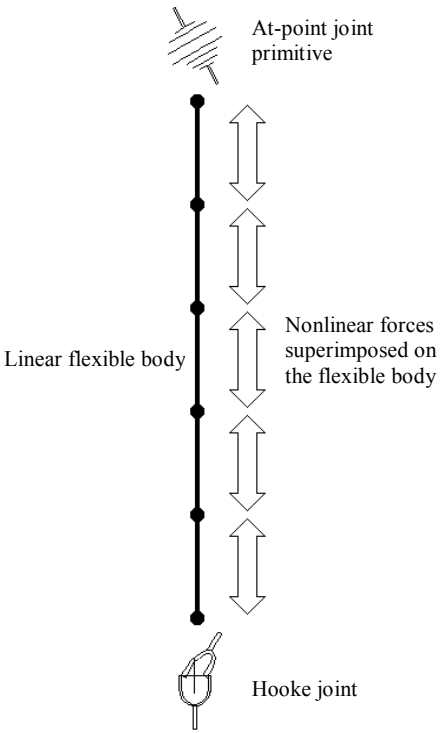
Mechanical Dynamics

Application Example: Valve Train

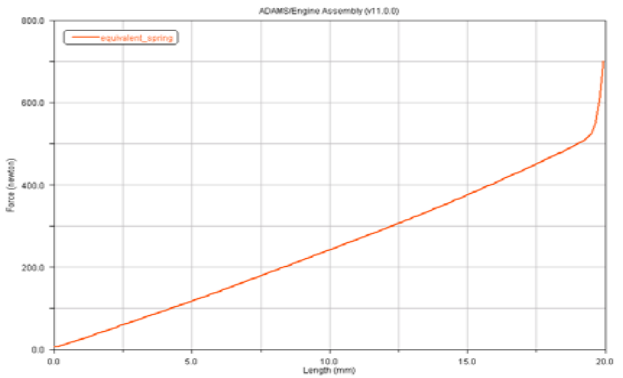
Flexible-Spring Approach

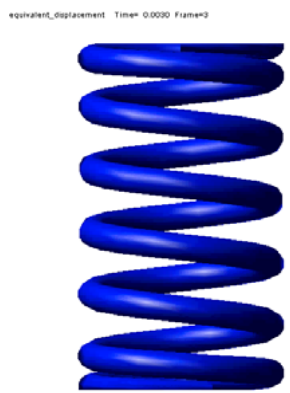


- **Equivalent Model**
  - 1 node per flexible body
  - Linear beams between nodes
  - Solution of the Eigen-value problem

One flexible body (modal)

Force vs. Displacement





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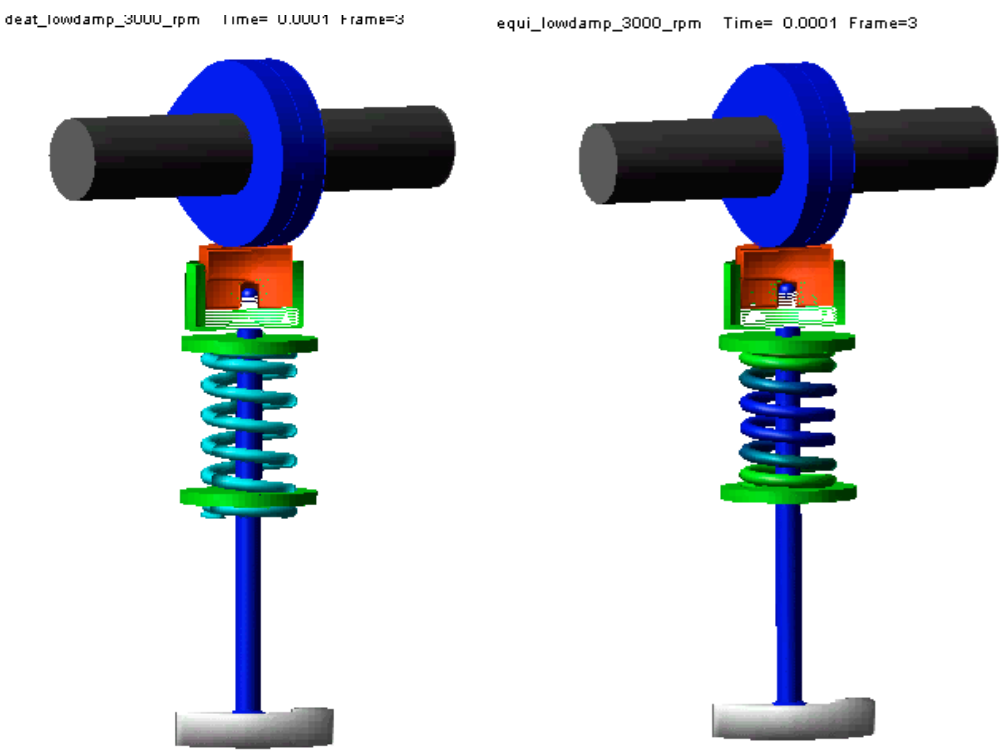
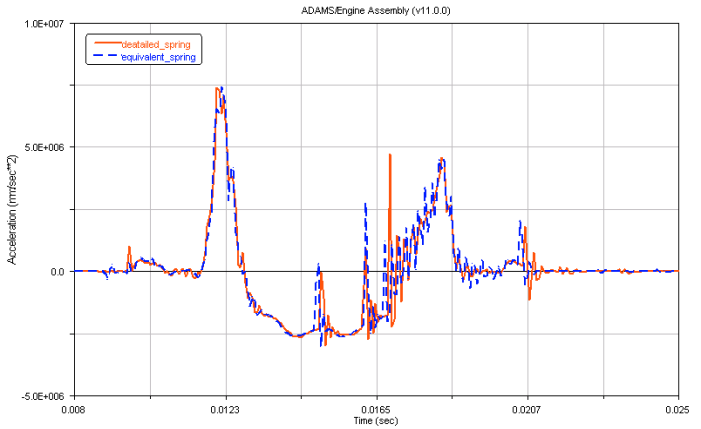
Mechanical Dynamics

Application Example: Valve Train

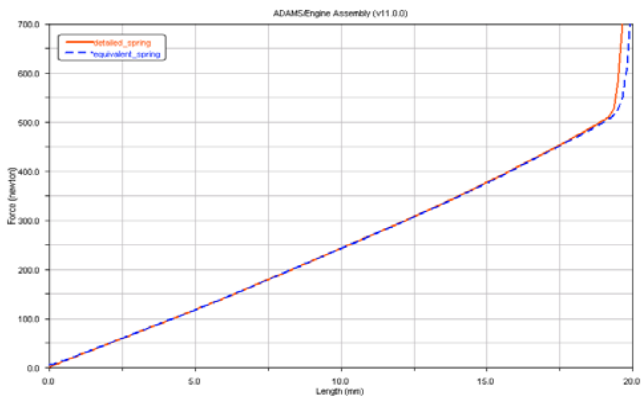
- **Comparison between Models**



Valve Acceleration vs. Time



Force vs. Displacement



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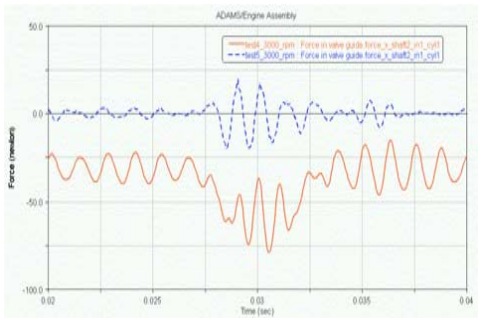
Mechanical Dynamics

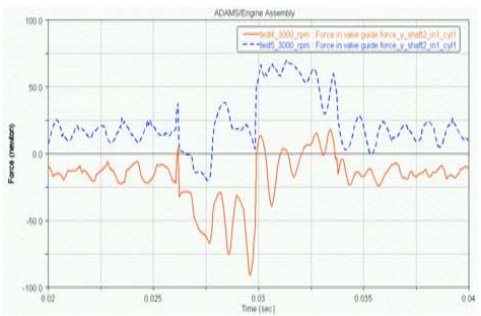
Application Example: Valve Train

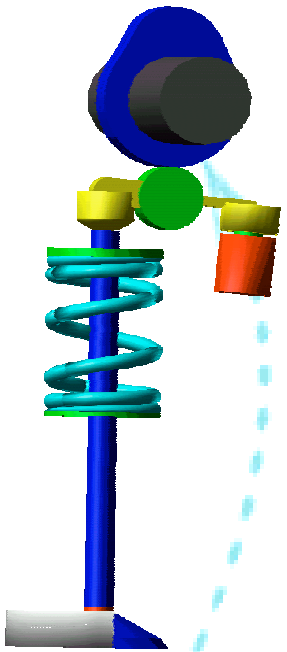
- **Component Optimization and Integration**
  - Small changes of the wire path
  - Neglectable influence on stiffness characteristic
  - Large influence on the lateral forces υ Loads on valve guide

X Force vs. Time



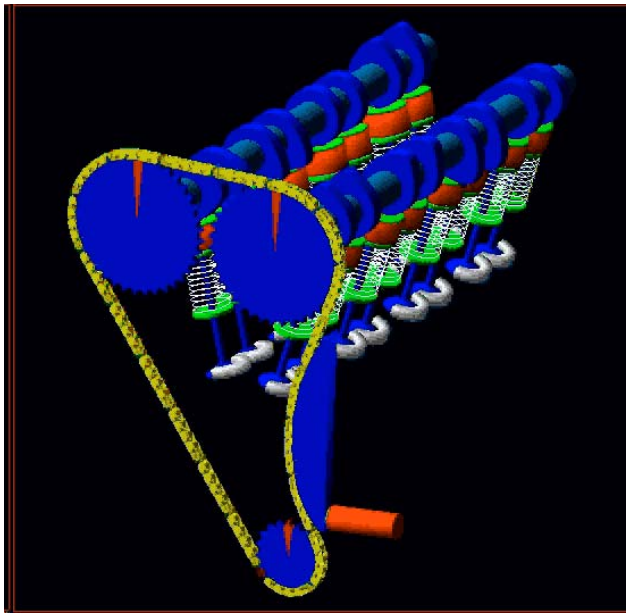
Y Force vs. Time

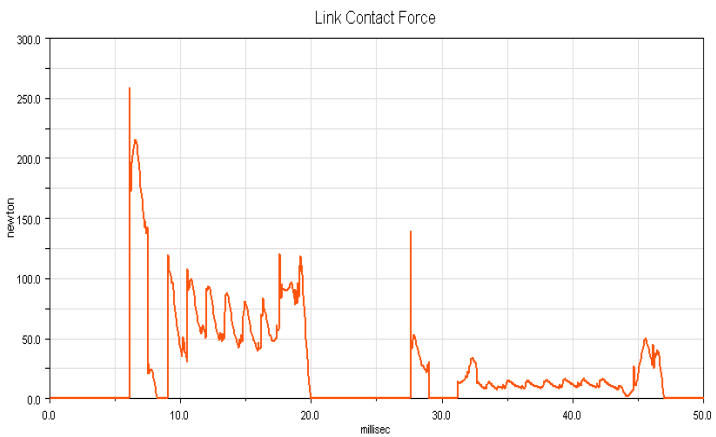




Application Example: Timing Chain

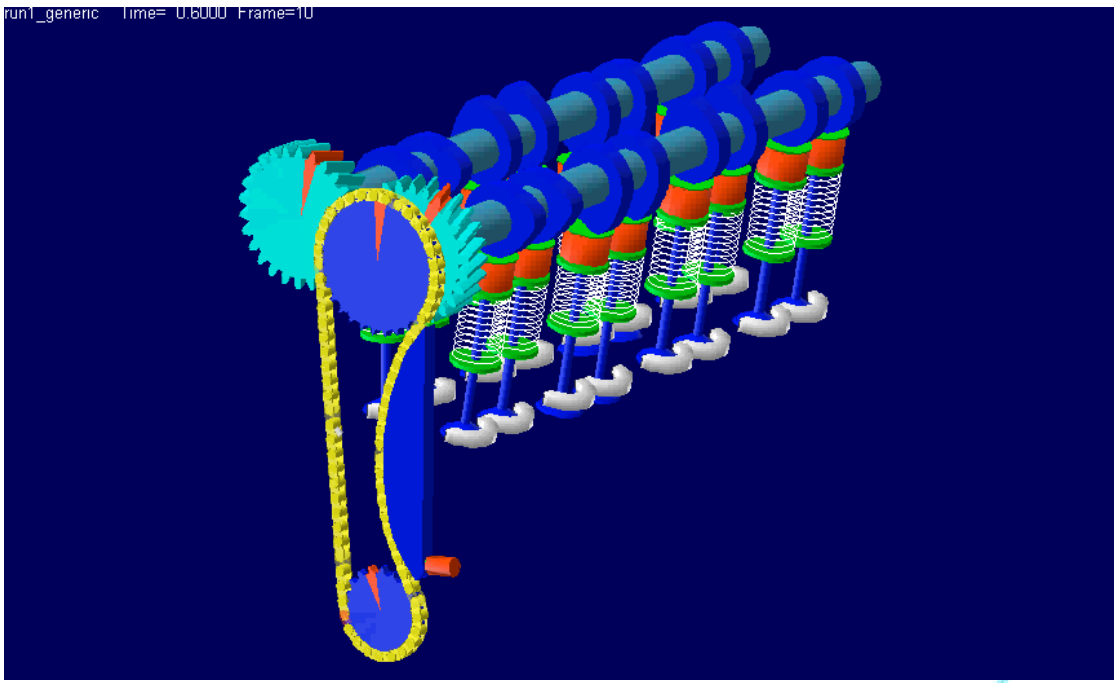
- Simple constrained based model
  - Rotational coupling
- Spring per span type model
  - Rotational vibration
- Detailed model
  - Roller/bush chain
  - Silent (toothed) chain
  - Contact forces
  - Chain internal forces
  - Tensioner studies





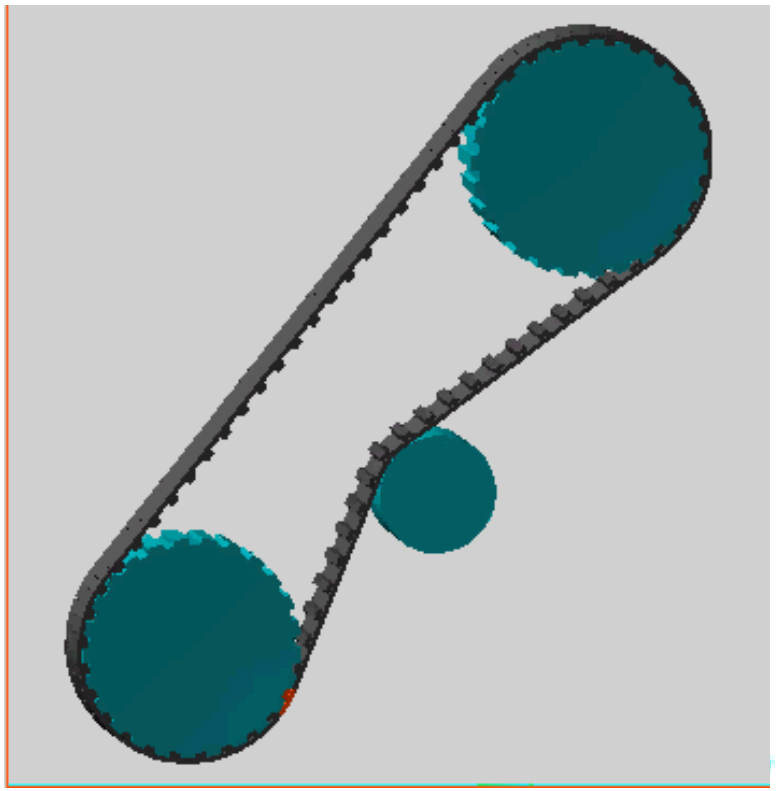
Application Example: Gear

- Constrained based model
  - Rotational coupling
- Force with backlash
  - Bearing loads
  - Rotational Vibrations
- Force considering tooth profile
  - NVH studies
  - Meshing frequency
  - Friction



Application Example: Timing Belt

- Simple constrained based model
  - Rotational coupling
- Spring coupled masses per span
  - Rotational vibration
- Detailed model
  - Trapezoidal belt
  - Non-linear material characteristic
  - Contact forces
  - Belt internal forces



Summary and Outlook

- Application
  - ADAMS/Engine applicable in all phases of the devlopment process in all areas
    - Modular
    - Adjustable refinement level
- Major Focus
  - New intermediate refinement levels
  - Advanced crank train analysis capabilities
    - FEM interface improvements
    - EHD bearings
  - Piston secondary motion
  - NVH analysis