Advanced Engine Dynamics Using MBS and a Mixed Nonlinear FEM and Super Element Approach

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Topics of the study

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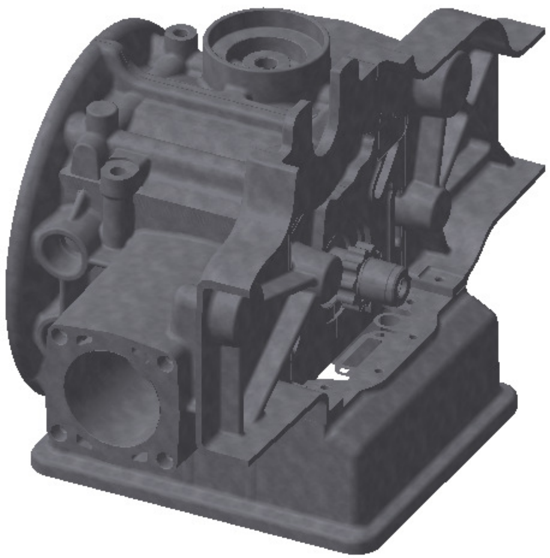
- Dynamic simulations of a twin–cylinder boxer engine using rigid and flexible parts models and stresses analysis of the engine crankshaft thanks to a finite element approach
- New approach combining super element technique and finite elements in the same part model
- Comparison of the results obtained with this approach to the ones obtained with classical approaches (finite element or super element models)

Twin-cylinder boxer engine

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



Simulation software

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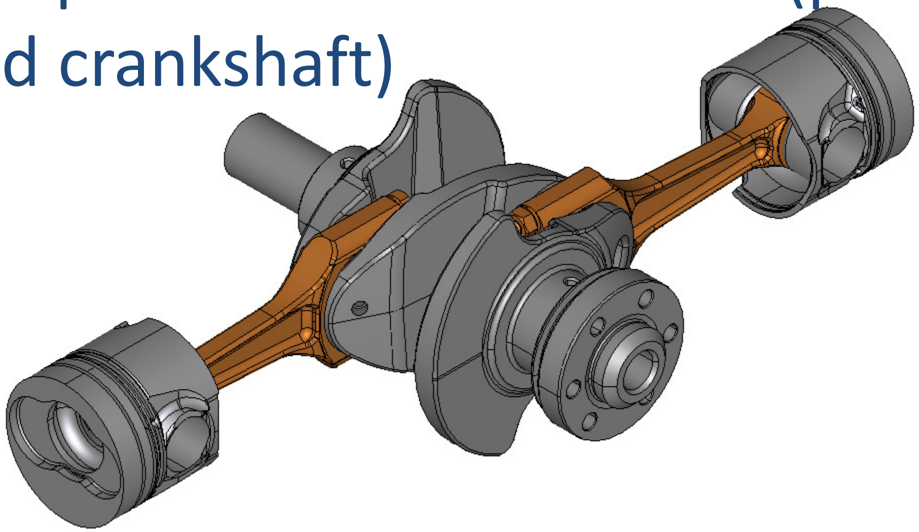
- Engine simulations are performed using finite element approach with SamcefField MECANO software developed by LMS Samtech and historically by the university of Liège

SAMCEF FIELD

Engine model

- Engine model is made with real geometry coming from the CAD model of a prototype engine (provided by Breuer Technical Development)
- Engine model is simplified, only the most significant mobile parts are kept for the simulations (pistons, connecting rods and crankshaft)

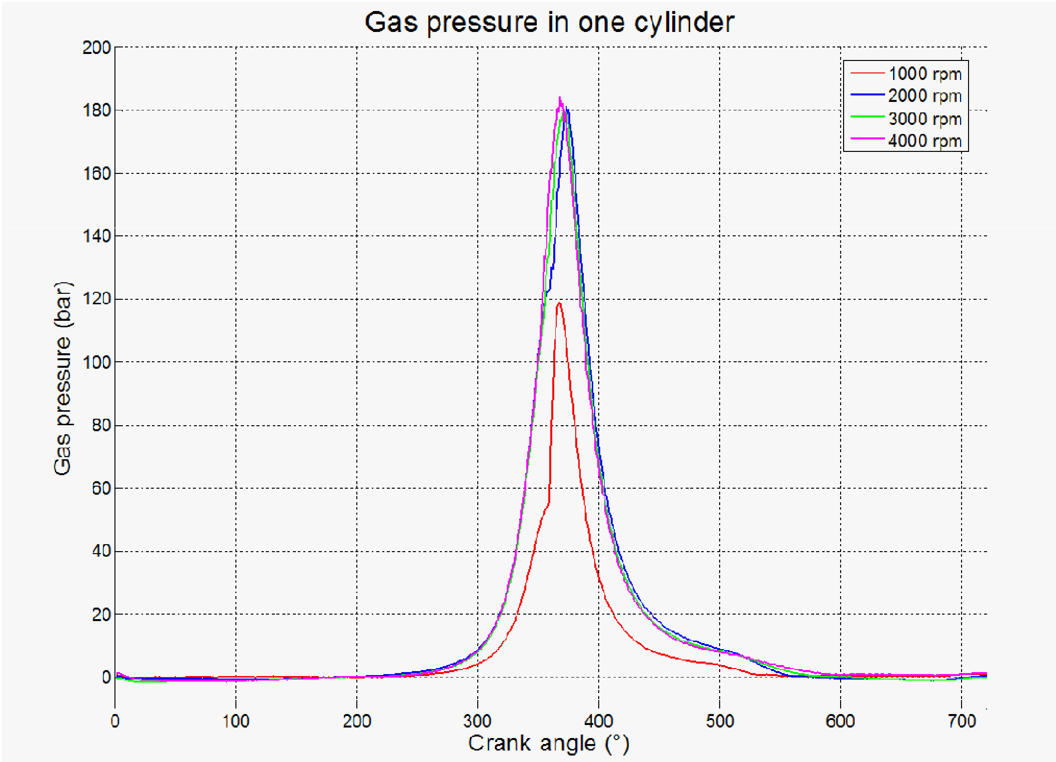


Engine model

- Pistons and connecting rods are considered as rigid bodies and the crankshaft is meshed with flexible finite elements thanks to the finite element approach of MECANO
- Crankshaft strains and stresses are calculated for the complete engine cycle in a dynamic simulation (with imposed crankshaft rotation speed including or not the gas pressure effect)

Gas pressure model

- Gas pressure inside a cylinder (experimental data)



Crankshaft finite element model

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- Classical finite element approach:
  - Crankshaft is meshed with 283700 first order tetrahedral elements of 3 mm average size (good compromise between result accuracy and computing time)
  - Rigid hinge model of bearing surfaces is used
  - Chung-Hulbert time integration algorithm

Crankshaft finite element model

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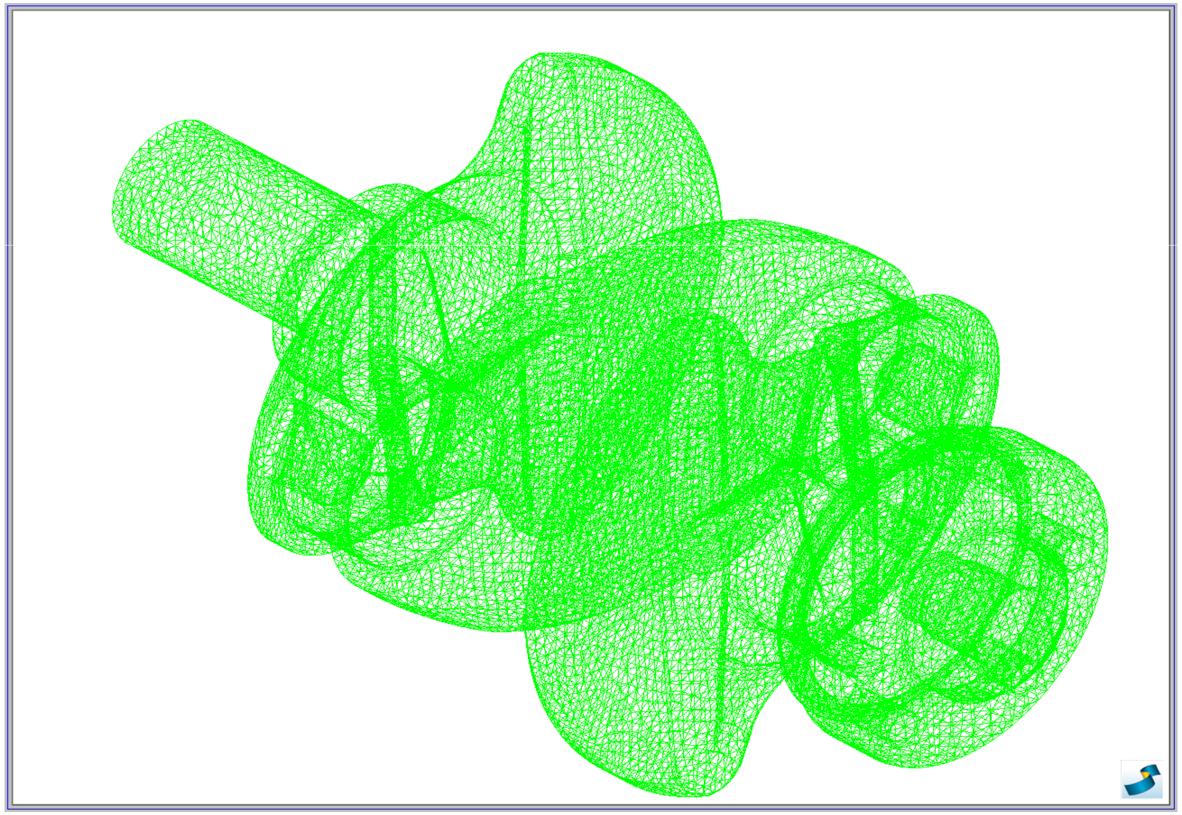
- Crankshaft mesh:



Crankshaft finite element model

- Simulations using fully detailed crankshaft geometry take a lot of time (50 hours for 2 engine cycles) and computing resources
- Need for simplified models:
  - Beam models
  - Simplified geometry 3D models
  - Super element models
  - Mixed model using super elements and classical finite elements

Super element approach

- Substructure technique used to reduce the size of a problem
- Nonlinearities are assumed concentrate in the joints
  - Motion (especially rotation) and the deformation of a body can be decoupled
  - Deformations of the body remain small and linear in a local frame attached to the body
  - The body is represented by a super element containing the internal modal information and linked to other bodies allowing to keep a relatively simple global dynamic model

Super element approach

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- Simulations using super element technique require 3 steps:
- Creation step:
  - Super element of the crankshaft is created by deleting some DOF and keeping only the boundary DOF and a reduced set of eigenmodes (Craig-Bampton condensation method)
  - The mass matrix and the stiffness matrix of the crankshaft are reduced and assembled with the rest of the system like an usual finite element

Super element approach

- Calculation step:
  - Super element is assembled in the global system
  - A dynamic multibody analysis of the global system (the engine in this case) is performed
  - Results from the global simulation are obtained (position, speed, acceleration, force, moment…)

Super element approach

- Results recovery step:
  - Some specific results of the crankshaft, for instance strains and stresses, can be recovered by a dynamic analysis of the super element

Crankshaft super element model

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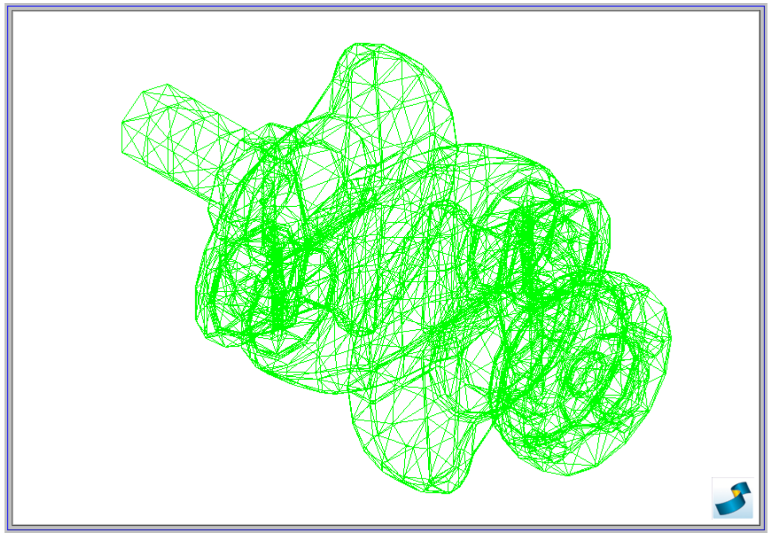
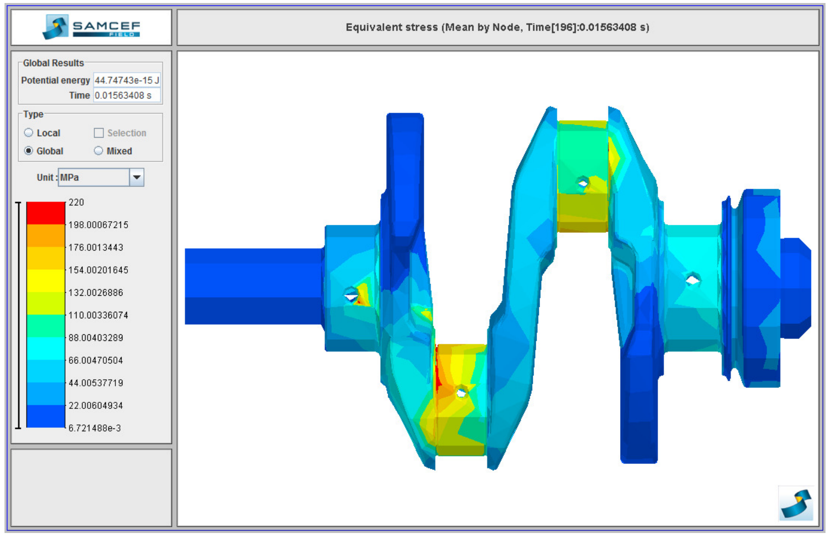
- Dynamic simulation of the engine using a super element model of the crankshaft
  - Super element is created with the crankshaft meshed with 283700 first order tetrahedral elements of 3 mm average size and keeping 1 eigenfrequencie
  - Rigid hinge model of bearing surfaces is used
  - Chung-Hulbert time integration algorithm

Crankshaft mixed model

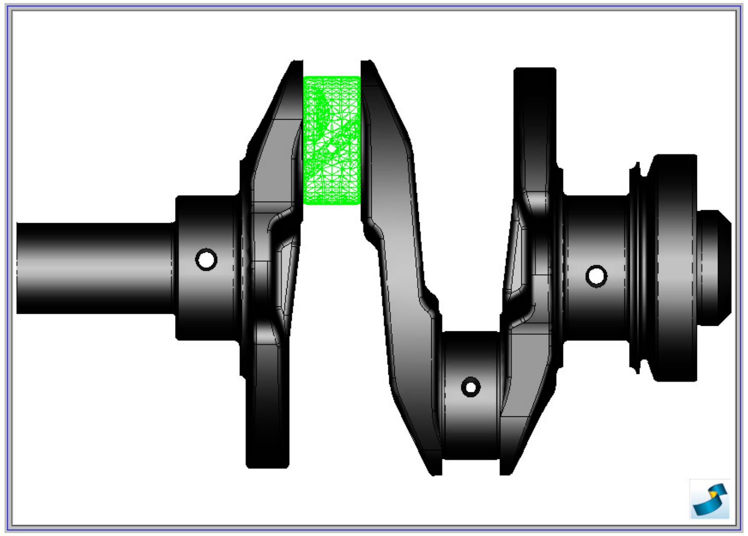
- A specific part of the crankshaft (the crankpin located on the distribution side) has been identified as critical thanks to a flexible multibody simulation performed with a coarse mesh





Crankshaft mixed model

- This critical crankpin is meshed with finite element (11300 tetrahedral elements) and each one of the two adjacent parts is modeled by a super element and linked using “glue” assembly constraints



Results of different models

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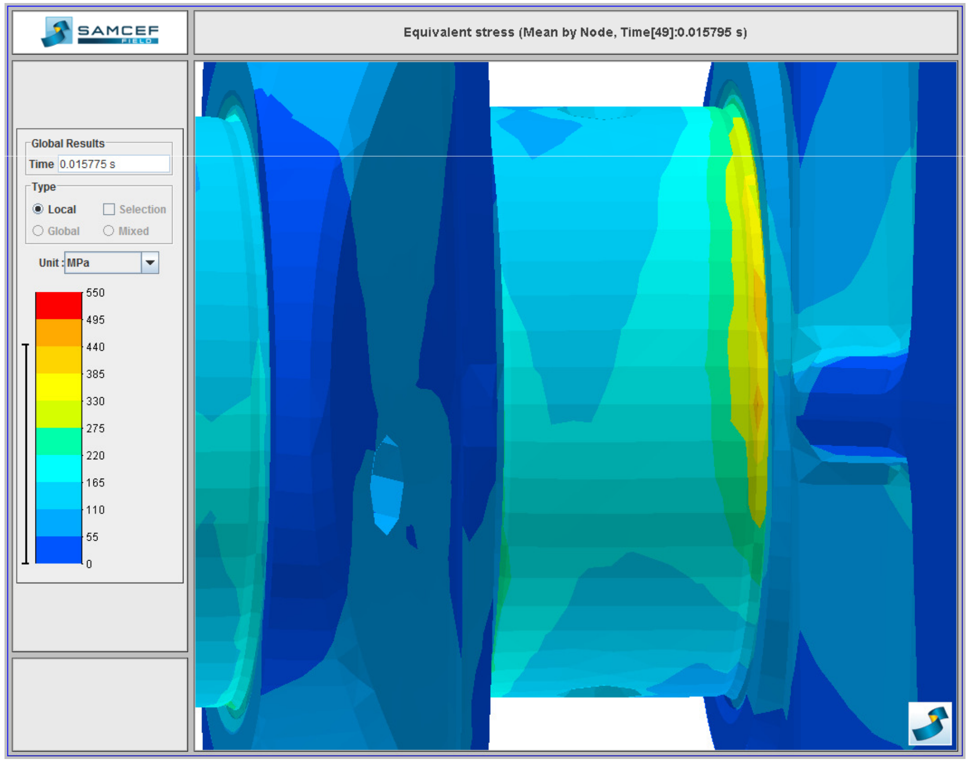
- The same engine dynamic simulation are performed (two engine cycles with imposed crankshaft rotation speed of 4000 rpm including the gas pressure) using the three crankshaft models.
- Different results will be illustrated and compared:
  - Simulation times
  - Maximum stress values
  - Time evolutions of the stress value of a crankpin particular node

Computation times

- CPU times (on a quad-core 2.8 GHz computer) for a simulation of two engine cycles at 4000 rpm (0.06 s):
  - Finite element model : 50 hours
  - Super element model : 10 hours
  - Mixed model : 7.5 hours

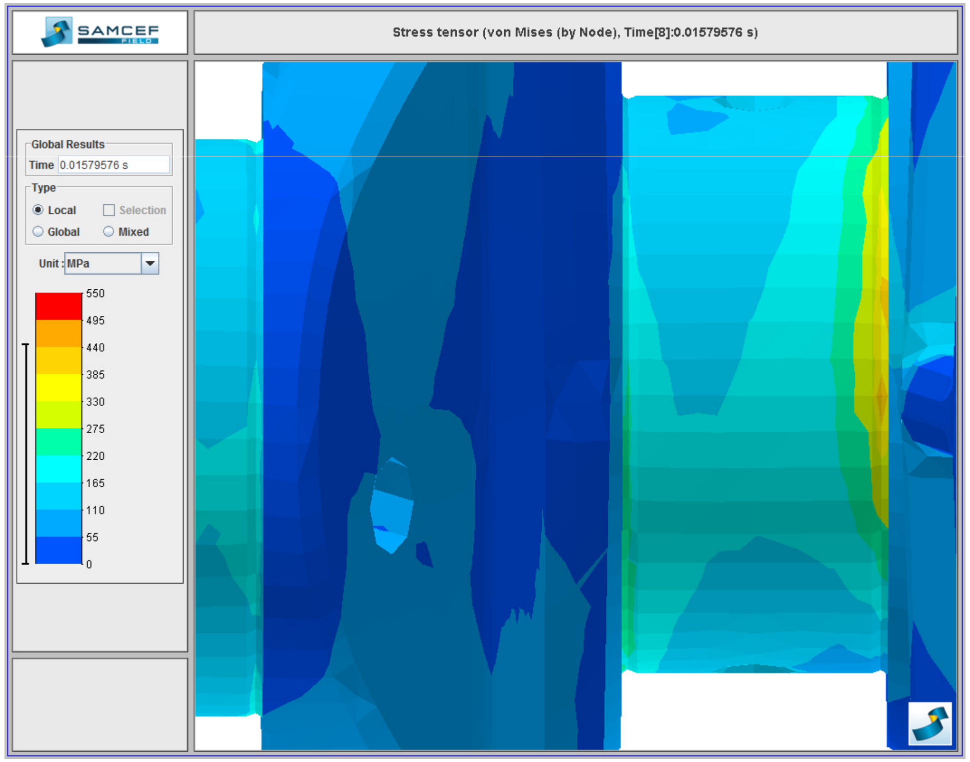
Finite element model

- Maximal stress (Von Mises) occurs at time 15.78 ms (18.7° after the TDC) and its value is 445 Mpa



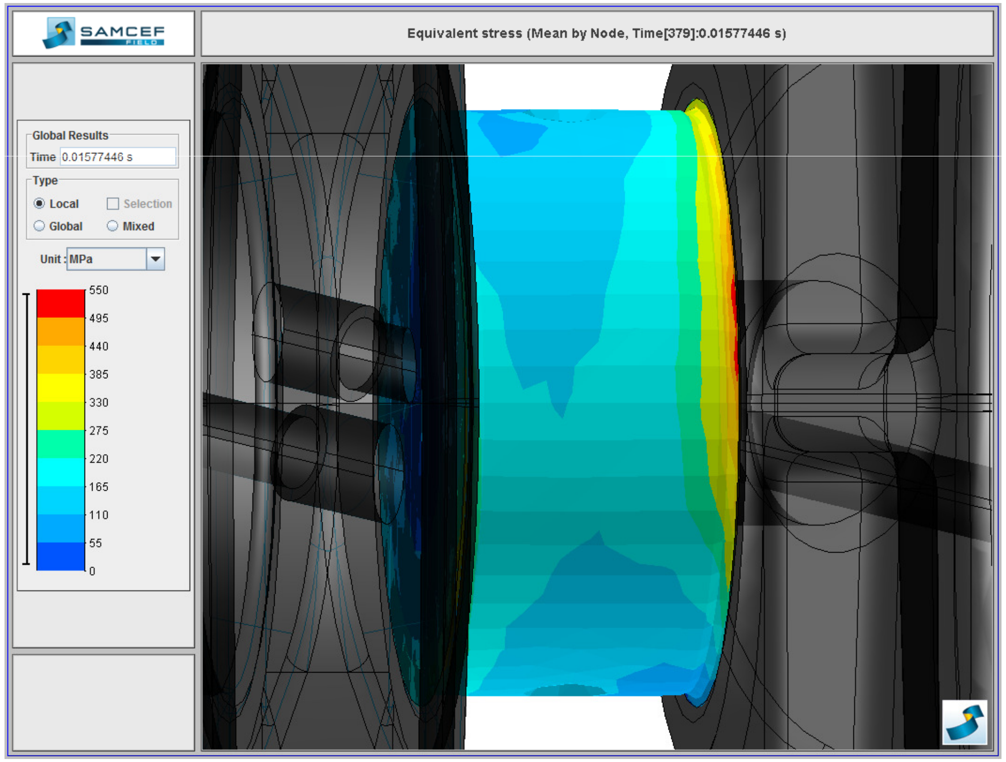
Super element model

- Maximal stress (Von Mises) occurs at time 15.795 ms (19° after the TDC) and its value is 447 Mpa



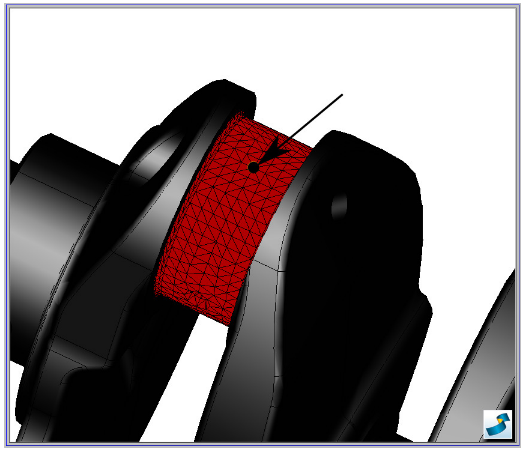
Mixed model

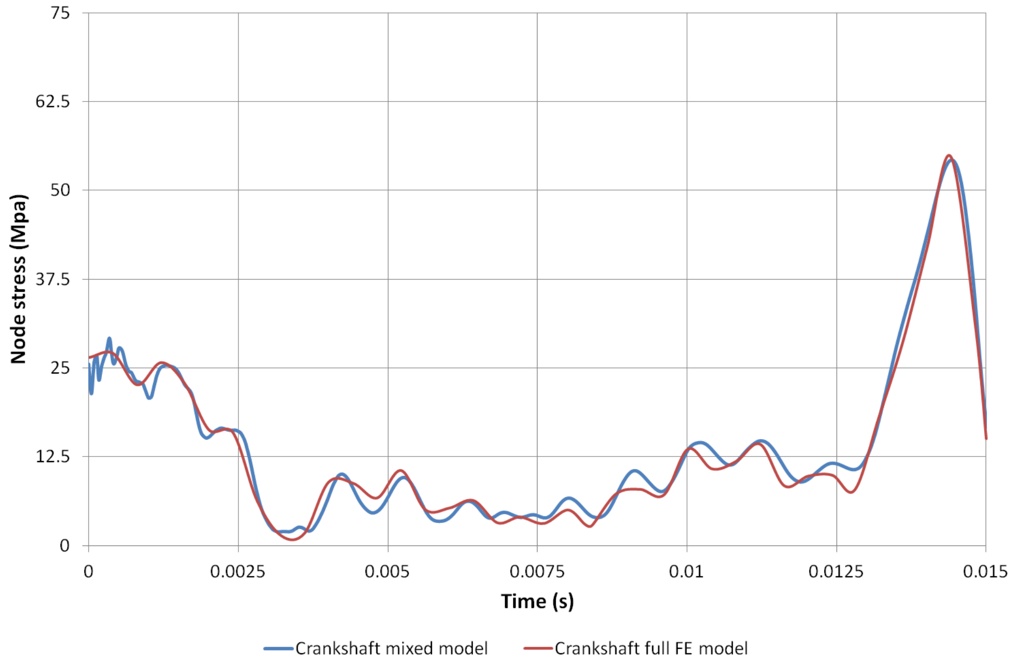
- Maximal stress (Von Mises) occurs at time 15.775 ms (18.6° after the TDC) and its value is 541 Mpa



Stresses evolution

- The stress versus time curve is plotted for a specific node (chosen in the middle of the contact surface of the crankpin) for the finite element model and for the mixed model





Conclusions

- Multibody simulations offer interesting prospects for engine design:
  - Determinations of forces and moments acting on each parts of the mechanism
  - Flexible body dynamic simulation allows strain and stress analysis for each time steps of the simulation but require lots of computing resources and time => need for **simplified models**

Conclusions

- Super element method allows to:
  - Perform faster simulations
  - Isolate the displacement coming from the deformation and from the rotation
- Furthermore, the super element combined with finite element permits:
  - Even faster computing (best compromise to find)
  - To avoid the recovery step of the super element approach

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Thank you for your attention