ADVANCED CRANKTRAIN SIMULATION at BMW AG.

SIMULIA European MBS User Group Meeting - Darmstadt - 9.11.2016

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Pöschl, Niedhammer, Dassault Systèmes Deutschland GmbH

BMW GROUP THE NEXT 100 YEARS

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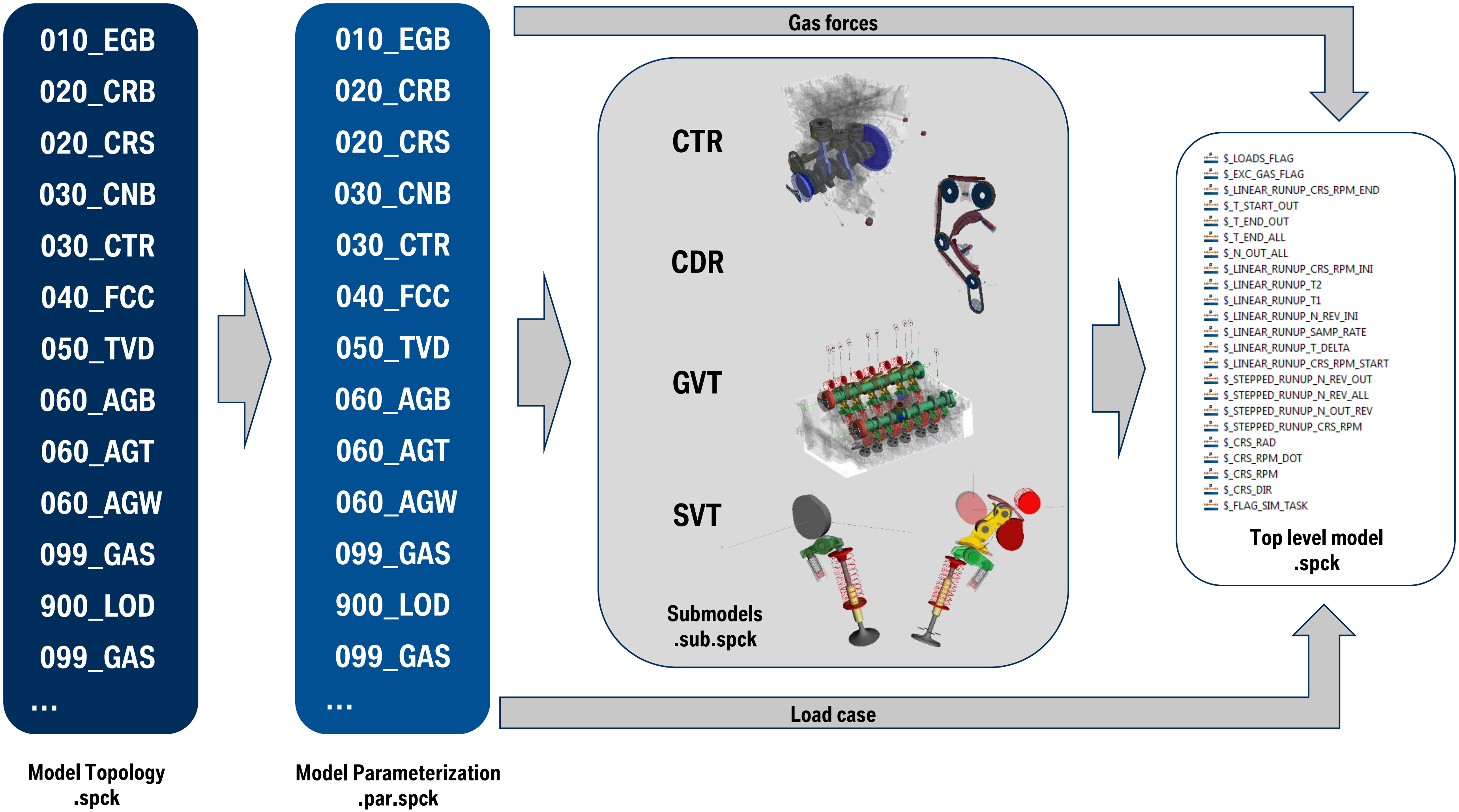
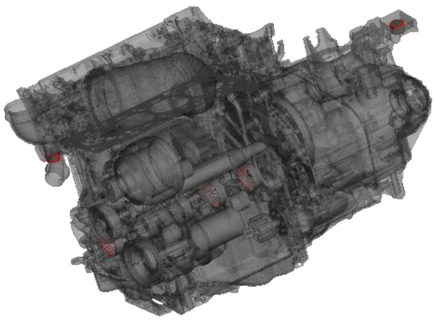
DATABASE STRUCTURE OVERVIEW.



CRANKTRAIN COMPONENTS WITH DIFFERENT LEVELS OF DETAIL.

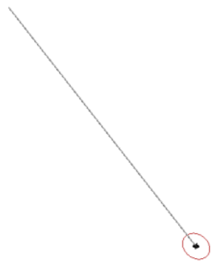
010_EGB



Engine block with gearbox

- Subtypes for different engine types
- Rigid or flexible depending on parameters

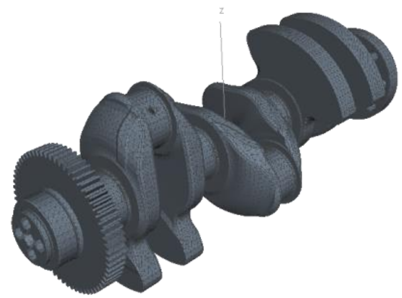
020_CRB



Crankshaft bearing

- Subtypes with different modelling approaches
- Simple bushing
- IST hydrodynamic bearings using impedance and online FEM method
- Simpack hydrodynamic bearings using approximating and hydrodynamics method

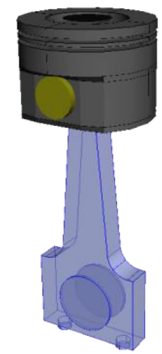
020_CRS



Crankshaft

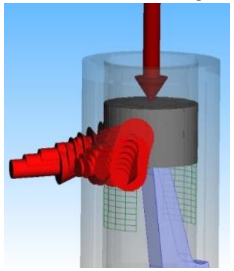
- Subtypes for different modelling approaches and engine types
- 1D torsional multi mass oscillator models
- 3D models, rigid or flexible depending on parameters

030_CTR

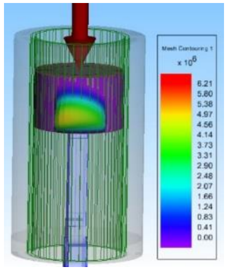


Crank train

- Subtypes for different modelling approaches
- Rigid or flexible depending on parameters
- Interface piston to engine block with translational joint or piston-liner contact or Simpack hydrodynamic bearing



Piston-liner contact



Hydrodynamic bearing

030_CNB

Conrod bearing

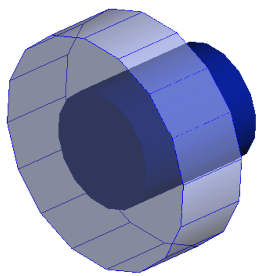
- Subtypes with different modelling approaches
- Constraint
- Simple bushing
- IST hydrodynamic bearings using online FEM Method
- Simpack hydrodynamic bearings using approximating and hydrodynamics method

CRANKTRAIN COMPONENTS WITH DIFFERENT LEVELS OF DETAIL.

040_FCC

Flywheel / Converter / Clutch
- Rigid or flexible depending on parameters
- Degrees of freedom depending on parameterization
- Could represent one or two mass oscillators

050_TVD

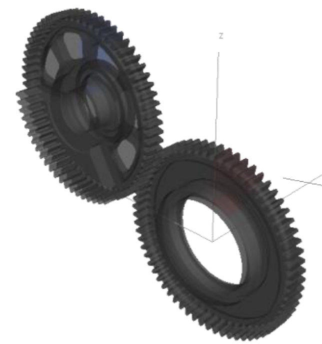


Torsional vibration damper
- Subtypes for different modelling approaches and vibration damper types
- Rigid or flexible
- 1D or 3D modelling of damper
- Rubber or viscous damper

060_AGB

Balancing shaft bearing
- Different models covering radial and axial bearing separately and in different levels of detail

060_AGT

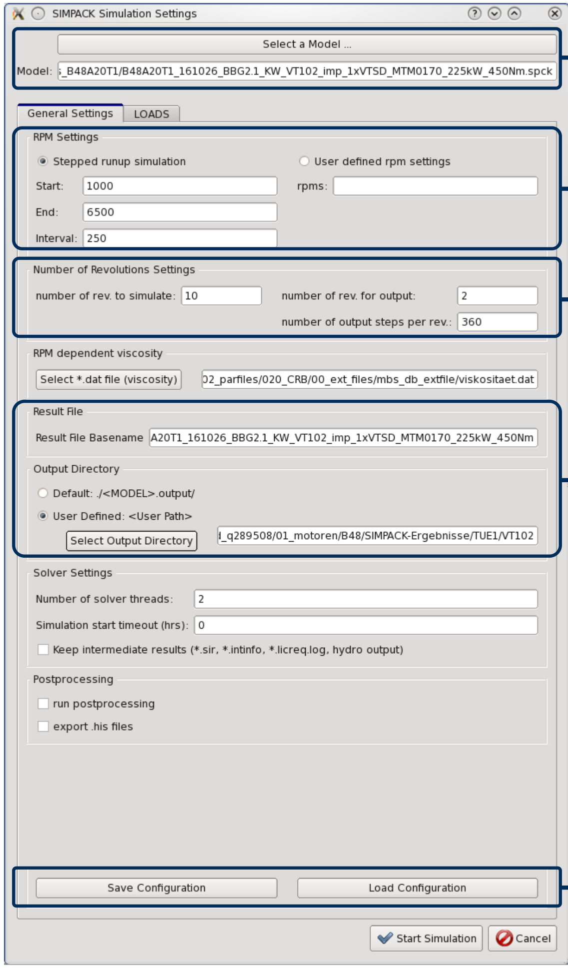


Balancing shaft gear drive
- Available for 3 and 4 cylinder engines
- Different modelling approaches using gear pair or a simple spring damper coupling including transmission ratio

060_AGW

Balancing shaft
- Available as general template
- For use in 3 and 4 cylinder engines
- Rigid or flexible depending on parameters

PROCESS AUTOMATISATION.



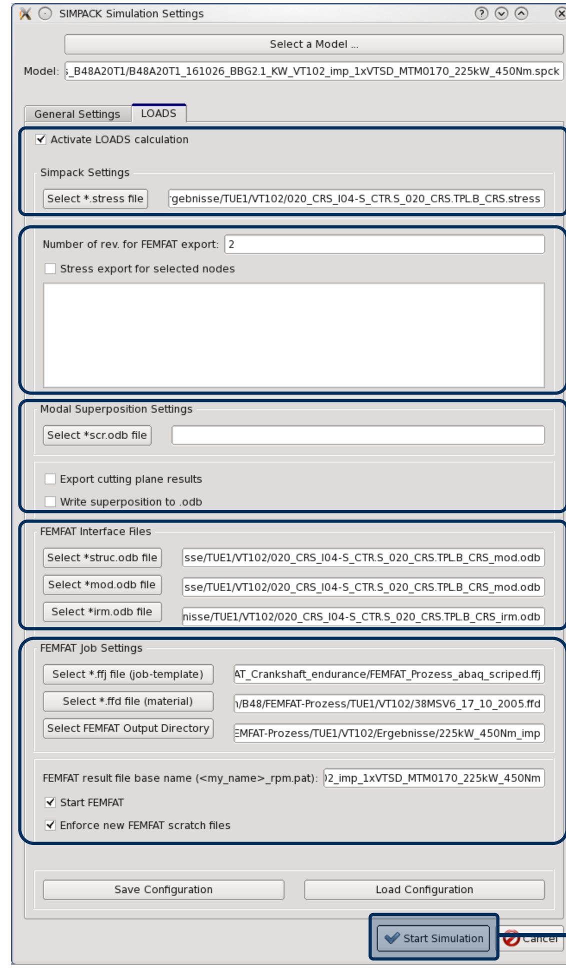
Selection of Simpack model

Definition of stepped runup

Calculation and evaluation period

Resultfile name and output directory for Simpack results

Every configuration could be saved and reused



Loads calculation and stress file

Stress export for selected nodes

Settings for cut plane loads calculation

FEMFAT Interface files

FEMFAT job template and material data, name and directory for results

Start Simulation

- Process automatisation of fatigue strength and cut load calculation of a stepped runup implemented as Simpack solver script
- Calculations in separate process
- Control via GUI-widget or shell only (Linux)

FATIGUE STRENGTH CALCULATION
ASSEMBLY OF SUBMODELS AND LOAD CASE.

010_EGB
Engine block with gearbox
- Flexible

010_CRB
Crankshaft bearing
- IST hydrodynamic bearing with impedance method
- Implementation of Simpack hydrodynamic bearing planned

020_CRS
Crankshaft
- 3D model
- Flexible

030_CNB
Conrod bearing
- Constraint

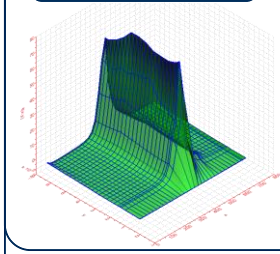
030_CTR
Crank train
- Rigid
- Piston with translational joint

040_FCC
Flywheel / Converter
- Flexible
- One mass oscillator, primary side only

050_TVD
Torsional vibration damper
- Rigid
- 1D

Submodel

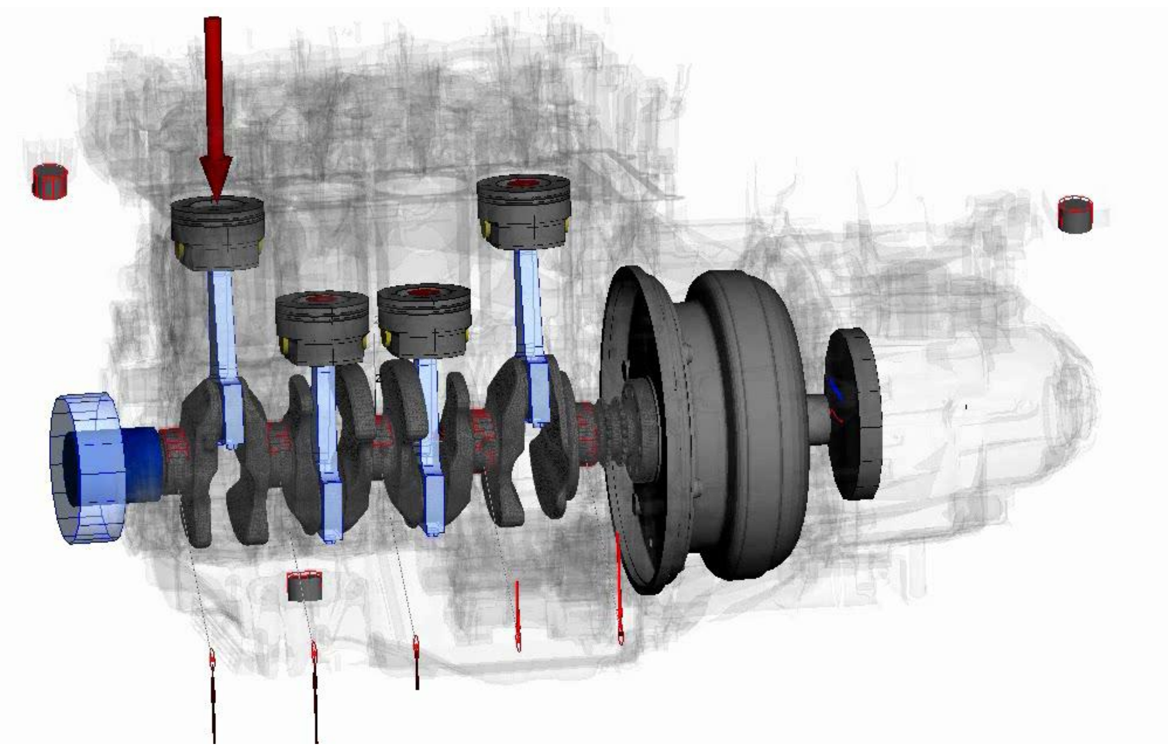
099_GAS



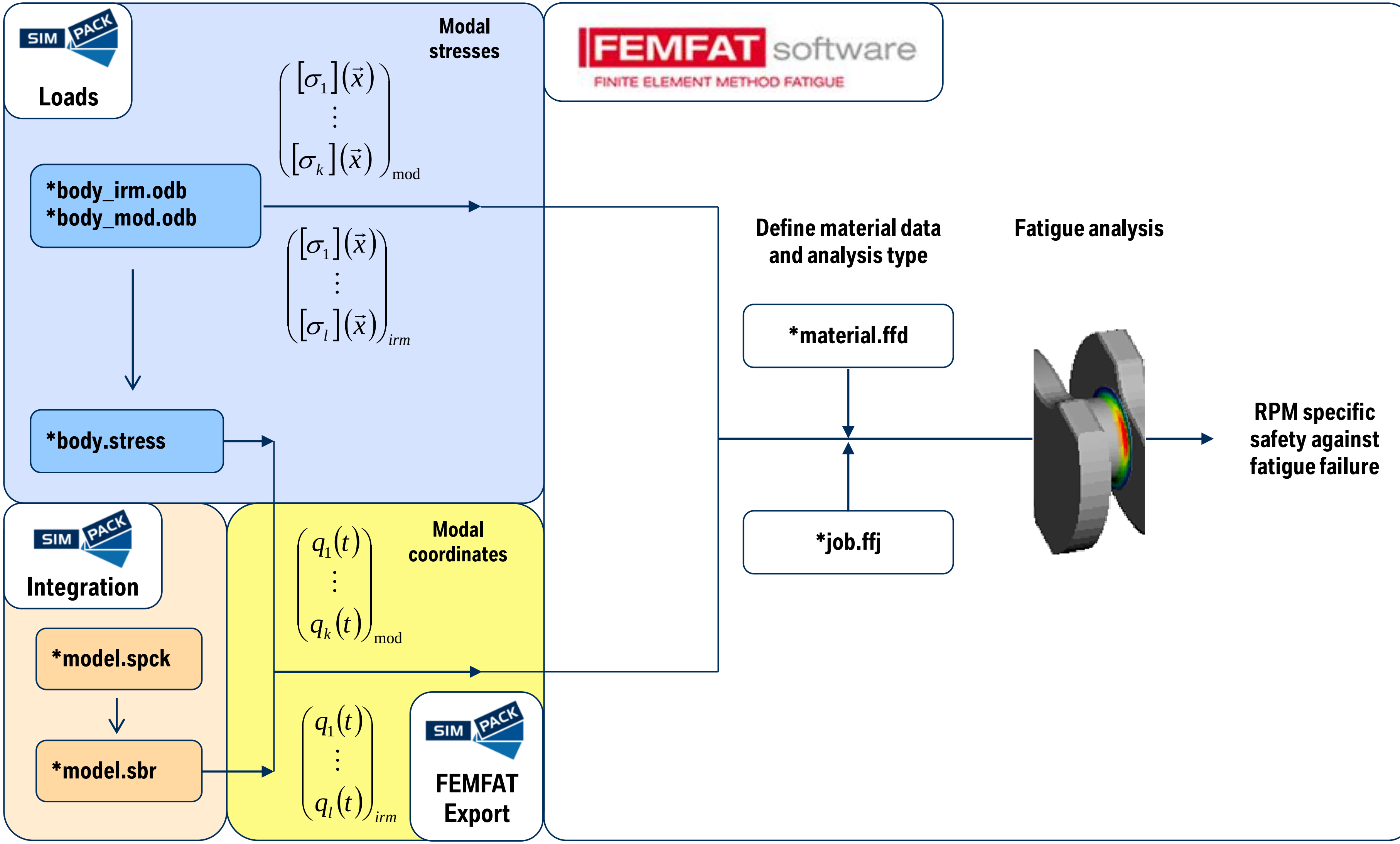
Gas forces
- Defines cylinder pressure time dependency by given crankshaft angle, angular frequency and ignition order
- Various engine subtypes
- Cylinder pressure acting at rigid piston

900_LOD
Load brake

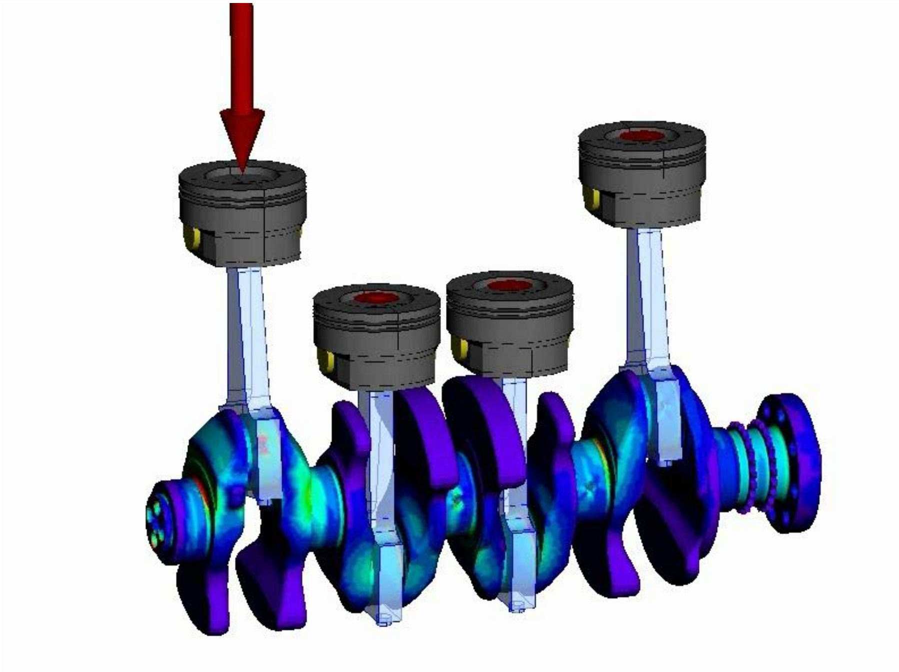
Load Case



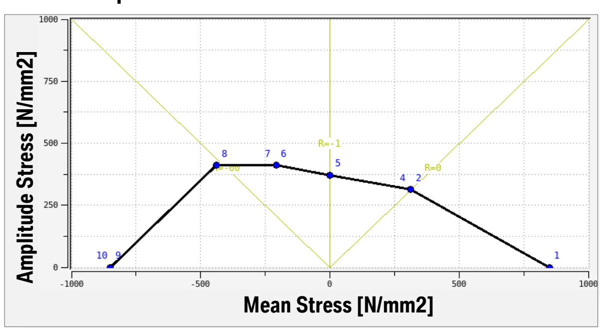
FATIGUE STRENGTH CALCULATION DATA FLOW.



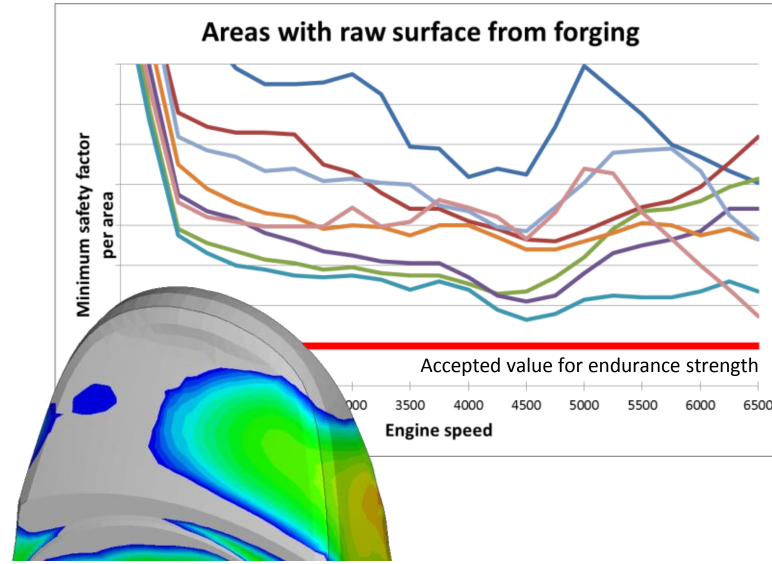
FATIGUE STRENGTH CALCULATION EXAMPLE.

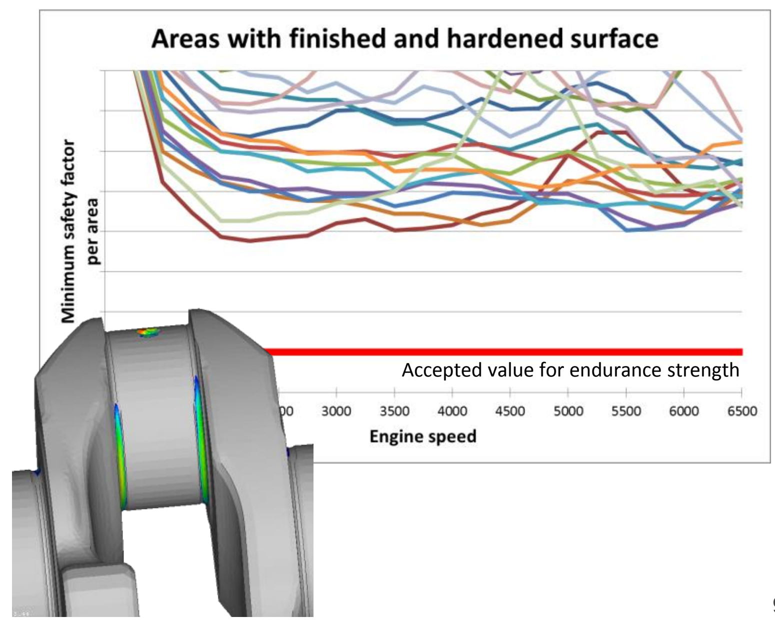


- Operational stresses



- Material data
- Technology influence





CALCULATION OF CUTTING LOADS DATA FLOW.

SIMPACK **Loads**

Modal stresses

$$\begin{pmatrix} [\sigma_1](\vec{x}) \\ \vdots \\ [\sigma_k](\vec{x}) \end{pmatrix}_{\mathrm{mod}}$$

***body_irm.odb**
***body_mod.odb**

$$\begin{pmatrix} [\sigma_1](\vec{x}) \\ \vdots \\ [\sigma_l](\vec{x}) \end{pmatrix}_{irm}$$

***body.stress**

Modal cut loads

$$\begin{pmatrix} \vec{F}_1(\vec{x}_i) = \int_{A_i} [\sigma_1]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \\ \vdots \\ \vec{F}_k(\vec{x}_i) = \int_{A_i} [\sigma_k]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \end{pmatrix}_{\mathrm{mod}} \quad \begin{pmatrix} \vec{M}_1(\vec{x}_i) = \int_{Ai} \left(\vec{x}_{A_i} - \vec{x}_i\right)\times [\sigma_1]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \\ \vdots \\ \vec{M}_k(\vec{x}_i) = \int_{Ai} \left(\vec{x}_{A_i} - \vec{x}_i\right)\times [\sigma_k]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \end{pmatrix}_{\mathrm{mod}}$$

$$\begin{pmatrix} \vec{F}_1(\vec{x}_i) = \int_{A_i} [\sigma_1]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \\ \vdots \\ \vec{F}_l(\vec{x}_i) = \int_{A_i} [\sigma_l]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \end{pmatrix}_{irm} \quad \begin{pmatrix} \vec{M}_1(\vec{x}_i) = \int_{A_i} \left(\vec{x}_{A_i} - \vec{x}_i\right)\times [\sigma_1]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \\ \vdots \\ \vec{M}_l(\vec{x}_i) = \int_{A_i} \left(\vec{x}_{A_i} - \vec{x}_i\right)\times [\sigma_l]\left(\vec{x}_{A_i}\right)\cdot \vec{n}_i \cdot dA_i \end{pmatrix}_{irm}$$

***scr.odb**

SIMPACK **Integration**

***model.spck**

***model.sbr**

Modal coordinates

$$\begin{pmatrix} q_1(t) \\ \vdots \\ q_k(t) \end{pmatrix}_{\mathrm{mod}}$$

$$\begin{pmatrix} q_1(t) \\ \vdots \\ q_l(t) \end{pmatrix}_{irm}$$

SIMPACK **FEMFAT Export**

Superposition time domain

$$[\sigma](\vec{x},t) = \sum_k [\sigma_k](\vec{x})\cdot q_k(t) + \sum_l [\sigma_l](\vec{x})\cdot q_l(t)$$

***sup.odb**

$$\vec{F}(\vec{x}_i,t) = \sum_k \vec{F}_k(\vec{x}_i)\cdot q_k(t) + \sum_l \vec{F}_l(\vec{x}_i)\cdot q_l(t)$$

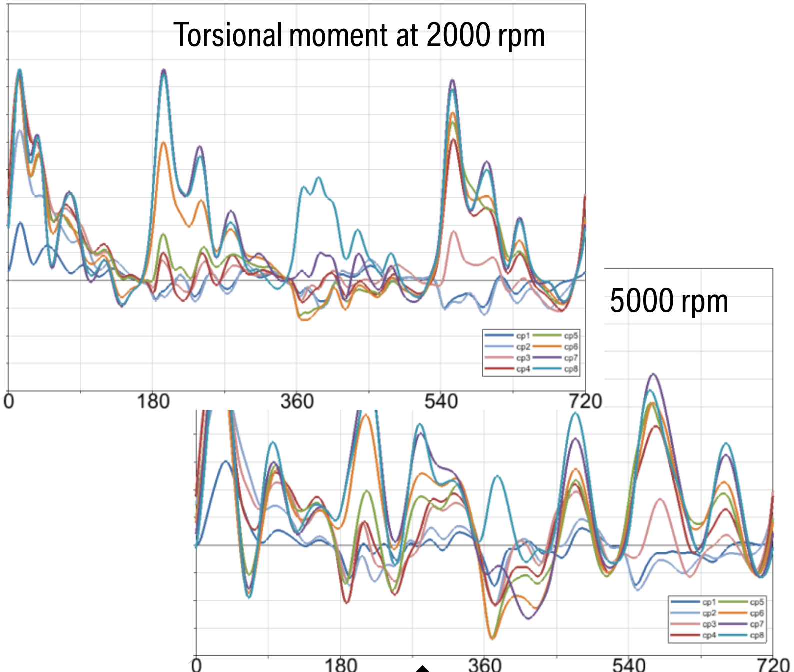
$$\vec{M}(\vec{x}_i,t) = \sum_k \vec{M}_k(\vec{x}_i)\cdot q_k(t) + \sum_l \vec{M}_l(\vec{x}_i)\cdot q_l(t)$$

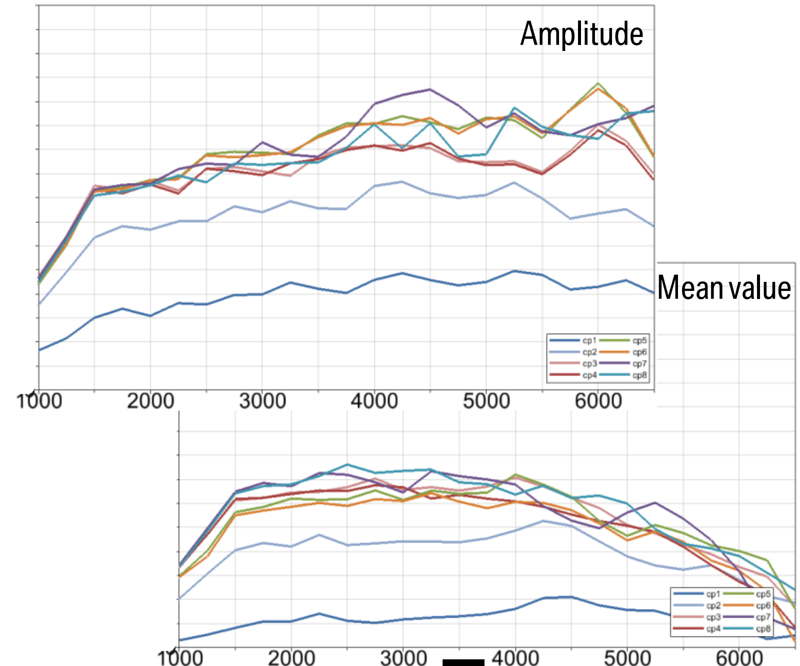
***sup.srf**

ABAQUS **Python**

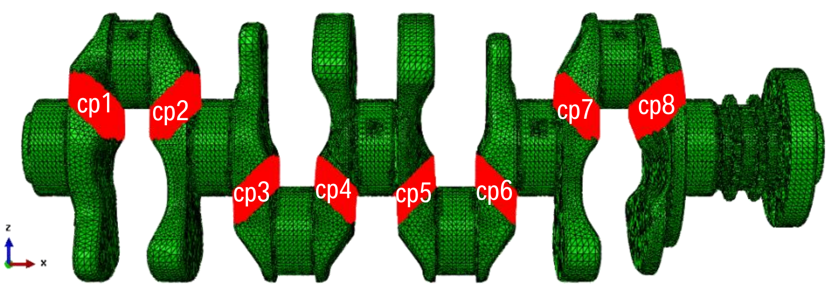
i : Schnittebene, l : IRM – Mode, k : Eigen – Mode

CALCULATION OF CUTTING LOADS EXAMPLE.

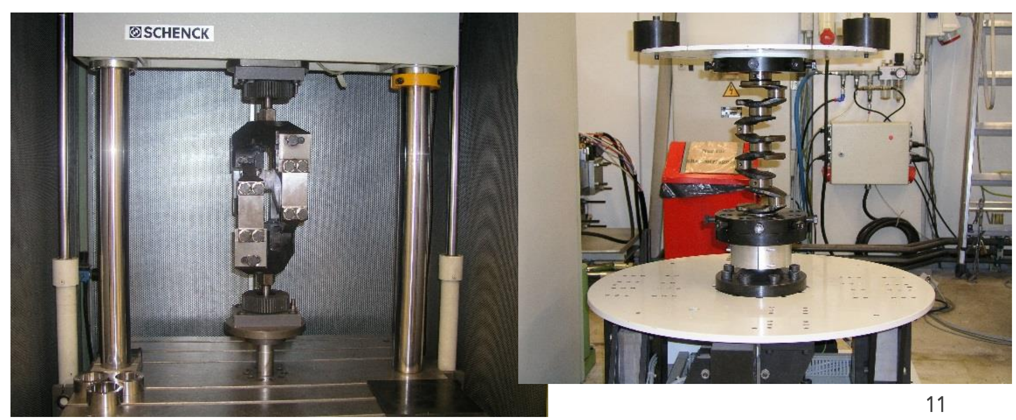




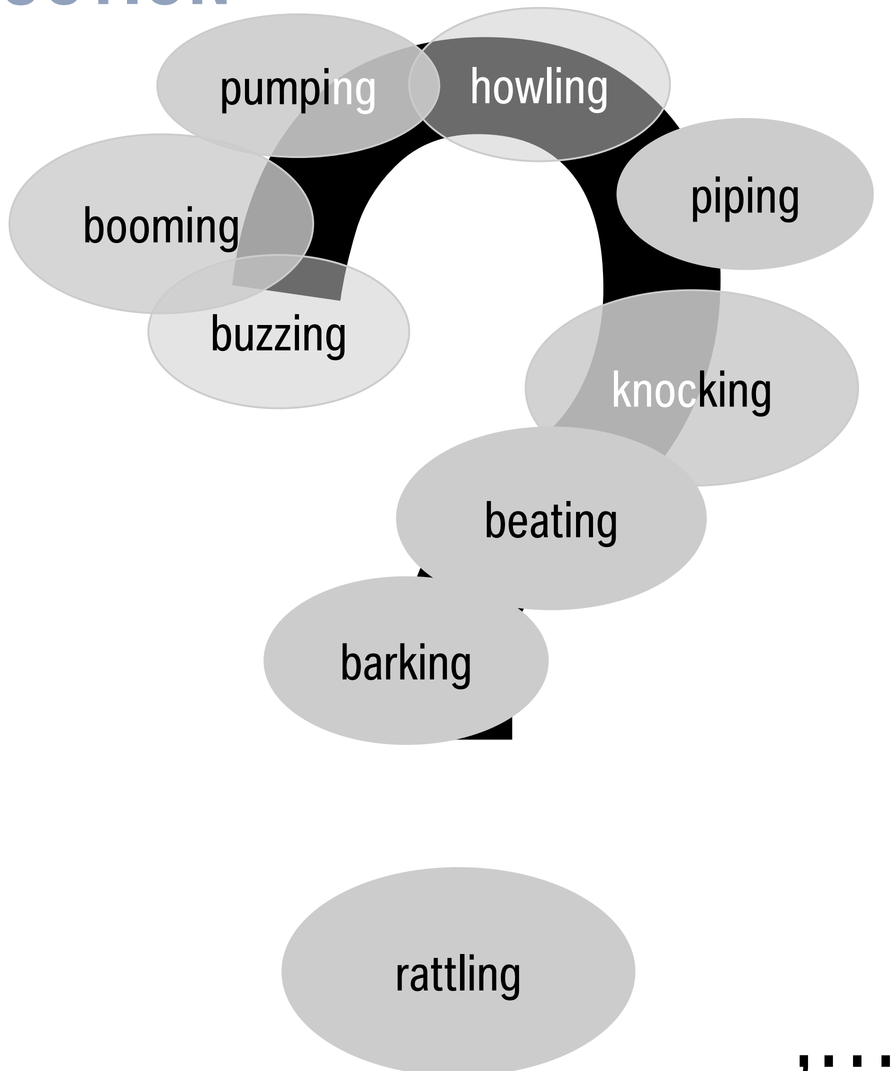
Definition of cutting planes



Input data for hardware testing



NVH INTRODUCTION



S: Many NVH-phenomena observed at engines are affected by the cranktrain as heart of the engine.

Our focus today: solid dynamics of crankshaft and its effects on the engine structure.

NVH INTRODUCTION

Governing equations ["trinity" of mechanics]:

$$\rho \ddot{u}_i = \sigma_{ij,j} + \rho f_i$$

$$\varepsilon_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i} + u_{i,n}u_{n,j}\right)$$

$$\sigma_{ij} \Leftrightarrow \varepsilon_{ij}$$

Focusing **structure** born sound in **time domain** for **linear elastic** with **linear strain kinematics** continua:

$$\boxed{\begin{aligned} \rho \ddot{u}_i &= \sigma_{ij,j} + \rho f_i \\ \varepsilon_{ij} &= \frac{1}{2}\left(u_{i,j} + u_{j,i}\right) \\ \sigma_{ij} &= C_{ijkl}\varepsilon_{kl} \end{aligned}}$$

$$t_i(x_k) = \bar{t}_i(x_k) \qquad x_k \in \partial B^t$$

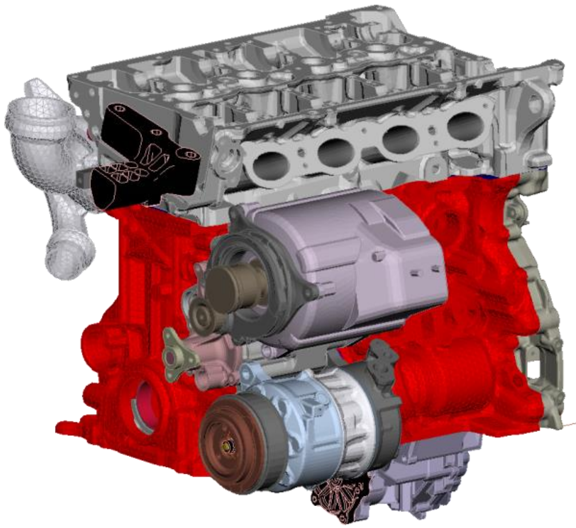
$$u_i(x_k) = \bar{u}_i(x_k) \qquad x_k \in \partial B^u$$

S: The big numerical solution part is already done by: DASSAULT SYSTEMES | The 3DEXPERIENCE® Company, thanks a lot!

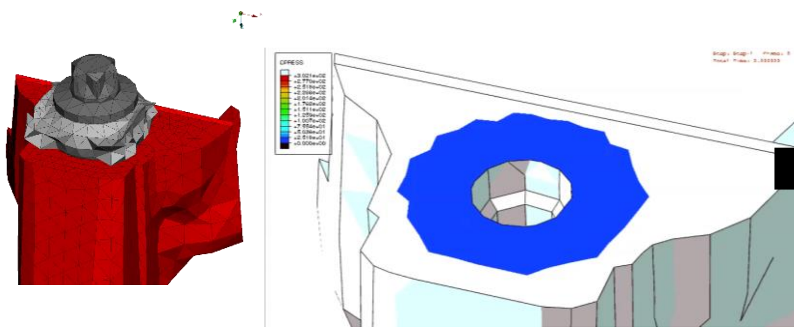
Q: Where is the damping?

MODELL DESCRIPTION.NVH

Structural mechanics world

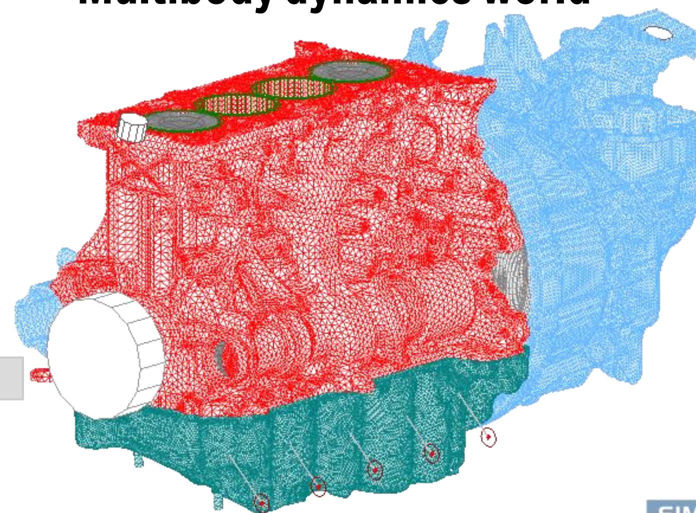


Division in substructures



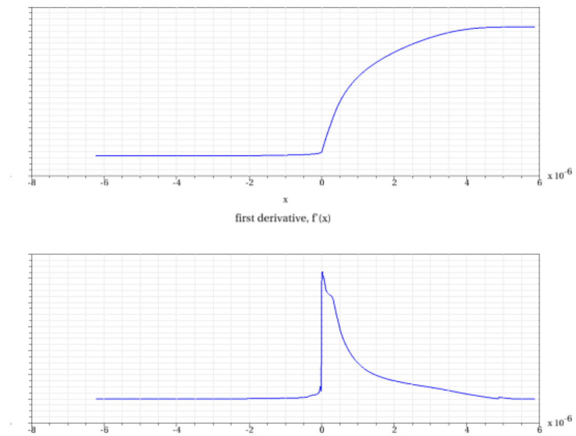
Parameter identification

Multibody dynamics world



SIMPACK assembly of engine model

?



?

S: The “boundarys” between FE and MBS Simulations are vanishing and they have to.

NVH CALCULATION
ASSEMBLY OF SUBMODELS AND LOAD CASE.

010_EGB
Engine block with gearbox
- Flexible

010_CRB
Crankshaft bearing
- Simpack hydrodynamic bearing with hydrodynamic method

020_CRS
Crankshaft
- 3D model
- Flexible

030_CNB
Conrod bearing
- Constraint

030_CTR
Crank train
- Flexible
- Simpack bearing with hydrodynamic method

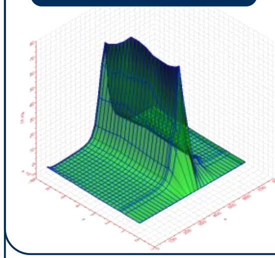
040_FCC
Flywheel / Converter
- Flexible
- One mass oscillator, primary side only

050_TVD
Torsional vibration damper
- Flexible
- 3D

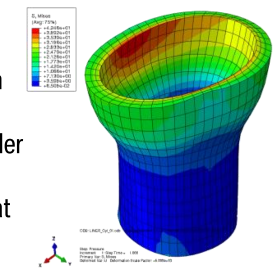
060_AGx
Balancing shaft
- Flexible
- Gear pair

Submodel

099_GAS

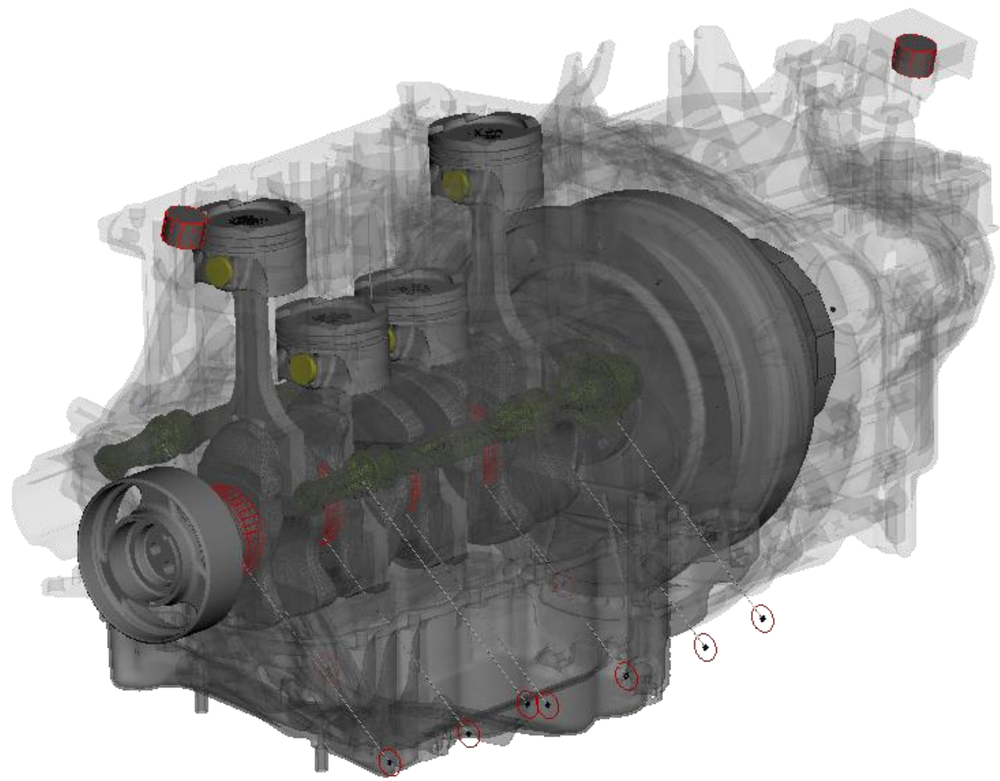


Gas forces
- Defines cylinder pressure time dependency by given crankshaft angle, angular frequency and ignition order
- Various engine subtypes
- Cylinder pressure acting at flexible piston and flexible cylinder



900_LOD
Load brake

Load Case

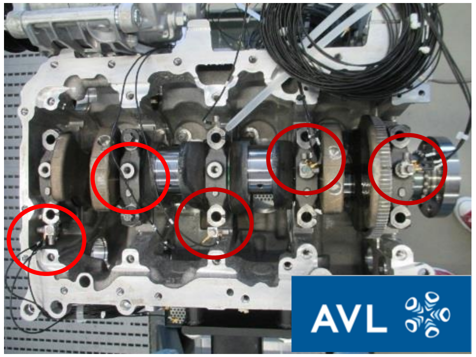


SOME RESULTS.NVH

Testing structural mechanics world

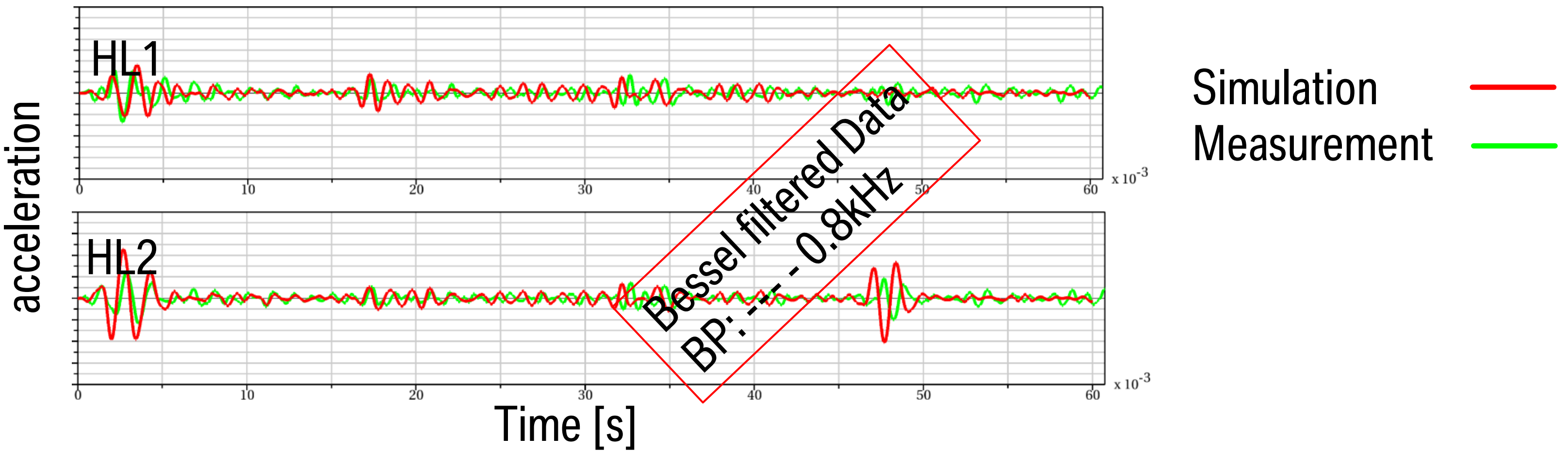
CMA and damping experiments on subsystems by ICS

Testing multibody dynamics world



Measurements at operating engine by BMW and AVL

Bringing it all together:



S: Simulation matches very well the measurements in the focused frequency range. At all sensor positions. But not yet so perfect in all directions. This enable us to study in detail **time dominated** NVH phenomena within linear structures, but with full beauty of **nonlinearity** of MBS.

SUMMARY AND OUTLOOK.

– Engine database concept leads to fast model setup with easy exchangeability between different components and levels of details
– Process control with minimum user interference by usage of solver script
– Fatigue strength calculation of crankshafts established as tool for design approval before hardware testing
– Calculation of cutting loads for hardware validation of fatigue strength calculation
– NVH calculations are leading to better understanding of acoustic phenomena
– Future Plans:
  - Parallel calculation of different engine speeds
  - Full scale introduction of Simpack hydrodynamic bearing and validation with measurements in an operating fast running engine
  - Further detailed calculation of NVH phenomena by growing together of MBS and FE models and prediction of NVH quality in early stages of development