325-hp model EPA 07 ISB Cummins diesel used with bus, RV, medium-duty truck, and fire or emergency vehicle applications

Fatigued by **Stress Limitations**

The combination of fe-safe and ANSYS software helps Cummins improve life prediction accuracy.

By Jeff Jones, Technical Advisor, Cummins Inc., Indiana, U.S.A.

In developing cutting-edge design solutions, diesel engine manufacturer Cummins Inc. uses a deterministic approach for predicting product life, one that considers complex materials and loading. Its current solution incorporates technology from two proven leaders — but the path to this approach was not a straight line.

A recognized technology leader in the global diesel engine market, Cummins faces increasingly stringent design requirements as it develops cutting-edge solutions. The company's roots are planted in soil nourished by innovation. For example, the firm was among the first to see the commercial potential of diesel engine technology. Even before the advent of commercial software tools, Cummins' engineers developed internal software for thermal, structural and design applications to ensure that its engine designs were cost effective, reliable and durable. Today, Cummins is no longer just an engine business but a global power leader with more than $11 billion (U.S.) in annual sales.

350-hp model 6.7 L Cummins turbodiesel used in Dodge Ram heavy-duty trucks

In the late 1970s, Cummins continued its pioneering efforts, becoming one of the first companies to embrace commercial tools for finite element analysis. It standardized on the mechanical analysis solver from ANSYS because of the technology's flexibility and performance. The relationship between the two companies has expanded since then: Cummins has been an active member of the ANSYS Advisory Board for more than a decade.

However, there was reluctance at Cummins to replace its internally developed fatigue analysis software because of rigorous internal requirements for depth and range of fatigue theories along with the need to handle proprietary materials and loads. In 2002, the company turned to Safe Technology Limited, which offered fe-safe™ for fatigue and durability analysis. The partnership that existed between ANSYS and Safe Technology ensured efficient and effective interfacing between fe-safe and simulation tools from ANSYS.

To verify that fe-safe offered accurate life prediction capability, Cummins executed a sophisticated test plan to compare fe-safe results to internal fatigue analysis software. The test plan included four finite element models:

- Simple 2-D plane stress uniaxial model
- Moderate 3-D biaxial stress model
- Fully featured engine block
- Fully featured engine head

Cummins engineers subjected each model to a number of different and appropriate loading scenarios. By using a range of models, it was possible to gain fundamental insights into the technology and to compare predictions against field data.

The baseline internal fatigue software was based on an advanced Goodman approach: one that is stress-based, in which damage prediction is based on stresses.

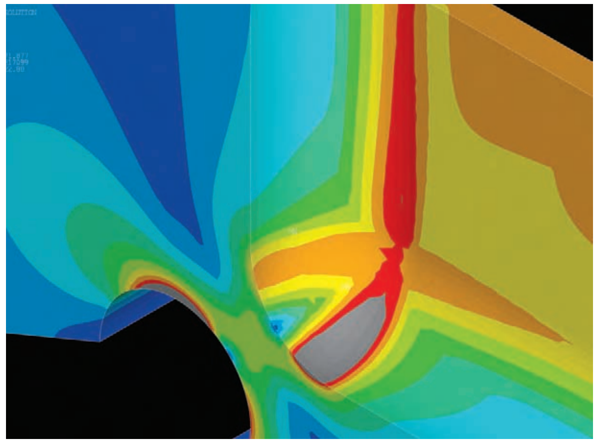
Stress-based fatigue analyses are severely limited when it comes to low-cycle fatigue problems. Low-cycle fatigue typically considers approximately 10^5 duty cycles, while high-cycle fatigue is appropriate for more than about 10^9 cycles. Cummins needed a unified approach for predicting product life for gray iron components that would be viable for both low-cycle and high-cycle fatigue. The company also wanted to determine if the strain-based methods employed by fe-safe, such as the Smith–Watson–Topper (SWT) algorithm with Neuber correction, were more suitable for meeting this low- and high-cycle requirement for gray cast-iron fatigue prediction.

For load cases dominated by tensile stresses, the Goodman-based internal software provided results that were consistent with the SWT approach. However, in the biaxial case dominated by compressive stress, the internal software predicted much more damage than fe-safe, implying that a stress-based approach in this case may result in an overly conservative design.

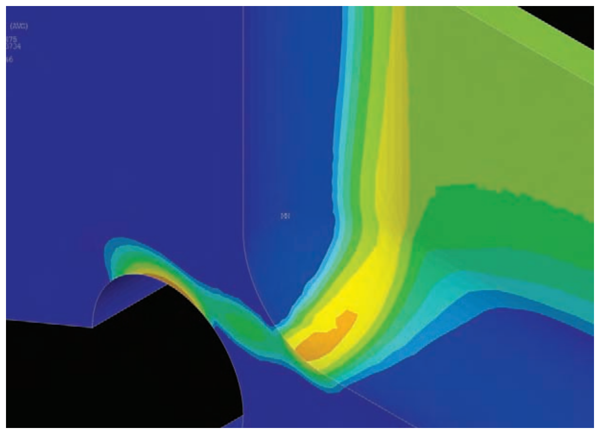
Complex real-world models of a cylinder block and head, considering standard proprietary loading conditions, produced more noticeable differences. Stress situations for two complex load cases were compared at more than 20 locations for which considerable test experience existed. In nearly all cases, fe-safe results were in line with expectations, while the Goodman-based approach predicted less damage at several locations (thus over-predicting product life). A closer review at three critical locations revealed that for cases with high mean, low alternating stresses, fe-safe provided results that agreed very well with test and field experience.

Cummins engineers made the following observations when considering the test results:

- While internal software over-predicted product life in some cases and under-predicted it in others, fe-safe results used in conjunction with the mechanical analysis solver from ANSYS correlated very well with Cummins' industry experience.
- Even with modifications, older stress-based approaches for predicting fatigue have limitations in comparison with modern strain-based methods.
- Use of the mechanical solver from ANSYS in combination with fe-safe offers opportunities to further increase reliability and reduce costs.
- A better understanding of fatigue facilitates design innovation.



Goodman method–equivalent fully reversed stress results identify spurious damage prediction in addition to high fatigue damage locations.



Factor of strength results from fe-safe plotted in ANSYS Mechanical software showing actual high fatigue damage locations

A noted contributing factor to the successful outcome of the testing was the tight integration between fe-safe and ANSYS Mechanical software. Using fe-safe, the ANSYS results (.rst) file is read, material properties and fatigue cycle (combinations of load steps) are specified, and the fatigue damage is calculated and written back to an ANSYS results file for display in ANSYS Mechanical software. Fatigue results may be plotted as contours of log-life (log-cycles to failure) or factors of strength (such as design margin). Another important factor was the ability to use comprehensive and user-configurable libraries, facilitating use of internal proprietary materials data with minimal effort.

With the development of the integrative ANSYS Workbench platform, all structural analysis and flow modeling tools at Cummins are being brought into one environment, further enhancing productivity.

Today at Cummins, nearly every engine component is analyzed using the ANSYS Mechanical product. fe-safe is used to perform fatigue analysis for many components, such as cylinder blocks, cylinder heads, pistons, connecting rods and main bearing caps. In engine cylinder heads with high assembly stresses, significant compressive stresses, and peculiar behaviors of gray cast iron, fe-safe software plays a vital role in helping to develop reliable, cost-effective designs. Advanced fatigue analysis using fe-safe with ANSYS Mechanical software helps to get the design right the first time, and it reduces development costs. ■

Reference

www.safetechnology.com