Subsystem- and full-vehicle-simulation of mobile machines using SimulationX

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Kurzfassung

Dieses Paper beschreibt die Entwicklung von Simulationsmodellen ausgehend von der Teilsystemsimulation bis hin zur Verwendung von Gesamtfahrzeugmodellen von Radladern der Firmengruppe LIEBHERR. Ziel ist es, die Fahrkomfort- und Fahrdynamikeigenschaften dieser Maschinen zu analysieren und zu optimieren.

Als Beispiel für ein Simulationsprojekt eines Teilsystems der Maschine wird die Modellierung der Kabinenlagerung vorgestellt. Die Kombination verschiedener Teilmodelle zu einem parametrischen Gesamtfahrzeugmodell inklusive verschiedener Reifenmodelle wird anschließend aufgezeigt.

Abstract

This paper describes the way from the simulation of single subsystems to the use of full-vehicle models to optimize operator comfort and vehicle dynamics of wheelloaders.

As an example of a subsystem simulation project, the analysis and optimization of the cabin suspension has been chosen. The integration of several submodels into one parametric full-vehicle model including several tire modelling approaches is described later on.

Motivation

Besides efficiency, quality and productivity characteristics of mobile machines, operator comfort and vehicle dynamic properties are becoming more and more relevant in customer decisions. State of the art wheel loaders today are equipped with multiple suspension systems to ensure a high level of vibration-, shock and noise isolation for the operator including multi-axis suspended seats, mass damper systems, elastic cabin suspensions and large and soft tires.

To meet future customer demands and reduce testing effort, system simulation is used at LIEBHERR wheelloader development to analyze and optimize existing suspension systems and to evaluate the potential of novel methods. Since wheelloaders' suspension systems are often composed of mechanical, as well as hydraulic and control systems, LIEBHERR has chosen SimulationX as a multi-domain platform for modeling and simulation.

Simulation of sub-systems versus full-vehicle simulation

To analyze and optimize a specific suspension system, depending on the case either a subsystem simulation or a full-vehicle simulation is performed.

While a multi-domain simulation model of the whole machine including complex tire models and plenty of degrees of freedom might provide the most flexibility, it also demands a maximum of effort when it comes to parameterization and validation as well as computation time. On the other hand, not all suspension systems can be simulated in a subsystem context.

Using SimulationX, various subsystem models of the machine developed over time – each created, analyzed and validated on its own - can be combined into a full-vehicle model due to its object-oriented structure.

Parameterization and parameter identification

When creating a model of a certain suspension system, parameterization is the key to ensure a realistic behavior of the model. There are different types of parameters, where some are easy to get from specifications or simple measurements (like masses, dimensions, inertias, …) and others which are not likely to be obtained from available sources (like certain stiffnesses, damping coefficients, …).

In those cases, parameter identification can be used to obtain these unknown parameters. The idea is to create an environment where the response of the physical system to a certain excitation is known by measurement and the dynamic behavior of the corresponding model is defined by only one or a few independent unknowns. By iteratively modifying these parameters the model response can be fitted to the measured reaction. By using several different situations, the validity of the identified parameters can further be increased.

In order to be able to gather data from real driving situations for model validation, a LIEBHERR wheelloader equipped with 42 channels of measuring equipment is used. Sensors include inertial units (acceleration, angular velocities), hydraulic pressures, torques and multiple joint angles, as well as laser-measured deflections of elastic mounts and dynamic vertical wheel loads using strain gauges.

Simulation of the subsystem "cabin suspension"

As an example of one of the subsystems which can be modelled and analyzed without the need for a full vehicle model, the optimization of the cabin suspension is described.

In this model, the rear frame of the wheelloader, which supports the cabin via four rubber mounts with hydraulic dampening is excited directly by measured data gathered in one of the inertial measurement units on the frame during different driving situations. For each driving situation there are six curves providing the model with acceleration- und angular velocity data over time which are linked to a 3D-MBS preset. In the global definition module, the user can choose the driving situation, which defines the set of curves which will be linked to the preset via if-queries. In addition, the module is used to globally define properties of the cabin mounts and their positions to ensure efficient parameter studies. Furthermore, the model incorporates a set of filter functions according to ISO2631 [1] which apply different frequency weightings to the virtual cab accelerations for direct calculation of human vibration values according to this standard.

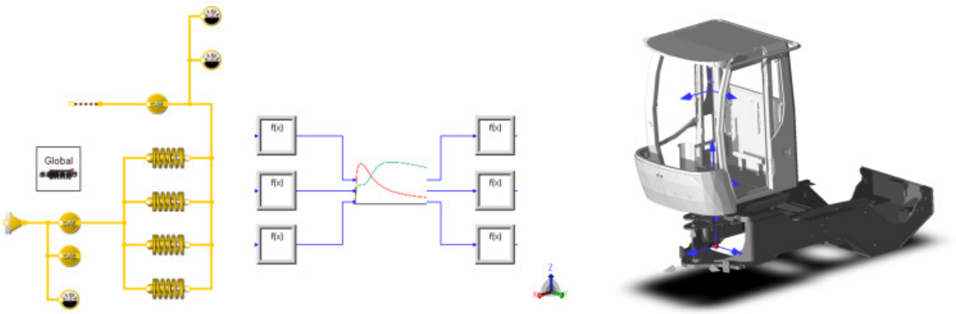

Figure 1: *Basic model of the cabin suspension including weighting functions*

After validation, this simple model can be used to efficiently study the effects of different mount characteristics and positions on operator comfort. A further stage of extension also includes the operator seat with its suspension systems or other degrees of freedom.

The advantage of this approach is the very accurate representation of the frame movement using measurements, on the other hand the excitations are limited to the driving situations which where actually measured on the real machine.

Creating a parametric full-vehicle model

After modelling, analyzing and optimizing several subsystems which can be viewed independently (like cabin, seat or lifting arm suspension), those models have been included into a full-vehicle model and combined with a tire model. This opens new possibilities to study subsystem interaction, analyze possible new suspension systems and experience driving situations which do not need to be measured beforehand, e.g. dangerous overtipping manouvers.

To ensure an efficient simulation process, the setup of the full-vehicle model is defined by several parameters which can be set in a global context. Before the simulation, parameters like lifting arm position and loading condition are set. Several joint angles, masses of ballast weights and visibility options are then set accordingly during the global symbolic analysis using if-queries.

The tire-ground-interface of the full-vehicle-model is described depending on the simulation task (handling vs. comfort). In the first case, an empirical Magic Formula type model [2] already included in SimulationX is used, whereas for comfort-related studies, the external, structural tire model FTire [3] is employed.

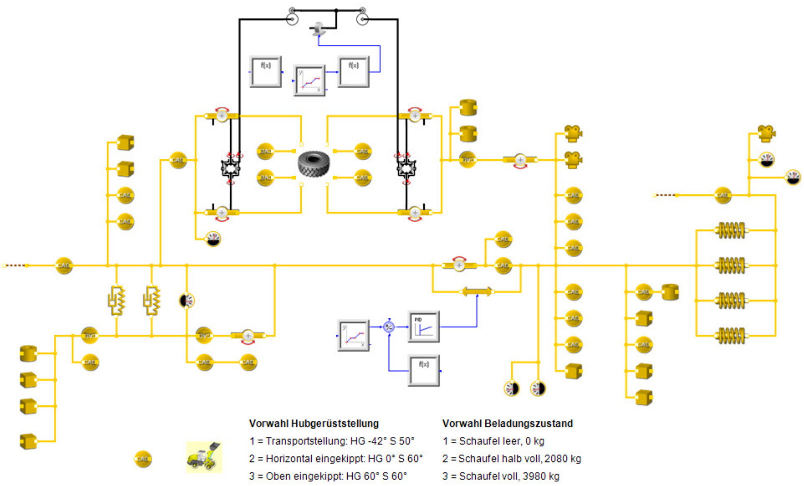

Figure 2: *Full-vehicle model overview*

The FTire interface

To connect the FTire model with SimulationX, an interface has been implemented which defines the communication between both tools resulting in a cosimulation. FTire comes with the so called cosin tire interface (cti) [4] which provides access to all FTire features. All functions are stored in a dynamic link library (.dll) and can be addressed by using external function calls in SimulationX.

Each FTire instance acts as a force element connected to the mbs model. In every simulation time step, several values like rim center position and orientation as well as translational and rotational velocities are communicated to FTire, which calculates the contact forces between all tires and the ground model and gives them back via the interface. Before the simulation, information like tire properties and road models can be set directly in SimulationX and are communicated to FTire automatically.

The FTire interface has been implemented using the SimulationX TypeDesigner.

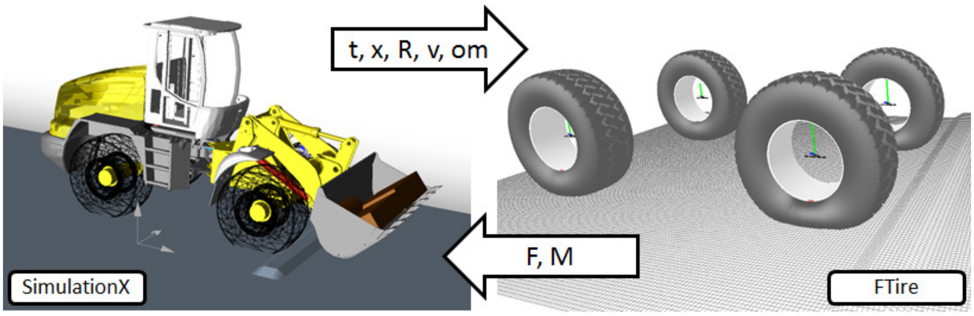

Figure 3: *Communication between SimulationX and FTire*

Summary

This paper gives a brief insight on subsystem- an full-vehicle-simulation used at LIEBHERR wheelloader advanced development. By using SimulationX in combination with advanced tire models, vehicle dynamics and operator comfort of those machines are further improved whilst minimizing testing effort through the support of multi-domain simulation.

[1] ISO 2631
Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration
2007

[2] Hans B. Pacejka
Tyre Modelling for Use in Vehicle Dynamics Studies
Delft University of Technology 1987

[3] cosin scientific software
FTire documentation 3-2012
http://www.cosin.eu

[4] cosin scientific software:
cosin tire interface (cti) documentation 3-2012
http://www.cosin.eu