ADAS impact tests of plated vehicles based on the ViL test concept
Motivation, preconditions and results

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Abstract

Safety-relevant ADAS (Advanced Driver Assistance Systems), like other vehicle components, will also have to be tested as part of the prescribed general periodic inspection in the future. This must be done reliably and independently of the manufacturer. For this reason, the Vehicle Inspection Organization KÜS has started a research project to develop and validate the technical possibilities for ADAS impact testing. For the research project, KÜS designed the *KÜS* DRIVE test lane and realized it until the end of 2022 with the help of various suppliers in a new hall. The investigations are carried out by means of impact tests in dynamic driving operation via OTA (Over The Air) stimulation of the ADAS sensors with a scenario-based environment simulation, i.e. without ADAS ECU communication. The difference to the "Vehicle in the Loop" tests in development is that this methodology can now be applied to plated vehicles without any upgrading effort at the test bench and any modifications at the vehicle. The first results of the research project are presented here in this paper.

1 Introduction and motivation

In the Federal Republic of Germany, vehicle inspection organisations such as the KÜS (**K**raftfahrzeug-**Ü**berwachungsorganisation freiberuflicher Kfz-**S**achverständiger) have the legal mandate to inspect the vehicle with regard to the design, condition, function and impact of its safety-relevant components and systems within the framework of the periodic main inspection (PTI) in accordance with German StVZO Annex VIIIa. Afterwards, the test engineer examines the design, i.e. the presence of two headlights, the condition, i.e. visual inspection with regard to damage to the headlights, the function, i.e. light can be switched on and off, and the impact, i.e. the measurement of the headlight adjustment with the help of a headlight adjustment tester (light box). This means that when testing the impact of the headlights, metrological traceable measured values of a DAkkS-certified light box are available according to legally prescribed tolerances.

The function and impact of the "classic" driver assistance systems (DAS - Driver Assistance Systems) such as ABS and ESP and the "extended" driver assistance systems (ADAS - Advanced Driver Assistance Systems) such as ACC, AEBS, LDW and LKA can currently only be verified by means of error messages in the fault memory of the motor vehicle.

From 06.07.2024, only passenger cars in addition to the existing ADAS will be registered with the following ADAS:

- Emergency Brake Assist (AEBS)
- Emergency Lane Departure Warning System (LKA)
- Intelligent Speed Assist (ISA)
- Emergency brake light (ESS)

In particular, the AEBS is a safety-relevant autonomous driving function that triggers emergency braking without the driver's influence if the vehicle's software detects a dangerous situation. If the dangerous situation is correctly identified, the AEBS prevents accidents or reduces the consequences of the accident. If the AEBS triggers emergency braking without a dangerous situation existing, accidents caused by rear-end vehicles can occur, especially on the motorway. Therefore, the correct function and impact of the AEBS over the entire life cycle of the motor vehicle is safety-relevant. This is because ADAS are also subject to the usual causes of defects throughout their entire life cycle, such as

- Degradation
- Manipulation
- Improper repair
- Accident.

For this reason, the PTI organization KÜS has set itself the task of exploring the technical possibilities of testing the function and impact of DAS and ADAS as part of a research project [1]. This is done with registered motor vehicles of vehicle categories M1/N1 and SAE level from 2 without communication with the ADAS ECU's. In the first step, we will concentrate on motor vehicles with a mono camera whose optical axis is horizontal and a front radar sensor (see red rectangle in Figure 1). The aim is to be able to inspect all motor vehicles under these conditions, regardless of the manufacturer.

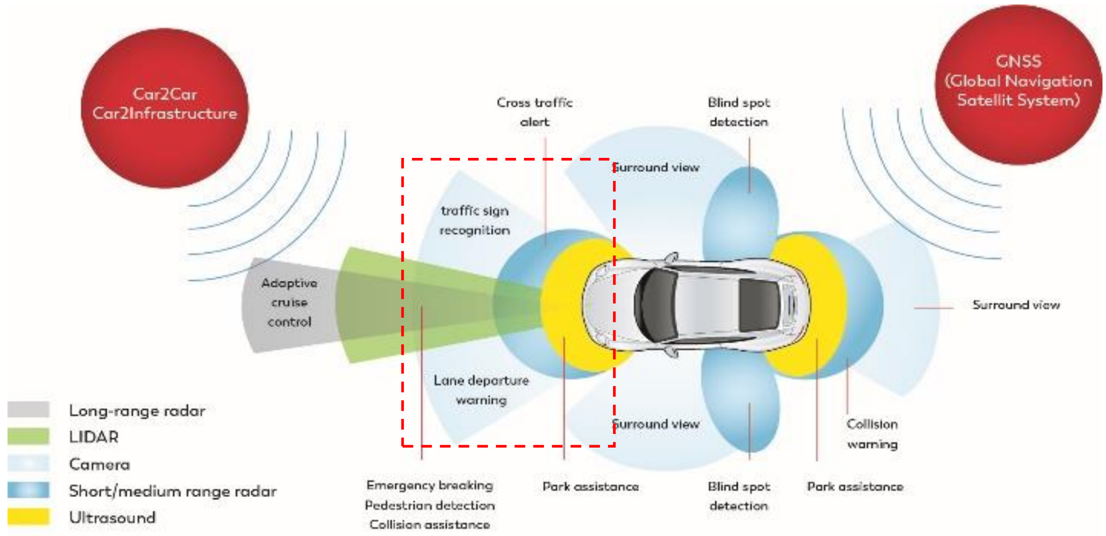

Figure 1: ADAS Overview (Source:KÜS)

Figure 2: Principal mechanical structure of the test line (Source: KÜS)

Description of the main plant components according to the numbering, see text below:

(1) Steerable functional test bench (SFT) from Dürr (brand name: x-road curve) described in detail in [1]. On the SFT, the vehicle can be driven up to 130 km/h without lashing, including moderate steering movements. Here, the vehicle symmetry axis of the motor vehicle is positioned on the symmetry axis of the SFT while driving with the help of rotatable double rollers at the front and a measuring system. (2) Portal system for positioning the monitor (3), the light collection box of the static headlamp alignment tester (4) and the radar target simulator (RTS) from dSPACE (5) in front of the vehicle. (6) 10 meter wall

of the company VisiCon (brand name: VisiLaserWall) [3] for the measurement of the adaptive high beam (AFS) as part of the dynamic headlamp alignment tester..

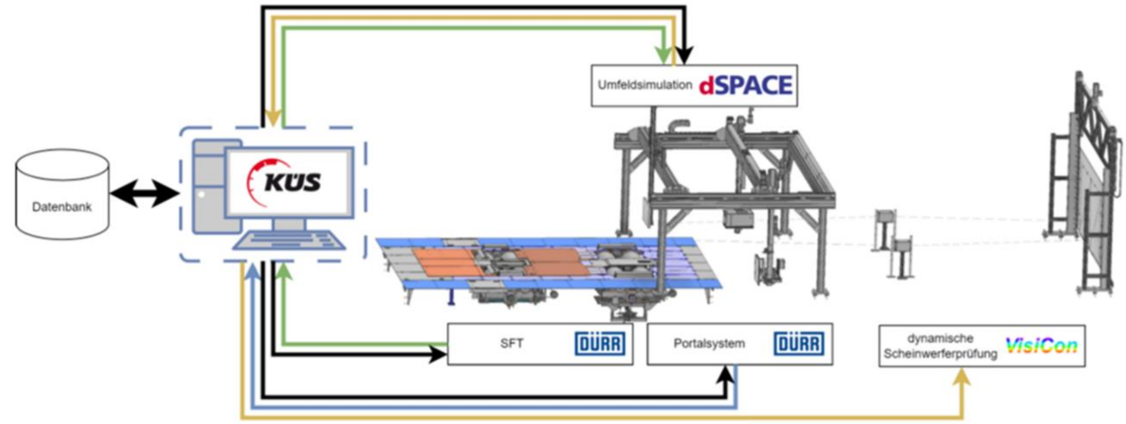

Figure 3: Control concept of the test line (Source: KÜS)

Glossary of English abbreviations used for ADAS:
- ACC Adaptive Cruise Control
- AEBS Advanced/Autonomous Emergency Brake System
- LDW Lane Departure Warning
- LKA Lane Keep Assistant
- ISA Intelligent Speed Assistance
- AFS Adaptive Front Light System

2 Preconditions

In order to investigate the function and impact of ADAS and ADAS, the motor vehicle is driven on the SFT by the test engineer and exposed to defined test scenarios (suggestions). The reactions of the motor vehicle are then recorded and documented with regard to the distance travelled s(t), the current speed v(t), the current acceleration/deceleration a(t) and the current steering angle φ(t) via the state of movement of the double rollers of the SFT coupled to engines. Furthermore, the reaction of the motor vehicle to corresponding suggestions can be checked on the 10 meter wall or by displays in the cockpit of the motor vehicle. This operating principle test (abbreviated efficacy test) is carried out under the following conditions.

2.1 Traceability of the measured values to national standards and unitary coordinate systems

As an "indoor" system, KÜS DRIVE is only exposed to defined external influences. This means that the impact tests are independent of the weather. Furthermore, all measuring equipment used in KÜS DRIVE must be suitable for testing equipment and machines with regard to specified tolerances. The calibration agents used are traceable to national standards. It is also important to define a unitary coordinate system (see Figure 4) for all stimulators (monitor and RTS) and for all measuring equipment in KÜS DRIVE.

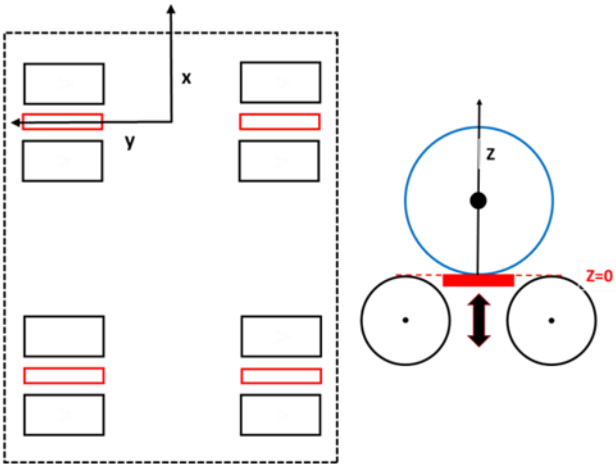

Figure 4: Unitary coordinate system for KÜS DRIVE: the x-axis is the symmetry axis of the SFT and the origin x=y=0 lies in the middle between the front pairs of double rollers and z=0 is determined by the lifted sleepers of the SFT.

The determination of the coordinate system is carried out by a special calibration gauge (see Figure 5), which is included in the SFT on the lifting bars.

Figure 5: Calibration gauge for KÜS DRIVE on the lifting bars of the SFT (Source: KÜS)

2.2 OTA (Over The Air) stimulation of the ADAS sensors

Since ADAS impact testing takes place without ADAS ECU communication, the ADAS sensors (camera and radar) must be stimulated "over the air" by means of a monitor and RTS “over the air”. For this purpose, the center of the monitor and the antenna of the RTS are positioned in front of the camera or in front of the radar sensor, defined in measured x, y, z coordinates of the uniform coordinate system. This is done using patent-pending efficient measurement methods that only need to be applied for motor vehicle types presented for the first time and are then available via the vehicle database. The advantage of this is that the SFT always positions the vehicle sideways while driving in such a way that the symmetry axis of the vehicle always corresponds to that of the SFT. This is also guaranteed if the test engineer steers while driving. This means that the position of the stimulators in relation to the motor vehicle is maintained during the test drive without the intervention of the driver.

2.3 "Digital Shadow" and scenario-based impact testing by means of freely editable environmental simulation

During the test drive, the current physical characteristics of the "vehicle movement" on the SFT, i.e. the distance s(t), the speed v(t), the acceleration/braking a(t) and the current steering angle φ(t), are simultaneously transmitted to a vehicle simulation. Together with the geometric data of the test object and the positions of the camera and radar, a "digital shadow" is created from the real motor vehicle on the SFT (see Figure 6). In the freely editable environment simulation, this moves according to the test drive on the SFT.

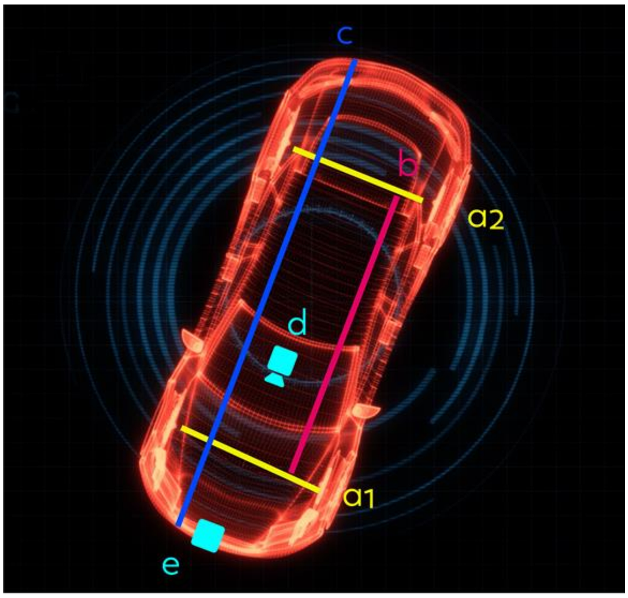

Figure 6: "digital shadow" with the following important data of the real motor vehicle:

- Mass/Weight
- Track gauge/width (a)
- Wheelbase (b)
- Length (c)
- X, Y, Z position of the camera (d)
- x, y, z position of the radar sensor(s)

The "digital shadow" is equipped with a virtual camera and a virtual radar sensor in the same position as the real motor vehicle on the SFT. The objects that the virtual camera or the virtual radar sensor detects during the virtual drive in the environment simulation are simultaneously transmitted OTA via the monitor to the real camera and to the test engineer on the SFT and OTA via the RTS to the real radar sensor (see Figures 7 &8).

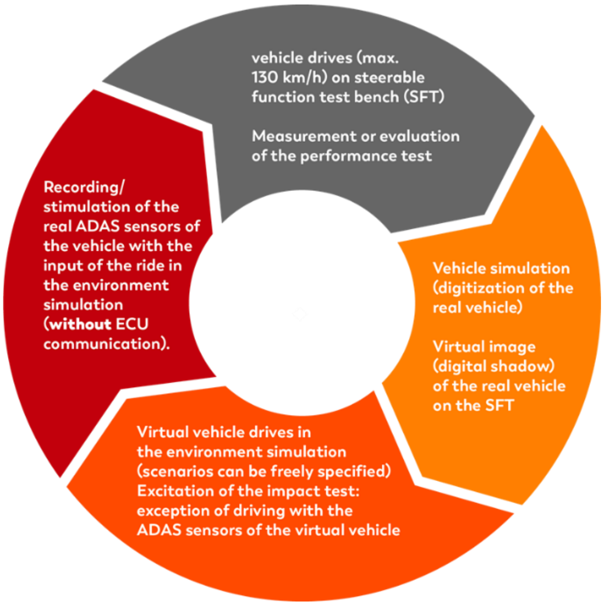

Figure 7: Procedure of the scenario-based ADAS impact test

Thus, the driver of the motor vehicle determines and controls the movement of the "digital shadow" on the SFT in the environment simulation. Because ADAS such as AEBS work by means of sensor data fusion of camera and radar, it is important that both sensors be stimulated simultaneously with signals that match each other. The reaction of the real vehicle to the virtual scenarios is recorded using the SFT's measurement technology and documented in the KÜS DRIVE results database.

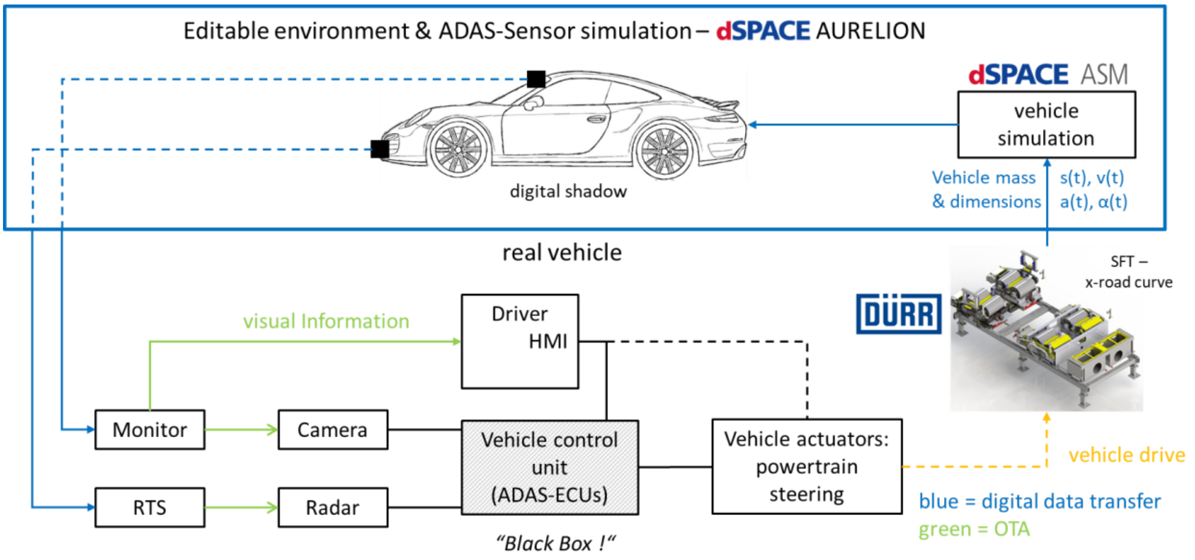

Figure 8: Schematic representation of the scenario-based ADAS efficacy test with OTA stimulation [4]

3 Results

During the commissioning phase, especially of our KÜS software components over the year 2023, many different vehicle types could already be tested on KÜS DRIVE. These include: KIA EV6, Tesla Model 3, Mercedes E-Class Hybrid, Porsche Taycan, Skoda Oktavia, Skoda Enyaq RS, VW ID.3, VW Polo.

3.1 Brake, ABS, ASR and ESP impact testing

The impact test of the brake system and the driver assistance systems (DAS) ABS and ESP are carried out on the steerable function tester (SFT). Its basis is a combined rolling, braking and ABS test bench, which is used at the end of the production line for brake testing and ABS and ESP testing. In these cases, however, usually with communication to the ABS/ESP control units via the vehicle's diagnostic interface.

In the case of the "static" brake test, the test engineer brakes against the driven double-roller units and the test bench measures the torque increase via the current of the motors in order to turn the wheel at a constant speed. The speed can be specified as desired in relation to the power of the test bench motors. In the test in Figure 9, 15 km/h were chosen. The increase in current then corresponds to the braking force per wheel. The brake test is carried out on the front and rear axles at the same time without the vehicle having to be moved as with a 1-axle brake test bench. Four-wheel drive vehicles can also be tested in this way.

In the case of ABS testing, two methods are used. In both cases, the test engineer brakes continuously.
The suggestion of method 1 is that the speed of the double-roller unit is reduced on each of the four wheels (simulation of a resulting wheel blockage).
The suggestion of method 2 is that the driving force of the SFT is temporarily reduced from 6 kN to 1.2 kN for each of the four wheels (simulation of a loss of grip).
These are two options for ABS testing which, according to our experience so far, work on many vehicles of different brands.

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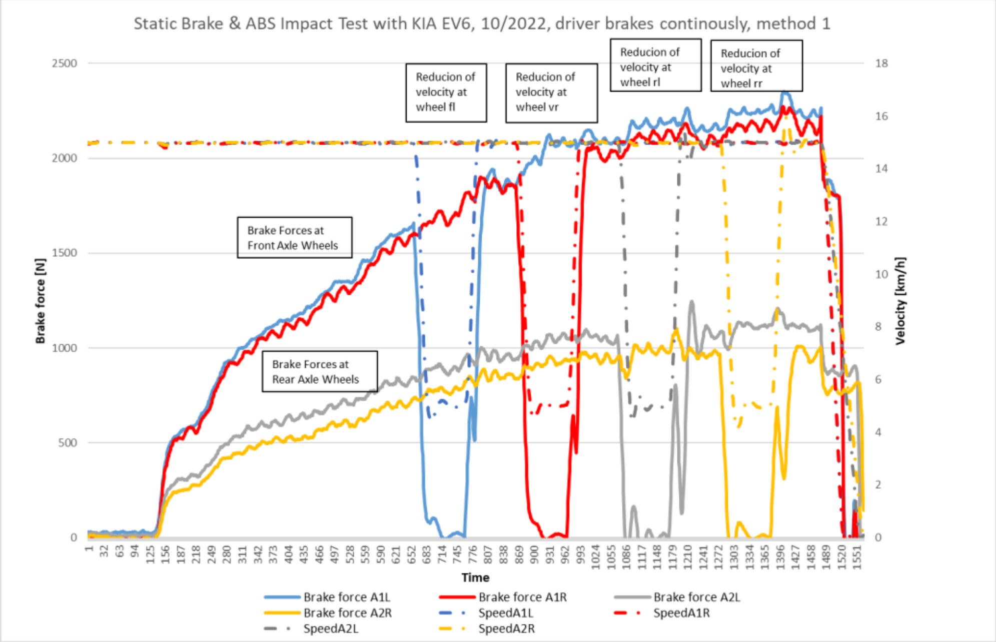

Figure 9a: The diagram shows the result of a brake and an ABS test according to method 1. Up to the black vertical line, you can see the increasing braking forces of the front and rear axles. From the black horizontal line, the speed of each wheel is successively reduced from 15 km/h to 5 km/h. The braking force on the speed-reduced wheel is then reduced to zero in each case, which documents the impact of the ABS.

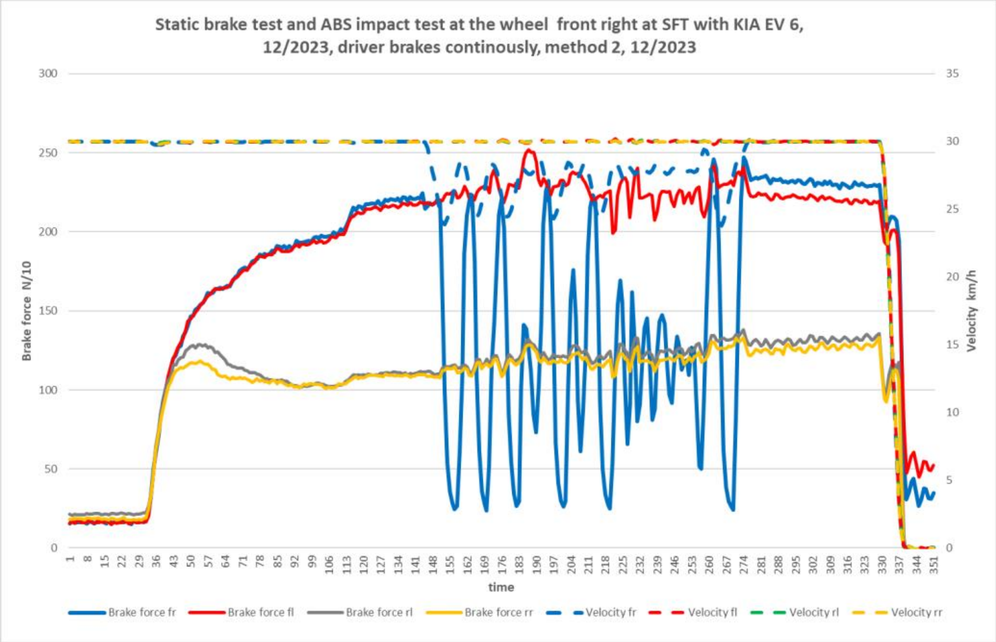

Figure 9b: The diagram shows the result of a brake and an ABS test according to method 2. As in Figure 9a, the increasing braking forces of the front and rear axles can be seen. Then, on the front right

wheel, the driving force of the SFT, which is set against the braking force of the vehicle, is temporarily reduced in such a way that the braking force is greater. As a result, the speed of the front right wheel drops and the ABS control intervenes with pulsating braking force to prevent the wheel from locking, which documents the impact of the ABS.

In the case of the ASR test (ASR – Anti Slip Control), the test engineer drives the vehicle at a constant speed. Now the speed of each wheel of the driven axle is increased one after the other (simulation of slippage on the wheel).

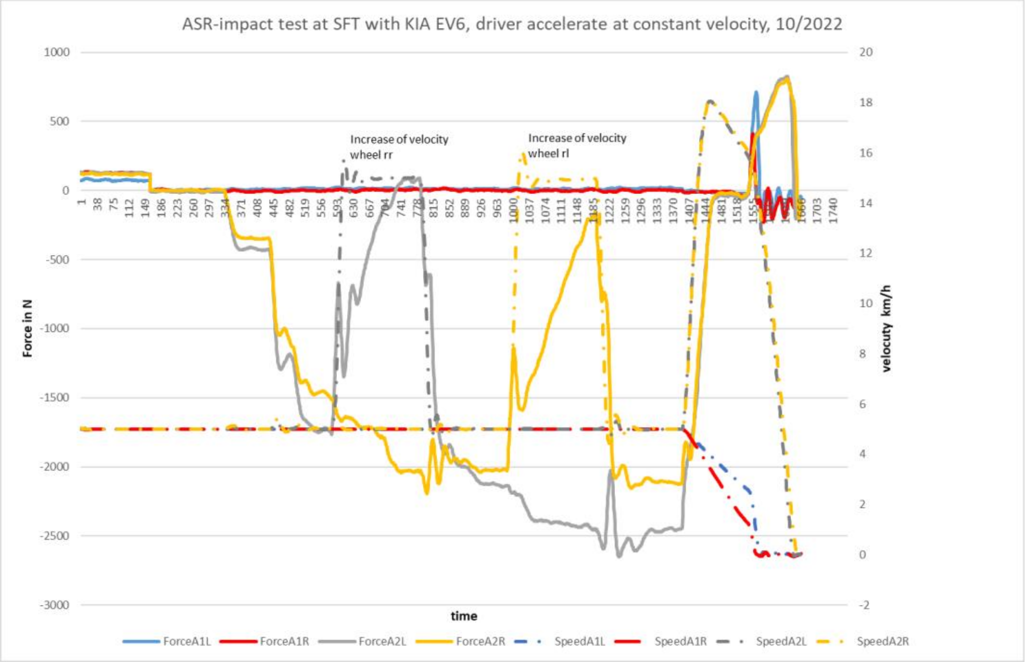

Figure 10: The diagram shows the result of an ASR test of a motor vehicle with rear-wheel drive. The speed of the rear wheel is increased successively from 5 km/h to 15 km/h. The drive force on the speed-increased wheel is then reduced to zero, which documents the impact of the ASR.

The ESP test is carried out on an all-wheel drive motor vehicle in the same way as the ASR test. This is one possibility of ESP testing. Further methods (e.g. with steering angle) are in preparation.

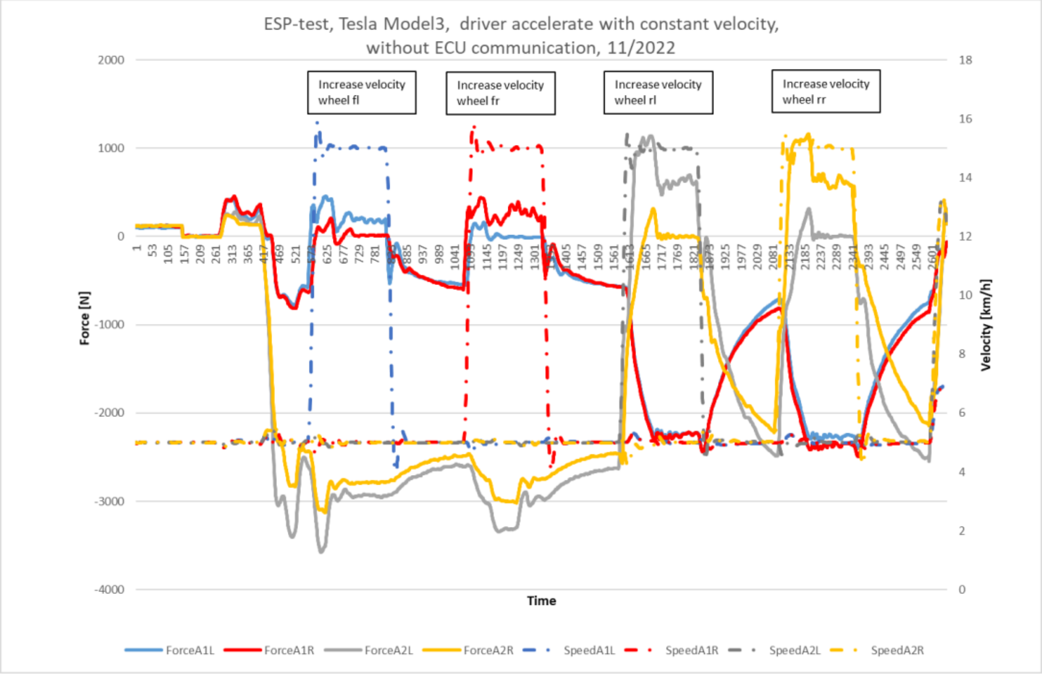

Figure 11: The diagram shows the result of an ESP test of a motor vehicle with all-wheel drive. The speed of each wheel is increased from 5 km/h to 15 km/h one after the other. The driving forces of the axle of the speed-increased wheels are then increased or decreased. This is done in the same way for each wheel of an axle to stabilize the vehicle.

3.2 Static and dynamic headlamp alignment test

For the static headlamp alignment test, the vehicle is first dynamically positioned on the SFT, then stopped and lifted out of the double rollers of the SFT by means of lifting bars. The lifting bars are levelled in accordance with the currently valid PTI headlight test guideline of 2018. The light collection box is positioned by the portal system in front of the headlight to be tested. The light image of the low beam is digitally measured in the light box with the help of image processing and evaluated on the basis of the position of the buckling point. It should be noted that the lateral adjustment (azimuth angle with respect to the symmetry axis of the vehicle) is recorded independently of the inspector and on the basis of an accurate measurement of the symmetry axis of the vehicle.

For the dynamic headlamp alignment test, the vehicle is lowered into the double rollers of the SFT and driven at an almost constant speed greater than 60 km/h. After the hall has darkened, the camera and the radar sensor of the vehicle are stimulated OTA with the scenario of a vehicle in front driving at night.

According to this scene, the green laser of the VisiLaserWall system dynamically projects the outline of the vehicle in front onto the 10m wall to scale - calculated from the environment simulation. When the automatic high beam is switched on, the headlights should be dimmed correctly at the position where the virtual vehicle is driving.

So if the outlines drawn with the laser are in the dark "gap" of the adaptive high beam (see Figures 12, 13), the correct function is given.

Figure 12: Functional representation of the adaptive high beam (Source: Opel Media/Stellantis)

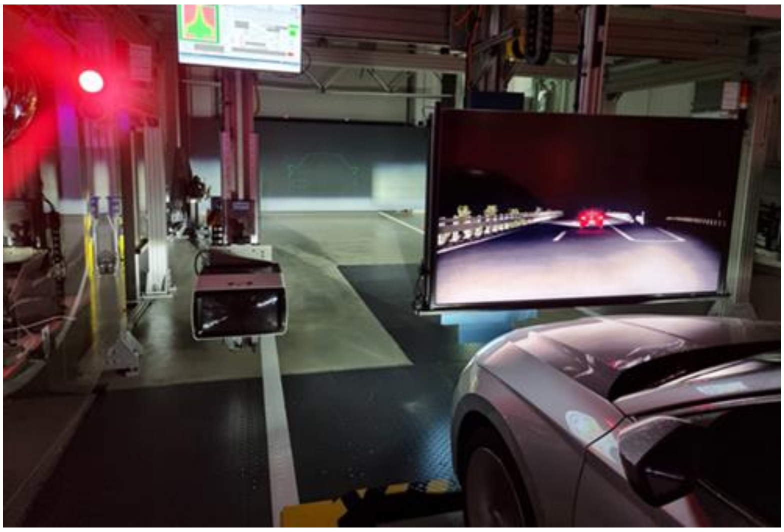

Figure 13: AFS inspection in KÜS DRIVE (Source: KÜS)

3.3 LDW, LKA impact tests

The LDW impact test is carried out according to the above principle with the vehicle driving on the SFT and the monitor positioned in front of the windscreen. The monitor shows an empty, straight road with middle and side stripes. The vehicle on the SFT is driven in such a way that the digital image between the center line and the side line is in the right lane. In the cockpit, two green lines are usually shown on the left and right as lane boundaries (Note: Depending on the implementation, the visualization in the display can be done in a different way). Then the real vehicle is first steered to the left by the test engineer until the left line in the cockpit display turns red. In the environment simulation, the distance between the left outer side of the tire and the center line is measured accordingly. The same procedure is performed by steering to the right with the sideline.

Figure 14: LDW impact testing in KÜS DRIVE (Source: KÜS)

The LKA impact test is carried out under the same boundary conditions as the LDW impact test, whereby a curvy road course is now simulated. The test engineer lets go of the steering wheel and the steering wheel rotation then follows the course of the road controlled by the LKA system so that both lines in the cockpit display remain green. The journey of the motor vehicle is recorded precisely in relation to the road markings.

Figure 15: Result of the LKA impact test in KÜS DRIVE (Source: KÜS)
The motor vehicle follows the red dashed lane boundary even when changing lanes.

3.4 ACC, AEBS impact tests

For the ACC, AEB impact test, the motor vehicle camera and the radar sensor OTA are stimulated with corresponding scenes (red car in front on the right lane of the highway) from the environmental simulation while driving on the SFT. The test engineer drives at a speed of approx. 60km/h on the SFT. He and the vehicle camera are shown a vehicle via the monitor. It accelerates to reduce the distance of the displayed vehicle. The vehicle should be detected by ACC and displayed in the cockpit display from a certain distance (see Figure 16). The ACC now ensures that the distance to the vehicle in front remains constant without the driver operating the accelerator pedal. The test engineer can now evaluate the vehicle's reactions to the stimulation.

Figure 16: ACC impact testing in KÜS DRIVE (Source: KÜS)

The function of the AEBS is checked by driving into a vehicle in front. As soon as the camera and radar sensor detect a critical undercutting of the distance to the vehicle in front, the vehicle to be tested must automatically initiate emergency braking. If this is not initiated in time and the tested vehicle does not come to a stop at a sufficient distance from the simulated vehicle, the AEBS is to be assessed as defective. In the AEBS impact test, the distance, the speed difference and the braking forces (see Figure 15) are continuously recorded. This means that AEBS impact testing can also be carried out at high speeds without the risk of accidents.

Figure 17: AEBS Efficacy test of a KIA EV6 in KÜS DRIVE. The figures show the difference in speed to the vehicle in front (target) and the curve of the braking force as a function of the distance to the target. (Source: KÜS)

4 Summary and outlook

For motor vehicles with a mono camera and a radar sensor, it was shown that KÜS DRIVE can be used to carry out impact tests without ADAS ECU communication and independently of the vehicle's self-diagnosis. With the aim of being able to examine as many motor vehicle brands as possible with ADAS impact tests, the basis of various motor vehicles will be significantly expanded in the next few years as part of the KÜS research project. On the one hand, the test methods will be further developed from the resulting experience and, on the other hand, criteria for the assessment of ADAS impact testing will be developed in cooperation with all interested parties.

Furthermore, it is planned to equip the test line with ADAS sensor calibration, Car2x and GNNS.

5 Acknowledgements

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6 Literature

[1] Dr. rer. nat. T. Tentrup & al., VDI Mechatronics Conference 2019
[2] Dr. rer. nat. T. Tentrup & al., VDI Mechatronics Conference 2022
[3] Paten DE 10 2018 121 144 B3
[4] dSPACE Magazine 2023-02, S56 to S61

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