Fatigue Analysis of Flexible Bodies with AVL EXCITE, FEMFAT and ABAQUS using Modal Data Recovery

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INTRODUCTION

- General overview of AVL and the AVL EXCITE engine simulation software
- Description of a new feature of AVL EXCITE which allows the use of modal stress recovery with the ABAQUS FE software and Magna-Steyr’s FEMFAT fatigue analysis software.
AVL’S SIMULATION SOFTWARE IS LEVERAGING FROM THE SYNERGIES OF ALL AVL BUSINESS UNITS

passenger cars  2-wheelers  racing
construction  agriculture  commercial vehicle
locomotive  marine  power plants

AVL PTE
Powertrain Engineering

AVL AST
Advanced Simulation Technologies

AVL ITS
Instrumentation and Test Systems
AREA OF APPLICATION

- Cranktrain and powertrain design in the concept phase (EXCITE Designer)
  - Hydrodynamics bearing analysis
  - Torsional crankshaft vibrations
  - Crankshaft strength analysis
- Transient strength analysis
  - Crankshaft
  - Connecting Rod
  - Piston
  - Main Bearing Wall
  - Flywheel Whirl
AREA OF APPLICATION

- NVH of power units
  - Low frequency vibration analysis (engine mounts)
  - Radiated noise
  - Turbocharger and accessories

- Advanced EHD contact simulation
  - Slider bearing design
  - Slider bearing failure
  - Piston-liner contact analysis
  - Detailed investigation in friction losses

- Dynamics / acoustics of transmissions and drivelines
  - Analysis of in-stationary conditions
  - High frequency noise phenomena
EXCITE CRANKSHAFT STRENGTH ANALYSIS – PROVEN FOR ANY ENGINE SIZE
Flexible MBS under transient conditions:

- Flexible bodies represented by linear FE models, such as:
  - Engine Block
  - Crankshaft
  - Connecting Rod
- Non-Linear Joints: connect the rigid bodies, such as:
  - Simple Joints (e.g. Revolute)
  - Engine Mounts
  - Highly complex thermo elasto-hydrodynamic joints including mixed lubrication
- Excited by external forces
The EXCITE Solver computes and evaluates the equations of motion in the time domain for several engine cycles.

Results include:

- Vibrational motion of the flexible bodies.
- Forces associated with each joint.
- EHD results:
  - Clearances
  - Pressure distributions
  - Temperatures
  - Fiction power loss.
- Oil flow through bearings and supply lines.
EXCITE BODY PREPARATION
SUBSTRUCTURING PROCESS FOR FE MODELS

Equation of Motion with Reduced DOF and Matrices.

\[ \{ \Delta \ddot{u}^R \} = [\bar{M}] \{ \Delta \ddot{u}^R \} + [\bar{C}] \{ \Delta \dot{u}^R \} + [\bar{K}] \{ \Delta u^R \} \]

$L_u^R$ Matrix relates retained DOF to the exclude DOF.

\[ u = u_0 + [L_u^R] \{ \Delta u^R \} \]

$L_{\sigma}^R$ Matrix relates retained DOF to stress data.

\[ \sigma = \sigma_0 + [L_{\sigma}^R] \{ \Delta \sigma^R \} \]

The substructuring procedure calculates $\bar{M}$, $\bar{C}$, $\bar{K}$, $L_u^R$, $L_{\sigma}^R$.

The $L$ matrices are stored in the ABAQUS .sim file.

- Finite element models are used to create flexible bodies for AVL EXCITE.
- Substructuring is used to eliminate degrees of freedom to generate a reduced mass and stiffness matrix.
- Matrices (L) are stored which allow the retained DOF to be used to recover stress and displacement information for the full FE model.
The main operation for recovering stresses is to carry out matrix multiplication:
- EXCITE provides a time-history of the retained degrees of freedom.
- FE stress data is stored in the “L” matrix found in the “.sim” file.
- An interface for FEMFAT to read the stress data in the ABAQUS “.sim” is not available.
- The new software tool reads the stress data from the “.sim” file, and directly creates the FEMFAT scratch files.
- This provides the ability to carry out fatigue analysis for stresses obtained through modal stress recovery.
APPLICATIONS AND LIMITATIONS OF MODAL STRESS RECOVERY

**Advantages:**

- Preprocessing effort for crankshaft fatigue analyses.
- Better accuracy for split pin V engines.
- Oil drilling breakout areas in crankshaft pins and main.
- The scratch files generated are common to different engine operating conditions.
- The ABAQUS substructuring procedure is quite fast: A typical crankshaft requires only one or two hours.

**Limitations:**

- Linear deformations of the flexible body are assumed. The assessment of stress states in locations which are characterized by non-linear behavior, such as bolted connections, should use other analysis methods.
- ABAQUS is limited to storing stress data for one “section point” to the “.sim” file, thus stresses cannot be fully recovered to shell and beam elements.
CRANKSHAFT FATIGUE ANALYSIS
STRUCTURED MODEL APPROACH - PROCESS OVERVIEW

CAD GEOMETRY

AUTOSHAFT

MESHING EACH WEB

FEA: STIFFNESS CALC

STIFFNESS MATRIX MANIPULATIONS TO REPRESENT WEB ONLY

SHAFT MODELER
ADD DAMPER, FLYWHEEL

BEAM CRANKSHAFT

DYNAMIC SIMULATION

AVL EXCITE
CRANKSHAFT FATIGUE ANALYSIS
STRUCTURED MODEL APPROACH - PROCESS OVERVIEW

- Stress analysis is carried out for each half throw with unit deflections.
- Fatigue analysis for each ½ throw is done using FEMFAT/ChannelMax with time histories from EXCITE.
The modal stress recovery approach involves fewer steps than the structured modeling.

The process uses the same FE structure for both the mass-elastic representation in EXCITE and also for the calculation of stresses.

Linear superposition is implemented through Magna Steyer’s fatigue software FEMFAT to calculate the fatigue safety factors in the FE model.

The entire crankshaft can be assessed in a single FEMFAT job.
The modal stress recovery and structured model approaches, when compared on inline engines, show small differences. Differences are usually within 5%.
The modal stress recovery and structured model approaches yield fatigue safety factors with greater differences on V engines with split pins. Differences may be as great as 20%. The modal stress recovery provides greater numerical accuracy.
The structured model approach assumes the stiffness for any 1/2 throw of the crankshaft is similar between the beam model used in EXCITE and the FE model used for the calculation of fillet stresses.

The similarity of the 1/2 throw stiffness matrix is better for inline than for V engines with split pins.
The structured model approach requires placing a rigid body boundary condition through oil drilling breakout locations. The substructuring approach allows fatigue safety factors to be estimated at oil supply outlets as the rigid region can be reduced to a smaller size near the journal or pin axis.

Rigid cross section for each web in structured crankshaft method interferes with oil supply outlet. With substructuring and modal stress recovery it is not assumed the whole cross section is rigid.
The calculation time required to conduct a full crankshaft assessment, covering a range of engine speeds, is minimized by executing tasks in parallel. Sophisticated scheduling software is able to maximize the number of concurrent CAE tasks, while abiding by limitations to parallelization such as those imposed by token based software licenses. The image below shows actual calculation times from a recent project.
The 2014 release of AVL EXCITE will feature the new possibility of using the modal stress recovery processes with the following combination of software:

- ABAQUS – Finite Element Modeling.
- EXCITE – Multibody Dynamic Simulations of Combustion Engines.
- FEMFAT – Finite Element Fatigue Analysis.

Benefits of the new workflow for crankshaft fatigue analysis include:

- Improved numerical accuracy for V engine crankshafts with split pins.
- Analyst preprocessing and solution efforts can be reduced, leading to overall shorter analysis durations.
- The direct evaluation of oil bore breakout regions is possible through MSR.