Less Pain to Predict Strain

An initial skid assembly tested by Cummins

By **Nathan Marks**
Sr. Mechanical Engineer
Applied Technology
Cummins Power Systems
Fridley, USA

Cummins provides generator sets to support the global demand for reliable electricity in backup and remote installations. Vibrations from large generator equipment can steadily weaken its supporting structures over time, which is often characterized by fatigue analysis. However, pure analytical models of the strain history on the metal frame are not accurate enough for fatigue prediction. The challenge is to achieve good experimental correlation. The Cummins Power Systems team developed a new spin on a decades-old challenge of generator set durability modeling by integrating True-Load's strain correlation models with overall structural analysis in ANSYS Mechanical to rev up its simulation workflow.

How long will it last? This question about a product's useful lifespan before it needs to be repaired or replaced is pertinent for almost every tool, component or system. But, when the equipment supplies off-grid electricity for large-scale continuous or backup power for hospitals, water treatment centers, data centers or military units, organizations must be confident in the durability of the generator sets (gensets) that supply that power.

Natural gas genset in Cummins testing facility. The gas combustion engine, alternator, cooling system and control system are all mounted on top of a metal support frame, or skid.

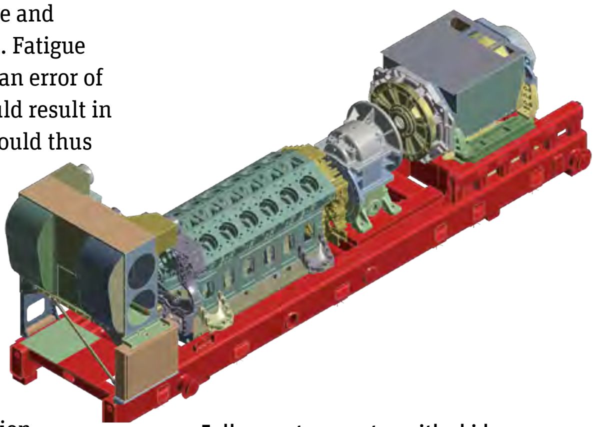
The size of the gensets required to meet electricity demands in the absence of grid power often means that they are isolated in a room. Repairing them might require taking the room apart at great cost. A genset's components, including the engine, crankshaft, generator, fans and radiators, are mounted on a metal frame that is known as a skid. Loading from the engine vibrations causes fatigue in the frame structure and connecting welds, which is the skid's primary failure mode of concern. For engineers at Cummins Power Systems, increasingly accurate prediction of the fatigue life of a skid based on a genset's actual operating conditions was desired.

A NON-TRADITIONAL APPROACH

Previously, the process used by the Cummins team was to develop an analytical modal model of the structure and perform an experimental survey using accelerometers under operating conditions. The engineers used these measurements to determine an overall modal scaling factor for each mode.

Looking at each mode separately, the results from ANSYS Mechanical would be scaled by this factor to review the stress and strain predictions. It was not possible to look at the summed modal response with this method.

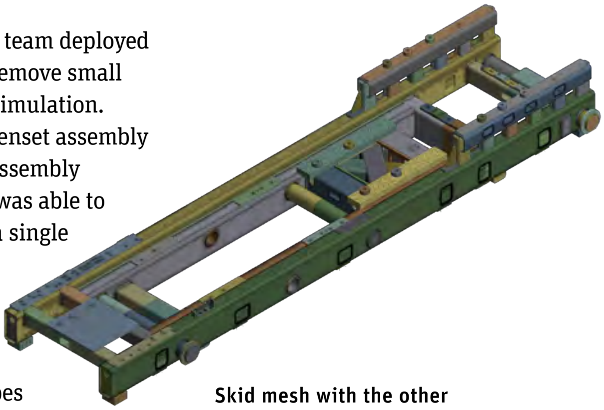
The team knew they needed a better process, because they were spending a lot of time and effort fixing problems that did not exist. Fatigue prediction is a log–log phenomenon, so an error of 15 to 20 percent in the strain history could result in a 200 percent error in the life model. It would thus be important to consider the complete participation of all the modes and to leverage industry standard tools for fatigue analysis. However, developing a better correlated strain history was paramount.



Full genset geometry with skid components shown in red in ANSYS Mechanical

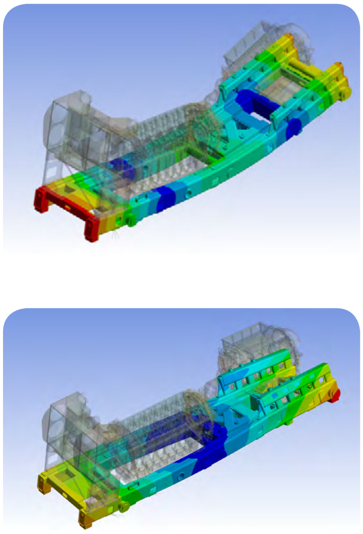
Cummins needed insight about where to place strain gauges on the skid to capture the right test data to correlate a model for the fatigue analysis. By adding the True-Load software package from Wolf Star Technologies into the simulation workflow with ANSYS SpaceClaim Direct Modeler and ANSYS Mechanical, the engineers were able to greatly improve speed and accuracy of skid durability modeling.

Beginning with an imported CAD geometry of the skid, the team deployed the defeaturing capabilities of the SpaceClaim technology to remove small gaps and faces that would not be important to the structural simulation. This reduced the overall mesh complexity. The mesh for the genset assembly model contained about 4 million elements. Using the model assembly function in the latest version of ANSYS Mechanical, the team was able to build the mesh three times faster than it would take to build a single model in the previous workflow. This model had much higher fidelity than any of the previous generations, largely due to the capabilities of SpaceClaim and Mechanical.



Skid mesh with the other genset structures removed

The structural simulation in Mechanical focused on a modal analysis, that is, determining the frequencies and shapes of the modes that are characteristic of the structure based on the



ANSYS Mechanical results showing the first and second modes of the vibration frequency modal analysis for the skid, representing vertical bending (top) and twisting mode shapes (bottom)

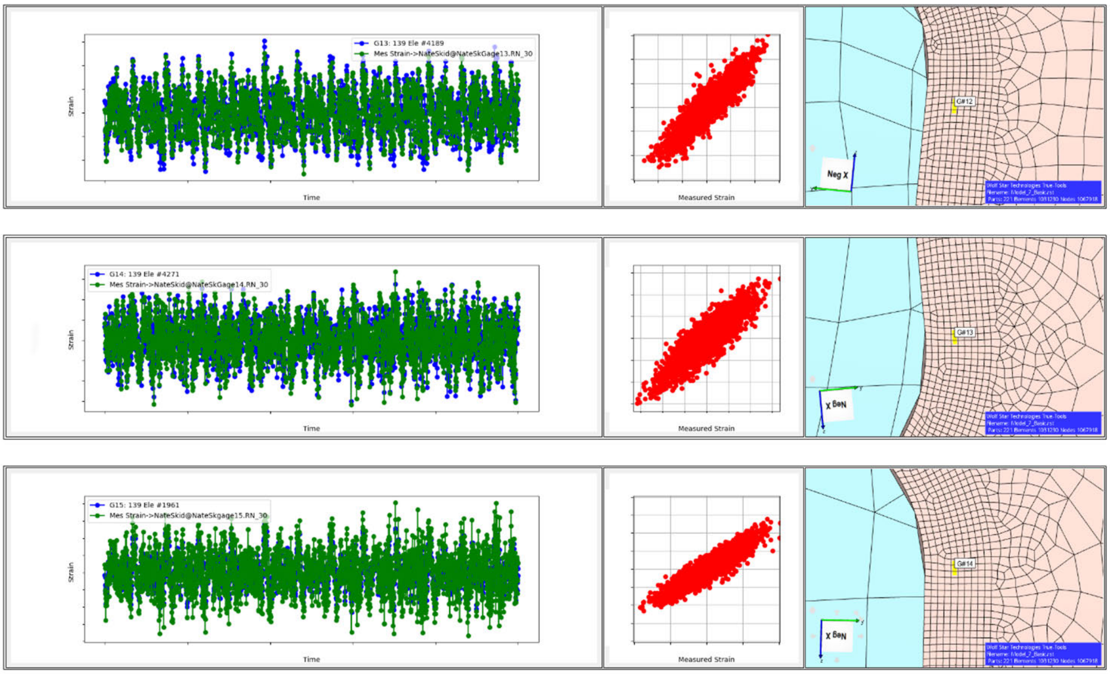
forcing functions that come from the engine vibrations. The team needed to understand both the total number of modes and the dominant modes that would determine the overall dynamic response. These modal excitations are what produce the stresses and strains on the skid, which is important for the downstream fatigue analysis. Using Mechanical's parallel computing capabilities with a 16-core desktop workstation, the time to solution was accelerated by a factor of 3 to 10, depending on the analysis settings and complexity of the mesh. The computational speedup was enabled, in part, by creating the bonded contact definitions in a way to allow the model to solve more efficiently. The result of the modal analysis was 24 modes that the team could use as unit loads for use with True-Load.

CORRELATING THE STRAIN HISTORY

From the Mechanical solution, the Cummins team brought the results file with the modal analysis into True-Load. Using True-Load/Pre-Test, the engineers obtained guidance for the best places on the skid structure to lay physical strain gauges for experimental testing. The team found that a major benefit of True-Load/Pre-Test was that they avoided laying gauges in the wrong places and thereby getting unreliable data.

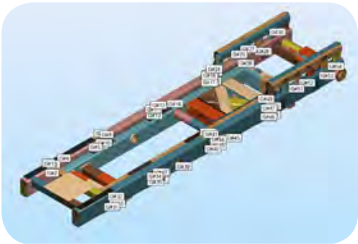
Generally, the guidance for experimental testing is that about one and a half to two gauges are needed for each unit load or mode. True-Load uses the deflected shapes from the Mechanical model. These shapes can be caused by static loads or eigen modes. In general, True-Load allows for the mixing of constraint modes (unit displacements), attachment modes (unit forces) and eigen modes (flexible modes).

The testing team was interested in 24 modes, which led them to use about 40 to 50 gauges for the skid. True-Load provided the team with the gauge locations by identifying the primary load paths for the structure based on the provided unit loads. With traditional techniques, a gauge may have been placed at what experience told the team was a relative hot spot, such as a weld, pin or notch. Using this new approach, True-Load instead guided them to place it at a more appropriate location for later use in the strain correlation.

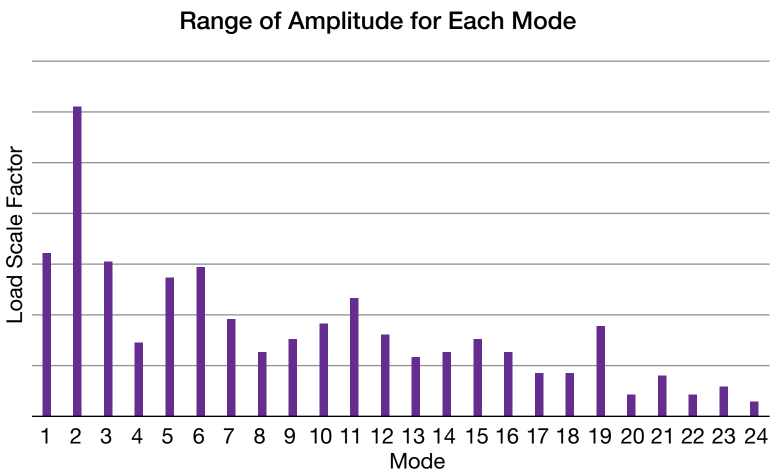


Left: Time history of measured strain data (green) compared to strain predictions using True-Load modal participation functions (blue). Right: Correlation graphs showing the strain predictions plotted against the measured data at three representative gauge locations for a test run. Perfect correlation would be a straight line with a slope of 1.

With the gauge locations in hand, the Cummins experimentalists collected data running the genset engine at speeds ranging from 1,350 to 1,650 rpm in one-minute intervals, including starting and stopping. At a high sampling rate, the team amassed a tremendous amount of data. This was not an issue since True-Load had no limit on the size of the data set and Cummins had plenty of hardware capacity to perform the correlation analysis. Using the experimental data with the unit loads from the Mechanical solution, True-Load/Post-Test calculated the modal participation functions. This produced the right combination of modes to correlate the simulated results to the measured strain data with an average error of about 6 percent (normalized root-mean-square). From there, the engineers took the True-Load load scale factors combined with the stress predictions from Mechanical and fed them into a fatigue analysis tool to generate the life contours for the skid.



Recommended locations for 54 strain gauges from True-Load/Pre-Test based on the modal analysis data



Modal participation functions calculated by True-Load/Post-Test define how much each mode is contributing to the total response. The graph shows that the amplitude range decreases as the modes and frequency increase, which should be the case.

> **"Using the model assembly function in the latest version of ANSYS Mechanical, the team was able to build the mesh three times faster than it would take to build a single model in the previous workflow."**

RESULTS AND PROCESS IMPROVEMENTS

The fatigue predictions showed that no damage to the skid would result from the specified duty cycle, which theoretically results in an infinite life for the structure. The team found that subsequent redesigns to reduce the skid's weight did not appreciably change the predicted mode shapes and frequencies for the first few modes in Mechanical. Since the first few modes were the most significant contributions to the total response, the loading functions of the tested design could then be used as an approximation to evaluate the redesign in True-Load and the fatigue software package.

Because the full-field strain results could be extracted from relatively few discrete measurement locations, the Cummins engineers found this to be a huge value-add through both reduced development and testing time and overall reduced part cost by eliminating overdesign. Furthermore, in comparison to the traditional approach, the new process has promoted additional collaboration between the analytic and experimental groups as part of a straightforward end-to-end workflow for fatigue evaluation. Due to the significant design and analysis process speedup, the team plans to use the new approach in the future for other genset structures where the modal response is of interest, including the fans, radiators, shrouds and crankshafts.

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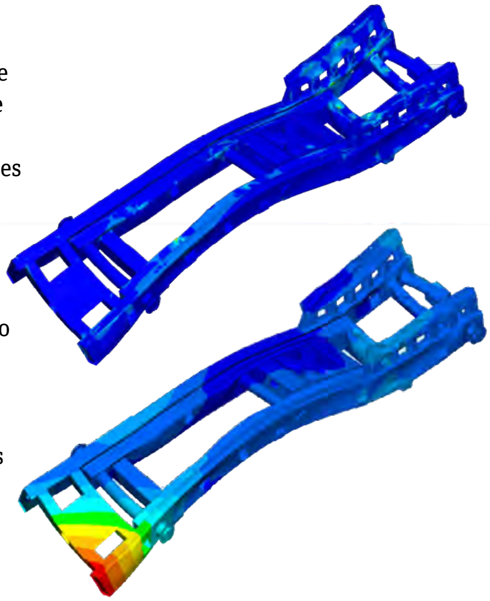

True-Load results showing first principal strain (top) and total displacement (bottom) over the entire skid at the same instant in time