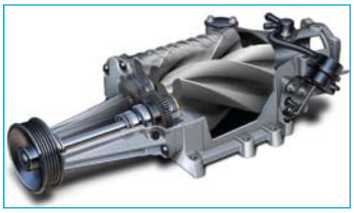
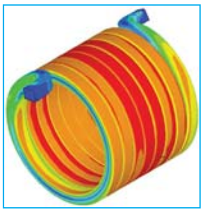
Customer Success Brief

fe-safe™

Ensuring the reliability of critical supercharger components





"The use of fe-safe™ software has improved our specific knowledge and confidence in the Single Spring Isolator (SSI) coupling and our fatigue prediction and related testing procedures in general."
Mike Otto, Senior Engineering Specialist, Eaton Corporation.

EATON
Powering Business Worldwide

Challenges:

- Develop a robust design process in which variations in geometry can quickly be assessed to determine the effects of tolerance on fatigue life
- Reduce original sources of noise and improve overall noise emission

Key fe-safe™ Capabilities:

- An intelligent signal processing algorithm which extracts a set of load points that achieve a near-equivalent fatigue damage with only a fraction of the original load points
- Integration with ANSYS Finite Element (FE) software and loading libraries
- A range of modern, advanced fatigue algorithms, including Coffin-Manson-Basquin, Brown-Miller and Neuber correction

Conclusions:

- fe-safe™ predicted what testsconfirmed: that the location of highest stress from the FE model was rarely the location of minimum fatigue life (the point of crack initiation)
- The integrated FE and fe-safe™ analysis process quickly revealed how changes in friction and geometry produced surprising and non-intuitive changes in spring deformation and fatigue life
- Using fe-safe™ and FE analysis enabled the development of a robust design process that met the design criteria set out to reduce noise emissions

Powering business worldwide

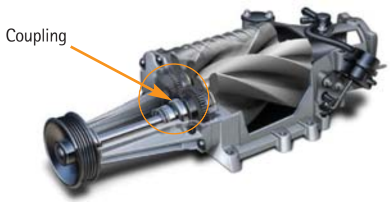
Eaton Corporation is a diversified power management company with 2008 sales of $15.4 billion. Eaton is a global technology leader in electrical components and systems for power quality, distribution and control; hydraulics components, systems and services for industrial and mobile equipment; aerospace fuel, hydraulics and pneumatic systems for commercial and military use; and truck and automotive drivetrain and powertrain systems for performance, fuel economy and safety. Eaton's automotive business plays an important role in the global automotive industry.

The innovation strategy at Eaton aims to meet an ever-increasing list of customer and regulatory challenges, from design and aesthetic choices to demands for improved performance and efficiency. Supercharger technology is a key part of this strategy: on small engines the aim is to boost performance whilst keeping fuel consumption low, and on larger engines the objective is to achieve higher acceleration for a given engine size. Eaton superchargers are used by many of the world's leading automotive OEMs, including Audi, Ford, GM, Mercedes-Benz, and Volkswagen.

Quiet and reliable

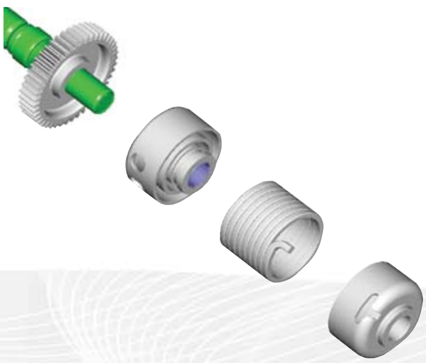
In the past, superchargers have been known to produce noise. One source of noise stems from the pressure pulsations that occur as the lobes of the pump mesh and un-mesh during boosted operation. Another source of noise occurs during un-boosted operation, e.g. when the car is stopped and the engine is idling. In this case, vibrations produced by the normal combustion of the engine can be transferred through the belt and cause gear rattle in the supercharger. In a race setting, these various noises are at most a nuisance, but in passenger cars they can be perceived as a lack of quality or perhaps even a more significant problem with the engine itself.

To meet these challenges, Eaton has invested considerable engineering resources to develop the world's quietest and most reliable superchargers, and has realised innovations in both reducing the original sources of noise and improving noise isolation.



Noise isolation

One approach that Eaton uses to isolate the supercharger gears from the engine vibrations is a noise isolating coupling, located as shown above on the new Eaton Twin Vortices Series (TVS) supercharger. A crucial component in this coupling is its Single Spring Isolator (SSI) which is situated between an inner and outer hub which enclose the spring in an internal cavity. Each hub is pressed onto its own mating shaft, with the input shaft connected to the front hub and with the rear hub pressed onto the shaft that drives the gears which compress and drive boosted air into the engine.



The mechanical characteristics of the spring are selected to match specific engine vibration characteristics, with a goal to reduce or eliminate the transmission of certain vibration frequencies to the supercharger gears from the engine. The inner and outer hubs form a free pocket, i.e. the spring under no load will actually float in the cavity formed by the hubs. The spring can travel in both directions: the spring "winds up" by tightening onto the inner hub; alternately, the spring can also "wind-out", in which case the spring grows larger and eventually contacts and becomes constrained by the outer hub. The total travel is limited by the radial clearances between the inner and outer hubs: if the clearances are too large the spring may wind-up or wind-out excessively, resulting in high stresses and decreased fatigue life. Thus, the specific design and related tolerances are crucial to optimise noise isolation and spring fatigue life.

Strain response and duty cycle

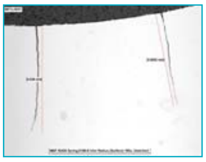
To assess the structural response of the spring under "wind-up" and "wind-out" conditions, an FE model was developed which captured three-dimensional strain conditions at over 170,000 points in the spring. Geometric nonlinearities, i.e. sliding contact with friction, were captured by the FE model whilst material nonlinearities were taken into account by fe-safe™. The FE model allowed Eaton to develop a response model that determined strain as a function of shaft torque. Next it was necessary to develop a composite set of (torque) loading scenarios (sometimes referred to as a duty cycle) for the spring, considering about a dozen different engine loading scenarios, e.g. strong acceleration from a standing start, gear change, pulling a trailer up a long hill, deceleration, etc.

Intelligent load processing

For most of the load cycles, the "as-measured" torque signature contained more than 300,000 points. To reduce analysis time, fe-safe™ includes a signal processing algorithm (peak-valley gating) which extracts a set of load points that achieve a near-equivalent fatigue damage with only a fraction of the original load points (for example 90% of the fatigue damage can often be captured by considering less than 10% of the load points).

Fatigue and material modelling

The next step was to determine which fatigue model was appropriate for the situation and the materials being considered. The spring was the main concern, and since it was made from a common high-strength steel, proven fatigue-related material properties were readily available.



In correlating fe-safe™ results with test, Eaton was able to capture some cracks in the spring during abuse testing. This also helped confirm which algorithm to use: the principal strain criteria, with Morrow's mean-stress-correction.

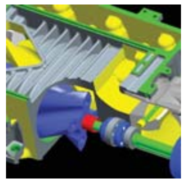
The "Coffin-Manson-Basquin" relationship between local strain amplitude and endurance was selected in fe-safe™ and a number of different relevant settings were selected, e.g. Neuber correction for local plasticity, mean-stress correction on critical plane analysis, shot peened surface finish, etc. The fatigue life analysis also needed to consider multiaxial stress components (i.e. bending together with torsion).

Important insights

Eaton realized a number of important design and reliability insights by combining its traditional FE stress analysis tool with the modern fatigue analysis methods available in fe-safe™.

Some of these insights included:

- The point of highest stress from the FE model was rarely the location of minimum fatigue life (crack initiation)
- The integrated FE and fe-safe™ analysis quickly revealed how changes in friction produced surprising and non-intuitive changes in loads and fatigue life
- Using fe-safe™ enabled the development of a robust design process; variations (within tolerance) in as-manufactured design geometry can now quickly be assessed to determine the effects of tolerance on fatigue life.



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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