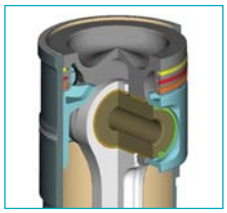
Customer Success Brief

safe4fatigue™

Predicting fatigue life from measured strain data



"With its ability to accurately predict fatigue life from measured strain data, safe4fatigue™ has proven to be a powerful ally to fe-safe™ and our overall fatigue process."

A statement shared by Qingzhong Li (Sr. Engineer) and Bill Moser (Sr. Specialist) VPD Technology, Applied Research of Caterpillar Product Development COE

Caterpillar Inc.

Challenges:

- Accurately predict fatigue life from measured strain data
- Assess impact of mean stress and surface finish on fatigue life
- Integrate and understand how simulation and test correlate

key safe4fatigue™ Capabilities:

- A wide range of fatigue algorithms for both brittle and ductile materials, including the principal stress method and Brown-Miller with mean stress correction, as well as surface finish factors
- Easy-to-use tools to identify spikes and other signal anomalies
- safe4fatigue™ is integrated into the fe-safe™ suite of software for the fatigue analysis of Finite Element (FE) models

Conclusions:

- safe4fatigue™ accurately predicted the failure location and relative life to crack initiation at locations different from strain gauge data
- The effect of mean stress correction is significant in areas of high compressive strain
- Surface finish is an important factor to consider
- The safe4fatigue™ signal analysis aproach to predict fatigue life proved to be a useful tool and will be used in other rosette strain analyses

Innovation in heavy equipment and engine technology

With sales and revenues in 2008 of $51.3 billion, Caterpillar Inc. leads the world in construction and mining equipment, industrial gas turbines, and diesel and natural gas engines.

Caterpillar is the foremost manufacturer of medium-speed engines and a leader for high-speed diesel engines, ranging from 50 to 20,000 horsepower. Besides Cat® construction and mining equipment, other OEMs find uses in trucks, boats, ships, and notably, electrical systems. Caterpillar helps power off-shore oil rigs, desert mining operations and even entire remote communities.

To support innovation in machinery and engine technology, Caterpillar continues to advance its leadership in computer-aided engineering whilst leveraging physical testing to improve its overall design process.

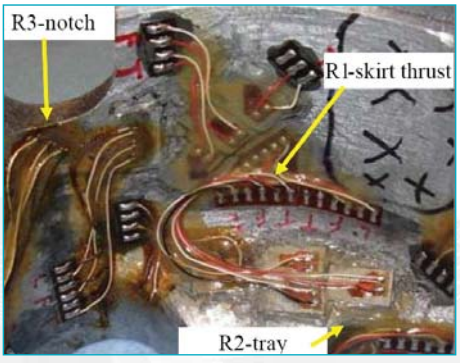
Innovation, integration and fatigue assessment

Caterpillar uses a wide range of techniques to develop powerful, fuel-efficient and reliable engines. Real-world engineering is rarely as simple as: design, analyse, test, manufacture. A real opportunity for innovation lies in integrating and understanding how simulation and test correlate, and determining how to best predict real-world behaviour.

The genesis of any new design process at Caterpillar is heavily computer-aided, having had an integrated CAD and FEA process since the early 1990s. In 2002, Caterpillar selected Safe Technology's fe-safe™ software for fatigue life prediction and it is now an integral part of their overall design process. In addition, Caterpillar employs a number of other methods to improve and support existing designs in the field. An example of this involved a piston experiencing a few field failures somewhat earlier than anticipated. The original fatigue prediction for this component had only involved hand calculations. This was a good opportunity to use a test-based process with Safe Technology's safe4fatigue™, measuring strains to predict fatigue life.

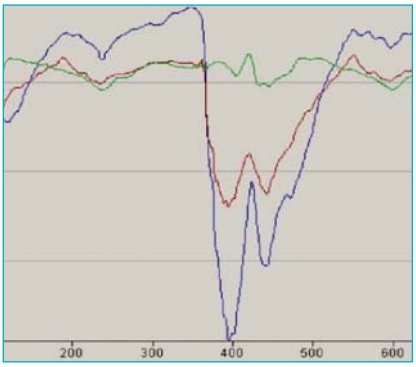
Measuring strains

Lab engineers arranged instruments around the piston skirt with rosette gauges at three locations. Signals were measured corresponding to the three components of strain.



Complex loads, signal processing and measured strains

The test-loading of a piston is complex, due to the various stages of the internal combustion process. A load cycle consists of two complete revolutions of the crankshaft. As the piston is loaded and unloaded, each strain gauge produces three signals. The signals are then processed by safe4fatigue™ to create valid strain histories. The measured strain approach has the valuable advantage that strains directly reflect the physical hardware and actual loading, whereas the accuracy of the FE approach entails careful application of loads and consideration of the mesh density near the areas of high strain.



Three components of strain around the "combustion" event (R3-"Notch" location)

Material properties and fatigue prediction

Material properties add complexity to accurate fatigue assessment and prediction. The piston skirt is made of proprietary cast aluminum, which exhibits behaviour "somewhere in-between" brittle and ductile behaviour. In order to consider situations for both material types, Caterpillar assessed the fatigue life in safe4fatigue™ using both maximum principal stress algorithm (based on NASA MSFC-388 S-N curve data) and Brown-Miller method (based on material data from an ASM book).

The former algorithm is appropriate for brittle material while the latter one (Brown-Miller) is more appropriate for ductile material.

The effect of mean stress correction was also investigated using three different methods: Goodman correction, the traditional hand calculation method and a mean stress correction curve for cast AISI material. In addition, the effect of surface finish was also considered in the safe4fatigue™ calculations.

Results, insights and discussion

The minimum life was predicted by safe4fatigue™ at the notch area of the piston skirt. This correlated with field observations. Using the maximum principal stress method, life was predicted at ~1.3 million cycles; the Brown-Miller method predicted ~1.6 million cycles until failure. In areas of high compressive stress—which is the case at the notch—the effect of mean stress was considerable. The hand calculation, which used a default mean stress correction curve, had predicted a fatigue life at the notch of more than 2.5 times the life predicted by safe4fatigue™, and of that seen in the field.

Considering the effect of surface finish also proved vital. Fatigue life decreased about 60% between "polished" (Ra<0.25mm) and "as-cast" (Ra~30mm) surface finishes (the polished surface has the higher fatigue life).

Overall, Caterpillar found that safe4fatigue™ accurately predicted fatigue life from strain gauge data, and proved to be a useful complement to fe-safe™ and its other predictive and test methods for product design.

safe technology limited

Safe Technology Limited is the technical leader in the design and development of durability software and is dedicated to meeting its customers' most demanding applications.

As a private company, Safe Technology is able to take a long-term view of software development and the research and industry collaboration needed to address real world, industrial applications. Its independence and focus enables quick response to customer feedback so that its software genuinely reflects the industrial and commercial requirements of engineers and designers.

In-depth knowledge of fatigue combined with expertise in software development allows Safe Technology to provide outstanding service - with standard and advanced training, software support, and consulting services provided by fatigue experts.

Safe Technology develops, markets and supports its software products directly from offices in the UK and USA, by a network of independent distributors worldwide and via the worldwide SIMULIA network.

To learn more, please visit our website where you can learn about our software products and related services, and register to download technical papers by our users on real world applications. You can also find the contact details for your local office or representative.

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