On-Site Test Data Analysis Helps Get Optimized Exhaust Flex-Joints to Market Faster and Reduce Design Risk

Solution requirements:
- Automate and simplify complex test data analysis.
- Handle test data and CAE fatigue analysis within a single environment.
- Evaluate design options and change the design if necessary in the early stages of the design process.

BOA Group

BOA specializes in the engineering and production of flex-joints for exhaust emission systems that decouple the engine motion from the exhaust structure. Exhaust flex-joints need to be custom engineered for each application in order to balance their static offset and dynamic motion, and ensure they meet fatigue life requirements for any automotive, commercial vehicle and off-road application. The data required for this custom design process is captured during road load data acquisition (RLDA) at a proving ground. In the past, several steps were required to analyze the data and it was necessary to manage every single step of this complex process using different software products which slowed the decision-making process.

BOA has streamlined its engineering process by implementing nCode GlyphWorks. GlyphWorks automates most of the test data analysis process and eliminates the need to convert file formats, thereby reducing the possibility of having to redo the analysis due to input errors. With some of the data analysis now completed on-site, soon after RLDA, preliminary engineering decisions can be made on the spot and the RLDA can be concluded with confidence that additional data will not need to be collected later.

BOA Group is a leading system developer and supplier of flexible element technology, bellows, hoses and decoupling devices worldwide. Its customers include almost all European and stainless steel plies. This tubular body is formed into corrugations by a hydroforming process that delivers close tolerances. The use of thin gauge material combined with a large number of corrugations per unit length reduces deflection forces acting on and increases the flexibility of the bellows.

Importance of physical testing

BOA creates custom mechanical bellows designs to meet the requirements of specific automotive, on-road and off-road applications for exhaust, on-engine and intercooler systems. The company uses finite element analysis software to simulate the ability of proposed bellows designs to decouple the engine motion from the rest of the system. The company then builds a prototype of the proposed design that the customer installs on a vehicle for testing at the proving grounds, capturing data from accelerometers, strain gauges and displacement sensors.

The primary purpose of physical testing for BOA is to validate the critical tradeoff between

Real Motion Acquisition (RMA) setup as an input to GlyphWorks for on-site data validation

Hose and Engine Motion Analysis Calculations (HEMAC) setup
static manufacturing/assembly offset and dynamic range. The exhaust flex joint has a certain amount of flexibility, or dynamic range, which is needed to accommodate the relative motion of the engine and the exhaust system. However, the initial variation in alignment between the engine and exhaust system, called the static offset, takes up a certain amount of that dynamic range. Physical testing is needed to determine the dynamic range required by the vehicle's operating envelope to ensure it is within the flex hose's dynamic range. Physical testing is also performed to determine the fatigue life of the flex joint on this particular vehicle. The required life of the flex joint might be 150,000 miles, yet there is rarely time to drive the prototype for this full distance. In any case, the life of the flex joint is determined not by how many miles the vehicle is driven but by the number and magnitude of severe loads it receives, such as when the vehicle goes over a pothole. The amount of damage produced by these events is estimated by driving a prototype with the flex joint installed over potholes, Belgian blocks, or other hazards designed to generate severe loads on the flex joint. The loads from each event are recorded by the sensors. The damaging events are converted to stresses and strains. The vehicle OEM determines a duty cycle that defines how many of each of these damaging events the vehicle is expected to see during its warranty life. The test data is compressed and accelerated to generate a damage profile that corresponds to the OEM's duty cycle and is used as input for a fatigue analysis that predicts the life of the flex joint.

Previous test data analysis process
BOA has previously used a number of different internally developed and commercial software packages for test data analysis. Each time engineers moved from one software package to another they had to go through a data conversion process. The test data was typically captured in Microsoft Excel. MATLAB routines were used to convert the test data to stresses and strains. Developing the duty cycle by combining many events from the road test data was a tedious, manual process. Data was then converted to the proprietary format used by a fatigue analysis software package. The data conversion and manual processes caused analysis delays, so a considerable period of time was required to determine whether or not the RLDA had captured all of the necessary data. By this time everyone involved had usually traveled back from the proving ground to their offices and were often involved in other projects, hence producing further delays.

"In the past, we were working with software that was more laborious and manual for the task and had difficulty handling test data," said Srinivas Gade, Product Development, Advanced Engineering for BOA. "Tools like Excel and MATLAB also require considerable effort to make them work."

Real Motion Simulator (RMS) drive file optimization & generation process using GlyphWorks

BOA's GlyphWorks process using scripts and Studio Display for automated reporting of results and plausibility checks for multi-file sensor data inputs

Load-based flex capability analysis using GlyphWorks scripting glyphs

"GlyphWorks is designed from the ground up for test data so it fits the task perfectly"
Switching to new test data analysis tool

BOA selected nCode software to streamline its engineering test data analysis because of its ability to handle the complete process within a single environment and its wide range of specialized tools for both test data and FE fatigue analysis.

BOA also switched from its previous fatigue analysis software to nCode DesignLife which integrates with GlyphWorks to enable test data analysis and CAE fatigue analysis in one environment. BOA is able to accurately predict the failure location by using capabilities in DesignLife such as hot spot detection in 3D, stress distribution in 3D, and virtual strain gauge analysis.

"GlyphWorks is designed from the ground up for test data so it fits the task perfectly," Gade said.

BOA now performs its complete analytical process within GlyphWorks. BOA engineers created the analysis workflow by simply dragging and dropping analysis building blocks. This approach eliminates the need to convert data to a different format and makes it possible to partially automate their test data analysis process. The company has developed custom scripts that use its own algorithms to convert RDLA into stress-life and strain-life curves needed for fatigue analysis.

BOA engineers also use GlyphWorks to perform post-processing of raw sensor data to 6 degree of freedom (DOF) relative motion data of an exhaust flex hose using complex mathematical algorithms. The data is automatically converted into reports that were defined by BOA engineers to expedite the design decision-making process. The reports make it easy to determine whether or not the original flex hose design has sufficient dynamic range to accommodate the vehicle's relative motion.

Optimizing the design

BOA engineers take advantage of GlyphWorks' capability to utilize test data to perform designed experiments to evaluate fatigue life as a function of design parameters such as the diameter of the flex hose. This approach is performed with DesignLife and can be used to improve the existing design without having to run additional RDLA. BOA engineers have also written scripts that evaluate each potential design combination for manufacturability so only designs that can actually be built are evaluated.

Engineers have developed a custom process within GlyphWorks to generate accelerated drive files for a 6 DOF simulation used to test the part without having to install it in a prototype vehicle and run it on the proving ground. This approach can be used after RDLA is performed on a vehicle to evaluate other flex hose designs without having to re-run the RDLA.

High frequency data acquisition is also performed using a microphone inside the passenger cabin to evaluate the impact of the flex joint on noise/vibration/harshness (NVH). BOA uses GlyphWorks to process the data and perform order analysis, which involves matching the accelerometer data to the speed of the motor and makes the data much easier to interpret.

"Improvements seen from using nCode GlyphWorks and DesignLife make it possible to completely process and analyze the data more efficiently," Gade said. "The result is that the post-RDLA analysis can be completed in real time while the proving ground testing is conducted. Engineers that are gathered together at the proving ground can study the test data and fatigue analysis results and make decisions on the spot. If the data indicates a problem with the design, a new design can quickly be fabricated and tested, avoiding the need for another round of testing at a later date. The ability to evaluate design options and if necessary change the design in the early stages of the design process increases confidence, reduces risk and helps get products to market faster."
About BOA

American BOA, incorporated in 1956, is member of the Stutensee, Germany based globally operating BOA Group. Organized in 3 business divisions: Automotive, Industrial and Aerospace, BOA offers a broad range of flexible metal solutions for pipeline systems conveying gases or fluids under severe pressure and temperature conditions. With more than 100 years of experience and 20 subsidiaries or major shareholdings across the world, BOA has become one of the technology leading groups in this particular industry.

BOA automotive engineering centers in Germany and in the United States develop specific customized flexible joints and expansion joints for exhaust system, EGR and Oil return lines for engines and mini-bellows for high pressure fuel injection systems which compensate for movements, thermal expansion and decouple vibrations in a reliable way. www.boagroup.com

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– Srinivas Gade, Product Development, Advanced Engineering for BOA

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