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Conrod Simulation: Integration of EHD – MBS – FE – Fatigue

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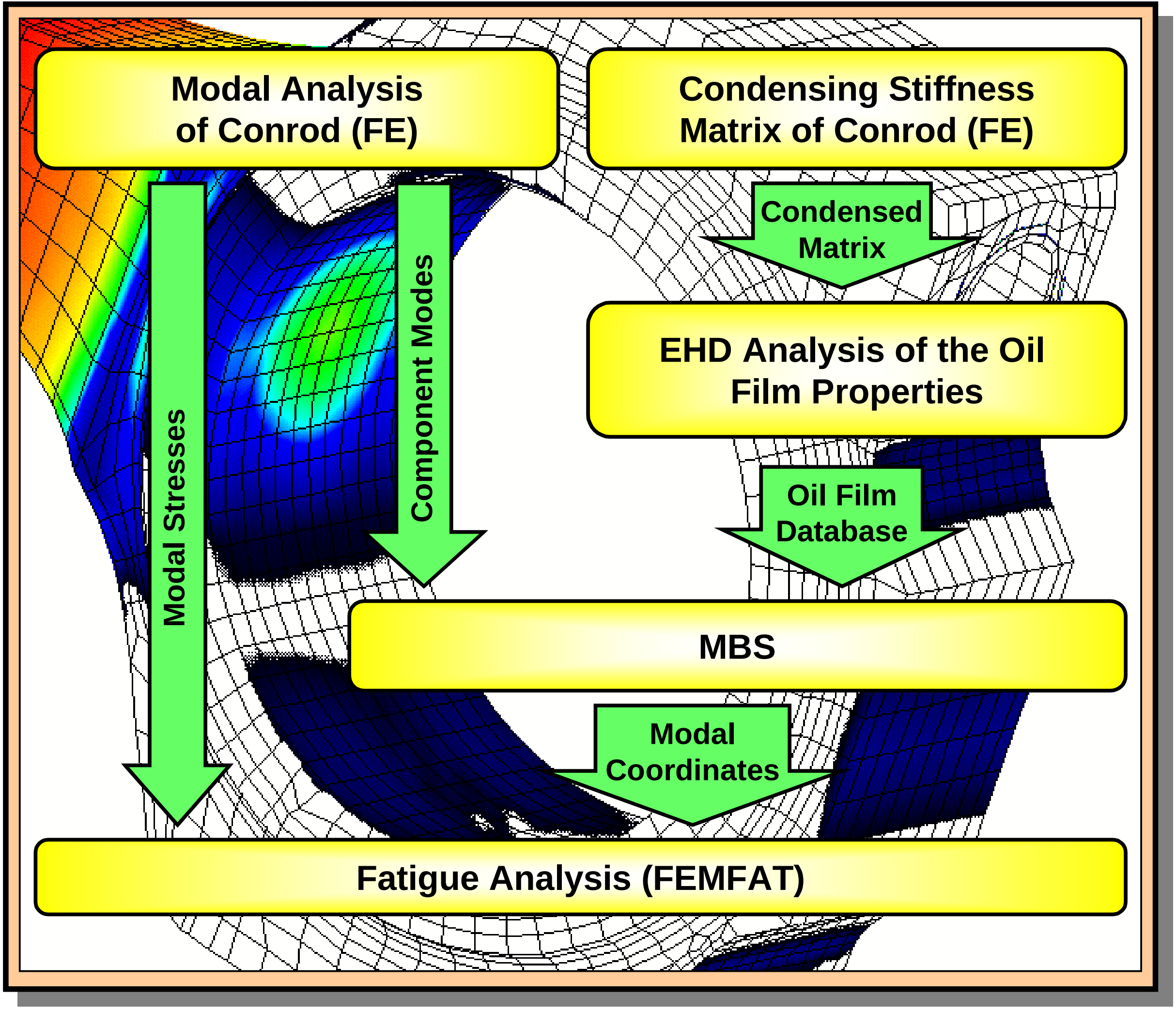


Figure 1: Principle of the integrated EHD – MBS – FE – Fatigue simulation

1 Summary

This paper presents a modally based fatigue analysis of a conrod incorporating the elastohydrodynamic (EHD) effects of the oil film. FEA, MBS, EHD and fatigue software contribute to the integrated simulation process with their particular advantages (Figure 1). The FE method is used to compute the conrods linear characteristics which are required by the EHD and MBS software. The MBS requires a suitable set of modes and the EHD software a condensed stiffness matrix of the conrod. The characteristic of the elastohydrodynamic oil film is computed by the software EHD 1.1 and stored in a database. This database and the modal representation of the conrod is imported into a MBS package. The results of the MBS simulation are the modal coordinates. These modal coordinates and the modal stresses computed in step 1 are the input for the durability analysis. The fatigue

result incorporates the effects due to quasistatic loads (ignition load case), dynamic effects (vibrations) and elastohydrodynamic effects of the oil film.

2 Introduction

An accurate fatigue computation of the conrod eye requires an elastohydrodynamic (EHD) oil film model.

The durability criterion of a conrod is the endurance strength. Critical design features are transitions areas of the shaft and the conrod eyes. While the shaft is not very sensitive to the used oil film model, the region of the conrod eyes is due to the complex elastohydrodynamic interaction between the FE structure, load condition and oil film. Figure 2 shows differences of oil film pressure and resulting endurance limit of a combustion engines main bearing chair using hydrodynamic (HD) and EHD oil film models [1]. It can be seen, that different pressure distribution and maximum value result in different endurance limits.

The conrod itself is a linear reacting structure which undergoes large nonlinear displacements. An efficient, fast and stable computation of these effects requires different algorithms (e.g.: FEA for linear reacting structures, MBS for large nonlinear displacements and EHD Software which is optimized to compute the oil film characteristics).

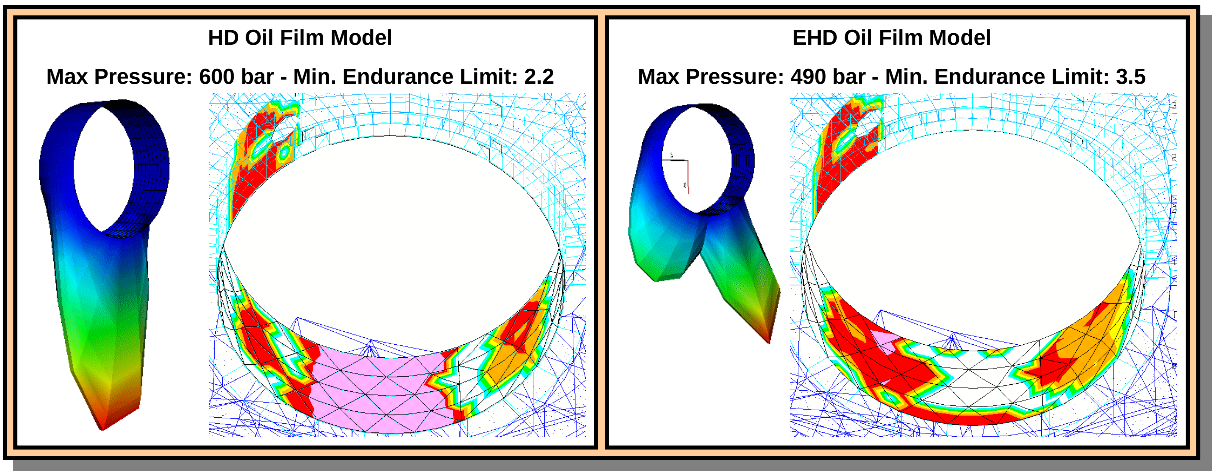


Figure 2: Difference between HD and EHD computation

The used software packages are NASTRAN (FE), ADAMS (MKS) and EHD. The software package EHD 1.1 is developed and distributed by the ENGINEERING Center Steyr.

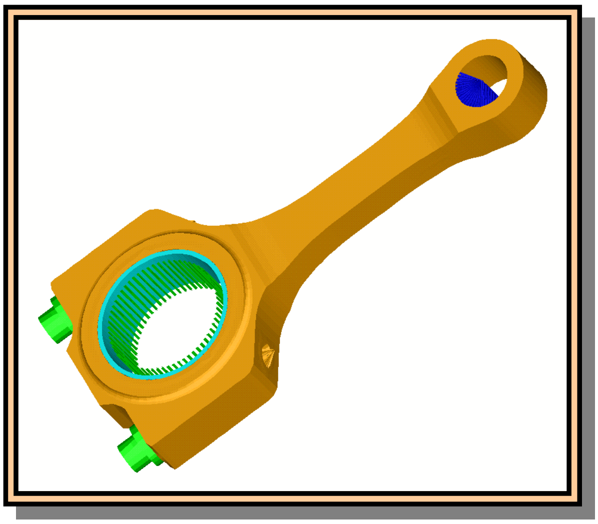
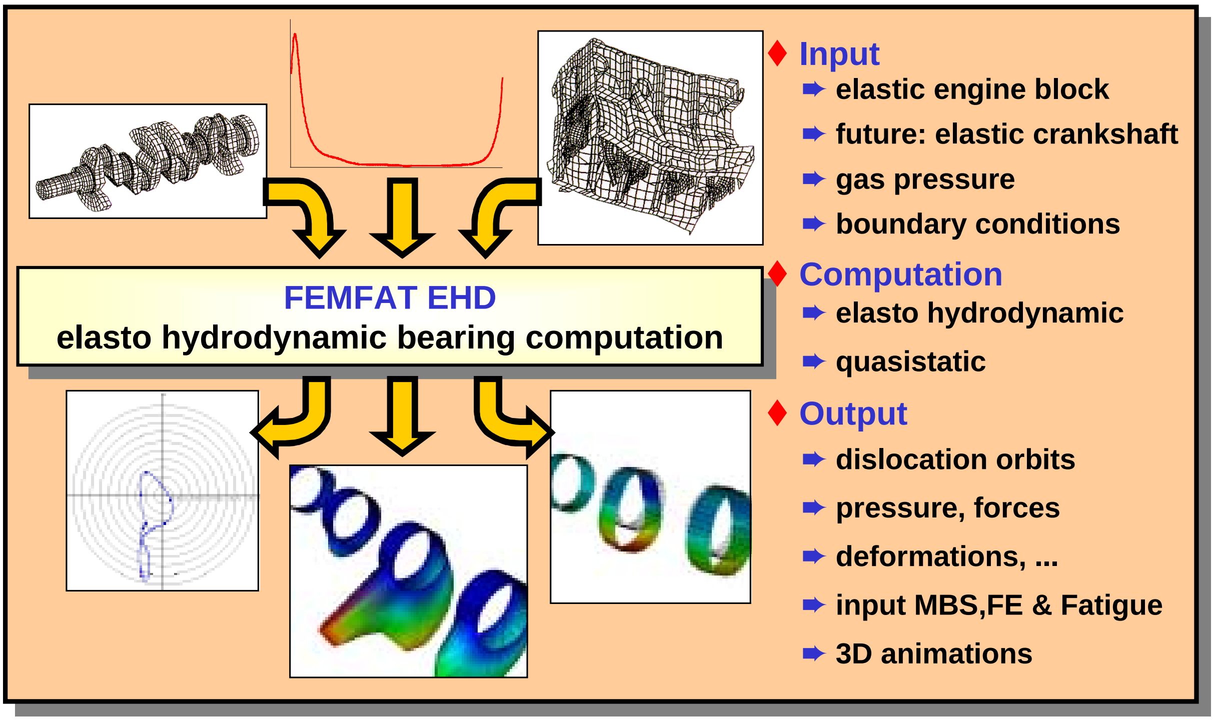


Figure 3: FE model of the conrod

3 FE Computation

The simulation procedure (Figure 1) starts with a FE analysis of the conrod (Figure 3). Two different types of analysis are required. The input for the EHD software is a condensed stiffness matrix and the one for the MBS software are the so called 'Component Modes'. Figure 6 shows two such Component Modes. For the theory of the Component Mode synthesis refer to [2,3,4,5]. Both analysis are fast and stable standard procedures.

4 EHD Computation



FEMFAT EHD
elasto hydrodynamic bearing computation

- ♦ **Input**
  - ➨ **elastic engine block**
  - ➨ **future: elastic crankshaft**
  - ➨ **gas pressure**
  - ➨ **boundary conditions**
- ♦ **Computation**
  - ➨ **elasto hydrodynamic**
  - ➨ **quasistatic**
- ♦ **Output**
  - ➨ **dislocation orbits**
  - ➨ **pressure, forces**
  - ➨ **deformations, ...**
  - ➨ **input MBS,FE & Fatigue**
  - ➨ **3D animations**

Figure 4: Brief overview - software EHD 1.1

Figure 4 contains an overview about the used software EHD 1.1. The inputs are the condensed stiffness matrix of the engine block, the gas pressure, geometric dimensions of the crankdrive and boundary conditions.

The computation is based on the Reynolds differential equation and on a quasistatic model. That means, no damping effects and no mass effects due to the elastic deformations are considered. If the simulated operating point of the engine isn't critical in terms of natural frequencies, the oil film characteristics are mainly dominated by the elastic effects of the structure, ignition and mass forces.

It is not practicable to compute the oil film characteristics inside the MBS. It would lead to enormous computation time. Therefore EHD 1.1 stores the oil film characteristics versus degree crankshaft angle in a database which is imported into the MBS software. Consequently, the database for the succeeding MBS is only valid for the specified operating point, simulated by the EHD software.

The basic idea of the oil film model inside the MBS is outlined in Figure 5. The oil film model is represented by an assemble of spring – dampers which are arranged around the bearing. Each of these springs and dampers coefficients are functions of degree crankshaft angle and stored inside the database computed by the EHD software.

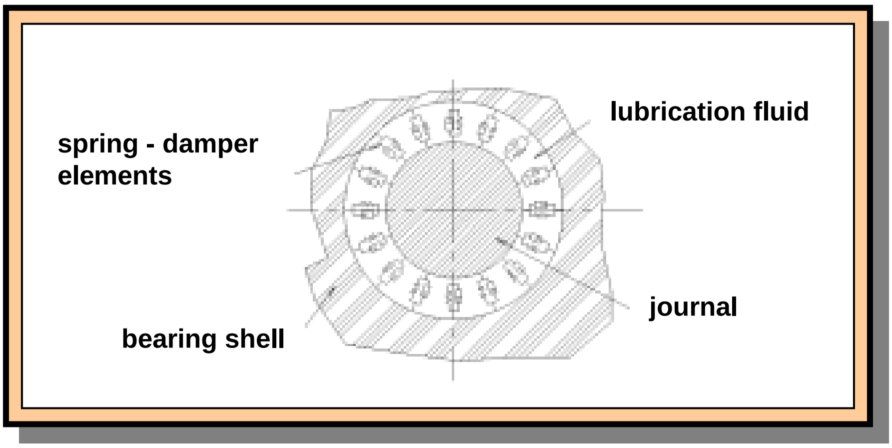


Figure 5: The oil film model inside the MBS

5 Multi Body Simulation

The ADAMS model consists of ADAMS modeling features, the Component Modes and the database of the oil film characteristic. The oil film connects the conrod eye and the conrod journal. It is modeled by means of SFORCEs. The function which is associated to one of these SFORCEs represents a spring damper element as outlined in Figure 5.

Even though the modal coordinates are defined as mathematical values, they give valuable hints in order to interpret the result. The modal coordinate of the compression mode (figure 6) shows, that the MBS uses this mode to simulate the compression of the conrod due to the ignition force. The torsion mode of the conrod (figure 6) is not only a component mode, it is a free – free mode as well. The time series of the modal coordinate indicates a natural vibration excited by the ignition. This is a well known effect of conrods used for racing engines. These conrods often fail due to such torsional vibrations. In this case, the vibration is dyed out during one combustion cycle. However, this vibration effect couldn't be observed as a simpler oil film model (e.g. HD) was used.

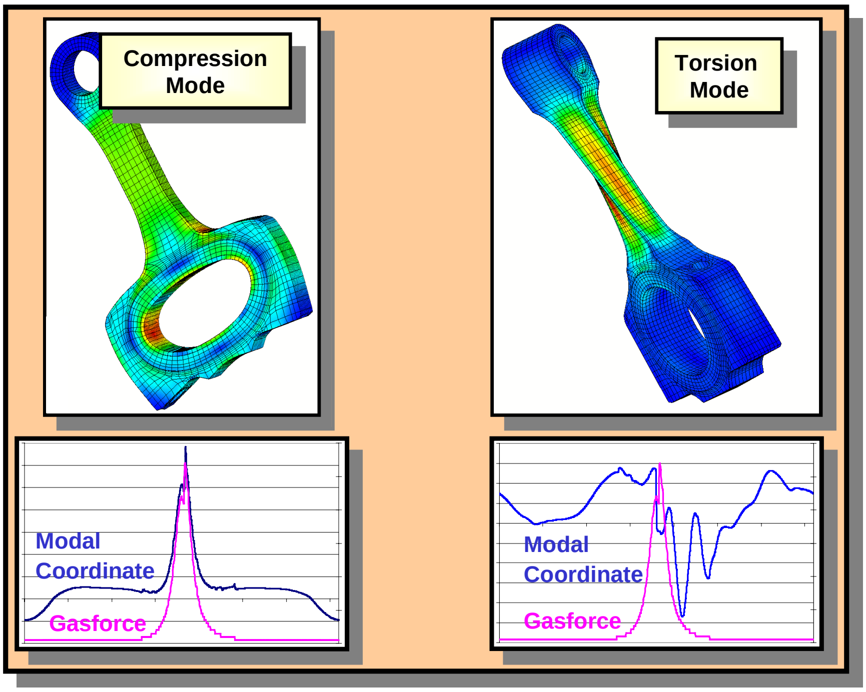


Figure 6: Two Component Modes and the time characteristics of the corresponding modal coordinates.

6 Modally based fatigue lifetime prediction [7,8]

The durability analysis is performed with the Software FEMFAT. The computation methods of FEMFAT range from simple durability analysis up to transient multiaxial fatigue analysis considering temperature, weldings, local plastification and so on [6].

The modal coordinates and the modal stresses are inputs for the durability analysis. The modally based durability analysis is a channel-based and multiaxial fatigue simulation [7]. Consequently, one channel is defined of a modal stress and the time series of the corresponding modal coordinate. Additional channels can be used to consider further load cases like temperature, prestress due to a screwing or stress due to other loads. FEMFAT computes the resulting stress state by superposing the channels which are weighted by the modal coordinates. Note, that the resulting stress state which is computed by FEMFAT considers all static and dynamic effects including vibration due to natural frequencies.

Figure 7 compares the results of the modally based durability analysis and a common, quasistatic analysis. The shaft of a common conrod is mainly stressed by the ignition load case. Therefore, the common, quasistatic procedure is very reliable and a good validation of the modally based approach.

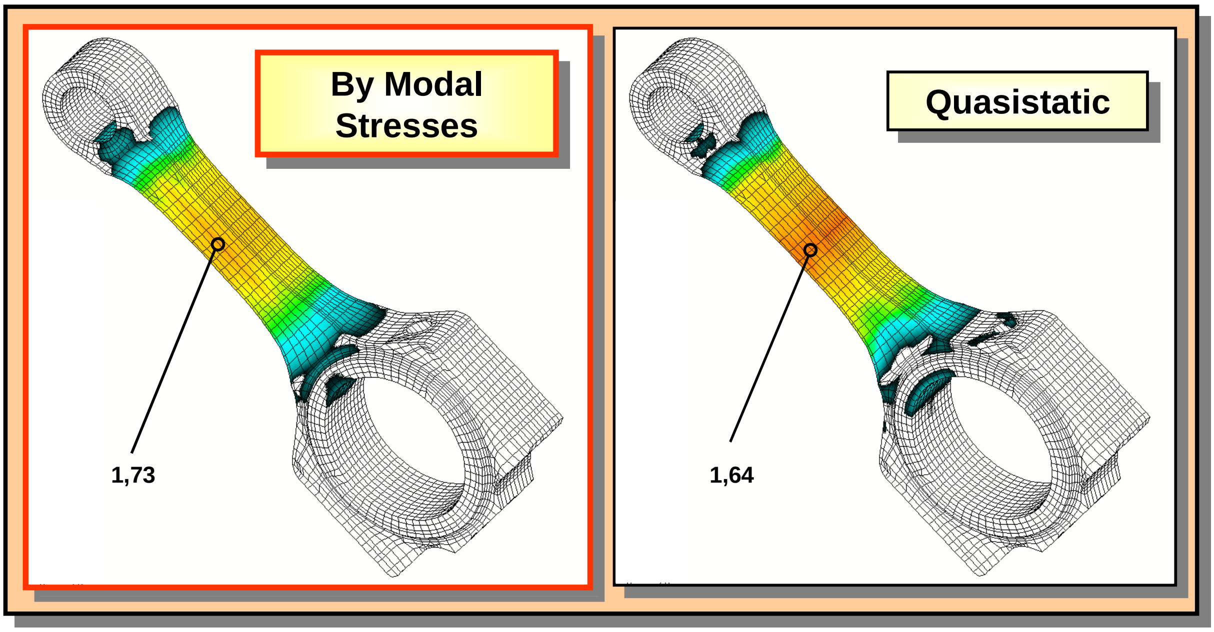


Figure 7: Comparison of the shafts endurance limit

The minimum endurance limits at the shaft are almost the same. This was expected because of the ignition load case’s dominants. The colour distribution of the modally based analysis is a little bit different. This indicates a small influence of the torsional vibration. In this case, it is possible to compute the shafts endurance limit with the common quasistatic method. It is not possible to compute an accurate result, if vibration effects became significant as it is known from special conrods.

As mentioned, the conrod eyes area is very sensitive to the boundary conditions. It is not possible to gain reliable results without an EHD oil film model. Figure 8 shows the endurance limit in the conrod eye. However, the min. safety factor is less critical than the one at the shaft but due to the EHD oil film model, there is a good developed damage-oval.

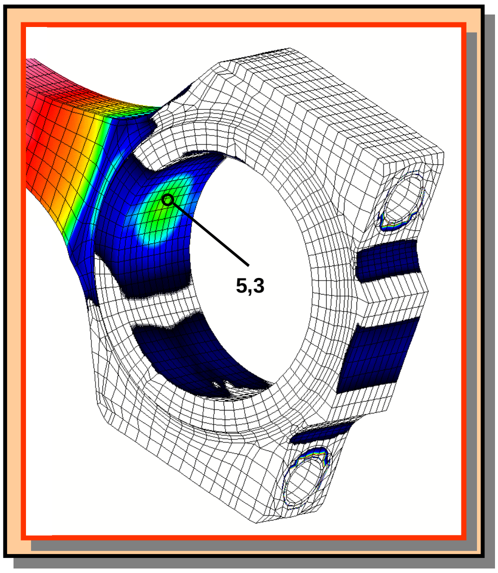


Figure 13: Endurance limit at the lower conrod eye

7 Conclusion

The introduced integrated EHD – FE – MBS – Fatigue approach enables the fatigue computation of dynamically stressed bearings.
The advantages of this approach are:

- It can be applied to ignition dominated problems as well as to vibration dominated problems.
- All dynamic effects (e.g. natural vibrations) during one load cycle are considered.
- The base of the fatigue lifetime prediction is the transient stress state of the complete load cycle. It is not necessary any more to determine a couple of representative load cases (e.g. ignition load case at the upper dead center and mass load case at the lower dead center and .....).
- The EHD oil film model delivers more accurate conditions for the conrod eye as any other approach. This is significant important in terms of fatigue lifetime prediction.

8 Literature

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