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PISTON HIGH CYCLE FATIQUE ANALYSIS VIRTUAL NUMERICAL PREDICTION

DJH Engineering Technical Newsletter

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Maximum potential of individual components

Heavy duty vehicles for the transportation of goods, construction sectors, agricultural segments and off-highway applications are still essential for the day to day functioning of our current modern world. Unlike the light duty vehicles, there are currently limited viable and economical alternatives to diesel propulsion when a constant high power density is required. Hence, improving the operational fuel efficiency of the heavy duty applications on one hand and finding the maximum potential of the individual components on the other hand remain a high priority. The technical letter shows how DJH EC, University of Zilina, a piston supplier and a software vendor have set and verified a predictive virtual numerical method to predict high cycle fatigue failures of diesel pistons. The numerical prediction was compared to tested cases of modern pistons, very good correlation between the prediction and tests was observed.

Key benefits, approach & software kit:

- Fast and reliable virtual numerical prediction to reduce time-to-market of a piston for diesel heavy duty engines
- Benchmarked against known cases
- Simulation process that consist of:
    1. Thermal analysis
    2. Dynamic analysis
    3. Structural analysis
- Software tools used in the analysis:
    1. FEARCE – FE pre & post-processing environment with and integrated linear and fatigue solver
    2. PISDYN – piston secondary dynamics

Piston simulation process

In general, the numerical prediction of piston thermal, dynamic and structural results can be expressed through a series of advanced analyses (OEM piston and ring pack analysis process, Letrich 2015). Thermal distribution across the structure of the piston and engine block is taken into consideration, as the temperatures affect the expansion and stiffness of the components; as well as the lubricant temperature-dependent properties. Using the additional inputs such as piston & cylinder profile, asperity surface properties, compliant models, engine operating conditions etc., the dynamic analysis is carried out to determine the secondary dynamic motion of the piston. This results in elasto-hydro-dynamic (EHD) pressure distribution between the components in interaction, i.e. piston and cylinder; piston and wrist pin. To determine the piston deformation, stress and high cycle fatigue results, the thermo-mechanical loads as calculated in the previous steps are used to load the piston structure along with piston inertia and combustion pressure loads at discretized time steps during an operating regime of an engine. The piston simulation process is shown in Fig. 1.

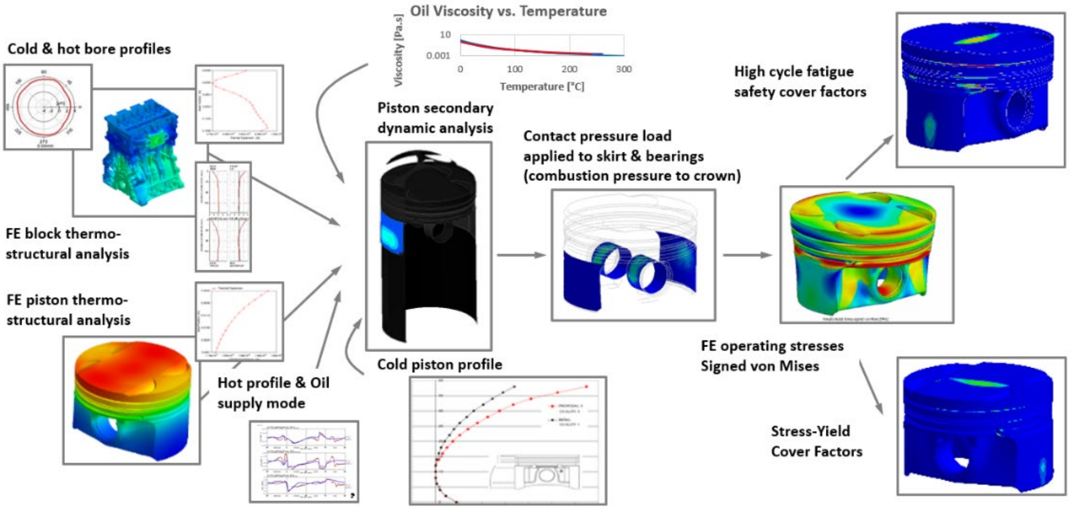

Figure 1. Illustration of Piston simulation process (Ricardo Software Conference, Letrich, 2015)

Benchmark against known cases

The virtual numerical method was benchmarked against two piston designs provided by a piston supplier. One of the designs exhibited high cycle fatigue failures spotted after a durability test. The additional design was a revised piston version that passed the test without any issue.

Fig. 3 details the location of the high cycle fatigue crack that started to propagate at the skirt cut-out, which was introduced to package a piston cooling nozzle that supplies the coolant for the sophisticated piston architecture. The piston contains an additional cooling channel casted in the piston crown. The cooling lubricant is injected through the injection port and outlets through a drain opening.

Figure 2. Piston crown – top view (no issues observed)

Figure 3. Piston bottom view – crack revealed (dye penetrant examination)

Comparison of high cycle fatigue results show very good correlation between the numerical prediction and tested cases. These results were obtained without the test cases available – the comparison was done after the simulations were finished to verify the proposed virtual numerical prediction. Fig. 4 details the location of the crack initialization of the design that failed, whereas Fig. 5 shows higher safety factors of the revised design that passed the tests successfully. This has well demonstrated the capabilities of the analysis method that can be used to predict the piston durability when designing the components in an early phase of a development process in order to reduce time-to-market of the pistons and overall development costs.

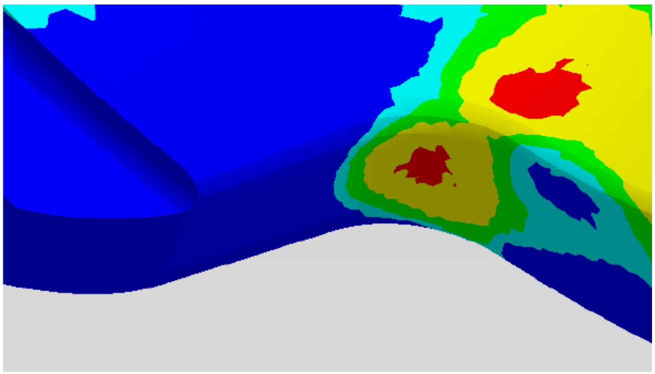

Figure 4. Cut-out detail of cracked piston. Low high cycle fatigue safety factors - lowest in red

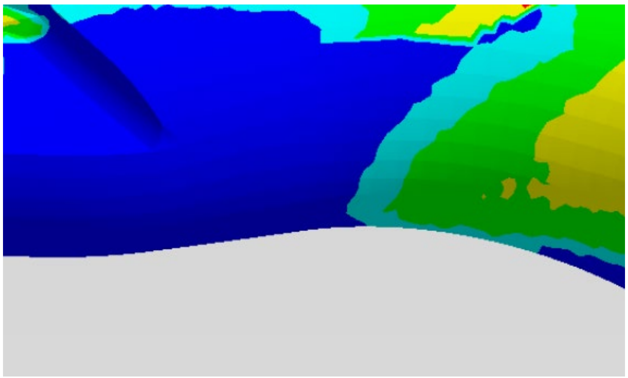

Figure 5. Cut-out detail of the revised piston design. No issues predicted – confirmed during the durability test

Acknowledgment

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