Simulation of an Engine Speed-Up Run

MBS - FE - EHD - FATIGUE

MAGNA STEYR

ENGINEERING CENTER STEYR
GmbH & Co KG

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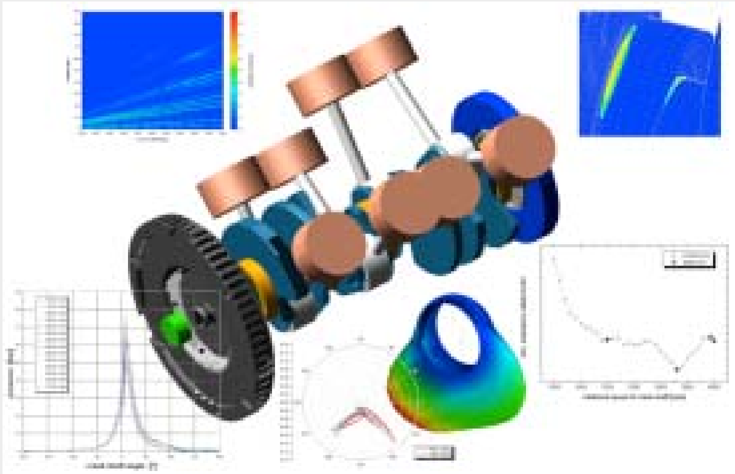
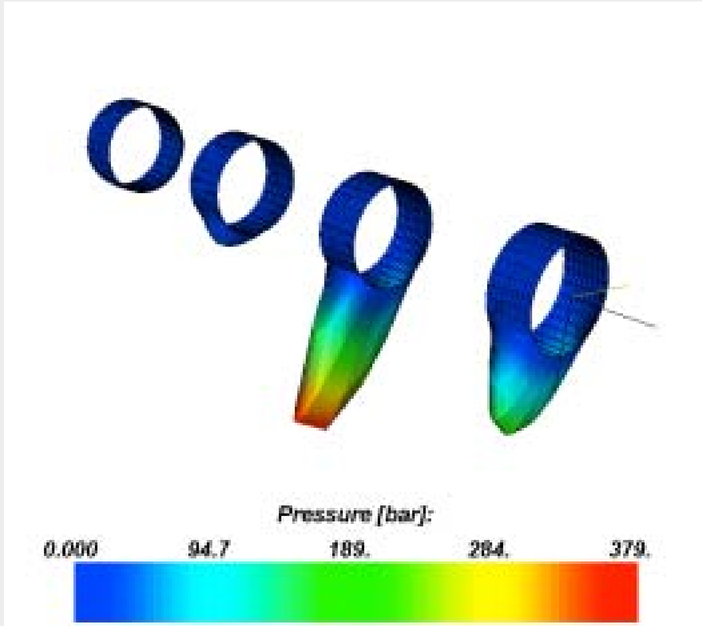
Introduction Fatigue lifetime prediction of a crank shaft:

Goal:

- consider bending line of crank shaft as accurate as possible

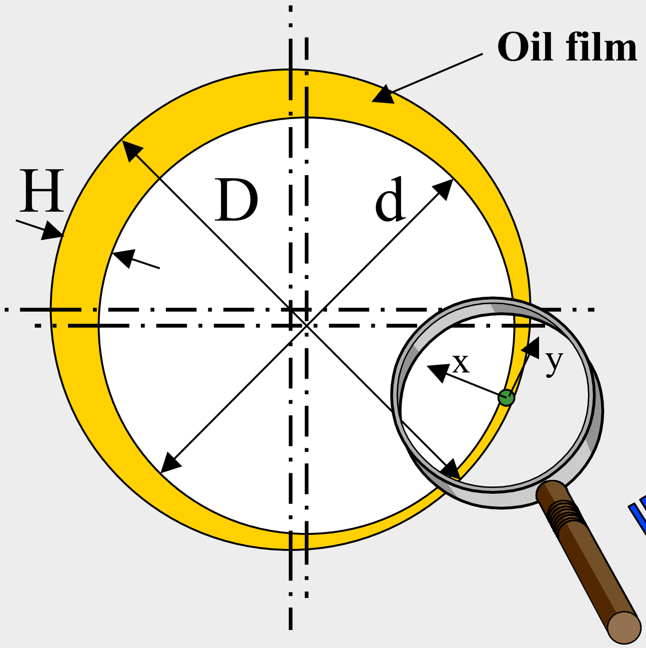


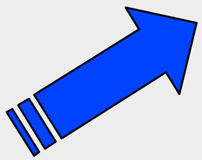


Approach:

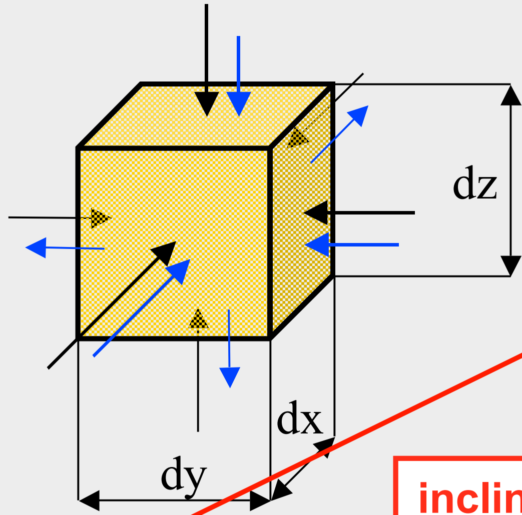
- linear reacting structure (FE)
- large nonlinear displacements (MBS)
- oil film in main bearings (EHD: elasto-hydrodynamic oil film model)
- modally based fatigue lifetime prediction (FEMFAT/MAX)

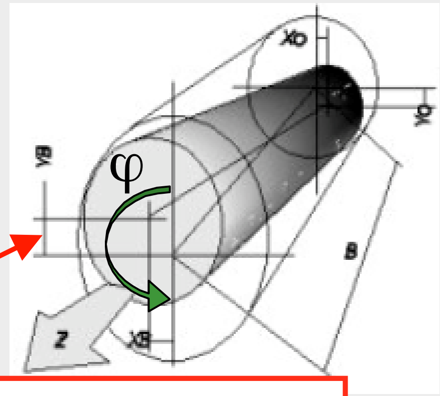
Oil film model (EHD)





differential fluid element:





inclined position of pin

Navier Stokes Equation

→ Reynolds differential equation:

$$\frac{\partial}{\partial\varphi}\left(H^3\frac{\partial p}{\partial\varphi}\right)+\left(\frac{D}{B}\right)^2\frac{\partial}{\partial Z}\left(H^3\frac{\partial p}{\partial Z}\right)=\frac{6c}{\psi^2}\left(u_B'\frac{\partial H}{\partial\varphi}+2\frac{\partial H}{\partial t}\right)$$

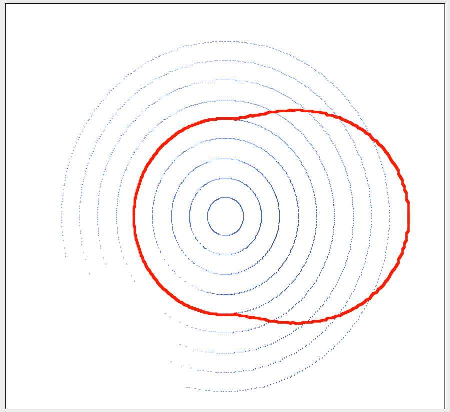
H(φ,z) .... lubrication gap geometry

squeezing and expulsion of oil film and dyn. deformations of bearing shell and pin due to local pressure inside bearing

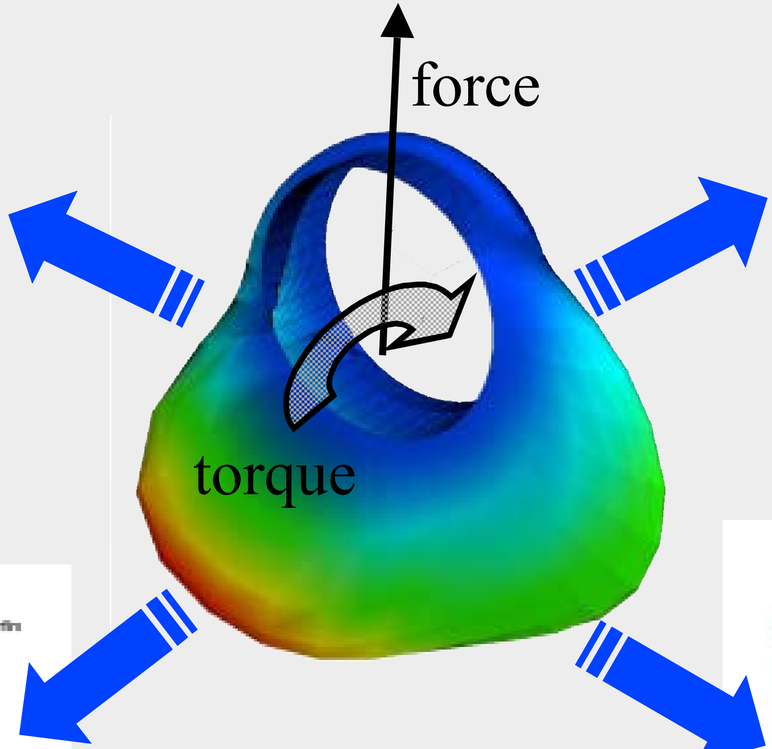
partial elliptic diff. equation

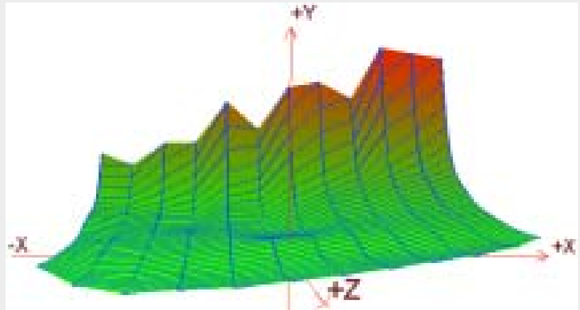
→ numerically solved (highly optimized)

Oil film model (EHD)

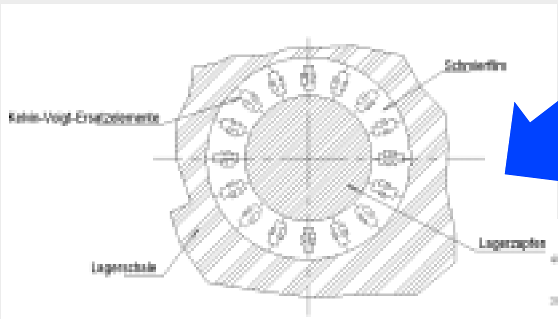


1 Idealized symmetric pressure distribution

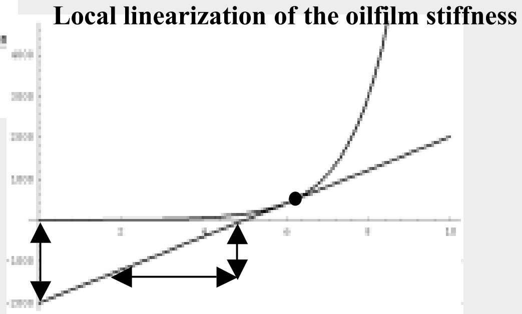


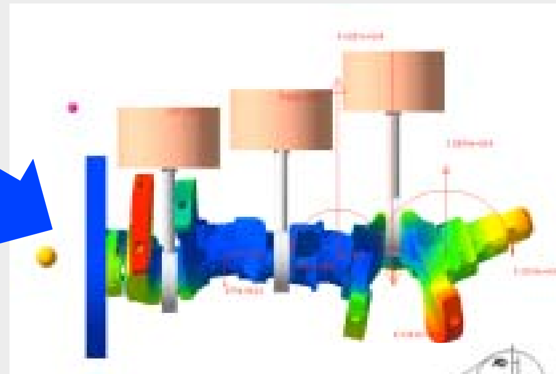


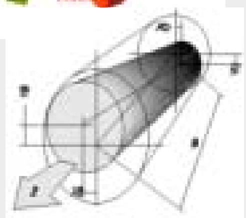
3 Computation of a characteristic map (up to 9 dimensions!)



2 Time and position dependent stiffness and damping values

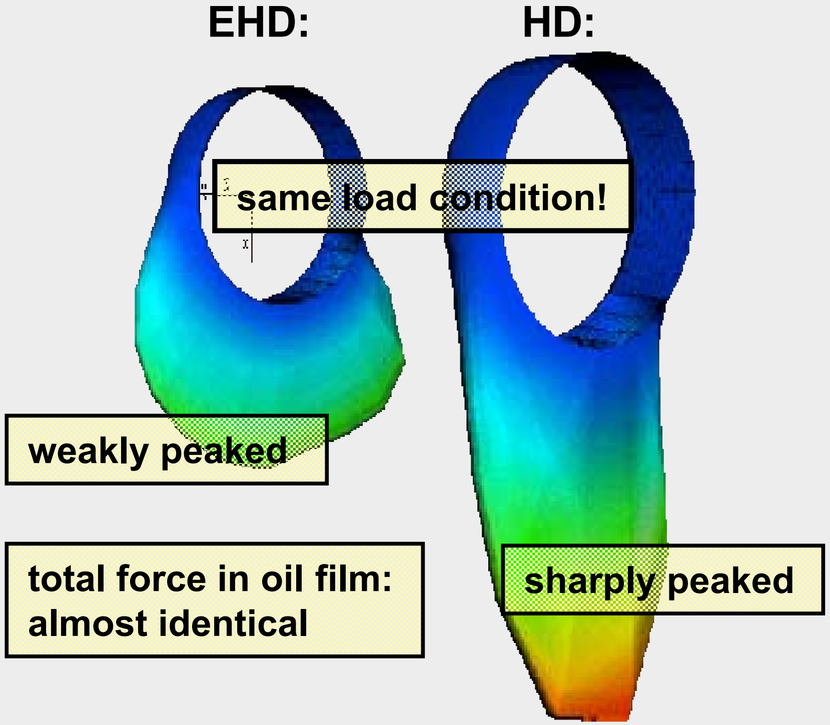






4 Co-Simulation

Oil film model (EHD)



➔ classical HD:

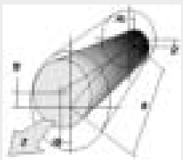
- ➔ cylindrical and stiff (rigid) bearing shell
- ➔ plain problem (no inclined position)

➔ classical EHD:

- ➔ bearing shell fully flexible
- ➔ inclined position of crank shaft

➔ therefore (E)HD:

- ➔ cylindrical bearing shell, but linearized stiffness (FE) against engine block
  - ➔ crank shaft dynamics: shape of pressure peak not so important (cylindrical shell)
  - ➔ global properties are important (stiffness & damping of oil film as well as flexing of bearing chair)

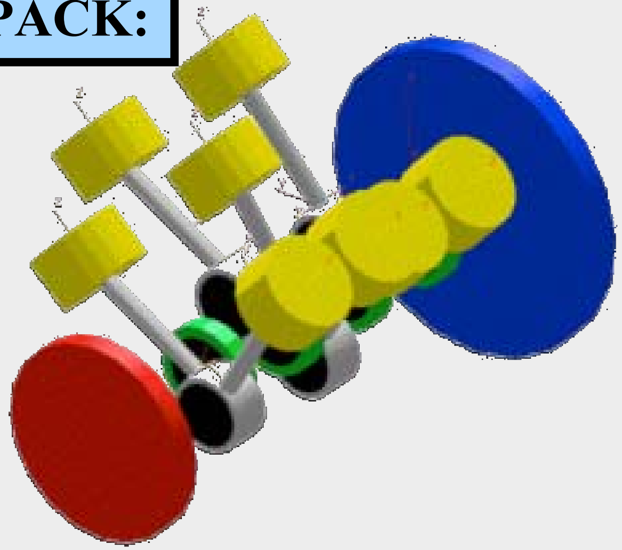


➔ <u>inclined position of crank shaft</u>

Integration of EHD in MBS

Co-Simulation process:

SIMPACK:



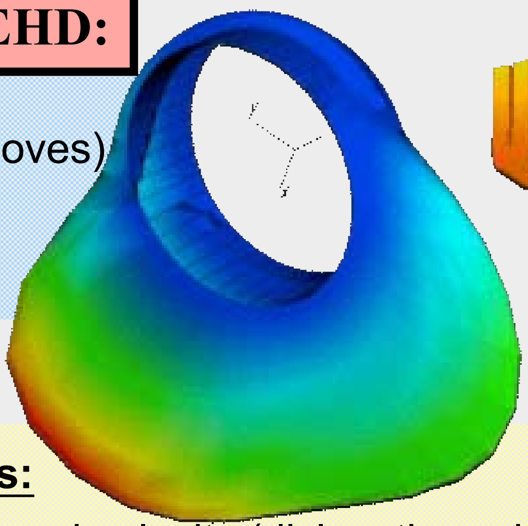
force & torque

positions & velocities:

bearing settings:

- diameter
- width
- clearance
- oil viscosity
- (lubricating grooves)
- (oil inlets)
- (oil outlets)

EHD:

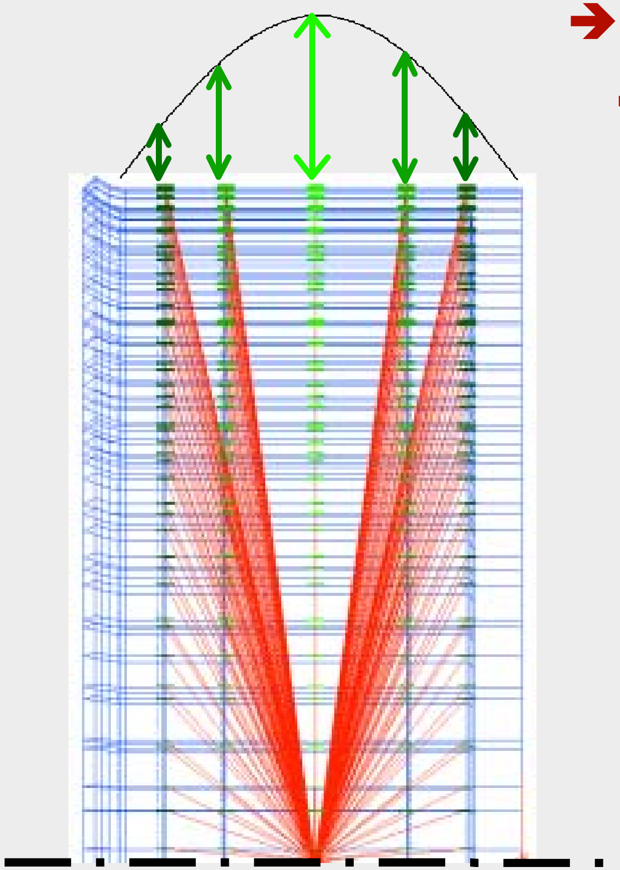


optional outputs:

- journal position and velocity (dislocation orbits)
- pressure distributions at definable intervals
- bearing forces und torques

FE - Modeling

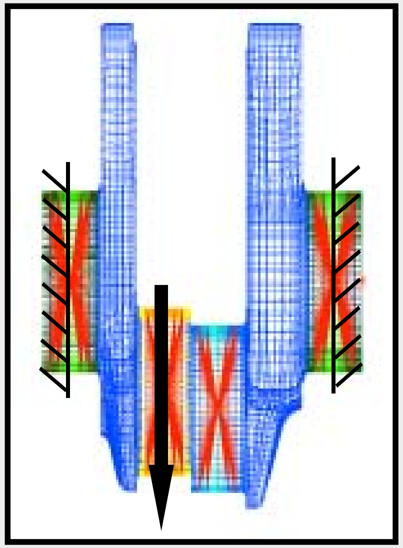
➔ application of bearing forces using radial springs and rigid cage

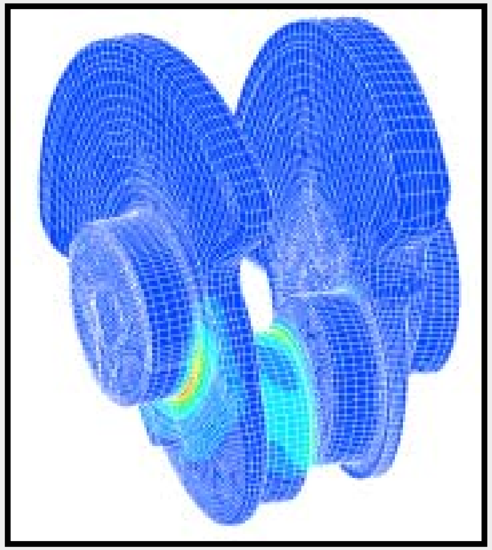


➔ pattern of radial spring stiffnesses: sine-wave

➔ stiffness: max. static ignition force ➔ displacement cage - crank shaft ≤ 0.5% bearing clearance

➔ application at surface (max. stress in notch area)



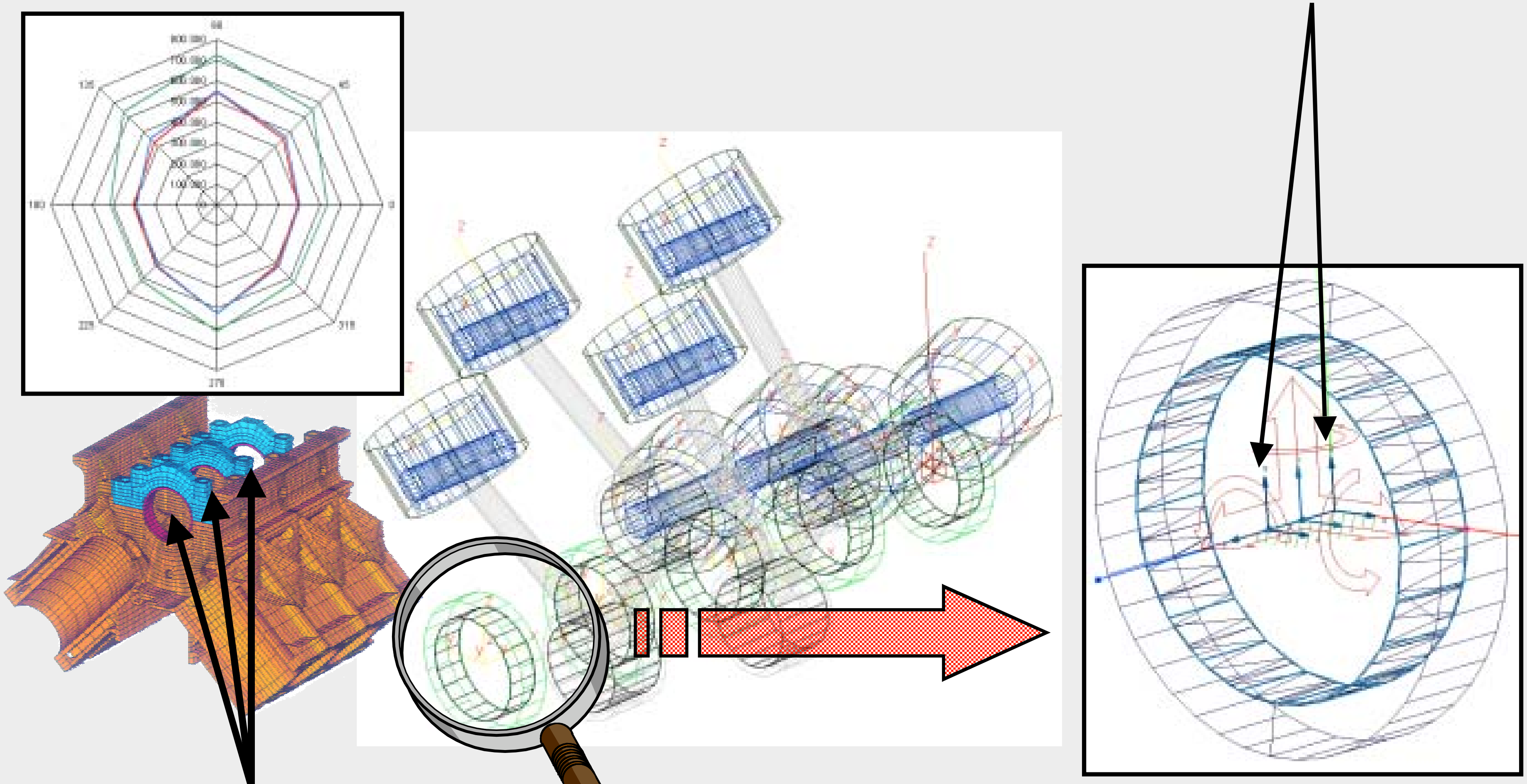


➔ local increase of stiffness: increase in eigenfrequencies: ≤ 1.4%

MBS - Modeling

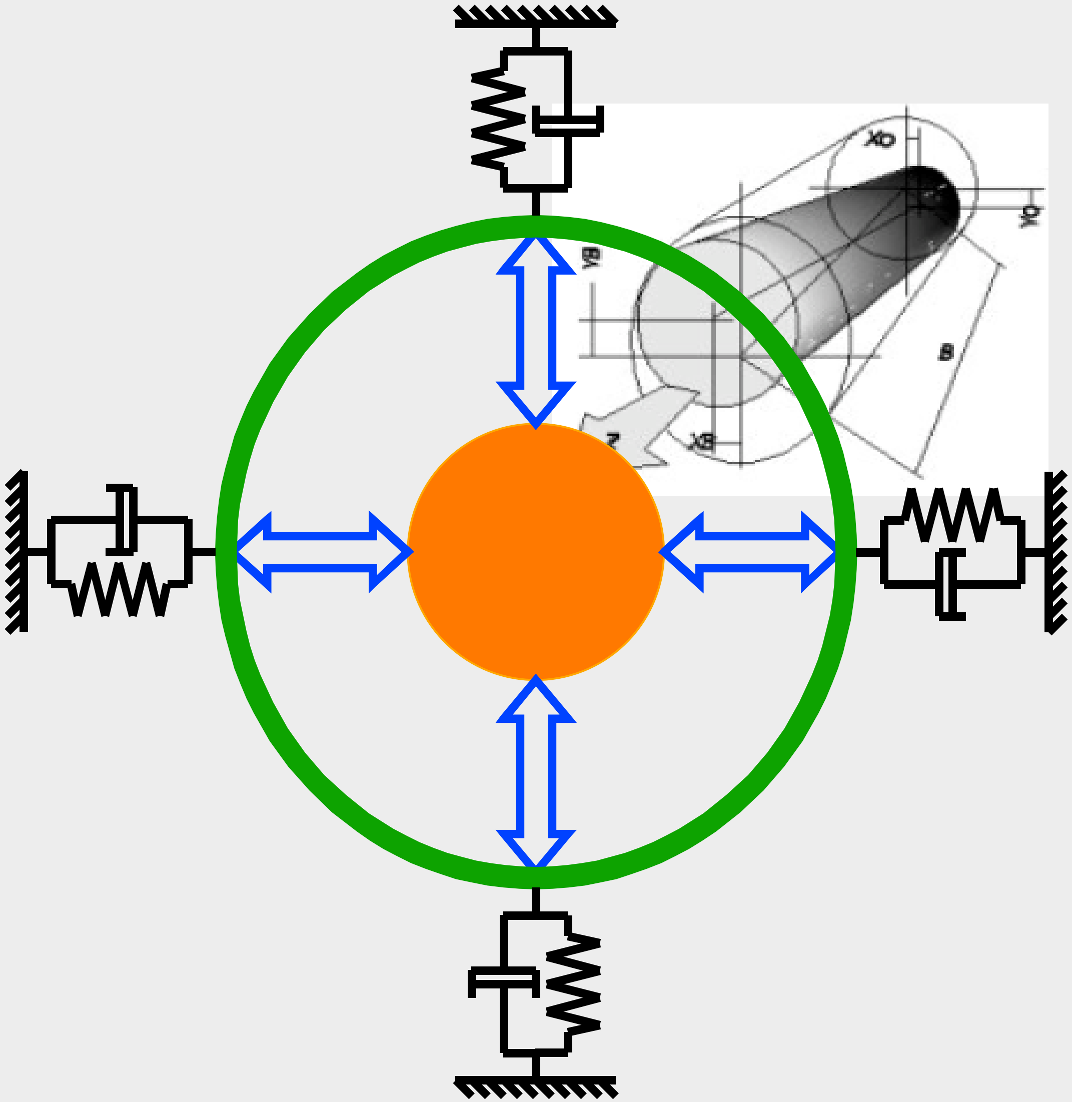
keeping track of actual bearing state:

two initially coincident markers (shell and journal) at each side



Linearized bearing block stiffnesses (GFORCE)

Topology



crank shaft (flex. body)

rigid bearing shell

oil film model:

Connecting bearing shell and crank shaft

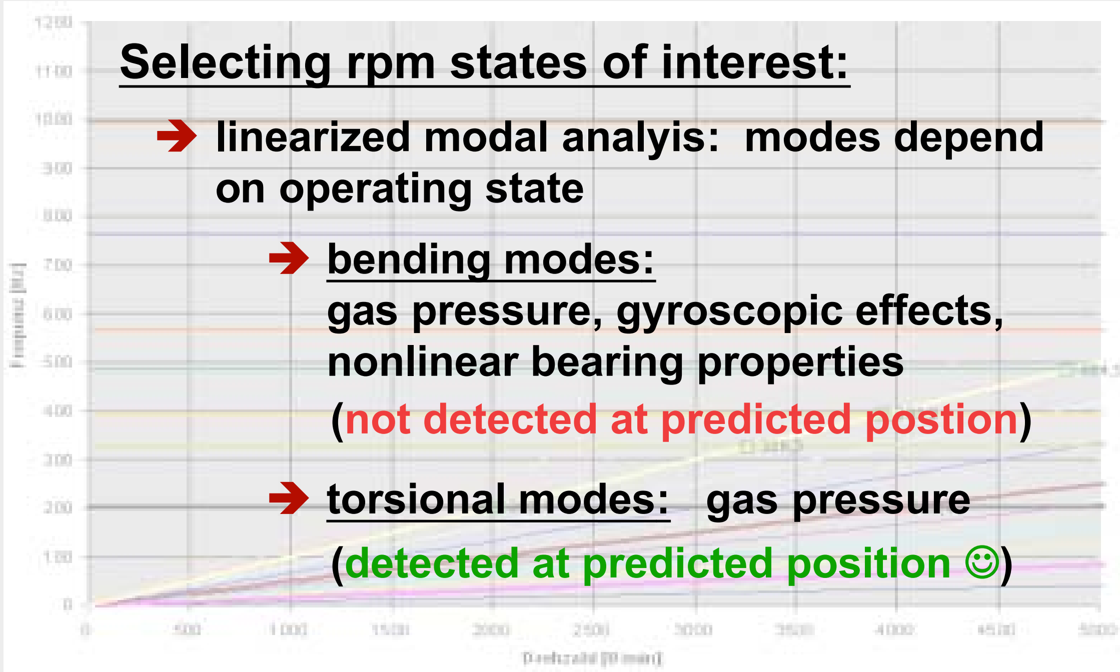
User Writen Subroutine

Output: Force and torque acting between bearing shell and crank

linearized stiffness of bearing housing

Simulation of an Engine Run-Up

- flexible crank shaft
- dynamics of crank train
- nonlinear 2 mass flywheel
- belt absorber
- ignition forces
- mass forces
- journal bearings (EHD)
- resonance excitation
- bearing block stiffnesses

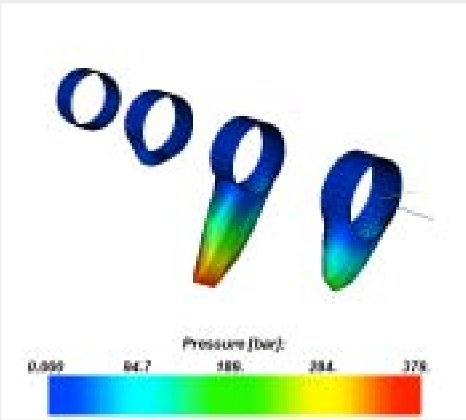


Selecting rpm states of interest:

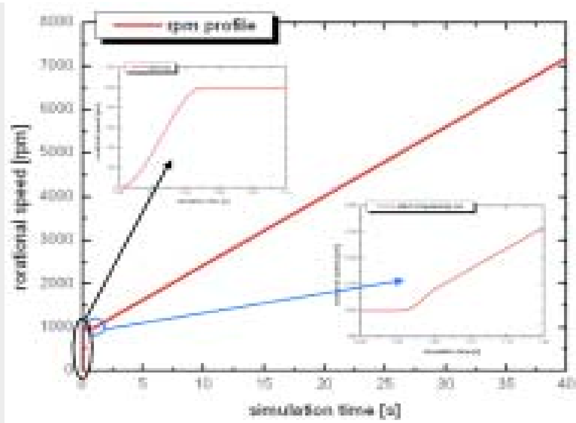
➔ linearized modal analyis: modes depend on operating state

➔ **bending modes:** gas pressure, gyroscopic effects, nonlinear bearing properties (not detected at predicted postion)

➔ **torsional modes:** gas pressure (detected at predicted position ☺)



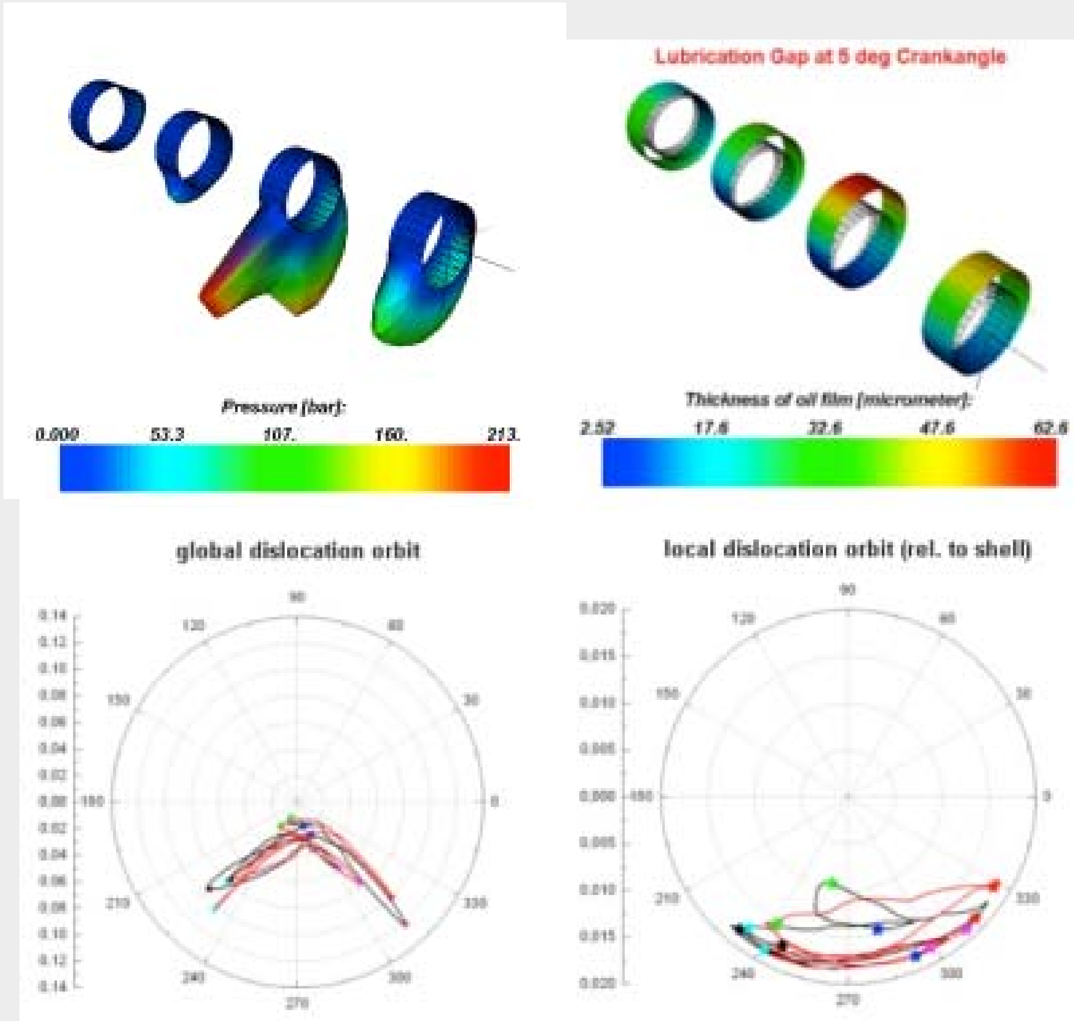
➔ engine run-up is necessary in order to detect all resonances in the rpm range



Simulation Results

User selectable outputs:

- dislocation orbits
- pressure distributions
- lubrication gap geometries
- bearing reaction forces



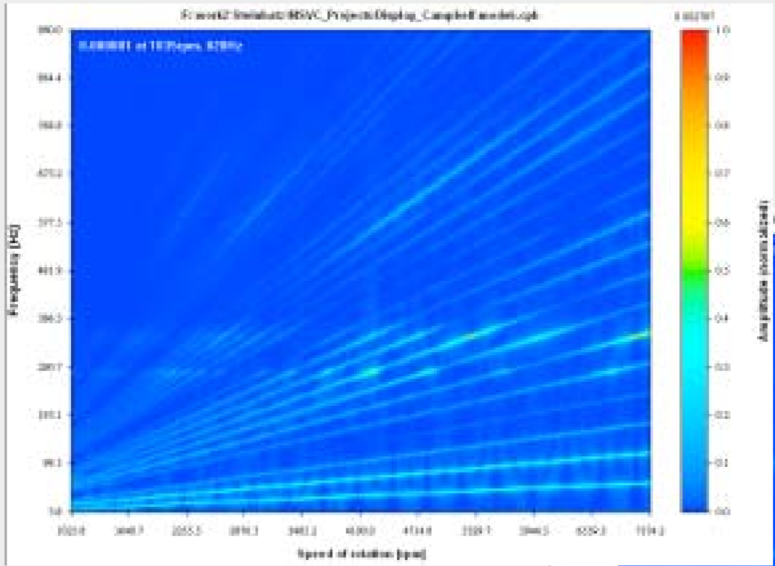
for further use in post-processing programs:

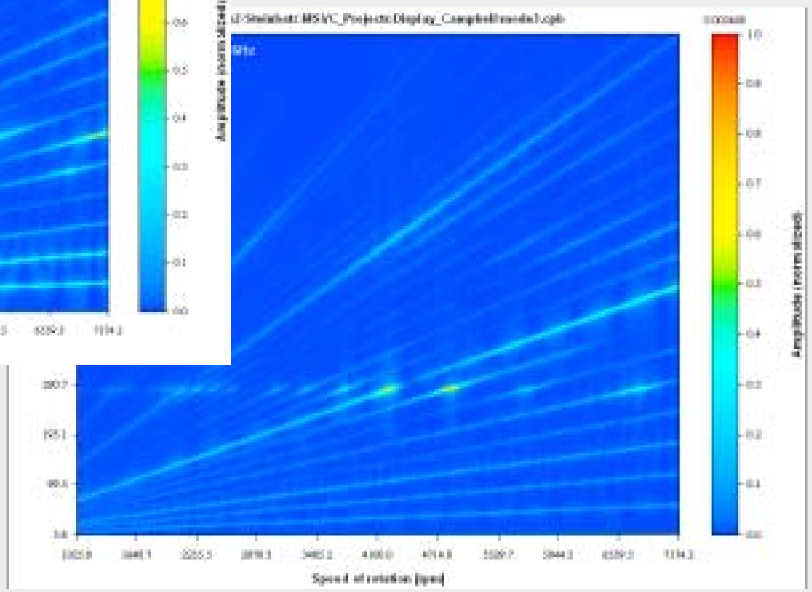
e.g.: **FEMFAT / EHD**

Identification of resonances

Use outputs of dynamic simulation to create Campbell diagrams

- characteristic rpm curve (rpm vs. time)
  - signal data (signal vs. time)
    - FFT of equally spaced rpm regions (done by software)

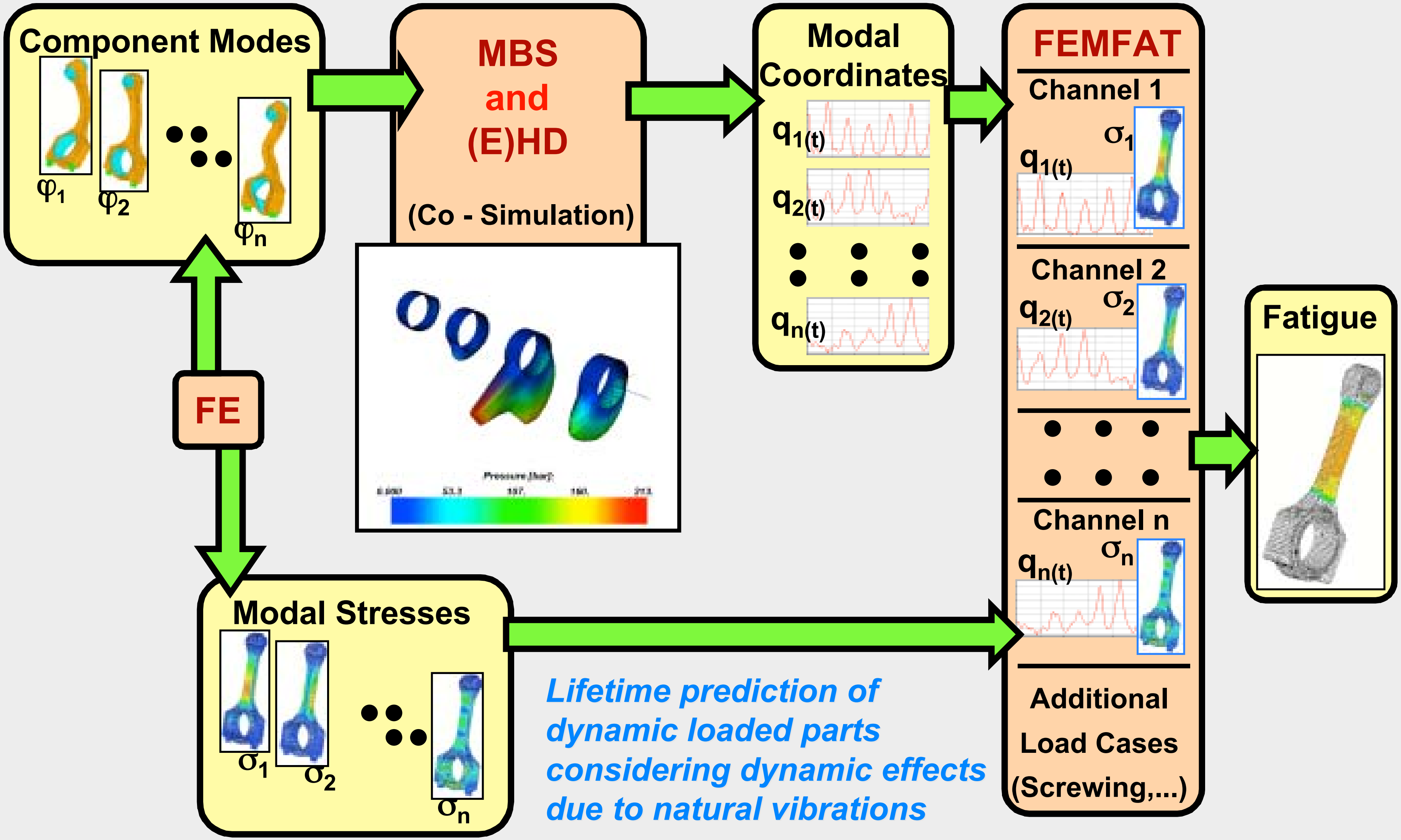




➔ modal coordinates (tosion, bending)

➔ SIMPACK measures (2 mass flywheel, belt absorber, acceleration sensor, ...)

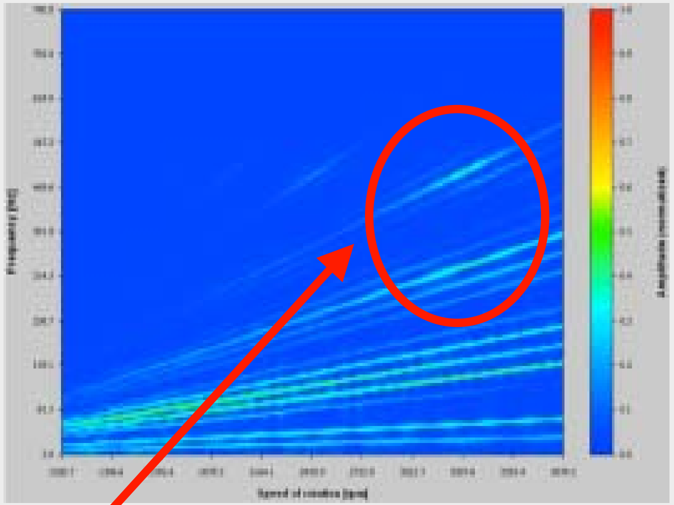
Fatigue - based on modal stresses

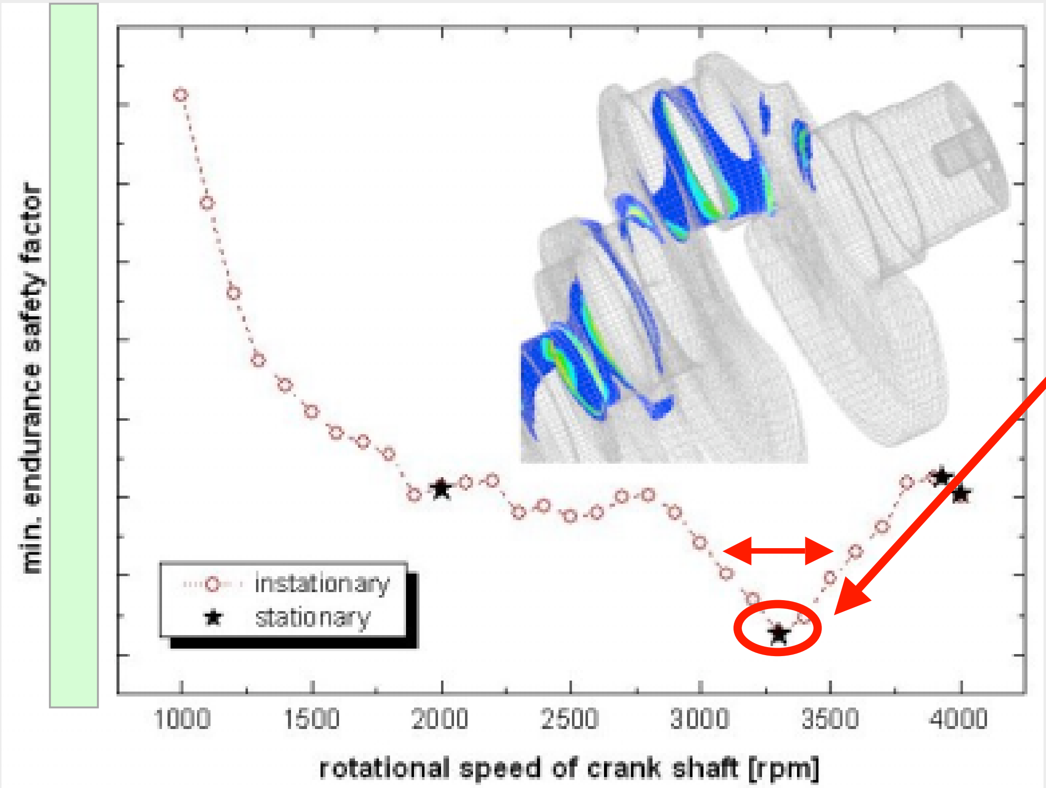


Fatigue results - V6 engine

- reasonable simulation time
  - rpm sensitive fatigue analysis
    - endurance safety distribution
      - identification of resonances

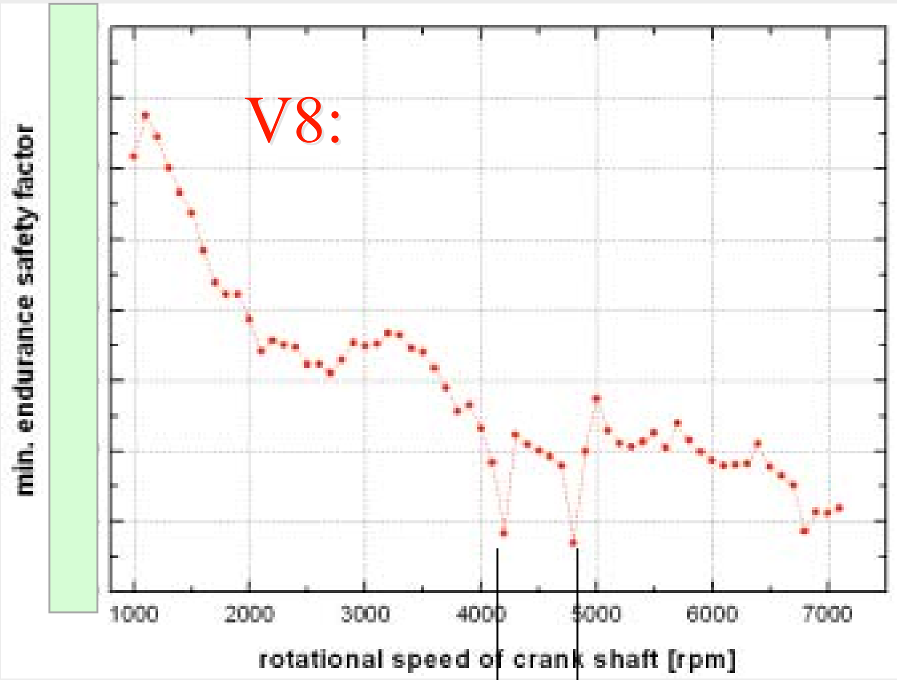
Campbell diagram:

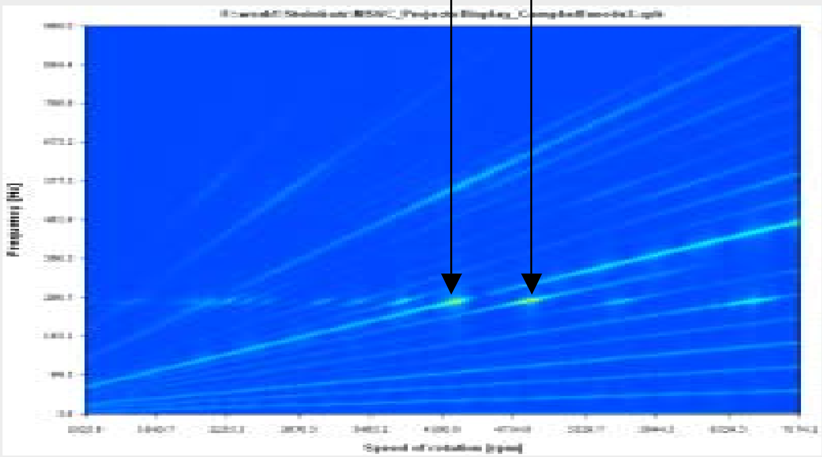


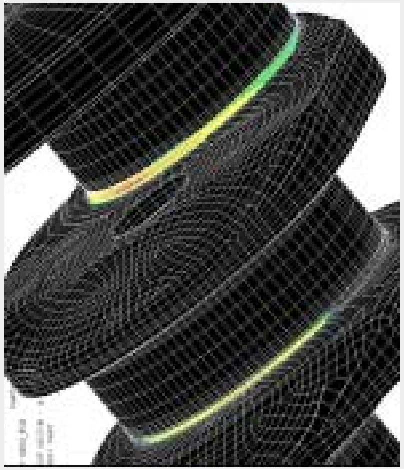


- boundary conditions: (constant moment, constant rpm)
- modally based fatigue lifetime prediction with ***FEMFAT-MAX*** considers dynamic effects like resonance excitations!

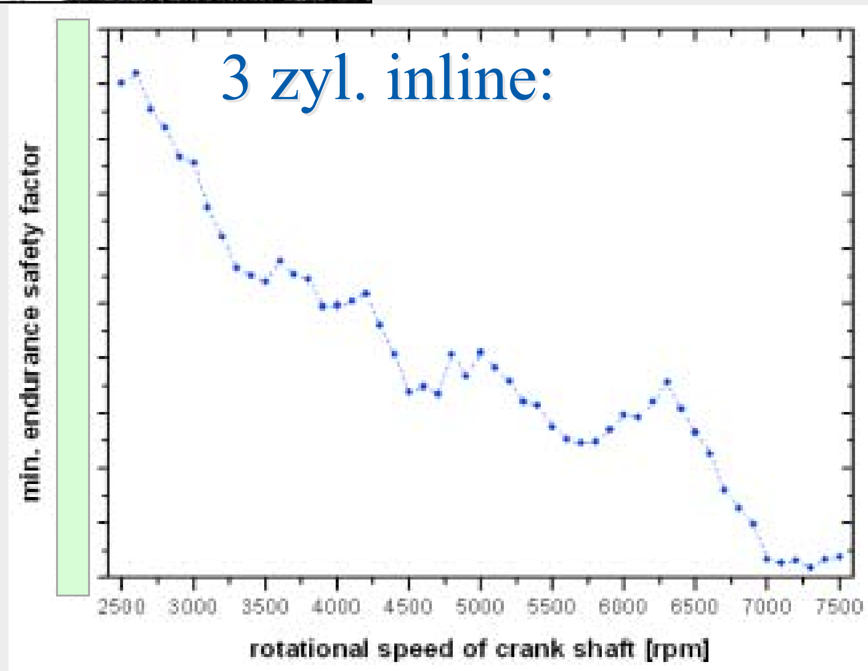
Fatigue results - V8 / 3 zyl. inline engine





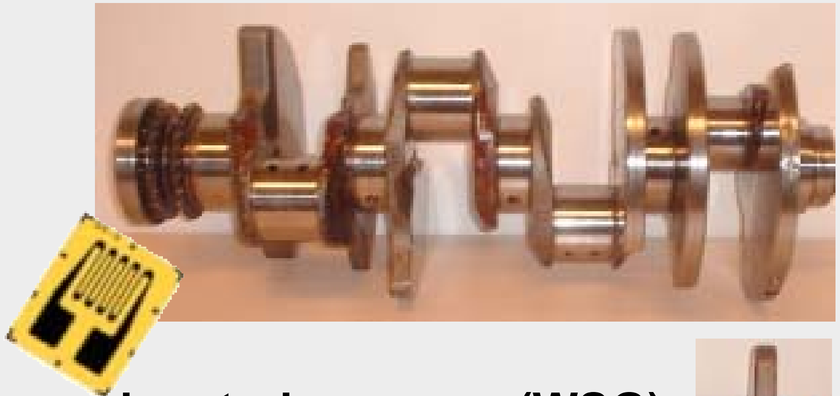


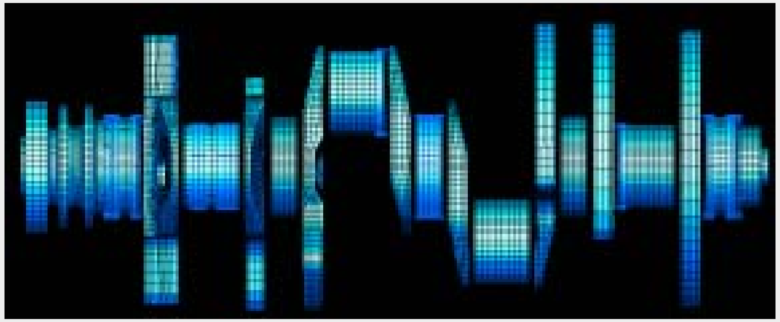
modally based fatigue lifetime prediction with ***FEMFAT-MAX*** considers dynamic effects like resonance excitations!



Verification of engine run-up 1000 to 7200 rpm at full load

Comparison of measured and simulated maximum strain amplitudes

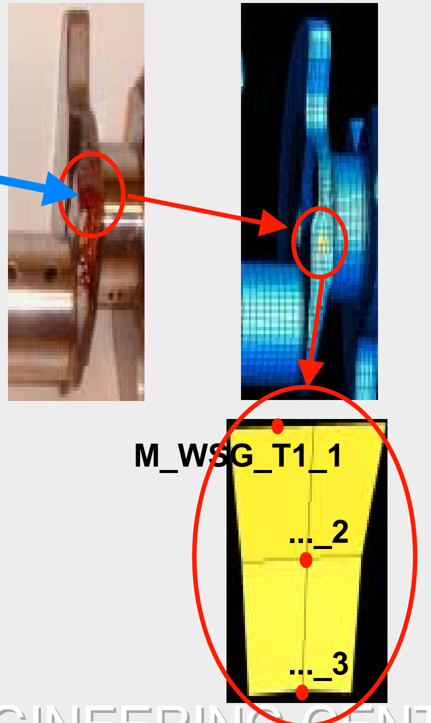




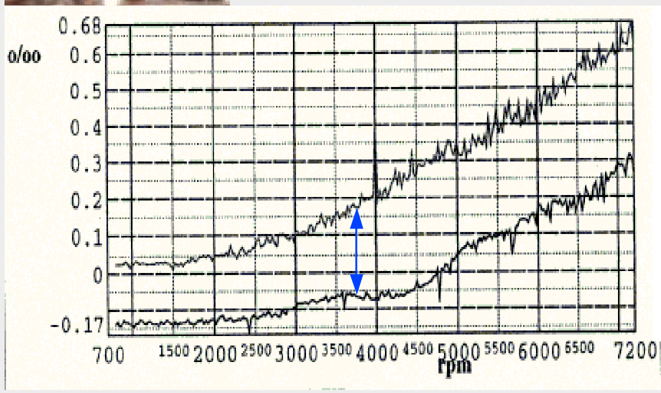
wire strain gauges (WSG)

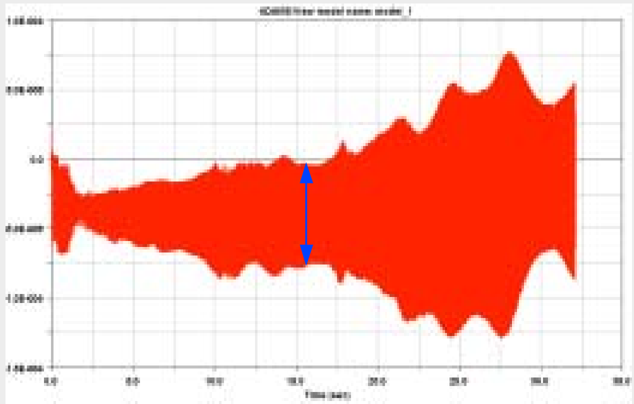
5 torsion WSG

5 bending WSG



$$\varepsilon = \frac{l_{stressed} - l_{unstressed}}{l_{unstressed}}$$

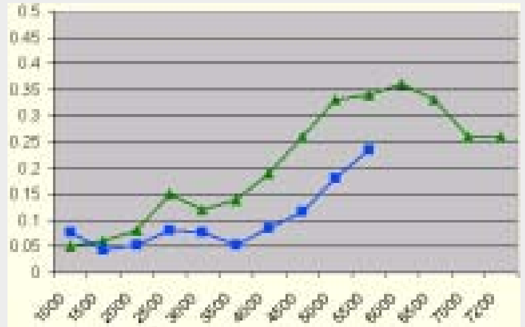


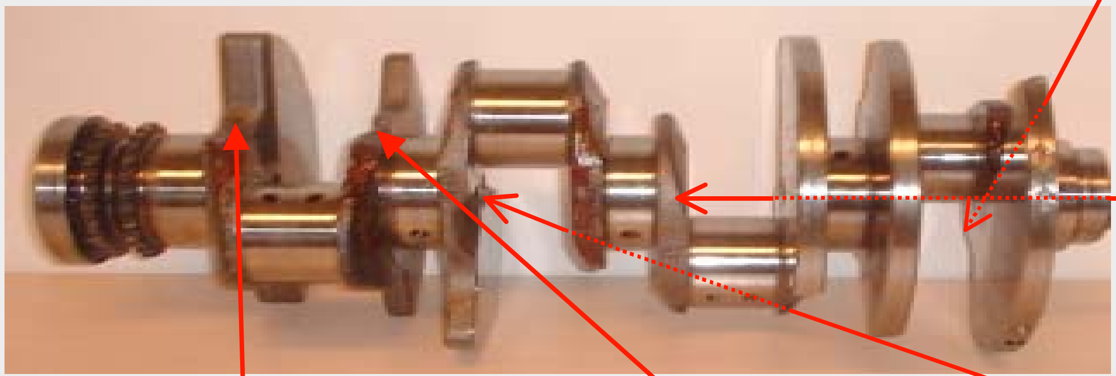


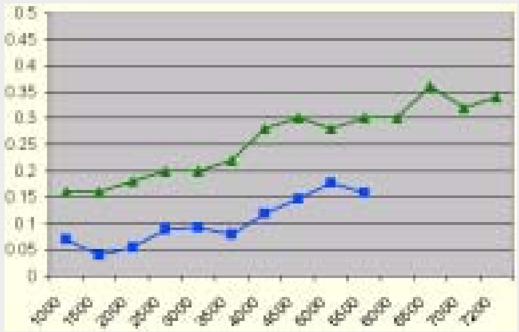
Verification of engine run-up

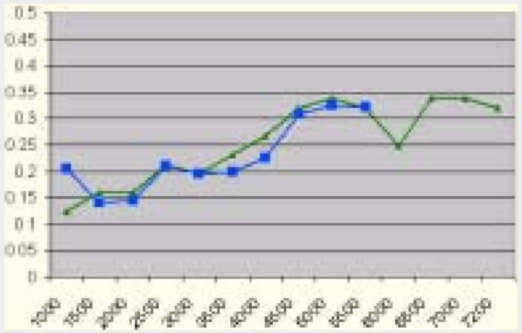
WSG sensitive to torsion:

strain measured [o/oo]
strain calculatetd [o/oo]
x - axis: rpm [1/min]







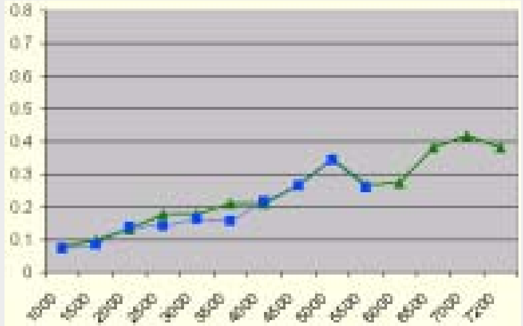


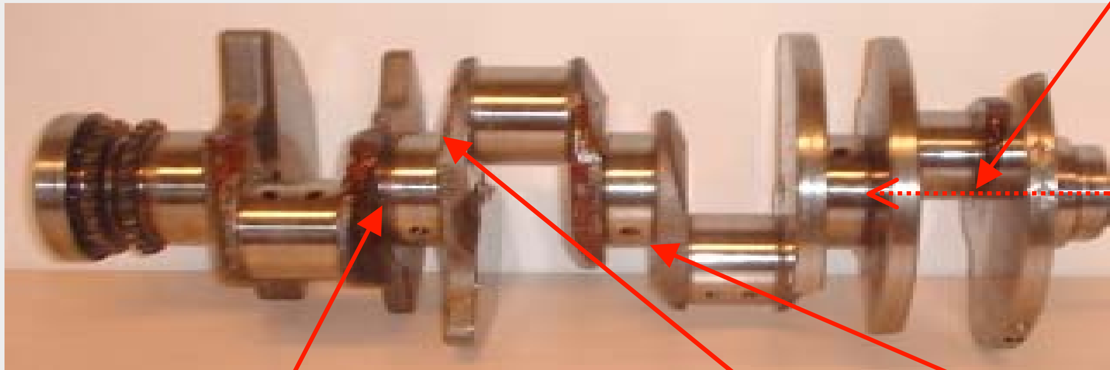
Verification of engine run-up

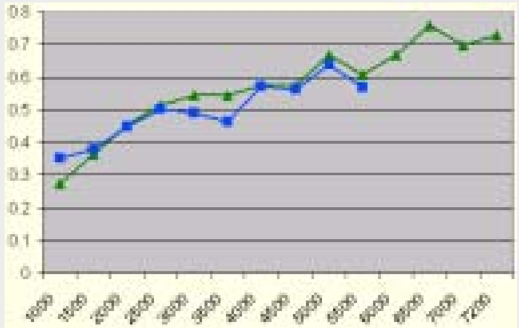
WSG sensitive to bending:

- strain measured [o/oo]
- strain calculatetd [o/oo]

x - axis: rpm [1/min]







Enhanced Dynamic Simulation by Combining FEA and MBS

Nastran

1. **Build FE model of flexible body**
   - ➡ define interface points
2. **FE modal analysis**
   - ➡ component modes, component mode stresses

SIMPACK

3. **Import FE - structure into MBS**
   - ➡ connect flexible body to rigid bodies
4. **Solve hybride FE-MBS-EHD system**
   - ➡ output time series of modal response

FEMFAT

5. **Import modal loads into FEMFAT**
   - ➡ modal stresses, time series modal response
6. **Multiaxial Fatigue Analysis in FEMFAT**
   - ➡ includes contribution of static and vibration loads