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Large bore connecting rod simulations

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Summary. On combustion engine a connecting rod converts the reciprocating motion of a piston to the rotating motion of a crankshaft. Simulation of a large bore connection rod has been performed in Abaqus Standard, using boundary conditions from AVL EXCITE Power Unit. By using the latest simulation technologies and the well known boundary conditions, simulated stresses correspond very well with the measured ones from a running engine.

Key words: connecting rod, medium speed engine, FEM, MBS, Abaqus, Excite PU, Wärtsilä

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Introduction

The boundary conditions are very important in the finite element analysis (FEA) [6, 7]. There are several loadings that we know very accurately from the real life as they can be easily measured or are defined in the design stage. This paper presents the simulation of a large bore connecting rod. By using the advanced multibody simulation (MBS) [8] with non-linear FE-analysis and the well-known boundary conditions, stresses and even contacts [9] are simulated very accurately. It is also possible to include all kinds of manufacturing effects and loading cases [4].

Simulation workflow

Connecting rod condensation (Abaqus)

The original finite element mesh of the connecting rod model contains millions of degrees of freedom. After a component mode synthesis (CMS) and the Craig-Bampton method [2] in Abaqus [3] where the retained nodes with master degrees of freedom and eigenmodes up to adequate frequency are selected, degrees of freedom drop to under one thousand. In this particular case, the fifty lowest eigenmodes were calculated and retained in the condensation. The FE model is the same as for the non-linear FE analysis although a *TIE connection is used in all contact interfaces. *TIE connection makes the translational and rotational motion equal for a pair of surfaces [3]. One node at the centre of gravity is coupled with a distributed coupling to its surroundings where all six degrees of freedom

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are retained. Point one millimeter thick shell mesh is tied to both small end and big end bearing inner surfaces where vertical and horizontal DOFs are retained.

Multibody simulation (AVL Excite PU)

Generally a dynamic simulation of a large engine is a very big problem to solve by using the full FE model. A very powerful method is to use the MBS with flexible bodies and reduced matrices, while the dynamic behavior of the full system stays precise up to a selected vibration frequency. This method enables the dynamic simulation of the whole engine in a time domain using flexible bodies. The flexible bodies, the so-called superelements, for the MBS are generated from the FE models of the components (Figure 1).

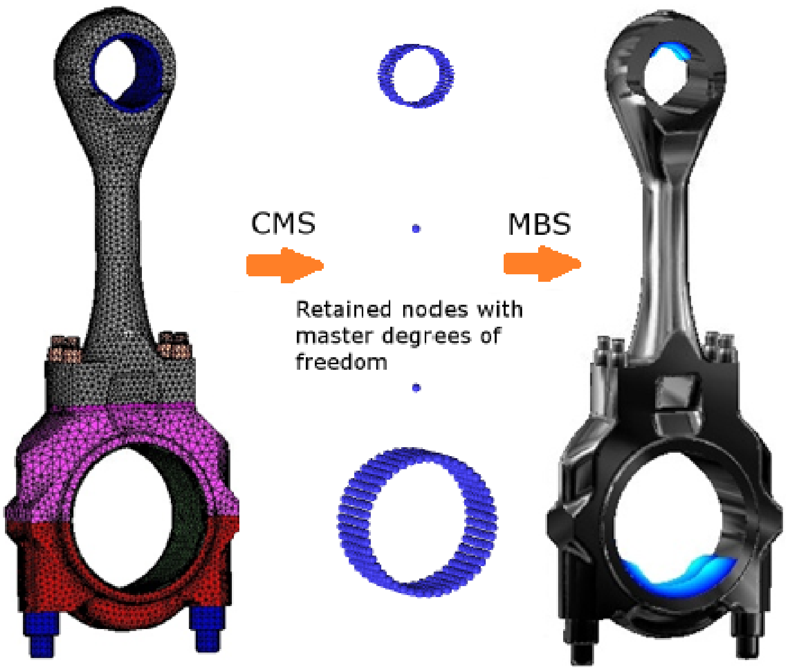

Figure 1. Flexible multibody simulation model of a connecting rod

The multibody simulation model in AVL Excite PU [5] consists of three flexible bodies: a crank pin predefining circular motion, a connecting rod as explained above, and a piston pin. Elastohydrodynamic (EHD) bearing models [1] couple these three bodies together. In addition, oil bores are modelled as boundary conditions for Reynolds equation solution. The liner, as a rigid body, is coupled to the piston pin using nonlinear compressible spring. Piston inertia is taken into account by adding it to the mass of the piston pin. Boundary conditions like the firing force and engine speed are also defined.

Non-linear stress and contact analysis (Abaqus)

The finite element analysis consist of three steps:

1. Pretension of the bolts using *CONTACT PAIR connection in all contact interfaces instead of *TIE connection. A bearing crush is settled and shrink fit is applied to the small end bearing.

2. If required, it is possible to include the machining of the big end bearing housing to the shape of perfect cylinder [9].

3. Dynamic loading from MBS is used as a boundary condition describing one engine cycle of 720 degrees. The oil film pressure at the small end and big end bearing surfaces and the acceleration field of the whole connecting rod assembly in a time domain are extracted to be used in the nonlinear FEA. The engine cycle is repeated until the contacts are fully stabilized.

Stresses from the big end housing were measured in a running engine. The simulated stresses correspond well with the measurements over the whole engine cycle. (Figures 2 and 3).

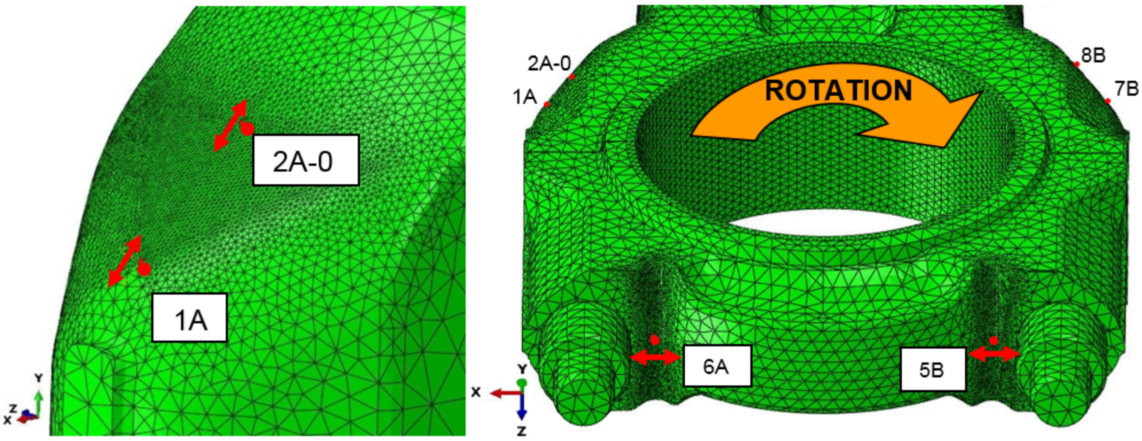

Figure 2. Points on FE model for measurement comparison

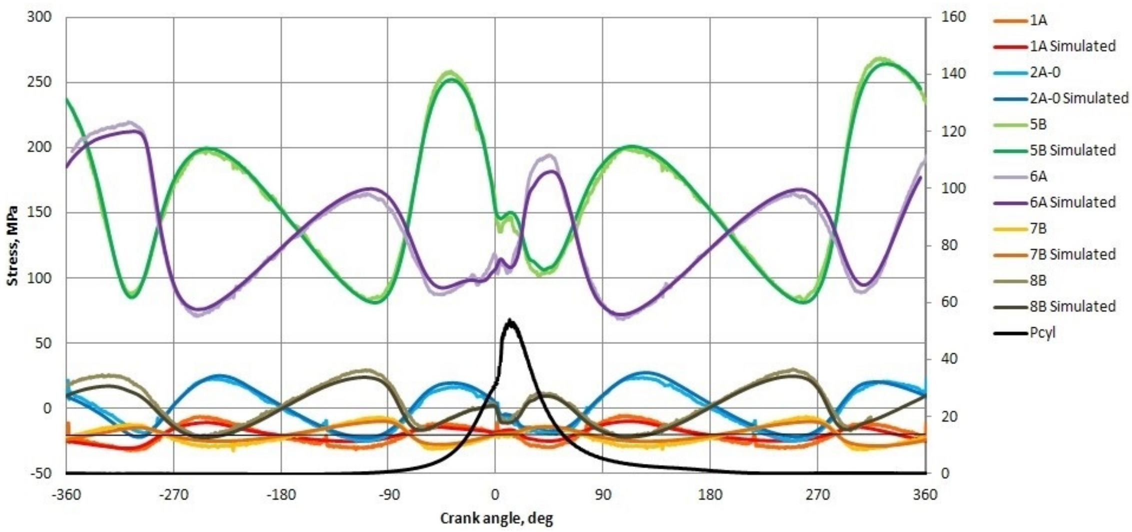

Figure 3. Simulated vs. measured stresses

Conclusion

The non-linear stress analysis with MBS loading has proven to be a good way to achieve a reliable stress state for the large bore connecting rod. The model was successfully validated by strain gauge measurements in a running engine, and there was a good correspondence between the simulated and measured stresses of the connecting rod housing. Using the above mentioned workflow, it is possible to tune the model to correspond all kinds of manufacturing effects and loading cases and, later on, make design changes to achieve better component lifetime and fatigue safety. Simplifying the FE model it enables to get reasonably accurate results in a shorter simulation time for a quick concept phase design and also a parametric optimization procedure.

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