Case Study: **Big Tyre**

Nonlinear Analysis Accelerates Development of Non-Pneumatic, Non-Solid Tire for Mining Industry

Overview

Designing the right tire for large wheeled vehicles used to haul coal and other materials in underground mines presents an enormous design challenge. Pneumatic tires present risks because of the danger of an explosion in a confined space while solid tires are associated with relatively large vibrations experienced by the driver. Big Tyre, a company that specializes in producing solid tires for mining vehicles, is developing a unique alternative which uses arrays of leaf-springs, typically made of composite materials, to provide performance similar to pneumatic tires without the risk of blow-outs. The company began designing the new tires in 2002. They first designed and built drive tires for a racing go-kart - these prototypes, built in 2006, proved the concept very well. Next they designed full-size prototypes for mining vehicles using finite element analysis but found that the software was incapable of modeling the rubber once it was bulging under load, causing the analysis of the wheel to always terminate early while carrying much less than full load. This seriously inhibited their ability to design the wheel – consequently the first full-size prototype for mining, while again confirming the concept, did not meet the design criterion they had set.

"We have been able to improve the design at a much faster pace than in the past. It even allows us to simulate driving maneuvers of the vehicles, including obstacles on the road."

"We were pleasantly surprised that Marc was able to handle such a demanding analysis problem in such a short period of time and deliver results that closely matched test results on the prototype."

Bruce Louden, Big Tyre

Challenge

Underground Tire Challenges

Big Tyre is a manufacturer of solid wheels that are primarily used in underground mining vehicles. "Many mining companies have switched from pneumatic tires to solid wheels because of the dangers presented by pneumatic tires underground," Louden said. "Mines underground have bolts sticking out of the walls that can easily cause punctures. Tires on heavy vehicles are inflated as high as 170 psi, so when they are torn or punctured a considerable amount of force is released. Due to space constraints underground, workers are often in close proximity to the tires so the potential for injury when a tire is torn or ruptures is a major concern." Because of these concerns, many mining companies have switched to solid rubber-tired wheels or solid tires comprising a pneumatic tire whose interior is filled with foam. These tires eliminate the risk of punctures but their dampening properties are inferior to pneumatic tires so operators experience considerably more vibration. In some mines, operators are restricted to spending no more than 90 minutes a day on machines with solid wheels due to the effects of vibrations. Another problem is that foam-filled solid tires don't provide as even a distribution of pressure on the ground as pneumatic tires. The highest pressure is usually seen in the center of the tire which can lead to the formation of ruts on the floor of the mine where the mine is working on soft strata.

Big Tyre has developed a non-pneumatic, non-solid segmented tire which it hopes will overcome these problems and potentially revolutionize the underground mining industry. The tire uses composite leaf springs that are more than four times as flexible as steel. The leaf springs are configured in opposing arrays so the wheels are completely balanced. The inner end of each leaf spring is connected to a steel hub, while the outer end is connected to steel or fiber segments that are bonded to a rubber tread. This design eliminates the need for the tires to be inflated so it eliminates the risk of punctures, reduces heat entrapment and is also expected to provide greater load, speed, haulage distance and longer life relative to pneumatic tires. Compared to solid wheels, the new design provides reduced vibration, increased ride comfort, lower contact pressure, more even pressure distribution, and improved lateral stability on slopes. While prototype wheels are open so that the springs can be viewed, the production models will be sealed on both sides for safety reasons and to prevent the tire from being contaminated by particles and debris from the mine.

Fig. 1: Inventor Bruce Louden with non-pneumatic non-solid wheel prototype

Solution

Introducing Simulation Into The Design Process

The design concept provides the flexibility and challenge of defining various design parameters including the number of springs in an array, thickness of springs, curvature of springs, length of springs, material properties of springs, geometry and material properties of the segments that the springs attach to on the outer diameter of the wheel, as well as many others. The design criterion is to provide a very efficient vertical loading for the size of the wheel while providing similar if not equivalent suspension to a pneumatic tire, with excellent torque capacity and lateral stability. "When you are designing something that has never been done before it can be frustrating," Louden said. "Using the traditional build and test method, without suitable FEA software, we would have had to build prototype after prototype, which would have been very expensive and time-consuming. It was clear that we needed to simulate the performance of the tire but this was a very challenging simulation problem."

In order to simulate the performance of the new tire, Big Tyre engineers needed to model the 3D contact between the springs and the segments and between the rubber and the road, the glued contacts between the segments and the rubber and the self-contact of the springs. They needed to address the hyper-elastic material behavior of

Fig. 2: Picture of Underground Mining Machine (Eimco 913) with Big Tyre's first full-size prototype wheel

Key Highlights:

Product: Marc

Industry: Heavy Equipment

Benefits:

- Accurate simulation that closely matches test results
- Flexibility of defining various design parameters to optimize final design

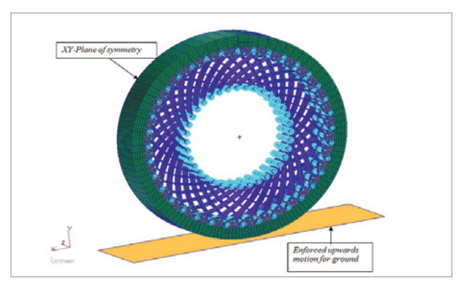

Fig. 3: Marc model of segmented tire prototype

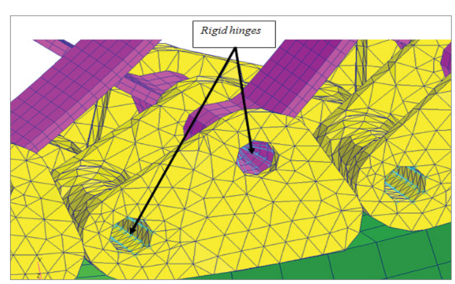

Fig. 4: Hinges connect leaf springs to segments

the rubber, the large deformation and (deliberate) buckling of the springs, and the elastic plastic material properties with failure for the composite leaf springs. They also needed to model the pin-joints between the segments while allowing for large deformations and driving the wheel. Big Tyre engineers tried to evaluate the performance of the new tire using the software package they had previously successfully used to analyze structures. "This software package is excellent for analyzing structures or assemblies with small deflections but could not cope with the highly nonlinear behavior found in the new tire," said John Shaw, Managing Director of Solidtech Engineering Services, a consulting company that provides engineering services to Big Tyre. "We were only able to solve about 40% of what we wanted and we were suspicious of these results because we were not sure that the nonlinear properties of the wheel were properly taken into account. Most important, we were unable to determine the failure point of the wheel which is the most critical design specification."

"We talked to Compumod because we discovered an article on the web that described how MSC FEA software was capable of re-meshing during an analysis to handle excessive strain in materials such as rubber," Louden said. "When we described the problem they told us that Marc was the right simulation tool to address it." Big Tyre commissioned Compumod to simulate the initial prototype. Big Tyre provided 3D geometry of the wheel and Compumod imported the geometry into Patran to create the finite element model. Hexagonal elements were used for the springs and rubber and tetrahedral elements were used for the steel segments. Symmetry in one plane was used to reduce the size of the model. The hinges between the different segments and between the springs and segments were modeled with rigid RBE2 elements that allowed free rotation around their own axes parallel to the wheel axis. 3D contact was defined between the ground and rubber. The rubber was glued to the segments through a special glued contact condition. Normal contact was defined between the springs and the segments and between the springs themselves. Big Tyre provided data for the material properties of the rubber and springs by conducting force-deflection experiments in their laboratory.

Results/Benefits

Nonlinear Analysis with Marc

Compumod first conducted a nonlinear static analysis on one spring to correlate the model material properties with experimental data. The material properties were tuned to replicate the measured reaction force in the experiment.

Then a nonlinear analysis was performed on the entire wheel to assess its strength. The wheel was given an enforced displacement of 150 mm which was solved in 100 nonlinear increments. The reaction force was then measured on the ground and graphed against displacement. The first negative slope indicated failure of the wheel at 252 kiloNewtons or 25.7 metric tons, which is well over the target of 16 metric tons. After the first collapse of the wheel, the contact between the springs and between the springs and segments added stiffness to the wheel and the reaction force increased again for increasing displacements. "We were pleasantly surprised that Marc was able to handle such a demanding analysis problem in such a short period of time and deliver results that closely matched test results on the prototype," Louden said.

"After seeing the benefits of the software, we decided to purchase Patran and Marc," Louden said. "Compumod organized training for us in their Sydney office and handed over the models they created in the consulting project. We very quickly began designing the second full-size version of our design, and have been able to improve the design at a much faster pace than in the past. It even allows us to simulate driving maneuvers of the vehicles, including obstacles on the road.

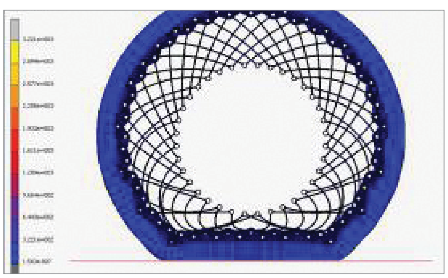

Fig. 5: Simulation results for vertical loading of symmetry model-b

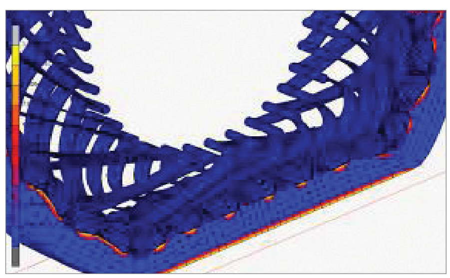

Fig. 5: Simulation results for vertical loading of symmetry model-c

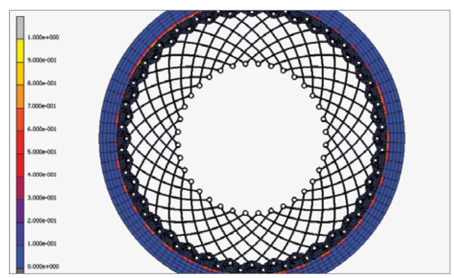

Fig. 5: Simulation results for vertical loading of symmetry model-a

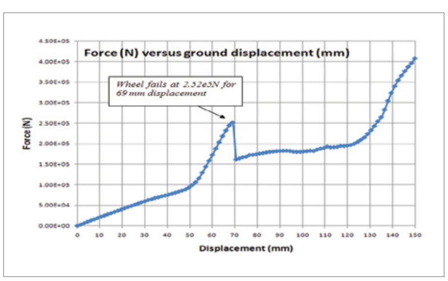

Fig. 6: Force vs. displacement curve

Fig. 7: Picture of prototype wheel advancing over an obstacle

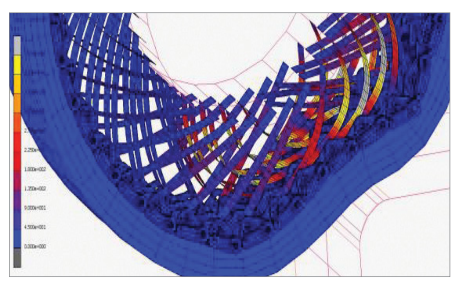

Fig. 8: Simulation results for moving wheel

For more information on Marc and for additional Case Studies, please visit **www.mscsoftware.com/marc**

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