Efficient Vehicle Dynamics Development via Simulation-Based Prognosis Tools

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Abstract

Models for the simulation of vehicle dynamics are an important component in today's vehicle development processes. The requirements include not only simulation models with sufficient complexity, but also tools with simple and intuitive usability. Furthermore, it must be possible to integrate certain actions, like the identification and optimization of toleranced parameters, into the overall development process and automate them. This is the only way to reach development goals efficiently and safely.

This paper presents a method for designing and tuning suspensions purposefully and quickly with the help of vehicle dynamics simulation. The method is based on the Automotive Simulation Models (ASM) from dSPACE, which have been extended for this use case. The ASM support design engineers through all phases, from creating a virtual prototype up to close-to-production fine tuning during the test phase. The paper specifically describes the necessary characteristics of the vehicle dynamics model, which go beyond those of a typical handling model. At Daimler AG, the ASM accompany the development during test drives, both for the pure vehicle dynamics design of the vehicle and for coupling the vehicle dynamics control systems to hardware-in-the-loop (HIL) systems.

Introduction

Increased expectations from the market and customers are leading to a steady increase in the number of vehicle variants related to the vehicle dynamics. In addition, stricter license requirements on the safety aspects of driving, such as electronic stability controls, are affecting the volume of development effort. Increasing the efficiency of the development process is the only way to meet the resulting requirements for validating this wide variety of variants. All this is accompanied by a demand for a method that reaches the vehicle dynamics goals while saving costs and reducing the number of test drives. This makes implementing reusable simulation models in all stages of development a fundamental necessity. While previous models were used primarily for the initial design of tuning-relevant components in early phases of the development process, the approach of the integrated vehicle dynamics analyses presented here can be used to support design engineers in all phases of suspension development and tuning.

Simulation-Based Prognosis

Integrated Vehicle Dynamics Analysis

Integrated vehicle dynamics analysis means combining pure simulation with pure test drives (Figure 1). The simulation models and techniques used in the early stages of vehicle development are also utilized for development in the subsequent test drives. Thus, one important constituent of simulation-supported development is prognosis tools that rely solely on virtual vehicle designs to determine which adjustments must be made on the actual components. This makes is possible to predict the driving behavior of vehicle variants that do not exist physically and for any maneuvers such as ones close to safety limits.

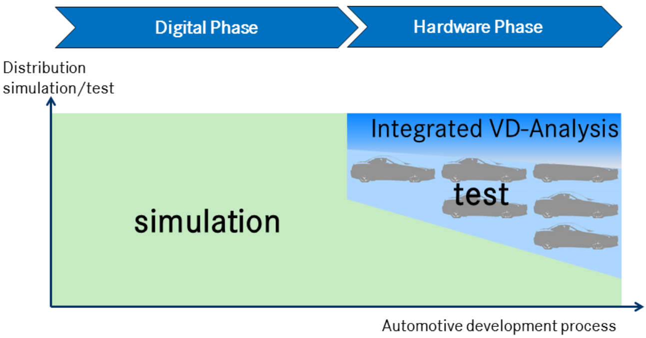

Figure 1: Timed interaction of simulation and tests at Daimler AG [1]

Real-Time-Capable Vehicle Dynamics Model

One important requirement on the simulation-supported development process is the ability to reuse the simulation model, including its parameterization, for offline validation on a PC and in hardware-in-the-loop (HIL) systems for testing with production ECUs. Daimler AG met this requirement by using an expanded tool suite based on the Automotive Simulation Models (ASM) from dSPACE in the vehicle development process. ASM are open Simulink models for the real-time simulation of automotive applications. The models are used for model-based function development and in ECU tests on hardware-in-the-loop (HIL) systems. The graphical tool ModelDesk lets users configure the vehicles and define the maneuvers and roads graphically. The required complexity of the simulation models depends decisively on the particular application.

Virtual Suspension Test Bench

To simplify suspension design in all development phases and determine what adjustments need to be made to the individual suspension components with reference to vehicle dynamics, the virtual suspension test bench ASM Kinematics and Compliance (ASM KnC) (Figure 2) can be added to the simulation system.

Figure 2: ASM Kinematics and Compliance test bench

ASM KnC is a pre-processing tool that helps specify the kinematics and elastokinematics behavior of different axle types by using the geometric values and component properties. The design engineer configures the preselected axle according to the underlying geometry obtained from sources such as computer-aided design (CAD) drawings. ASM KnC uses the geometry to calculate maps that describe the displacement and rotation of the wheel body during compression/de-compression and steering. The characteristics of specific elastomeric bearings, such as the elasticities, are also defined. This information is used with zero-point solvers to calculate the characteristics of the bearings as functions of the applied forces and torques. In addition to the most common axle types, such as McPherson, double wishbone, and 3-link, 4-link or multiple-link suspensions, there are also special versions such as control blades or subframe couplings. By using a specially developed generic algorithm for closed kinematic chains, almost any custom axle types can be calculated.

In addition to giving design engineers a simple, intuitive way to parameterize each individual axle type, ASM KnC also lets them use 3-D animation to study the axle behavior during compression/decompression and steering and under the influence of force and torque excitation. Thus, ASM KnC can be used even in early development stages to create preliminary virtual suspension designs.

Workflow and Optimization Process

The possible applications of simulation models and processing tools in vehicle development range from the initial suspension design, to validating the digital clone's parameters, to predicting component alterations that will produce new desired vehicle dynamics behavior.

For the initial basic parameterization of the suspension, raw data from the corresponding CAD drawings is used. The kinematics of the axle suspension is described by the geometric coupling points. For the elastokinematics, the individual curves of the various bushings are transferred to the virtual suspension test bench ASM KnC. This virtual test bench calculates the corresponding maps and curves for the entire assembly, and they are managed in the parameterization tool ModelDesk. From ModelDesk, the collected vehicle parameters and associated maneuvers are written to a selectable simulation platform, such as MATLAB/Simulink or a dSPACE processor board (Figure 3).

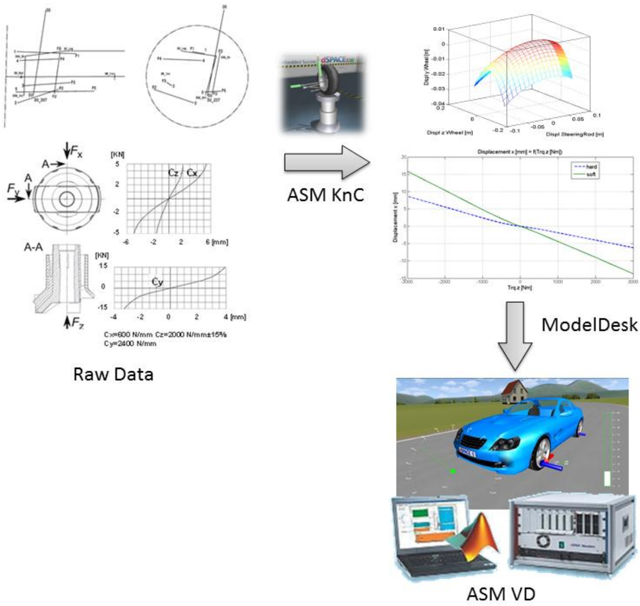

Figure 3: Workflow for parameterizing the simulation model’s suspension

When the basic parameterization of the vehicle is available, the simulation model's toleranced parameters are varied iteratively to optimize the model's driving behavior until it matches that of a real vehicle. During the test drives at Daimler AG, it became apparent that the parameters to be optimized are those for the center of gravity height, the static and dynamic tire parameters, and the yaw moment of inertia [1]. A digital clone of the real vehicle, based on the ASM Vehicle Dynamics Model, was produced by running maneuvers such as steady-state circular tests, driving with constant longitudinal acceleration, and sine curve maneuvers for frequency response analyses, and then comparing the results with the corresponding measurement values for the lateral acceleration, yaw rate and roll angle (Figure 4).

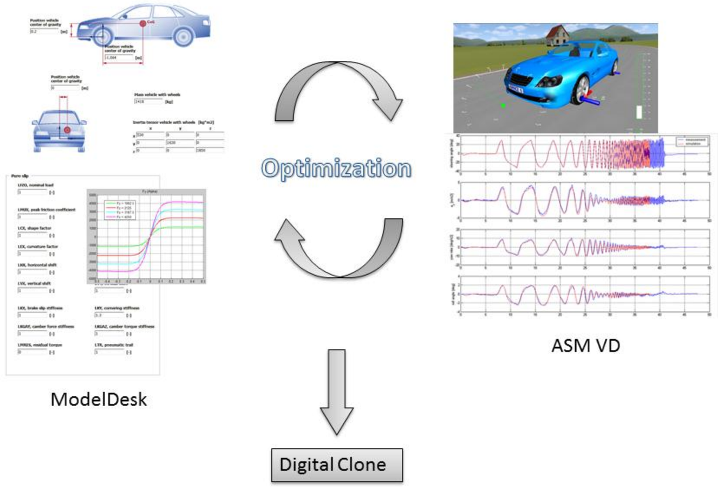

Figure 4: Optimization process for obtaining a digital clone

Figure 5 shows the comparison of the simulation results with real measurement data and the impact of the tire parameter. With the help of a specific optimization routine of Magic Formula tire parameters, it was possible to match the measured curves with the simulation model in a few iteration steps [1].

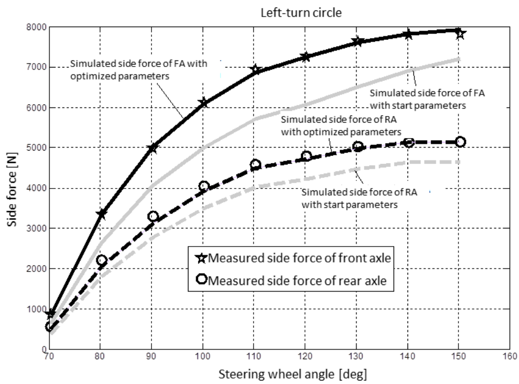

Figure 5: Optimization process for identifying tire parameters

The digital clone serves as the basis for subsequent parameter prediction (Figure 6). The aim of this prediction step is to identify the individual components whose component characteristics have the desired effect on the vehicle dynamics behavior. This ensures that the design of the virtual prototype can follow solely on the basis of automatable simulations. The development engineers use the data on the components to be adjusted, such as the stiffness of the individual bushings in the wheel suspension, to make the design of the real vehicle more efficient for the test drives in the hardware phase.

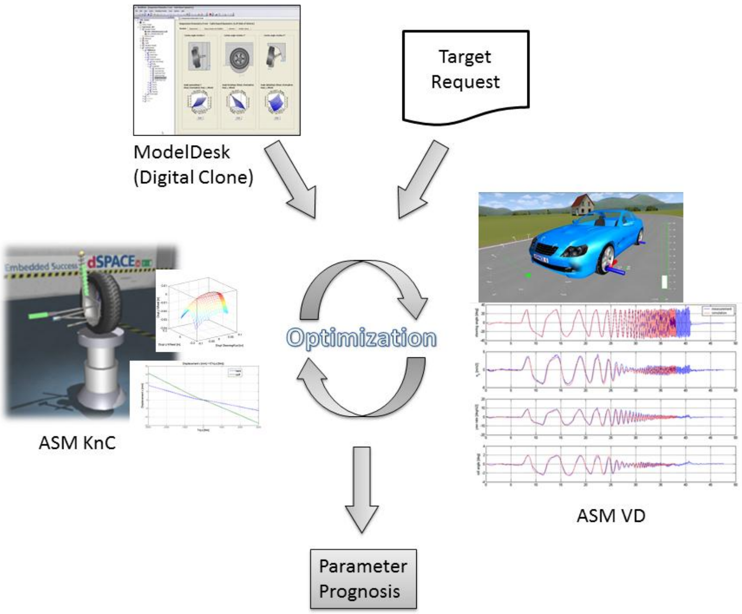

Figure 6: Workflow for parameter prognosis

Example of Parameter Prediction of a McPherson Suspension

The following section describes the relationship between an alteration in the stiffness of a McPherson wheel suspension’s bushing in the transverse direction and the resulting driving behavior for a circle drive.

The rear bushing of the McPherson wheel suspension is configured softer in the transverse direction. This alters the elastokinematics behavior of the entire axle (Figure 7):

i.e., a modified wheel body rotation and displacement occur due to the forces and torques. It should be noted here that the design engineer only needs to alter a single bushing. The summing up nonlinear elastokinematics curves necessary for the real-time-capable vehicle dynamics model are created automatically by means of the virtual suspension test bench ASM KnC.

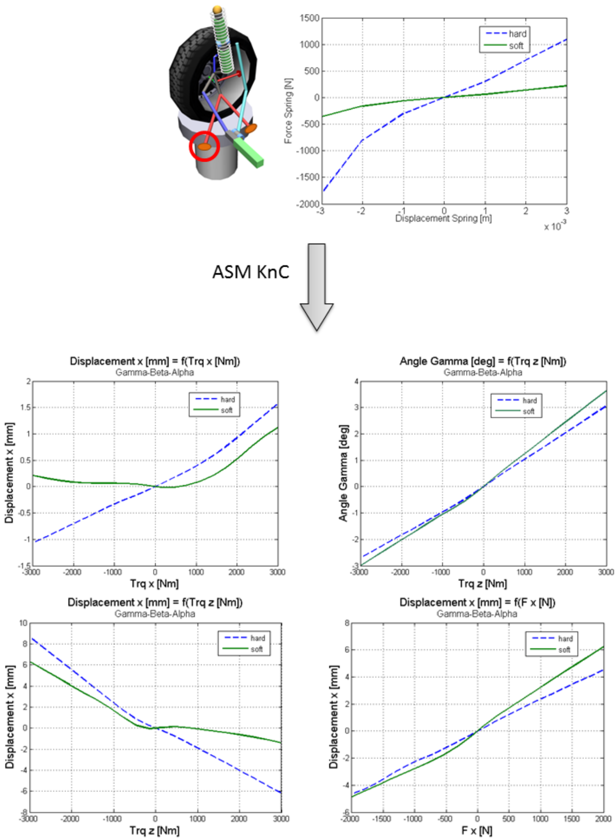

Figure 7: Changing a single bushing characteristic of a McPherson suspension

With the resulting characteristic curves, a circle trajectory with increasing velocity is driven through to evaluate how the parameter adjustment affects the vehicle dynamics related values as the understeer behavior of the vehicle. Figure 8 shows the impact of changing one bushing characteristic on the self-steer gradient[1]. The advantage of a virtual preliminary suspension design becomes apparent here, because getting knowledge of the correlation between the single bushing characteristic and the overall vehicle dynamics behavior via simulation within minutes saved time and reduced cost-intensive real test drives.

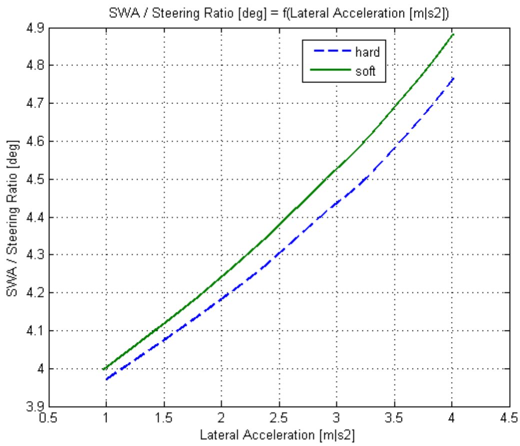

Figure 8: Simulation results from an altered McPherson bushing

The other way around, it is now possible to specify a target vehicle dynamics behavior, such as a desired self-steer gradient, and then automatically run the process described above in an optimization process. ASM KnC, and also ModelDesk and the ASM simulation model itself, can be controlled and executed via command line calls. This is an efficient, simulation-supported method for determining the components whose characteristics need to be adjusted.

Integration of Real Electronic Control Units

The vehicle fine-tuned with the process described above must be evaluated not only with regard to its pure vehicle dynamics behavior, but also when subjected to electronic controls such as ESP. Because the prognosis tool can be utilized in all vehicle development stages, in particular the hardware phase, validation on a HIL test bench

1 The self-steer gradient is defined as the slope of the curve showing the steering wheel angle (SWA) divided by the steering ratio as a function of the lateral acceleration.

is the obvious answer. At Daimler AG, the ASM Vehicle Dynamics Model was operated with an integrated brake-hydraulic control system on a dSPACE SCALEXIO[2] system in conjunction with a real ESP control unit (Figure 9).

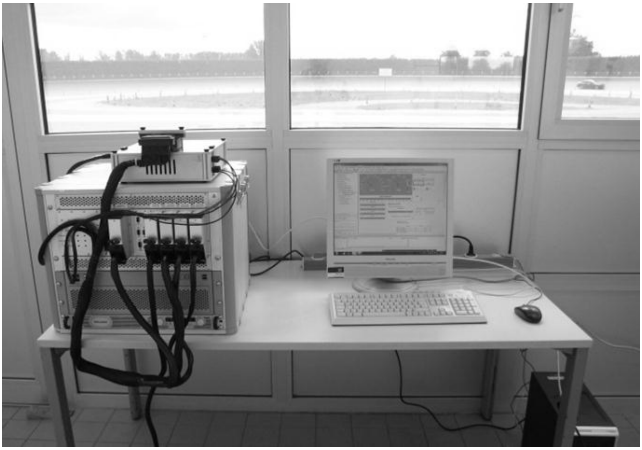

Figure 9: dSPACE SCALEXIO at a Daimler test track for integrated vehicle dynamics analysis including a control system

As with the creation of a digital clone for pure vehicle dynamics described above, exactly known parameters and toleranced parameters also have to be treated differently when designing a virtual brake system. The toleranced parameters, such as friction values of the wheel brakes, the pressure-volume curves of the brake cylinder, and the curves of the intake and switch valves, are determined by special analysis methods [1].

Summary

By integrating the virtual suspension test bench ASM KnC into the simulation-based development process for suspension design, the desired vehicle dynamics behavior can be reached faster and more cost-effectively. The applications of this prognosis tool range from virtual prototypes up to close-to-production fine-tuning. Engineers can obtain direct correlations between the individual bushings and their effect on the dynamics behavior of the overall vehicle. Because the ASM tool suite is completely

2 SCALEXIO is an innovative, new HIL system with high channel flexibility, granular expandability and complete software configuration.

automatable, meaningful results can be achieved efficiently through various parameter optimizations. The processing results can be integrated easily into the real-time-capable ASM Vehicle Dynamics Model, so it can be run on a HIL test bench for further validation with measurement data.

References

[1] Lindau, J.; Diebold, L.; Schindler, W.: *Fahrdynamik effizient gestalten.* SIMVEC – Berechnung, Simulation und Erprobung im Fahrzeugbau, 2012, Baden Baden

[2] Peperhowe, M.; Haupt, H.; Liem, K.; Schindler, W.: *Efficient Testing of Controller-Influenced Vehicle Dynamics* IFAC-AAC – Symposium on Advances in Automotive Control, 2013, Tokyo