MSC Software: Case Study - American BOA

Finite Element Analysis Helps Reduce Time to Develop Exhaust Expansion Joints From 5 Weeks to 2-3 Weeks

American BOA specializes in the engineering and production of thinwall flexible metal components and systems for automotive and industrial applications. The company frequently creates new designs to meet the requirements of automobile original equipment manufacturers (OEMs). The damping characteristics and stiffness of the flexible joints are configured to optimize the noise vibration and harshness (NVH) characteristics of the vehicle. In the past, American BOA used engineering formulas to develop a rough design and then built and tested the physical prototypes in 6DOF (Degrees Of Freedom) for characteristics and durability to fine-tune the designs, which took about five weeks.

The company has switched to a new methodology in which MSC SimXpert is used to model the initial concept design and MSC Nastran is used to simulate the ability of proposed bellows designs to decouple the engine motion from the rest of the exhaust system. Then a more detailed nonlinear analysis is performed on the bellows to quantify its loading, durability and identify its resonant frequencies. The new approach reduces the design and development lead time by 50% to two to three weeks and also has greatly reduced prototyping as well as empirical 6DOF validation expenses.

Tough Design Challenge

BOA pioneered the multi-ply bellows design which absorbs thermal expansion and vibration in engine and compressor piping systems. The multi-ply bellows is manufactured from a laminated tube that consists of thin gauge 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.

Key Highlights:

Industry

Auto

Challenge

Reducing time to develop exhaust expansion joints

MSC Software Solutions

SimXpert is used to model the initial concept design and MSC Nastran simulates the detailed nonlinear analysis on the bellows to quantify its loading, durability and identify its resonant frequencies.

Benefits

- Simulated Expanded Physics
- Improved Design Performance
- Validated with Physical Test

“MSC Nastran and SimXpert have helped us reduce the time to market on a typical project by 50% while achieving a huge reduction in prototyping expenses.”

Srinivas Gade, American BOA

Depending on the operating pressure the end forces acting on anchors or engines may be substantial. The multi-ply bellows’ favorable corrugation profile and low spring forces reduce the end forces thereby improving engine and turbocharger efficiency. The contour of the thin gauge multi-ply convolution is designed to keep pressure induced and deflection stresses at a minimum. The resulting low stress levels improve fatigue life.

American BOA creates custom mechanical bellows designs to meet the requirements of specific automotive applications. In many of these applications, the automotive OEM provides the design of the complete exhaust system and American BOA optimizes the properties of the bellows to decouple the engine motion from the exhaust system.

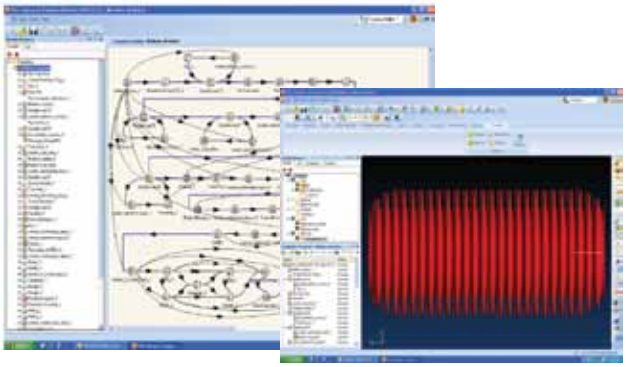
The OEM also provides the critical engine frequencies. The goal is to optimize the bellows so that it is stiff enough to provide a long life and flexible enough to minimize the coupling between the engine and exhaust system for good NVH performance. It’s also important to ensure that the bellows itself does not have any natural frequencies that could be excited by the engine.

In the past, American BOA engineers developed an initial design based on Expansion Joint Manufacturers Association (EJMA) formulas. “FEA has increased the accuracy of the design & durability predictions by using 3D geometry and 6DOF loading,” said Srinivas Gade, Product Development Engineer for American BOA. “For this reason we used to build physical prototypes and perform a series of physical tests. This involved building special hydroforming tools and often purchasing materials as well. The cost and leadtime were so high that we usually had to settle for the first design that met the customer’s requirements rather than searching for the best possible design.”

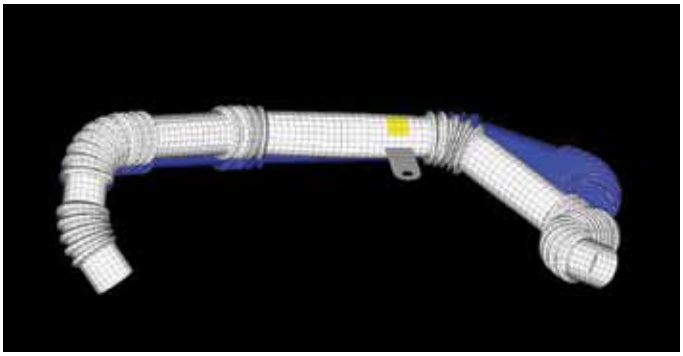
Move to Simulation-Based Design

American BOA decided to move to a simulation-based design process based on MSC Nastran. “MSC Nastran is the most user-friendly of the strong nonlinear solvers,” Gade said. After adopting MSC.Software tools, American BOA developed a new design process that replaces hardware prototypes with software prototypes to improve product performance while saving time and money.

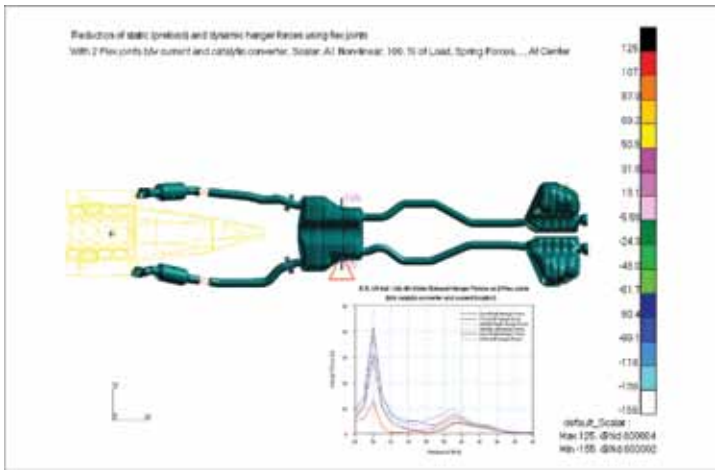
The process typically begins when the customer provides a CAD file that defines the geometry of the exhaust system along with the engine roll information, time history data that defines the engine’s motion. The stiffness of the engine isolator is another value that is usually provided by the customer. The customer also provides the critical engine frequencies so that American BOA can check for resonances.



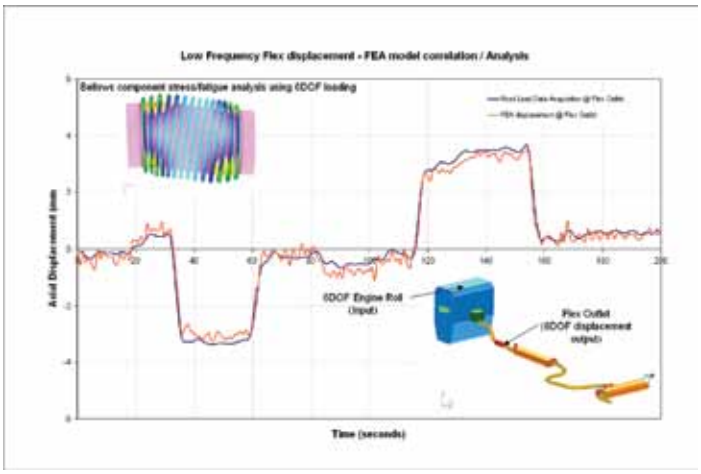
SimXpert automated GUI based parametric macro process



EGR pipe, mode and frequency analysis using the FEM



Reduction of static preload and dynamic hanger forces using flex joints in an exhaust system



Validation of FEM model using Road Load Acquired Data

American BOA is in the process of moving to SimXpert as their modeling tool. “The biggest advantage is that SimXpert provides a platform for graphical development of automated processes without having to write a line of code,” Gade said. “We connect pipes to develop an end-to-end design process. For example, we have developed templates that enable our engineers to generate a model of a multi-ply bellows simply by inputting the critical dimensions such as diameter and length and the materials and material properties. Our new automated process substantially reduces the time required to iterate from the initial concept to an optimized design.”

The first part of the simulation process tunes the bellows to optimize NVH performance of the entire exhaust system. The longer the bellows the more engine motion it can absorb. But lengthening the bellows also reduces its natural frequencies, which increases the potential for the bellows to be excited by the engine. American BOA engineers normally use MSC Nastran CBUSH elements to model the exhaust system. A CBUSH spring is similar to a conventional beam element in that its orientation uses a local coordinate system defined by the element’s “i-j” directional vector in space. Unlike conventional spring elements, CBUSH elements also have damping properties. American BOA engineers perform stress analysis to evaluate the stress and strain on the bellows. The goal is to make sure the bellows is not operating in the plastic region. If the stress is too high, then engineers change the design of the bellows so it absorbs more motion, typically by varying multiple parameters in combination like convolution radius, pitch, height, ply thickness, etc. This process optimizes the bellows from the standpoint of the complete exhaust system.

Component-Level Analysis

The next step is component-level analysis. If the OEM provides force-frequency input then it is used to load the model. If not, American BOA engineers perform a normal modes analysis for the whole system. The resulting frequency response plot is evaluated for resonances and other frequency spikes. Spikes are acceptable as long as they are not too close to the operating range of the engine. In many cases engineers then perform a full-fledged fatigue analysis. MSC Nastran solves the static load cases to determine the stresses, which are then input to fatigue analysis software. “We typically do 5 to 10 iterations to optimize the bellows from a frequency response and fatigue life standpoint,” Gade said. “The automated design process based on SimXpert has substantially reduced the time required to model these designs and evaluate their performance. We have reduced the time required to optimize a bellows at the component level from one week to only two days. Once the component analysis is complete then we build a prototype and take it to the automotive proving grounds.”

The component analysis is nonlinear because the bellows might have self-contact resulting in geometric nonlinearities and also might go beyond elastic limits resulting in material nonlinearities. The goal is to always stay in the elastic range because it is easier to predict the fatigue life of the component. But in some cases it is necessary to operate in the plastic range because there is not enough room to increase the length of the component. In this situation, empirical testing is used to validate the simulation results. So far, according to Gade, the correlations have been good.

Other Uses for Simulation

American BOA also uses MSC Nastran to simulate the performance of tooling used in the hydroforming process. Finite element analysis is used ensure the tooling can withstand the high pressures involved in hydroforming. The company also recently used MSC Nastran to evaluate fixtures used on a hydraulic shaker to hold parts during durability testing. Finite element analysis was used to evaluate several design alternatives for resonances that would have interfered with testing. “MSC Nastran and SimXpert have helped us reduce the time to market on a typical project by 50% while achieving a huge reduction in prototyping expenses,” Gade concluded.

About MSC Software

MSC Software is one of the ten original software companies and the worldwide leader in multidiscipline simulation. As a trusted partner, MSC Software helps companies improve quality, save time and reduce costs associated with design and test of manufactured products. Academic institutions, researchers, and students employ MSC technology to expand individual knowledge as well as expand the horizon of simulation. MSC Software employs 1,000 professionals in 20 countries. For additional information about MSC Software's products and services, please visit www.mscsoftware.com.

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About MSC Nastran

Accurate, Efficient & Affordable Finite Element Analysis

MSC Nastran is the world's most widely used Finite Element Analysis (FEA) solver. When it comes to simulating stress, dynamics, or vibration of real-world, complex systems, MSC Nastran is still the best and most trusted software in the world – period. Today, manufacturers of everything from parts to complex assemblies are choosing the FEA solver that is reliable and accurate enough to be certified by the FAA and other regulatory agencies.

Engineers and analysts tasked with virtual prototyping are challenged to produce results fast enough to impact design decisions, and accurate enough to give their companies and management the confidence to replace physical prototypes. In today's world, nobody has time or budget to spend evaluating the accuracy of their FEA software – you need to know it's right.

MSC Nastran is built on work done by NASA scientists and researchers, and is trusted to design mission critical systems in every industry. Nearly every spacecraft, aircraft, and vehicle designed in the last 40 years has been analyzed using MSC Nastran. In recent years, we've applied some of the best and brightest scientists in CAE to extend MSC Nastran's power and efficiency, resulting in its continued status as the world's best, most trusted, and most widely used FEA software – period. New modular packaging that enable you to get only what you need makes it more affordable to own Nastran than ever.

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