Simulation of Hydro-Pneumatic Suspension of a Rubber Track Undercarriage

Fig. 1: Rubber track undercarriage

CLAAS INDUSTRIETECHNIK GMBH

Since the 1990s, agribusiness has focused on track systems for harvesters because of the benefit to farmers. CLAAS Industrietechnik, located in Paderborn as a member of the CLAAS group, has set the benchmark with its rubber track undercarriage Terra Trac.
Since 2010, the Terra Trac system is suspended through two integrated piston accumulator cylinders, and the different components of the track are pivot-mounted. This combination enables movement of the components toward each other, and the track is perfectly fitted to the ground. The analysis of motion dynamics requires use of the multi-body simulation tool SIMPACK.
The complex hydro-pneumatic suspension system significantly influencing the overall motion has been modeled in Simulink® and was coupled to SIMPACK using co-simulation via SIMAT.

Multi-body simulation technology is found to play a crucial role in designing and developing state of art, optimized rubber track undercarriages at CLAAS. This work includes an in-depth modeling of damping characteristics of hydraulic and pneumatic mechanisms in the system, and subsequent validation of the model, with measured experimental data. In particular, since the characteristics of gas springs are progressive in nature,a realistic modeling through a polytrophic relation and a linear damping model with no pressure loss is adopted.

OVERVIEW

As a first step to setting up the hydraulic network, knowledge of the hydraulic components was necessary. There are two piston accumulator cylinders connected to the mechanical system. In contrast to an external bladder accumulator, a piston accumulator stores the gas inside the piston rod where gas and fluid are separated by an additional gas piston. The forces of the mechanical system are transmitted to the piston and the piston rod of the cylinders.

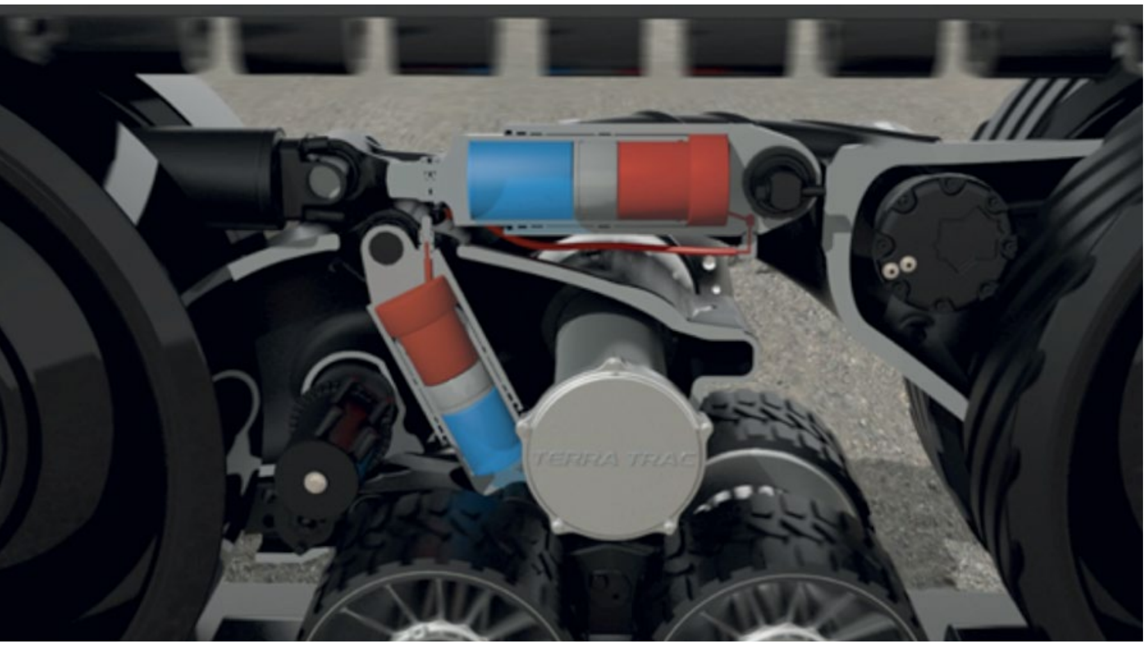

Fig. 2a: Hydro-pneumatic system

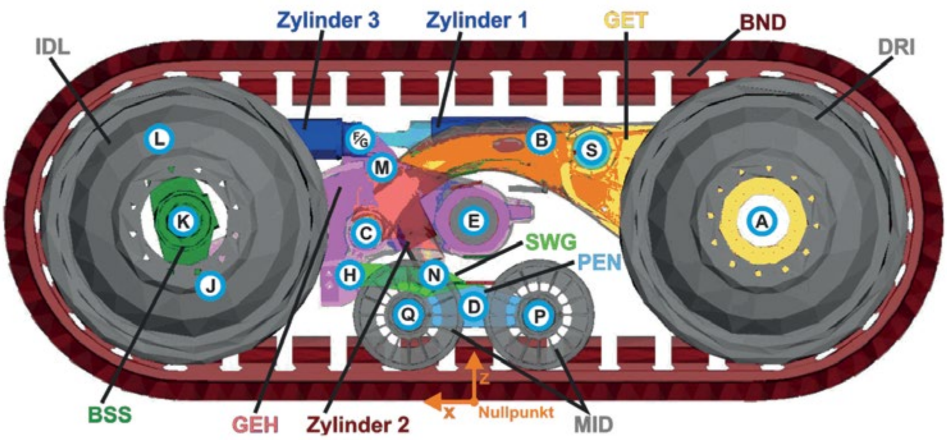

Fig. 2b: Rubber track undercarriage CAD model

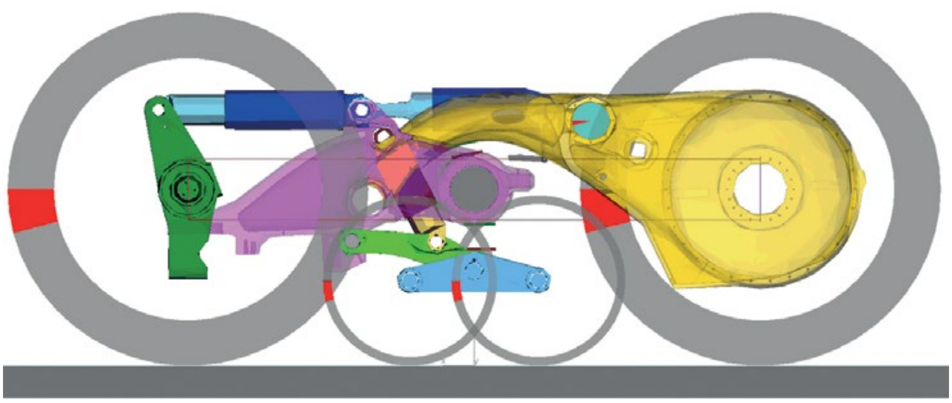

Fig. 2c: Rubber track undercarriage SIMPACK model

Inside, the external forces are sprung by the compressible gas mass. The oil chambers of these two cylinders are connected through a tube-hose combination consisting of two hoses, bent tube and miscellaneous couplings, with the effect of a permanent exchange of hydraulic fluid. That exchange produces viscous friction in the fluid and leads to the necessary damping for the decay of the oscillations caused by the gas spring. Additionally, a choke damps the volume flow of the oil which has significant influence on the system.

MODELING

Once the hydraulic components were identified, the next step was to find corresponding analytical elements for these and implement them in Simulink. Therefore, differential equations were set up for each sub-model. Generally, the dynamic hydraulic model is based on three describing analogies: hydraulic resistance, hydraulic inductivity and hydraulic capacity. Because the system already exists, parameters are already available. Subsequently, these mathematical equations were connected through different volume flows of the system. The input to the hydraulic system is the excitations of the cylinders coming from the mechanical model. The output is the cylinder force, i.e., oil pressure multiplied by the cylinder head area.

PLAUSIBILITY CHECK

After connecting the different sub-models, the hydraulic model was checked for plausibility by giving different simple excitations on the Simulink model. The pressure inside the cylinders followed the expected qualitative development. The pressure loss caused by the choke could have been quantitatively validated with the help of the flow curves of the choke. Even the oscillating gas mass caused by the hydraulic inductivity could be seen.

SIMULATION OF THE OVERALL SYSTEM

With the help of the SIMAT interface, it was easy to connect the existing multi-body model of the track in SIMPACK with the hydraulic system in Simulink. The overall system with its inputs and outputs is shown in Fig. 3.

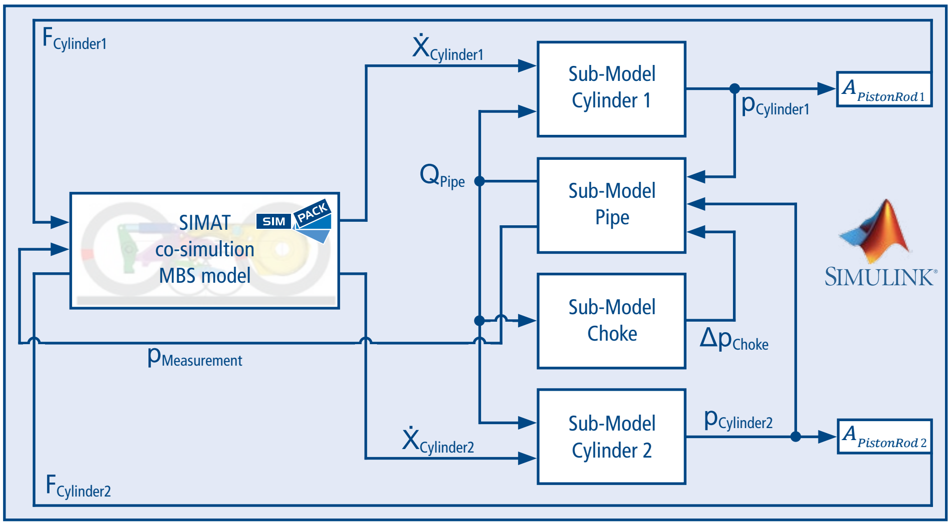

Fig. 3: Co-simulation SIMPACK and Simulink®

MEASUREMENT DATA

For validation of the system, measurement data was available. It was logged in the course of different test drives with a combine using the Terra Trac system. For validation, the vehicle was driven over a sinusoidal obstacle at different velocities. Both the obstacle and the driving torque have been modeled in SIMPACK. The concrete values for the validation are the "measurement pressure", located between the two hoses, and a torsion angle in the mechanical system.

RESULTS

The comparison of measured to simulated data shows adequate correlation. Fig. 4 (top) shows the development of the measured (black) and the simulated pressure (blue) of the test drive with a velocity of 10 km/h.

The offset of the initial pressure is caused by different reasons and parameters. On the one hand, it is possible that there are measuring inaccuracies in the weighing of the combine and the idealized modeling of the combine itself. On the other hand, the assumptions in the hydraulic network could also be a reason for the offset. Certainly the simplification of the ground contact plays a role, too.

Furthermore, stretching in the simulation data could be detected, which is caused by the low modeling depth of the speed controller.

Nevertheless, it can be seen that development of the simulated pressure conforms to the measured data very well since most peaks correspond. Fig. 4 (bottom) shows the value of the angle sensor. It becomes apparant that there is a qualitative correlation between the measured and simulated angle. The analysis of the other test drives shows a similar result.

CONCLUSION

Overall, the results are very satisfying. The goal to model the hydraulic system of the rubber track undercarriage has been fulfilled. Future work can be based on this model which is fully parameterized and ready for DoE, Design of Experiments.

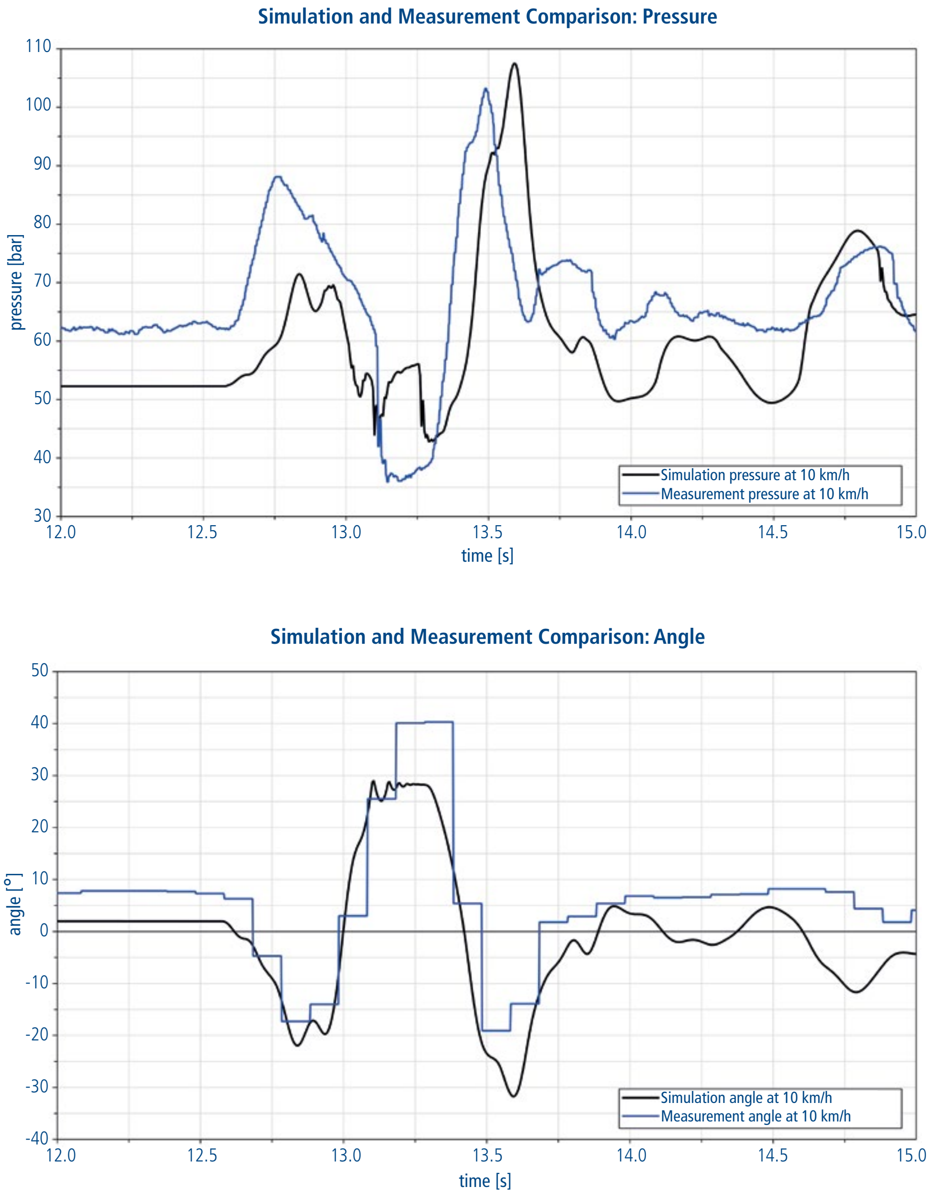

Fig. 4: Comparison between simulation and measured data (pressure and angle)