MSC Software: Case Study - Race-Tec Sealing Limited

High Performance Seals

Nonlinear Simulation Helps Automotive Supplier Design Longer Lasting CV Boots

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Race-Tec Sealing Limited is a leading supplier of high performance seals and precision elastomeric products such as constant velocity (CV) joint boots and gaskets. CV boots used in racing, military and off-road vehicles undergo large amounts of deformation as the vehicle is steered and the suspension moves up and down. Boots must be designed to withstand the deformation without damage while keeping the size of the boot as small as possible to present a reduced area for flying object strikes. Virtually any geometry can be made out of rubber but the cost of building a prototype of and testing a proposed boot design is high.

Race-Tec engineers overcome these challenges by simulating the performance of CV boots with MSC Software's Marc® nonlinear finite element analysis software. Marc enables them to very quickly evaluate alternative designs and iterate to

an optimal solution. "In a recent typical example, we reduced the height of a boot for a military vehicle from 180 mm to 32 mm while maintaining stress under maximum deformation at constant levels," said Richard Kennison, Senior Design Engineer for Race-Tec. "The new boot lasts much longer than the previous design because its lower profile makes it less vulnerable to object strikes and significantly reduces self-contact."

Race-Tec has been supplying high performance sealing solutions to the racing industry for over a decade and has utilized its sealing expertise to enter other markets including high performance production vehicles, military vehicles and all terrain vehicles. The company specializes in compact designs that can be integrally mounted to the differential assembly, reducing drag and offering a substantial space savings for adjacent components.

Key Highlights:

Industry

Automotive

Challenge

To design a CV boot that will be able to withstand articulation angles without excessive stress, deformation or contact.

MSC Software Solutions

Marc for nonlinear finite element analysis to quickly evaluate alternative designs and iterate to an optimal solution.

Benefits

• Consistent and Reliable Problem Solving

• Accurate and Robust Nonlinear Analyses

• Considerable Cost and Time Optimization

"Nonlinear analysis with Marc helps us dramatically improve the design of CV boots and other products. Our simulation capabilities enable us to design boots that substantially outlast competitive designs. The result is that we have been able to increase our market share in our traditional markets and successfully enter new markets."

Richard Kennison, Senior Design Engineer, Race-Tec

CV Boot Design Challenges

The function of the CV boot is to cover and protect the mechanical components in the CV joint from humidity, dust, mud, while ensuring that lubricant does not leak out. The boot may be mounted to the hub or transmission using an interference press fit, mechanical retention with a custom designed circlip, cable tie or clamp or chemically bonded into the housing. The most common boot materials used are hydrogenated nitrile, silicone and fluoroelastomers. CV boot performance is critical even though the boot itself is not expensive to replace because the failure of a boot can cause lubricant to leak out and abrasive particles to enter, leading to the failure of the CV joint itself.

The greatest challenge in designing a CV boot is ensuring that the boot will be able to withstand articulation angles without excessive stress, deformation or contact. Physical testing can provide a good understanding of a proposed design, however, the cost and time involved in building and testing a prototype is considerable. Not long after the company began operation, Race-Tec engineers began looking for a way to simulate the performance of a boot under real-world operating conditions.

"CV boots present one of the most difficult analysis challenges because they exhibit large displacements, large strains, incompressible material behavior, susceptibility to local buckling and varying boundary conditions caused by the 3D contact between various parts of the boot," Kennison said. The boot undergoes complex nonlinear deformation during the combined rotation and bending of the CV joint. During bending and axial movements in normal operation, contact between the boot and itself or with other vehicle components should be minimized to avoid abrasive wear. Simulation needs to be able to predict and determine the effects of contact during boot operation.

"Traditional finite element analysis tools are limited to solving within the limits of linear material properties, small strains and small rotations," Kennison continued. "Some software packages claim to have nonlinear capabilities but are not able to consistently and reliably solve problems involving highly complex frictional contact, large deformation, large strain and hyperelastic material behavior."

"We selected Marc because it was built from the ground up to consistently obtain converged solutions for such highly nonlinear problems," Kennison said. Marc represents elastomeric material behavior with tried and tested material models including Generalized Mooney-Rivlin, Boyce-Arruda, Gent and Ogden using a built-in graphical curve fitting capability to establish appropriate material coefficients from experimental stress/strain data. Smart contact and load incrementation algorithms ensure accurate and robust nonlinear analyses while simplifying model setup.
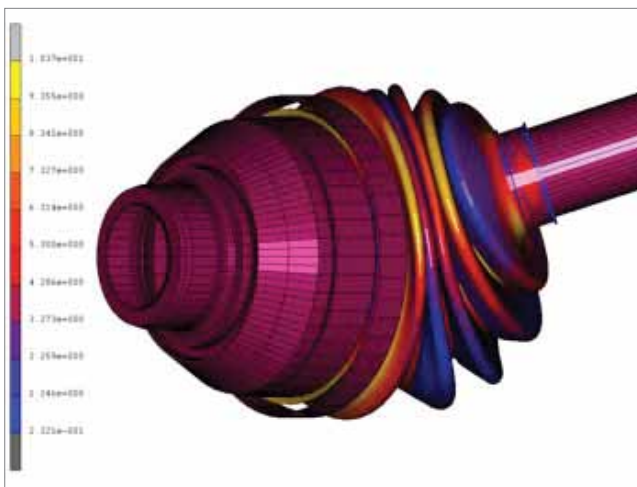

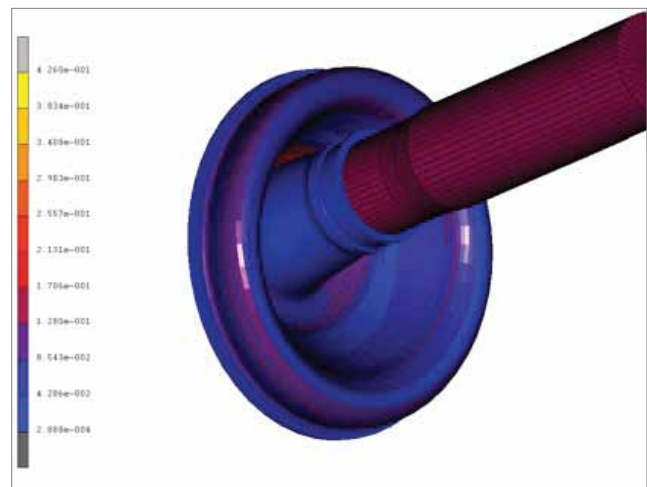Figure 1: Marc simulation results for initial CV boot design

Figure 2: Marc simulation results for final CV boot design

In the presence of large deformations, elements can distort to such a degree that they are unable to adequately capture an accurate strain distribution. Marc automatically remeshes, mapping all the element state variables and contact conditions to ensure that the analysis can proceed to the desired final loading condition. Marc also offers a local adaptive remeshing capability in which an existing mesh is repeatedly refined until one of several user-defined error criteria are satisfied.

Simulating a CV Boot

Race-Tec engineers prepare for simulation by creating a computer aided design model of the proposed boot design. Then they import the model into Marc. They define the mesh manually in the most critical areas and use the preprocessor's automeshing capabilities to define the remainder of the mesh. Race-Tec engineers apply centrifugal forces to the boot to account for the fact that it is rotating. Further boundary conditions are applied using rigid contact bodies. In this way, very complex translational and rotational deformations can be readily applied to the boot to simulate shaft loading behavior identical to that experienced in the real world.

The boot is made from a hyperelastic material that exhibits a nonlinear elastic response up to a very large strain. Such materials are challenging to represent mathematically because their behavior depends on a large number of variables. Race-Tec uses its on-site facilities for tensile and compression testing of hyperelastic materials at large strains at temperatures ranging from -30oC to 175oC as shown in Figure 4.

The Marc solver performs the nonlinear analysis in load steps called increments. The user defines acceptable tolerances for force, displacement, strain energy and other parameters in seeking equilibrium for each increment. Within each increment, the program seeks a solution by iterating until equilibrium is achieved before proceeding to the next increment. Depending on the level of nonlinearity experienced at each increment, Marc automatically modifies the step size in order to achieve a converged solution using the minimum number of increments.

The simulation typically begins with the shaft at a zero angle of rotation and ends with the shaft at the maximum angle. In the case of the CV boot for the off-road vehicle, Race-Tec engineers simulated the existing design at worst case conditions consisting of 37 degrees of steering, 19 degrees of suspension travel and 3 degrees of camber for a combined 3D angle of 42 degrees. The design objective was to withstand these extreme conditions without any contact and while minimizing the size of the boot. With CV boots used on racing cars, which are typically tri-lobe joints, Race-Tec engineers normally take a somewhat different approach by simulating both ends of a plunge condition with the suspension at maximum and minimum vertical height.

Iterating to an Optimized Design

The Marc analysis predicted the displacement, stress levels, strains and the points where the CV boot contacts itself and where it contacts the steel shaft. The initial design case helped Race-Tec engineers understand how the boot was deforming in response to the movement of the CV joint as shown in Figure 1. They created and evaluated a series of design iterations with the goal of continually reducing the size of the boot while minimizing stresses and contact.

Over a series of 60 design iterations, the engineers succeeded in dramatically improving the boot design as shown in Figure 2. Figure 3 shows the height was reduced by 82% from 180 mm to 32 mm. The reduction in height ensured the boot presents a substantially reduced area for impact strikes from road debris and reduced self contact. Somewhat different benefits are typically seen in CV boots for racing applications. The accurate prediction of buckled shapes and levels of strain allows the boots to be run closer to the tri-lobe joint, reducing the size and mass of the boots while improving the aerodynamic profile of vehicle.

"Nonlinear analysis with Marc helps us dramatically improve the design of CV boots and other products," Kennison concluded. "The smaller we can make the boot, the longer it will last. Our simulation capabilities enable us to design boots that substantially outlast competitive designs. The result is that we have been able to increase our market share in our traditional markets and successfully enter new markets."

Figure 3: Height comparison of initial and final design

Figure 4: Race-Tec tensile test machine

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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 Marc

Advanced Nonlinear & Multiphysics

Marc is a powerful, general-purpose, nonlinear finite element analysis solution to accurately simulate the response of your products under static, dynamic and multi-physics loading scenarios. Marc's versatility in modeling nonlinear material behaviors and transient environmental conditions makes it ideal to solve your complex design problems. With its innovative technologies and modeling methodologies, Marc enables you to simulate complex real world behavior of mechanical systems making it best suited to address your manufacturing and design problems in a single environment.

With the solution schemes that are smarter and designed to provide the performance that you need by taking full advantage of your hardware combined with an easy to use modeling solution, you can truly discover and explore nature's inherent nonlinearities. Whether your problems involve large deformation and strains, nonlinear materials, complex contact or interaction between multiple physics, you have reached the end of your search and with Marc, you can now focus on your improving your designs.

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