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Advanced engine dynamics using MBS: Application to twin-cylinder boxer engines

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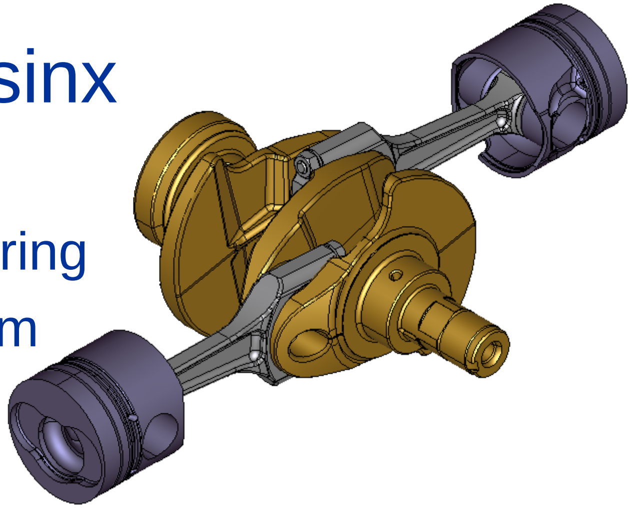

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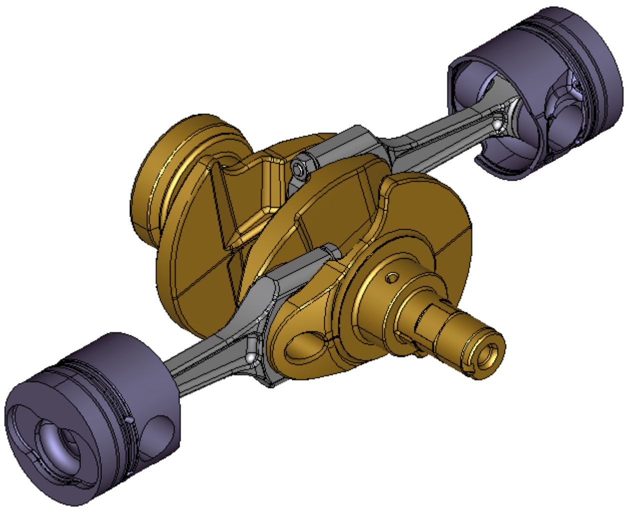
Introduction



Project background

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- Growing industrial interest for small internal combustion engine (ICE) for urban or hybrid vehicles
- Support to the prototyping of a twin-cylinder diesel engine by BTD
- Research efforts in non-accurate methods for the design of unusual engine configurations
  - Preliminary design tools
  - Calculation based on multibody systems simulation

Topics of the study

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- Rigid multibody simulations of a boxer twin-cylinder engine running at constant speed
- Simulation of the gas pressure effect
- Flexible multibody simulations of the engine to calculate component’s strains and stresses (crankshaft)
- Estimation of speed variation effects
- Development and validation of crankshaft simplified models

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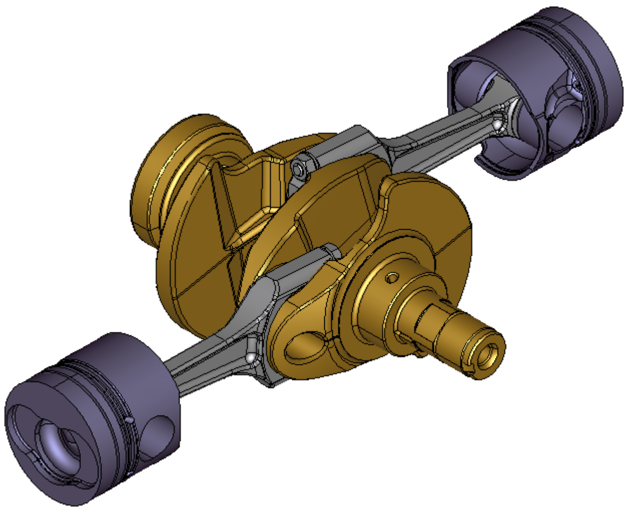
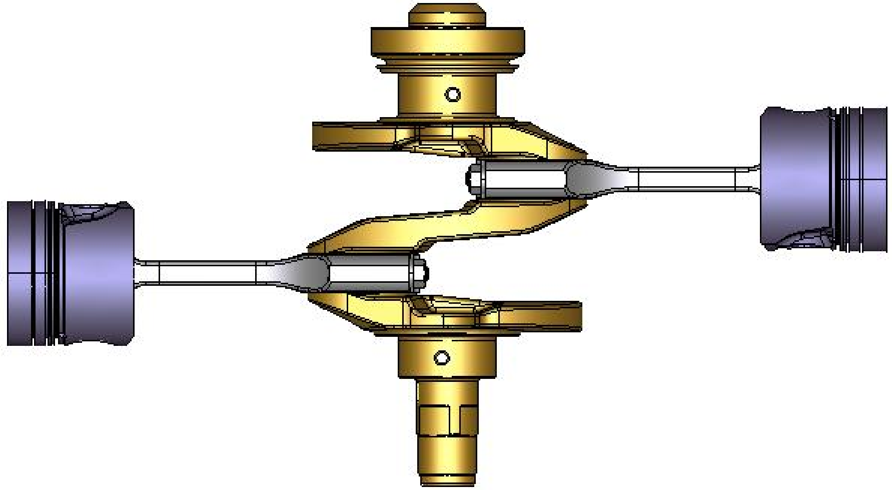
Constant speed simulations



Engine configuration

- Twin-cylinder boxer engine:
  - Flat engine with pistons moving in phase (reaching their top dead center simultaneously)
  - Naturally balanced, do not require a balance shaft
  - Low center of gravity



Rigid multibody model

- Rigid multibody model using finite element approach (with ***SamcefField Mecano*** software)
- Real engine parts geometry from CAD models (pistons, connecting rods and crankshaft)
- Two simulations are performed:
  - Kinematic simulation with imposed crankshaft rotation speed => position, speed & acceleration (inertia force)
  - Dynamic simulation with gas pressure effect => total forces acting on each part of the engine

Rigid multibody model

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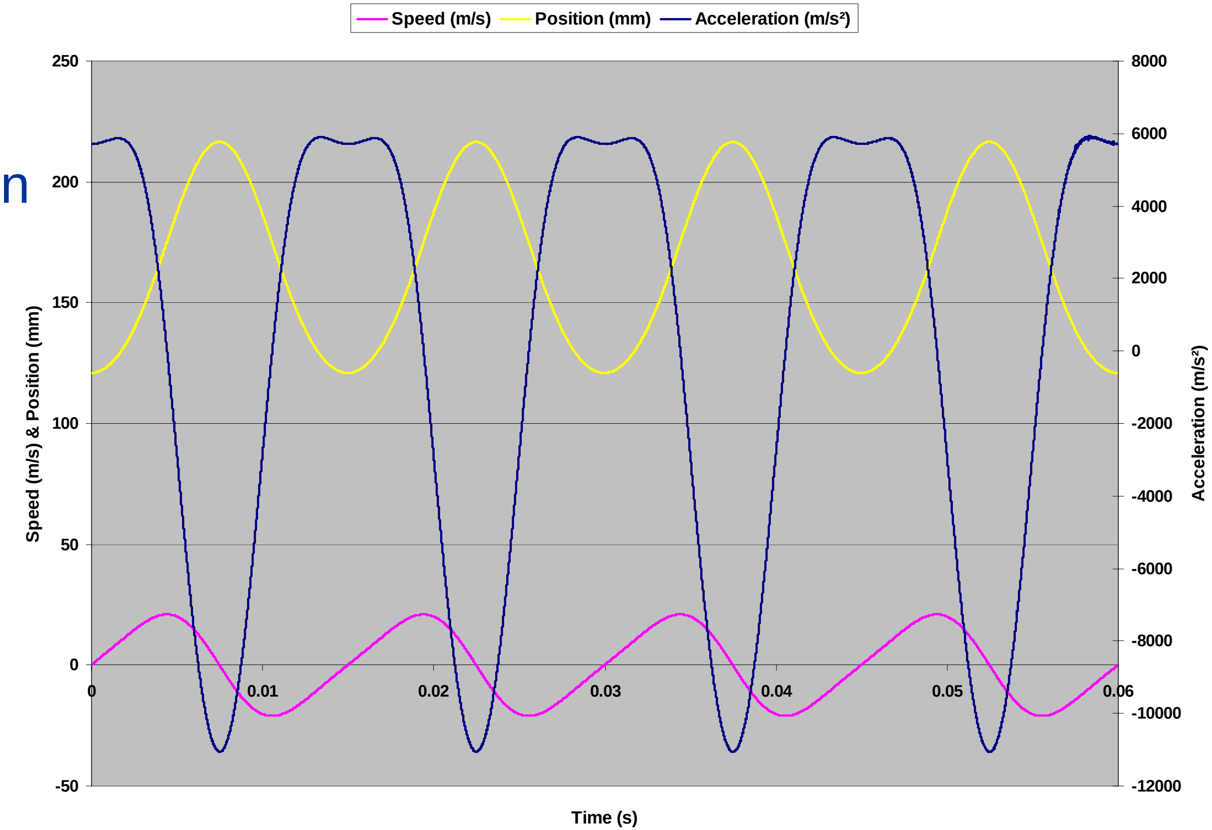
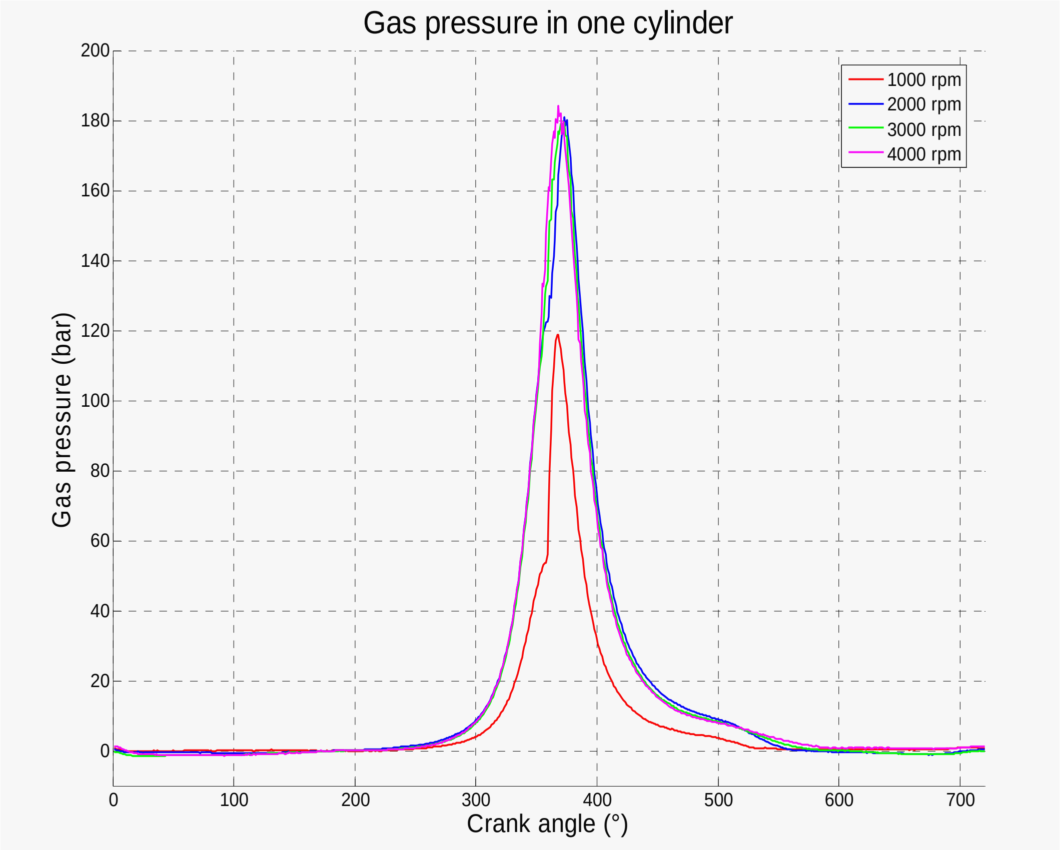
- Kinematic simulation with imposed crankshaft speed (4000 rpm)
  - Position, speed and acceleration of one piston:



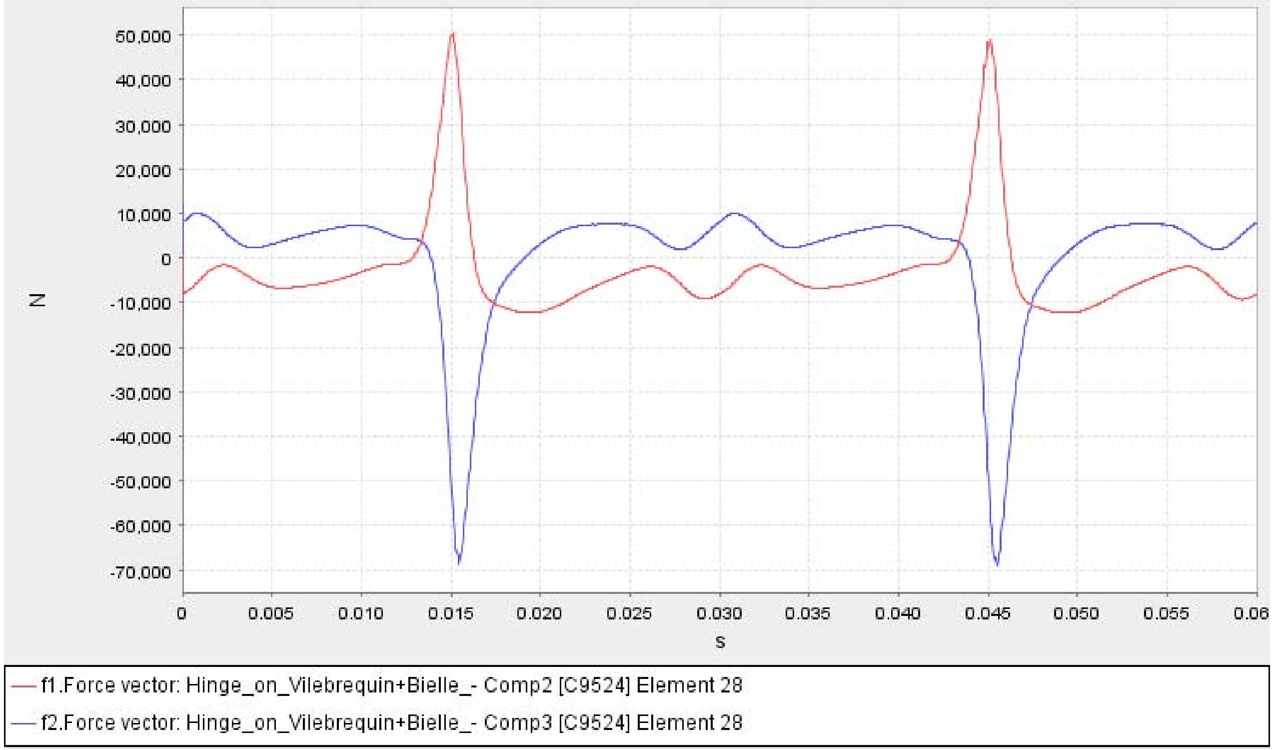
Gas pressure model

- Gas pressure inside one cylinder (experimental data)



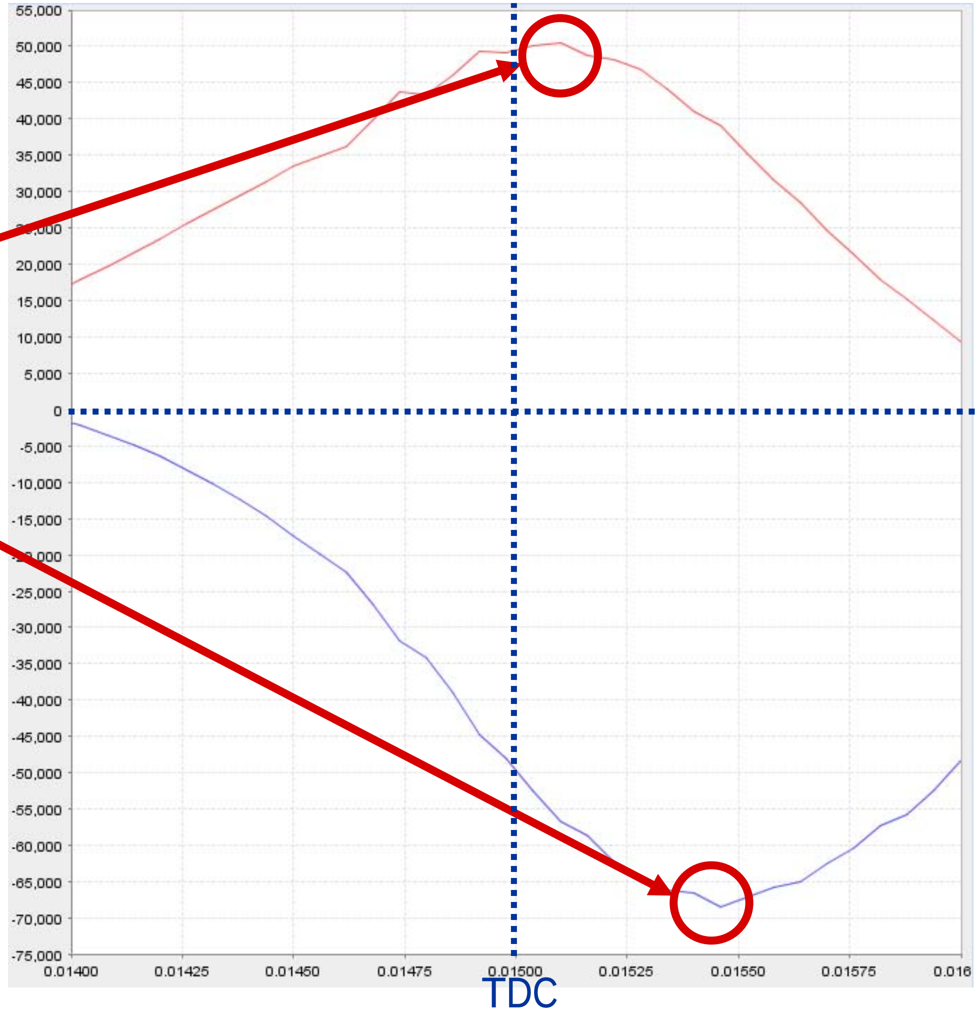
Rigid multibody model

- Dynamic simulation taking into account the gas pressure force
  - Radial (red) and tangential (blue) forces acting on one crankpin



Rigid multibody model

- Forces acting on one crankpin
  - Maximal radial force
  - Maximal tangential force



Flexible multibody model

- Simulation of flexible engine parts thanks to the finite element approach
  - Dynamic multibody simulation with pistons and connecting rods considered as rigid bodies and crankshaft meshed with flexible finite elements
  - Crankshaft strains and stresses are calculated for the complete cycle
  - Several models of bearing surface were compared (rigid hinge, flexible-rigid contact, radial bushing, hydrodynamic bearing)

Flexible multibody model

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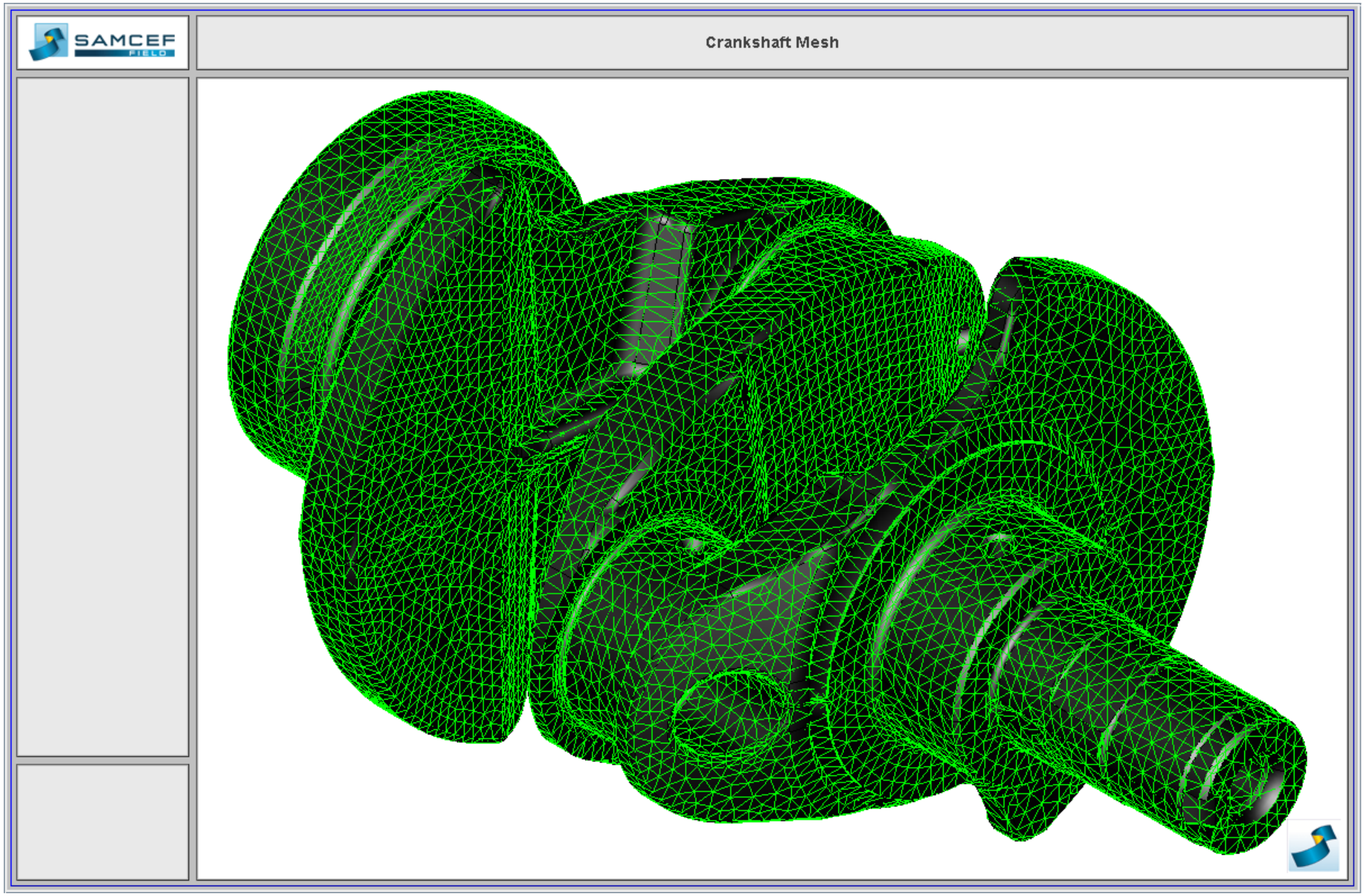
- Dynamic simulation of the engine
  - Rigid hinge model of bearing surfaces is used
  - Crankshaft is meshed with 3,3 mm first order tetrahedral elements (232281 tetrahedral elements)
  - Chung-Hulbert time integration algorithm
  - Maximal constraint occurs at 320 µs (8° after the piston has reached the TDC) and its value is 242 Mpa

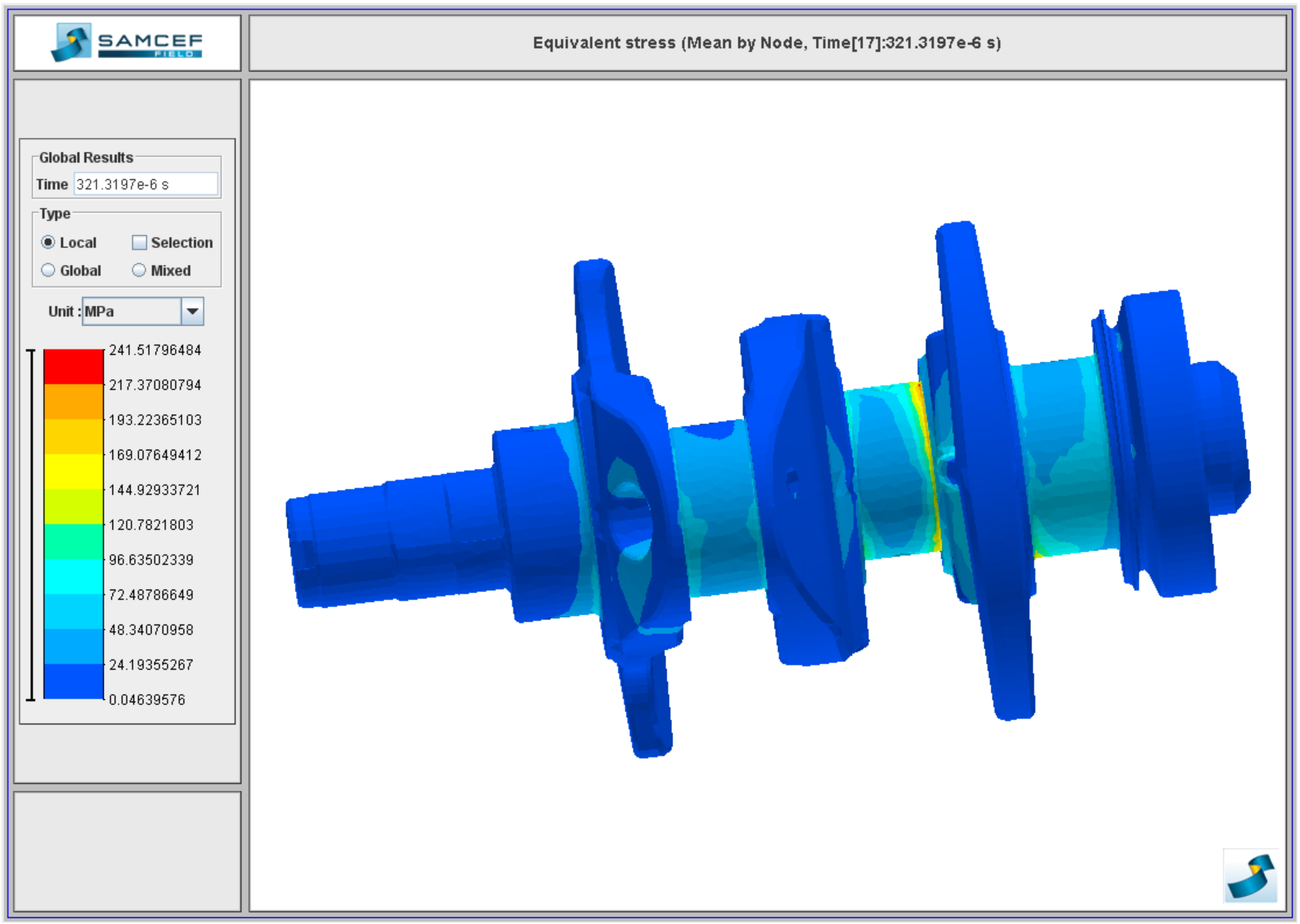
Flexible multibody model

– Crankshaft mesh



Flexible multibody model

– Crankshaft constraints at time 320 µs



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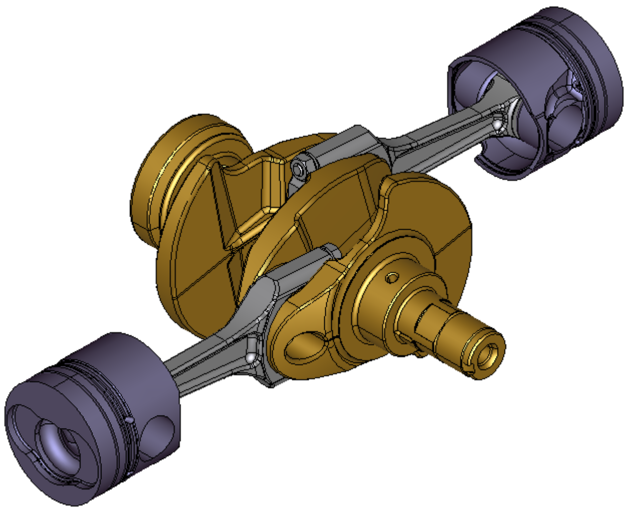
Variable speed simulations



Rigid multibody model

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- Rigid multibody simulation with variable engine speed (speed varies from 3800 rpm to 4200 rpm in 0,18 s)
- Rigid multibody model of engine developed in the constant speed simulation (including gas pressure) is used

Rigid multibody model

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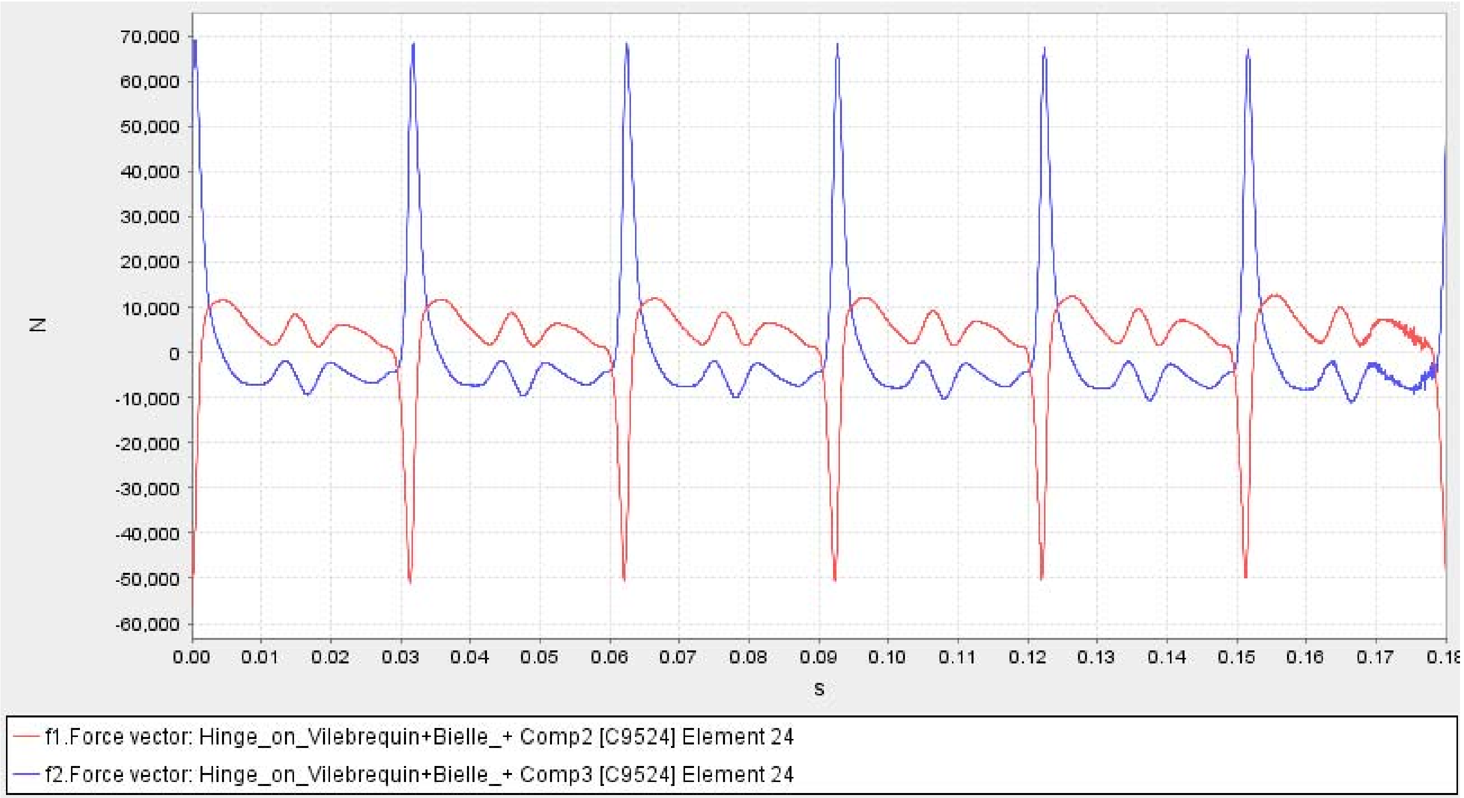
- Dynamic simulation of the engine acceleration
  - Radial (red) and tangential (blue) forces acting on one crankpin



Flexible multibody model

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- Dynamic simulation of engine running at variable speed and using a flexible crankshaft model
  - Due to the complex shape of the crankshaft, working with the fully detailed geometry in such simulation is difficult => Creation of simplified crankshaft models
- Validation of these simplified models in 3 steps
  - Modal analysis
  - Dynamic properties (inertia forces and moments)
  - Flexible dynamic simulation at constant speed

Simplified crankshaft models

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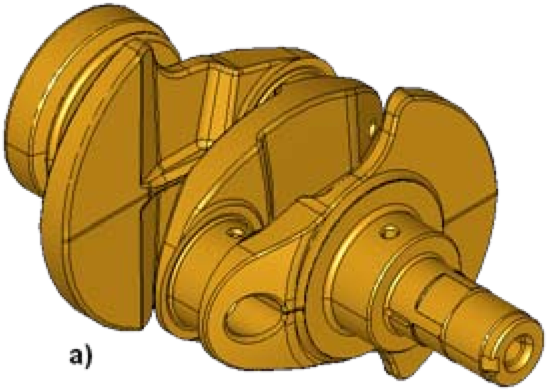
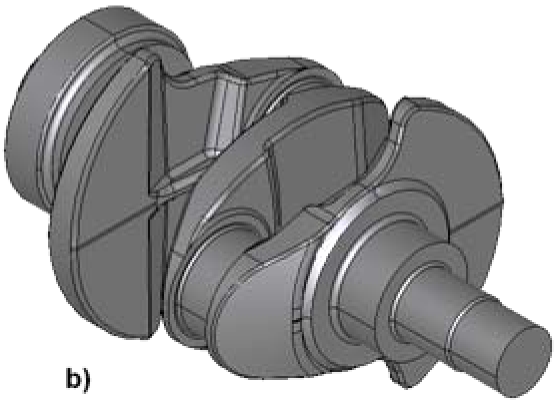
- Crankshaft models:
  - a) Fully detailed
  - b) Simplified geometry
  - c) Beam model


a)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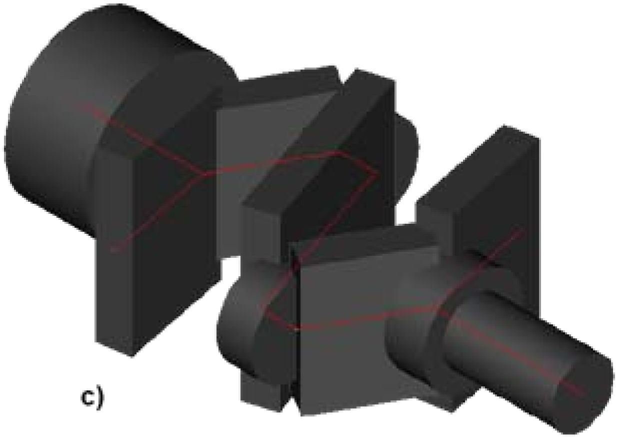
c)

Simplified crankshaft models

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- Modal analysis of the 3 crankshaft models:

	Frequency 1	Frequency 2	Frequency 3	Frequency 4	Frequency 5
Fully detailed model	746 Hz	1099 Hz	1389 Hz	1716 Hz	2057 Hz
Simplified 3D model	847 Hz	1232 Hz	1235 Hz	1851 Hz	2287 Hz
Beam model	504 Hz	690 Hz	1162 Hz	1381 Hz	1588 Hz

Simplified crankshaft models

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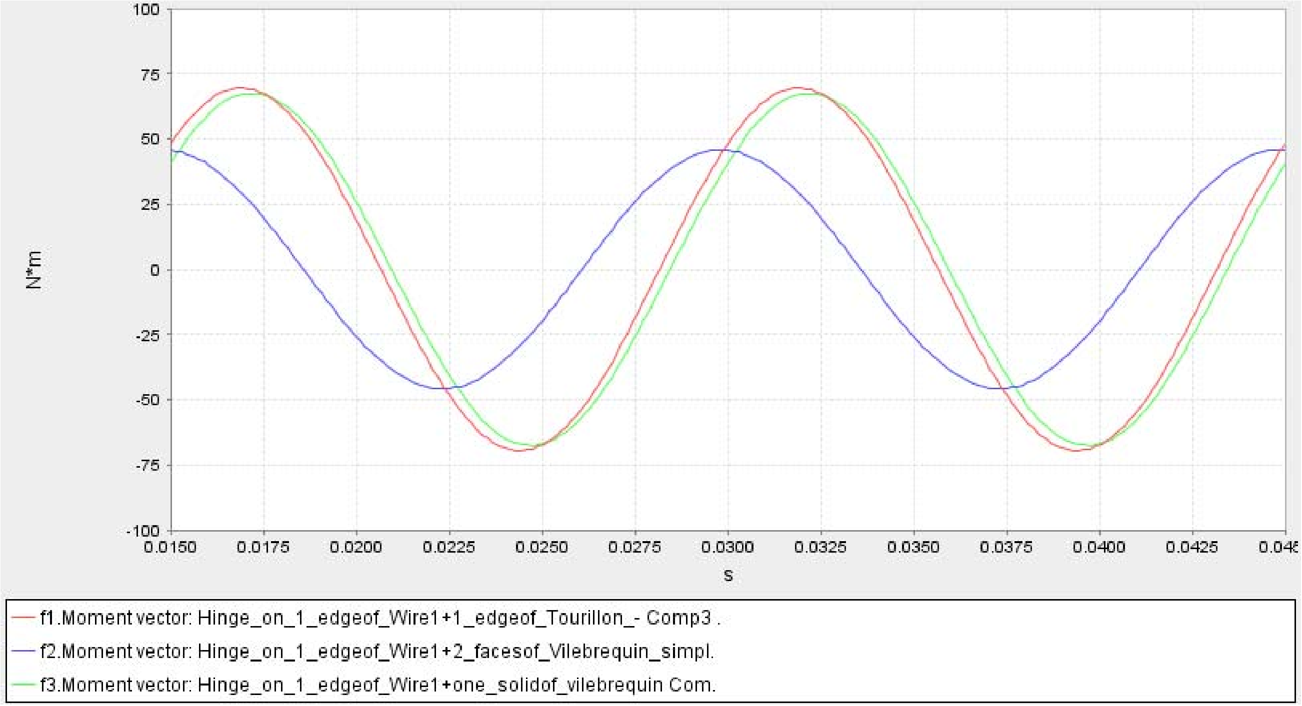
- Comparison of the inertia yaw moment created by each crankshaft model when rotating at 4000 rpm
  - Fully detailed --- Simplified geometry --- Beam model ---



Simplified crankshaft models

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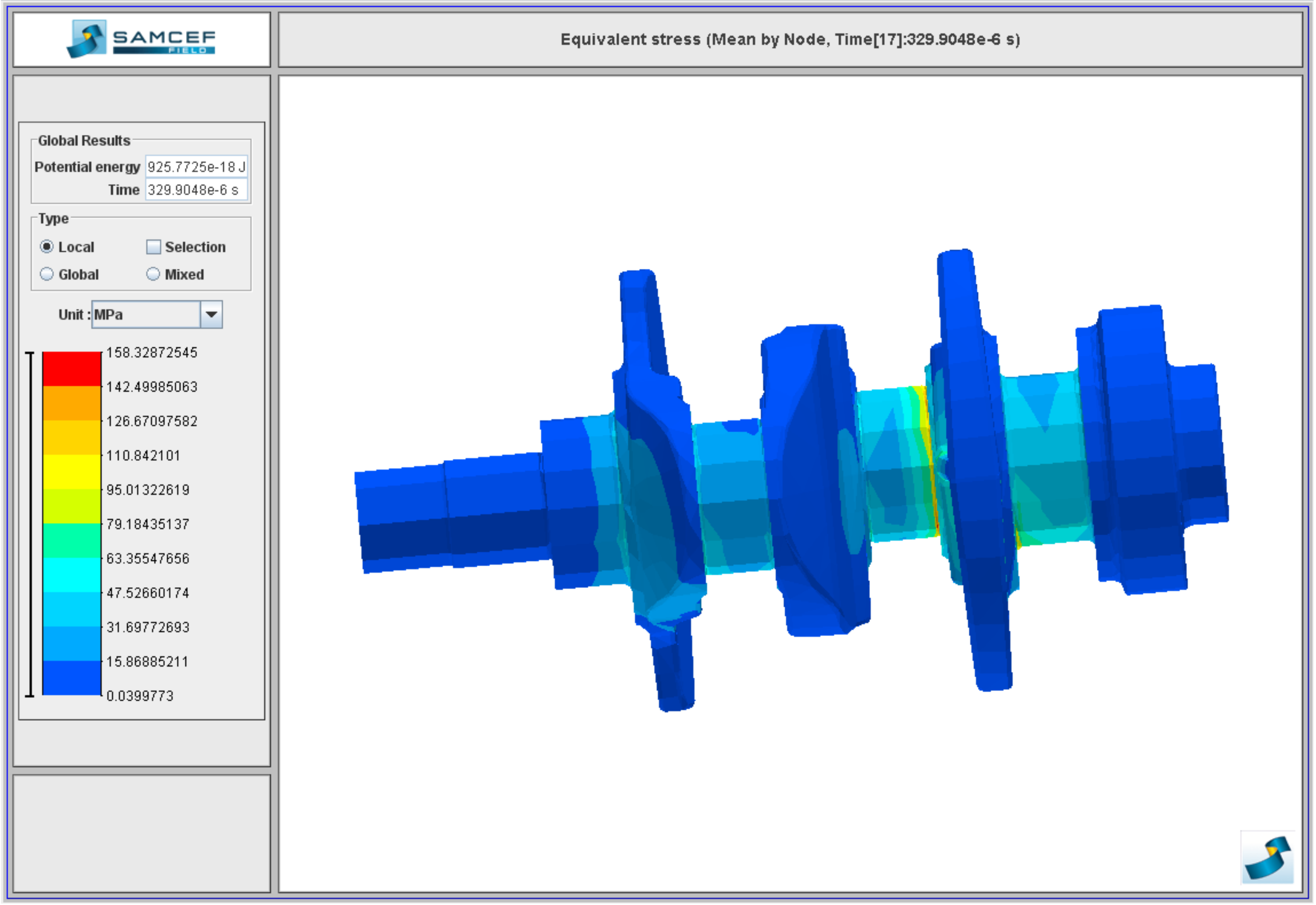
– Constraints in the simplified 3D crankshaft model at 320 µs



Simplified crankshaft models

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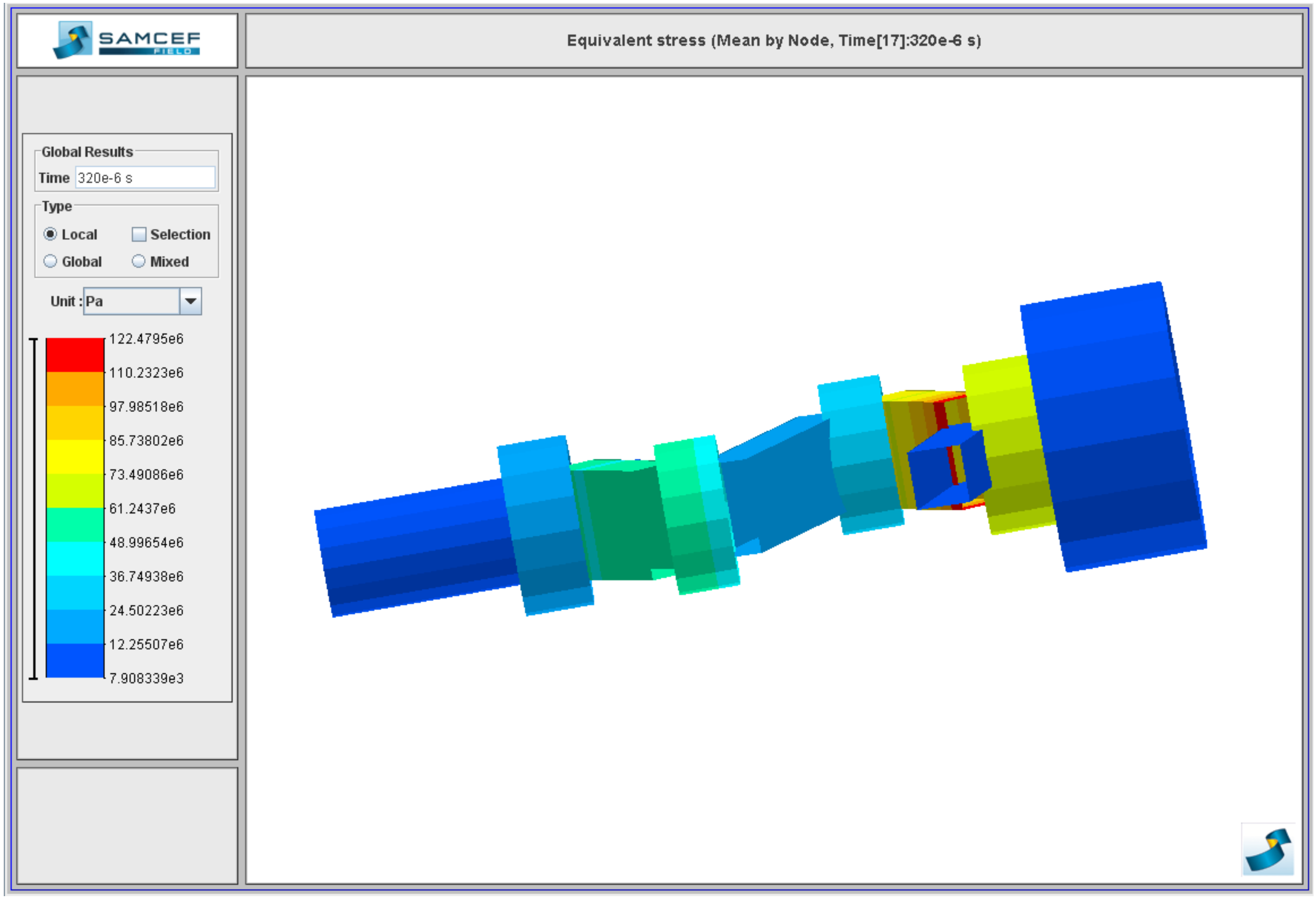
– Constraints in the beam crankshaft model at 320 µs



Flexible multibody model

- Dynamic simulation of engine running at variable speed and using a flexible beam crankshaft model
  - Maximal value of the crankshaft stress at different time of the simulation but at the same angular position (17° after TDC)

Time (s)	0,00075	0,09295	0,15189
Speed (rpm)	3801	4007	4138
Maximal stress (MPa)	146.5	143.9	142.3

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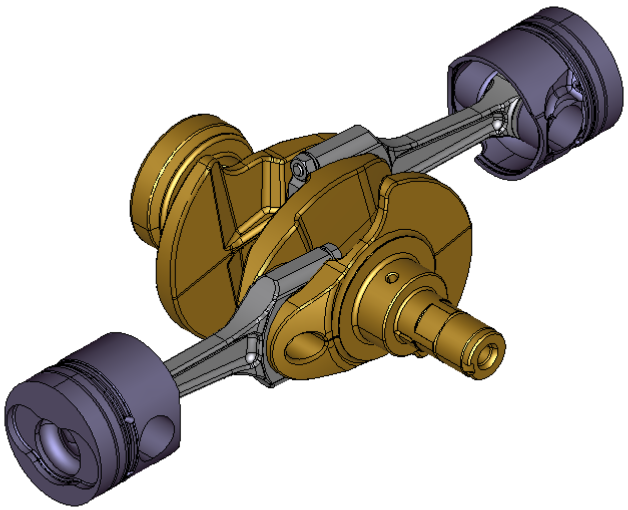
Conclusion



Conclusion

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- Multibody simulations offer interesting prospects for engine design:
  - Easy calculations of inertia forces and moments (rigid body simulation)
  - Calculations of the exact forces acting on each engine parts
  - Flexible body dynamic simulation allows strain and stress analysis for all crankshaft positions but require lots of computing resources and time => need for **simplified models**
  - They allow doing faster simulations
  - They are useful to determine critical times and highly loaded areas but they do not permit to make precise stress calculations

Perspectives

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- Improving quality of the simplified models to better fit to the fully detailed crankshaft model
- Creating a super element model of the crankshaft
- Stress analysis of other engine parts (pistons and connecting rods)

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Thank you for your attention