John Deere Uses LMS Simulation Tools to Dramatically Improve Tractor Comfort

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John Deere engineers made extensive use of LMS multibody simulation to develop a new electronically controlled hydraulic cab suspension that dramatically improves operator comfort in the field and on the road. Up to now, cab suspension systems have used coil springs or air cushions with high natural frequencies that do little to dampen vertical oscillations. When physical prototypes were built and tested, the results correlated very closely to the simulation and confirmed that operator comfort was dramatically improved.

Ride comfort is becoming an increasingly important issue in agricultural vehicles. Excessive vibrations are uncomfortable and reduce the time that operators can spend on the job. Prior to the last decade, nearly all tractors had only a seat suspension and relied heavily on their large tires to deal with vibrations. The problem was that the damping ratio provided by this approach is very low, typically only 0.02. As a result, most of the major tractor manufacturers have added suspension systems in recent years that are designed to improve operator comfort and provide the real economic benefit of allowing the tractor to be operated at higher speeds both on the road and in the fields. Deere's approach was to develop a front axle suspension, the so-called Triple Link Suspension that is connected to the chassis at three points. A panel rod link ("Panhard rod") transfers lateral forces between the suspension and the chassis. A hydraulic cylinder that uses a nitrogen accumulator as the suspension element provides another link. Finally, a spherical joint in the middle of the tractor provides the third link. "This suspension very effectively improves ride comfort and also helps keep the front wheels on the ground to better transfer the steering forces," Dr. Thomas said.

"The use of multibody simulation helped us improve the performance of the new suspension while substantially reducing time to market by providing accurate performance predictions prior to prototyping."

Evaluate designs prior to prototyping

In the early stages of designing this suspension, Deere engineers recognized that it was far too complex to predict its performance with handbook calculations. Yet building and testing every major design iteration would drastically limit the number of alternatives that they would be able to consider. John Deere looked for a commercial software package that would help them to predict the performance of suspension designs without the need to build hardware prototypes.

"We selected LMS DADS during the early stages of the Triple Link Suspension design process because the quality of the results we achieved and the calculation speed were higher than the other alternatives that we considered," Dr. Thomas said. "The people at LMS worked with us very closely in the early years to improve their program to the point that we feel today that it is ideally suited for suspension analysis. For example, they added suspension modeling elements such as McPherson struts, short-long arms and pivoting beams. LMS DADS played a major role in the design of the Triple Link Suspension by providing very accurate performance evaluations of concept designs without prototyping expense and helped us iterate to a very effective design within our time schedule. We varied the natural frequency and damping and tried many different iterations before we specified the components for the initial prototype. When we finally built and tested the suspension the results met all of our expectations. As a result, we purchased a worldwide site license for LMS DADS and it has become one of the baseline tools that play an important role in our product engineering efforts."

Developing design specifications

More recently, Deere management made the decision to further improve ride comfort by offering a unique cab suspension system. Most cab suspension systems up to now have used coil springs and have natural frequencies higher than 1.6 Hz. The result was that they reinforced rather than counteracted vibrations in the range of 2.3 Hz that are the strongest under typical operating conditions. Another factor to consider is that the natural frequency of a driver's seat is in the same range, so resonance problems may occur between cab and seat. In an effort to improve the situation, Deere engineers performed a series of multibody simulations on a simulation model of the tractor with cab suspension. These simulations confirmed the well known theory that suspension systems isolate the cab only from excitations with frequencies that are a factor higher than the natural frequency of the cab suspension system. The engineers therefore determined that the ideal natural frequency of the suspension had to be targeted at 1 Hz. This insight guided the rest of the design process and made it possible to iterate to an optimal design in much less time and at a lower cost than would have been required if performance parameters had been developed on the proving ground.

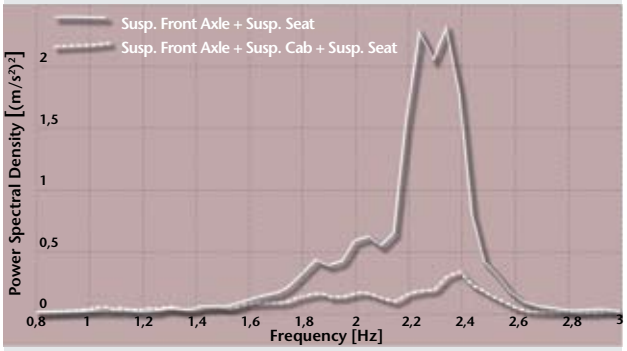
Combined with the planned attachment of isolators at the rear end of the cab, the 1 Hz specification meant that a static spring deflection of 60 mm was needed between a fully loaded and minimally loaded cab. With such a soft suspension, a load-leveling system was needed in order to achieve sufficient spring travel for different loading conditions. This functionality could not be achieved with conventional coil springs so the decision was made to use a hydro-pneumatic system. Multibody simulation was used to select an appropriate nitrogen gas volume and initial pressure setting to adjust the system to a natural frequency of 1 Hz.

LMS DADS delivers accurate performance evaluations of conceptual designs without prototyping expense.

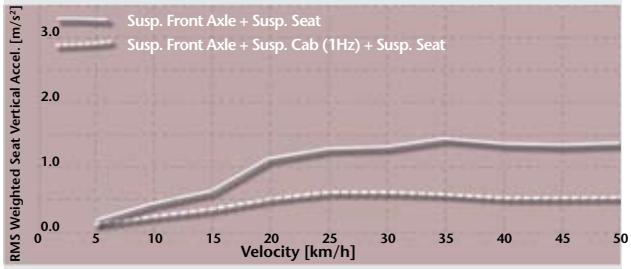
Predicting comfort of alternative designs

At this point, the first prototype was built and testing confirmed that it provided substantial improvements in ride comfort over existing cab suspension systems. In order to compare the comfort of subsequent design iterations, the frequency-dependent means of evaluating human comfort described in the International Standard Organization's 2631-1 specification were used. This specification describes two measurement standards, Root Mean Square (RMS) and power vibration dose. The RMS value of the frequency-weighted seat accelerations was selected as the primary means of evaluating subsequent iterations. This measurement was easily generated from DADS simulations for road and field conditions. As Deere engineers evaluated various design parameters and components in completing the design, they were able to quantify the impact of their decision on operator comfort.

The figure above provides a comparison of the ride comfort of a Deere tractor with and without cab suspension. The figure clearly shows that an unloaded tractor with front axle and cab suspension driving at a speed of 50 km/h is more comfortable from the operator's perspective than a tractor equipped only with a front axle suspension driving at 20 km/h. The comfort gain at 50 km/h is about 31%. Since operators spend a considerable proportion of their time driving to and from the worksite, the potential for significant productivity gains is obvious. The effect of the cab suspension system becomes even clearer by comparing the power spectral density curves of the vertical seat accelerations in the following figure. This figure demonstrates that drivers in a tractor without cab suspension are exposed to high oscillations in the frequency range around 2.3 Hz. A cab suspension system whose natural frequency lies far below this range can isolate them from this vibration. The hydro-pneumatic low-frequency cab suspension provides a demonstrably superior technical solution.



Power spectral density of the vertical seat accelerations.

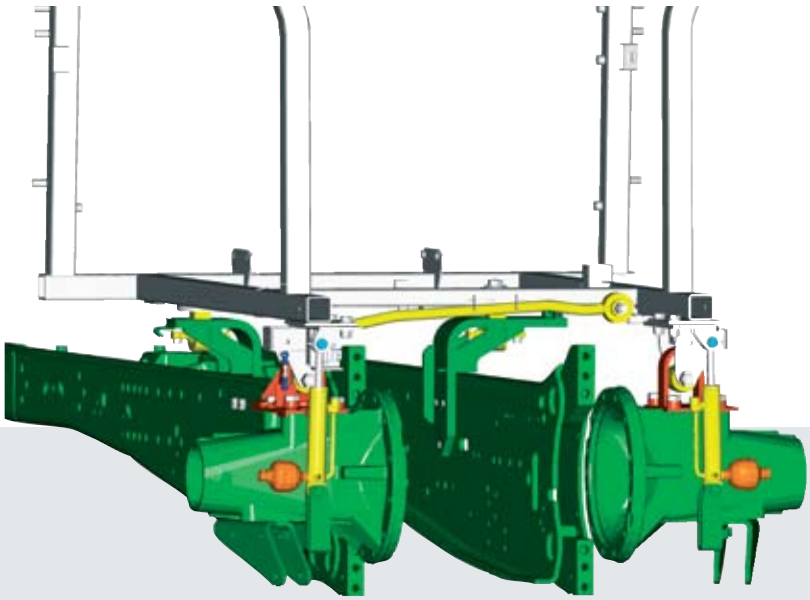


RMS of the weighted vertical seat accelerations.

Predicting component loads for fatigue studies

Multibody simulation provided another benefit during the design process by making it possible for engineers to consider fatigue durability earlier than would have normally been possible. A simulation run was set up representing the conditions on the test track used to evaluate component durability after prototyping. The simulation, which included obstacles of the same height and geometry as the test track, made it possible to generate component loads that were used as input to Finite-Element (FE) analysis programs used to finalize component design from a fatigue standpoint. Deere engineers also used MATLAB mathematical computing and Simulink modeling software coupled to DADS to evaluate suspension control systems. These included: filter design for ride comfort calculations, front axle and cabin suspension hydraulics, automatic leveling system, driveline model and simplified driver model.

The new cab suspension system was recently introduced to the market on the Deere 6020 series tractors as an option with the existing TLS II front axle suspension on models from the 6320 upwards. The new electronically controlled hydraulic cab suspension provides permanently active self-leveling of the cab with up to 100 mm of suspension travel to improve operator comfort both in the field and on the road. Dr. Thomas concluded that: “multibody simulation played a key role in this major design innovation by helping the product development team evaluate the importance of critical design parameters early in the design phase and also by making it possible to optimize various design parameters prior to prototyping."



"We selected LMS DADS because result quality and calculation speed were higher than the other alternatives."

LMS INTERNATIONAL
Researchpark Z1, Interleuvenlaan 68
B-3001 Leuven [Belgium]
T +32 16 384 200 | F +32 16 384 350
info@lmsintl.com | www.lmsintl.com

Worldwide

For the address of your local representative, please visit www.lmsintl.com/lmsworldwide

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