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NUMBER OF VARIANTS IS INCREASING

Electronic stability control (ESC) makes a valuable contribution to active driving safety [1, 2]. Therefore ESC has become mandatory in many markets globally as an original equipment of new vehicles. As a consequence the type approval of a new model requires proof of an effective ESC system. To date this is done via physical ESC homologation test driving. For that purpose the vehicle is equipped with a steering robot to go through the so-called sine-with-dwell manoeuvre. This requires a considerable amount of time and effort as the test takes at least a day per vehicle for preparation and carrying out. Also the test is subject to weather conditions.

At the same time the number of variants of global vehicle projects in particular has increased dramatically. An example from Opel highlights this: While the Corsa (model year 2005) was available in roughly 70 variants, the same figure totals at around 150 for the Insignia (model year 2008), while the Astra/Zafira (model year 2009) can be ordered in roughly 400 variants. Without a powerful simulation environment this would result in a clash between the number of variants and economic constraints.

However, the ECE-R 13H regulation offers a solution for braking systems. The regulation permits a combination of real-world testing and simulation-based methods. Opel has taken this path and has demonstrated to the industry for the first time that simulation-based passenger car ESC homologation with CarMaker/HiL by IPG Automotive is ready for use [3]. The same had already been proven for heavy commercial vehicles by a brake system supplier [4]. Opel wants to use this strategy to speed up the time-to-market of new vehicles, and to lower the development cost by reduced use of hardware and prototypes.

SIMULATION-BASED ESC HOMOLOGATION

The European regulation ECE-R 13 H says that simulation-based methods may be used for the ESC homologation of vehicle variants. However, this still requires a driving test with a real vehicle first. Based on the results from the real vehicle, a vehicle simulation environment using the IPG Automotive CarMaker tool was parameterised and thoroughly validated during virtual test driving. The correlation between the simulation results and the measurements collected in a reference vehicle soon reached the level of matching which is required by the technical service and the type approval authorities.

The pilot application to the Opel Meriva, portrayed here, laid the foundation to present simulation results to the type approval authorities in order to receive the homologation for all vehicle configurations on the basis of a single vehicle tested in the real world. This approach fits seamlessly into Opel's existing "Road to Lab to Math" strategy (RLM) [5]. It

SIMULATION-BASED ESC HOMOLOGATION FOR PASSENGER CARS

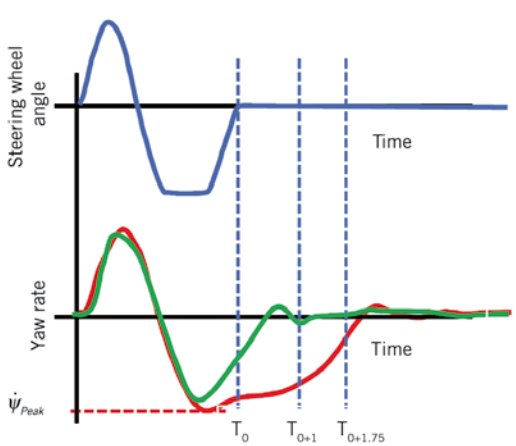
As of 2012 the type approval of a new passenger car in the EU requires proof of an effective ESC. To increase the efficiency of vehicle variant ESC homologation for vehicle variants, Adam Opel AG has applied its dynamics simulation environment, which very much relies on CarMaker/HiL, to the minivan Meriva. The results of simulation and real-world driving tests on the proving ground of Idiada match so well that a simulation-based ESC homologation according to ECE-R 13H is reliably feasible.

aims to support real-world testing on the track by a combination of simulation and Hardware-in-the-Loop (HiL) testing, and ultimately by purely mathematical simulation (Software-the-Loop, SiL).

SINE-WITH-DWELL DRIVING MANOEUVRE

The sine-with-dwell test with the ECE-R 13H is a dynamic driving manoeuvre which standardises an abrupt evasive action in front of an obstacle. Basically the test follows the NHTSA Federal Motor Vehicle Safety Standard, FMVSS No. 126 [6]. The sine-with-dwell test consists of a pre-test and the actual driving manoeuvre. The pre-test serves to measure the steering angle amplitude A that is needed at a steering speed of 13.5°/s to generate a lateral acceleration of 0.3 g while the vehicle travels on a circular path at a steady speed of 80 km/h (required steering angle).

At the beginning of the actual test manoeuvre the vehicle coasts without steering or braking action in the highest gear at 80 km/h ± 2 km/h. The test starts with a steering angle of 1.5 × A. During each test run the steering angle is increased by 0.5 × A up to a maximum steering angle of 270°. The test runs with increasing steering angle levels are run in a right-left and left-right sequence each. The applied sine steering with 0.7 Hz provokes a massive yaw reaction while the 500 ms dwell time represents the reaction time of an average driver. In total the manoeuvre is a reproducible version of a critical double lane change situation. ❶ shows the steering angle curve during the manoeuvre plus an exemplary vehicle reaction with and without ESC action.



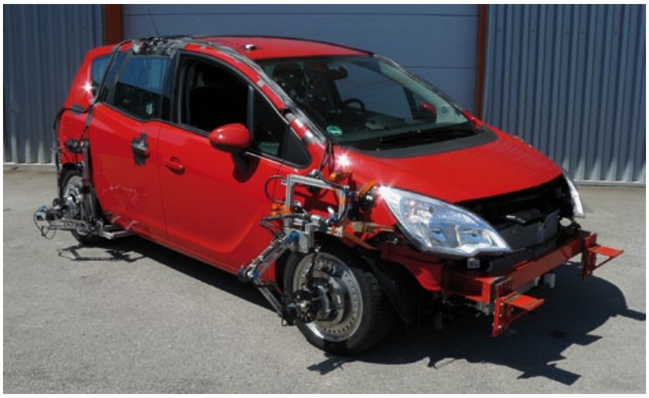
❶ Sine-with-dwell test: Steering angle during the manoeuvre plus yaw rate curve with (green curve) and without ESC activity (red curve)

The sine-with-dwell test is assessed against three criteria of vehicle stability. The crucial element is to check how fast the ESC reacts and how fast the vehicle is brought back to a stable state by reducing the yaw rate. For that purpose the yaw rate and vehicle position are measured at three points in time. To get the homologation the yaw rate has to be ≤35 % of the maximum yaw rate 1 s after the end of the steering action (T_0+1 s). At T_0+1.75 s the yaw rate must not be higher than ≤20 % of the maximum yaw rate.

In addition there is a vehicle reaction criterion which assesses the vehicle's capability for sideways displacement to avoid an obstacle (minimum requirement is 1.83 m or 6 ft for a vehicle with under 3.5 t of overall weight). Within the limits of meeting the before mentioned three criteria of stability, the vehicle manufacturer has the freedom to choose a more conventional or a more sporty ESC setting, depending on the brand philosophy.

DATA ACQUISITION WITH THE REFERENCE VEHICLE

During this pilot project the validation scope was purposely expanded far beyond what is required for the actual homologation. With a view to future projects this was done firstly to gain fundamental insight into the validation quality of subsystems, and secondly to completely understand the interdependencies within the chain of effects. For the measurement of the objective vehicle behaviour Adam



❷ The Opel Meriva reference vehicle with Idiada instrumentation for dynamic driving tests

❸ Visualisation of the CarMaker vehicle model used for ESC homologation

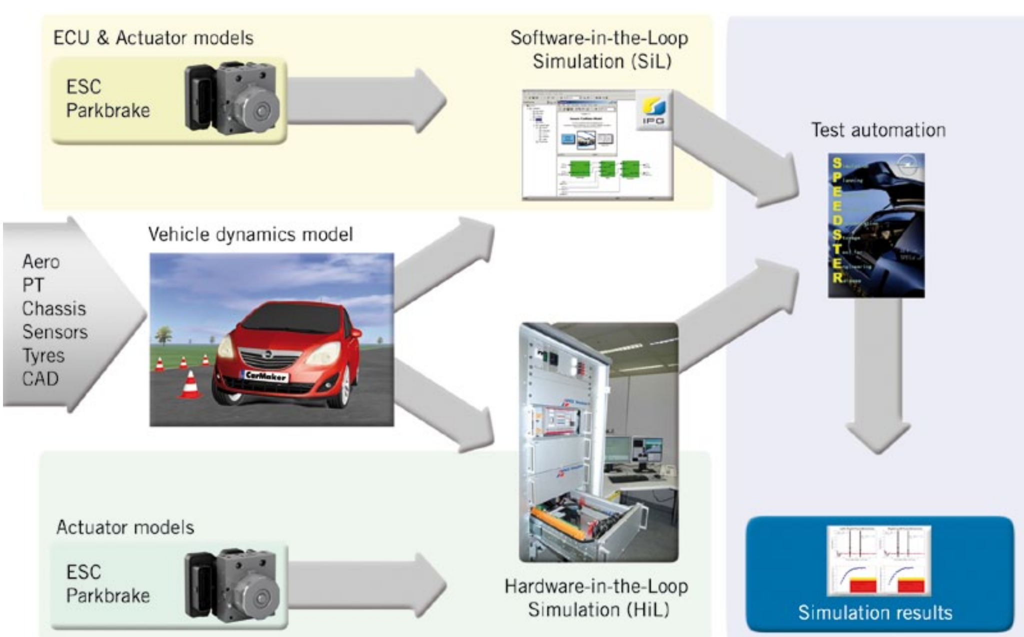
Opel AG cooperated with Idiada, where a Meriva was equipped with a very comprehensive set of sensors. Static measurement of fundamental parameters of the reference vehicle's wheel suspension was carried out for the front and rear axle on a kinematics & compliance rig (K&C rig).

The comprehensive tests delivered detailed data on the geometric position of the suspension and its joints, plus data about the controlled movement of the wheel within the suspension during load influence like on the road. The following dynamic measurements carried out with and without steering robot, provided data about the real vehicle behaviour on the test track. ❷ depicts the reference vehicle as instrumented by Idiada. This was used to analyse dynamic details such as effective forces, wheel centre positions, slip angles, toe and camber, a beginning wheel spin, and the resulting vehicle reaction (centre of gravity acceleration, speed, inclination etc.).

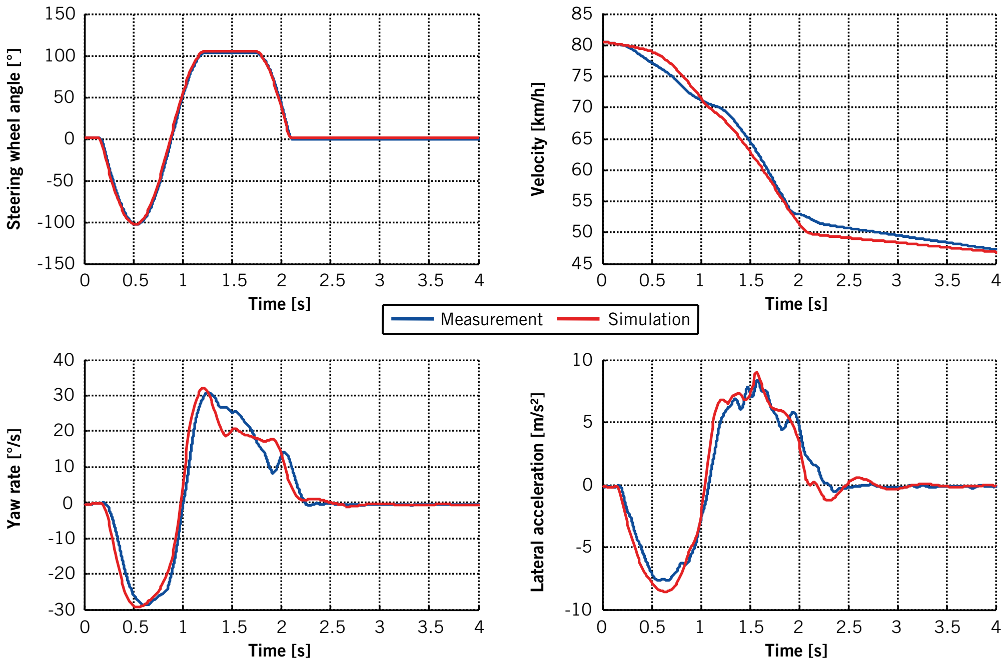
VEHICLE SIMULATION MODEL AND VIRTUAL DRIVE TEST

Adam Opel AG uses an integrated software tool chain to simulate driving dynamics with optimum precision [7]. A multi-body simulation (MBS) is the starting point. Within the MKS the vehicle is generated and parameterised. As this MBS is not a real time tool, however, the model is subsequently transferred to the test and development environment CarMaker/HiL. The hardware used is a dSpace HiL hardware platform which is controlled from the CarMaker simulation environment, and which interacts with the CarMaker vehicle model, ❸. The HiL simulation environment which is used by Opel and which was applied for the simulation-based pilot project of Opel Meriva ESC homologation is shown in ❹.

A proprietary Opel test automation of the drive manoeuvre catalogues ensures that the HiL systems can be used around the clock. The automation contains features for a remote configuration of the CarMaker environment (vehicle, driver, road parameters) as well as automated execution and evaluation of a large set of



❹ HiL simulation environment that was used



❺ Good correlation between measurements, gained in the reference vehicle (blue curves), and results of the simulated sine-with-dwell test (red curves)

virtual driving manoeuvres. In addition the test automation generates an automated test report.

VALIDATION RESULTS

Prior to the simulated homologation test, the complete simulation environment was intensely validated. Beginning with simple driving manoeuvres the model was tested with increasingly complex manoeuvres. Finally the sine-with-dwell test according to ECE-R 13H was carried out. During the validation of the vehicle model the main focus was on the model representing the brake hydraulics. Input parameters were the brake pedal force, valve actuation and pump actuation. The wheel brake pressure and wheel brake torque served as outputs. The complexity of simulated manoeuvres was increased from a simple straight line braking procedure through an ABS stop and on to the highly dynamic wheel-individual modulation of brake pressure during ESC activity.

❺ depicts the ultimately achieved excellent match of the simulation carried out on the HiL simulator with the real-world measurements gained via the instrumented reference vehicle. The results shown come from a manoeuvre with around 100° of steering angle and a right-left sequence. Both, the gradients and the maximum values of yaw rate and lateral acceleration show a very good match. This indicates that the simulation environment used reproduces the relevant parameters of dynamics with the precision required by the regulation ECE-R 13H.

SUMMARY AND OUTLOOK

Within a pilot project Opel has analysed together with Idiada and IPG Automotive whether and how a simulation-based ESC homologation according to ECE-R 13H is possible. The use of an integrated tool chain which includes the driving dynamics development and testing environment CarMaker has demonstrated that this kind of valid homologation testing in a HiL environment is feasible. The preconditions include a stable process, a precise vehicle dynamics model, and a sophisticated integration solution to facilitate model expansions and hardware coupling.

Validation of the simulation environment based on static and dynamic measurements confirms an excellent level of correlation. This is also confirmed by the simulated sine-with-dwell test which delivers results that are very close to the real-world measurements. Hence the simulation solution used has reached the required precision for ESC homologation.

What is more, the development and optimisation process from the real-world measurements to the simulation and on to homologation is fully transparent and well documented. As a conclusion it can be said that the number of real-world vehicle tests during ESC homologation can indeed be considerably reduced by the method of simulation.

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