KÜS DRIVE
Impact testing of dynamic safety-relevant driving functions within the periodic vehicle inspection

Dr. rer. nat. Thomas Tentrup, Dipl.-Ing. Peter Schuler, Dipl.-Ing. Stefan Schuler, Dipl.-Ing. Thomas Auer, Dipl.-Ing. (BA) Florian Mai
KÜS Bundesgeschäftsstelle, Zur Küs 1, 666679 Losheim am See, ttentrup@kues.de, www.kues.de

Abstract

Safety-relevant driver assistance systems that are continuously advancing must also be tested in the future as part of the mandatory periodic vehicle inspection (PTI). The tests must be reliable and OEM-independent and should be implemented by means of impact testing in dynamic driving operation. This is done by the "KÜS DRIVE" test lane (to be set up in 2022). Among other things, it consists of a special functional test bench (SFT) on which steering motions can be initiated while driving up to 130 km/h. In addition, a monitor and a radar target simulator integrated into a gantry system stimulate the vehicle sensors with scenarios generated by the driving the digital vehicle simulation in the environment simulation synchronously with driving the real vehicle on the SFT. The responses of the real vehicle are recorded via the measurement technology of the SFT and compared with the target responses from the environment simulation. In contrast to "**V**ehicle **i**n the **L**oop" tests in vehicle development, this methode is applied here to approved vehicles and without ECU communication.

1 Introduction

As early as 2016, it was clear that automation was also making further progress in the automotive sector and could no longer be stopped. Consequently, the requirements for the legally binding periodic vehicle inspection are also constantly increasing to keep pace with technological progress in the field of functions for automated driving and driver assistance systems.

It must be possible to check the function and reliability of safety-relevant systems OEM-independent and without ECU communication. This is the only way to reliable and independent test vehicles of all automation levels, from assisted (level 2) to autonomous (level 5) driving, for their road safety as part of the periodic inspection.

Therefore, the vehicle inspection organization KÜS (Kraftfahrzeug-Überwachungsorganisation freiberuflicher Kfz-Sachverständiger) has asked itself the following research question "How can the mandatory periodic technical inspection (PTI, in German: Hauptuntersuchung HU) most effectively keep up with the technical development of vehicles?"

The answer to this question is years of development and the subsequent setup of the "test lane of the future" for passenger cars in 2022. The corresponding project, called *KÜS* DRIVE (**D**ynamic **R**oadworthiness **I**nspection for **Ve**hicles), aims to integrate the tests performed in the proven periodic inspection into a test lane in which the safety-relevant driver assistance systems can also be tested by means of impact testing. This project requires a leap in technology, since the classic HU tests are carried out on a de facto stationary vehicle (exception: brake test with a rotation of the wheels v=6 km/h) or at low speeds within a limited route, the conditioning drive. For most safety-relevant driver assistance systems, however, a vehicle speed of v>50 km/h is necessary for a meaningful test.

In this publication, it is useful to classify driver assistance systems as follows:

a. *Classic* driver assistance systems (DAS) such as ABS and ESP, which stabilize the vehicle in critical dynamic situations and receive their input via in-vehicle sensors such as angular rate sensors in the wheels, acceleration sensors and sensors for measuring the steering angle.

b. *Advanced* Driver Assistance Systems (ADAS) such as ACC, AEB, LDW, and LKA, which warn the driver or automatically prescribe braking and steering maneuvers based on environment situations. These receive their input via the vehicle's environment sensors such as cameras and radar sensors, among others. The intelligent networking of ADAS with each other ultimately leads to automated or autonomous driving.

Glossary of English abbreviations used for ADAS:

- ACC Adaptive Cruise Control
- AEB Autonomous Emergency Braking
- LDW Lane Departure Warning
- LKA Lane Keep Assistent

The currently planned KÜS Drive test scopes include:

- Exhaust emission test at idle speed as well as extended measurements under various load conditions while driving on the steerable function test stand (SFT)
- Brake test, as well as testing of DAS such as ABS and ESP
- Static and dynamic headlamp adjustment test (SEP), where dynamic SEP refers to the testing of adaptive high beams as example
- Testing of ADAS, ACC, AEB, LDW and LKA

2 Requirements for *KÜS* DRIVE

2.1 Safeness

All test benches are CE certified.

2.2 Accuracy and reproducibility

In order to always maintain the same conditions for the periodic vehicle inspection, as an accredited inspection service, *KÜS* DRIVE is designed as an *indoor* system, independent of external influences. Furthermore, all test benches must be test equipment- and machine-capable [1] with regard to the specified very small tolerances. The calibration means used are traceable to national standards.

Note: The specified tolerances for the detection direction of ADAS sensors (i.e. direction of the optical axis in the case of cameras or direction of the wheel lobe in the case of radar sensors) to the geometric driving axis of the vehicle are between 3 and 30 angular minutes! For example, the radar sensor, which is used to reliably detect targets at a distance of up to 250 m, shows a lateral deviation of one meter in 250 m when the radar beam deviates from the geometric axis of travel by 14 angular minutes.

2.3 Impact testing without ECU

The impact-principle test (in short: impact test) checks the response of a technical overall system to a known, defined impulse and evaluates the difference between the response of the system and the target impulse. For the impact testing of driver assistance systems, this means that the stimulation via the sensor system is physically direct, as on the road. Thus, ECU communication is not considered necessary.

2.4 Testability of vehicles of all automation levels

Even fully autonomous driving cars must be testable on the KÜS DRIVE test lane.

2.5 Modular extensibility

The current test scopes focus on the ADAS at the front of the passenger car (see red rectangle in Figure 1). It must be possible to extend the tests for foreseeable technological trends. Possible future enhancements include ADAS testing on the side and rear of the passenger car. The possible integration of Car2X and GNSS is also planned.

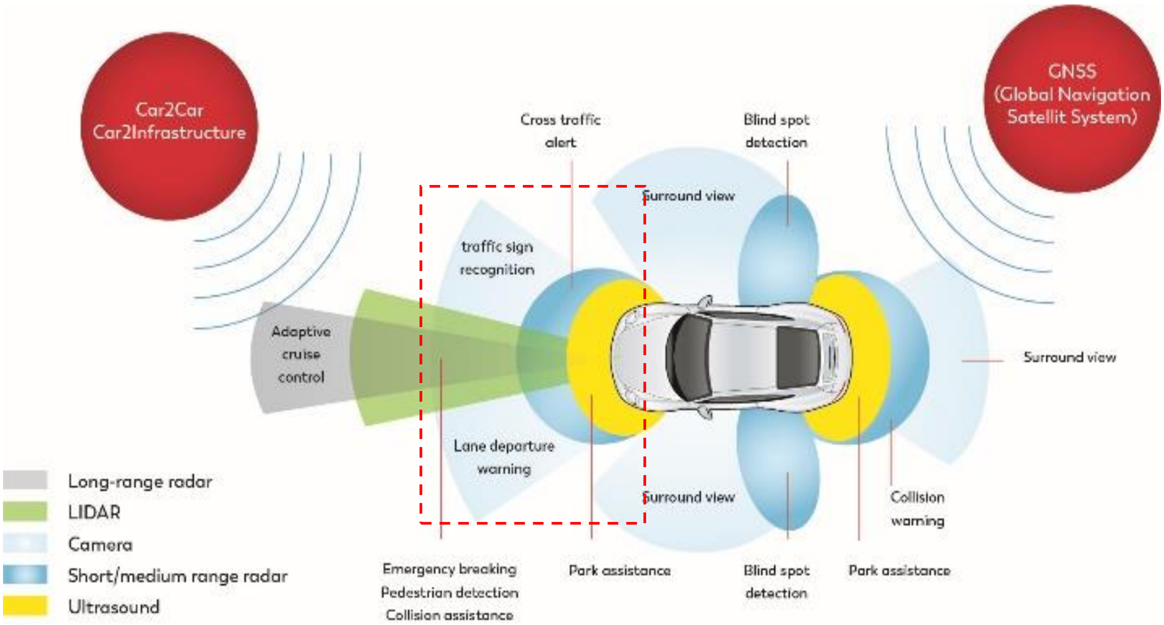


Figure 1: ADAS overview (Source: KÜS)

2.6 Indoor testing

The low tolerances of the ADAS sensors caused by the sensitive measurement technology require constant and defined environment conditions (see 2.2). Furthermore, the test field must be darkened for certain tests (e.g., testing of adaptive high beam).

3 Basic structure

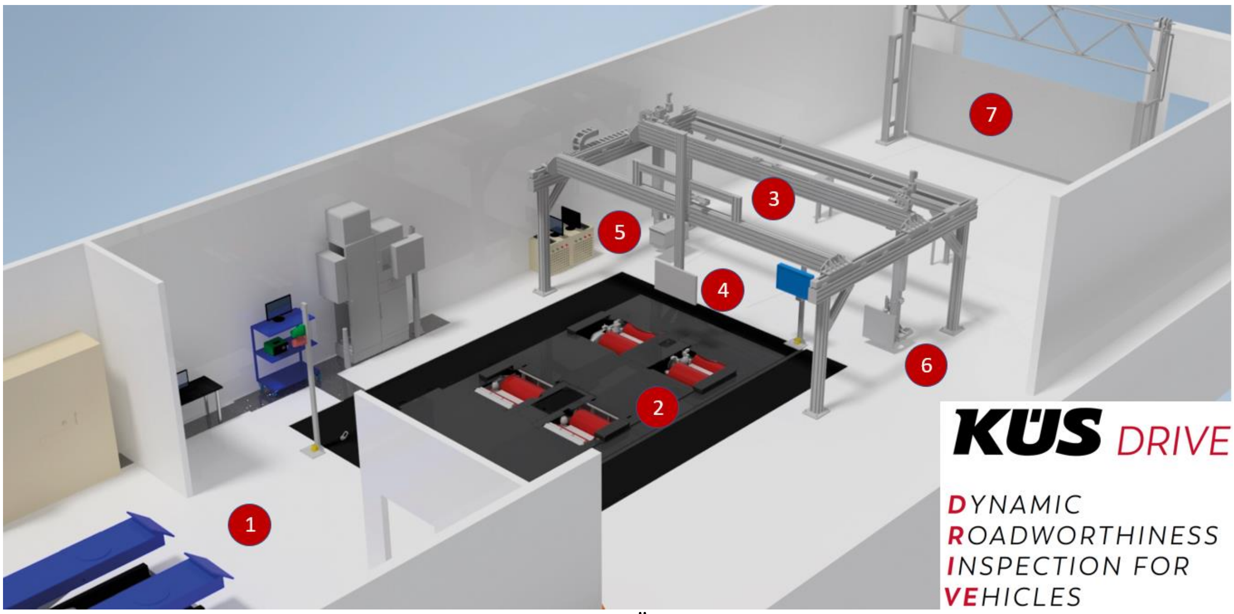


Figure 2: Basic structure of the test lane (source: KÜS). Refer to the text below for a description of the main system parts according to the numbering.

(1) Lifting platform for vehicle inspection by the test engineer.

(2) Steerable function test stand (SFT) from Dürr (brand name: x-road curve) described in detail in [2]. On the SFT, the vehicle can be driven **untethered, including moderate steering movements**, at speeds of up to 130 km/h. Here, with the help of rotating double rollers at the front and a measuring system, that continuously measures the position and orientation of the vehicle, the vehicle symmetry axis is positioned on the symmetry axis of the SFT while the vehicle is moving.

(3) Gantry system for positioning the monitor **(4)**, the light collection box **(5)** of the static headlamp adjustment test (SEP, German abbreviation) and the radar target simulator **(6)** from the company dSPACE in front of the vehicle.

(7) 10 m wall from VisiCon (brand name: VisiLaserWall) [3] for measuring the adaptive high beam within the framework of dynamic headlamp alignment tester.

4 Brake, ABS and ESP Testing

The impact test of the braking system and the driver assistance systems (DAS), ABS, and ESP are performed on the steerable functional test bench (SFT), basing on a combined roll-, brake-, and ABS-test bench, without additional or new devices. In these tests, all double roller assemblies are driven at the same constant speed, regardless of whether the vehicle is braking or accelerating.

In *static* brake testing, the test engineer applies the brakes, and the test bench measures the torque increase per double roller assembly to turn the wheel at a constant speed, which then corresponds to the braking force per wheel. The brake test is performed separately on the front and rear axles without the vehicle having to be moved, as is the case with a single-axle brake tester.

In the case of the ABS test, the test engineer brakes continuously, and the speed of the double roller unit is reduced at one of the four wheels at a time (simulation of an emerging wheel lock).
During the ESP test, the test engineer accelerates the vehicle, and the speed of the double roller unit is increased at one of the four wheels at a time (simulation of wheel slip).
The response of the ABS or ESP to the stimulus ‘speed change at one wheel’ is recorded and evaluated on the base of the force curves at the four wheels.

The test methods described above, carried out on a roll-, brake-, and ABS-test bench, have long been state-of-the-art end-of-line tests in automotive plants. In contrast to this, the static and dynamic SEP as well as the effectiveness testing of the ADAS are now being carried out for the first time on a steerable functional test bench (SFT) with a gantry system and 10 m wall.

5 Static and Dynamic Headlamp Adjustment (SEP) and ADAS tests

5.1 Requirement - unitary coordinate system

A fundamental requirement for static and dynamic SEP as well as for ADAS testing is the implementation of a coordinate system and the synchronization of the coordinate systems of all test and measurement equipment with a calibration gauge.

For this reason, a calibration gauge was developed according to the KÜS concept, which is positioned in a defined manner on the leveled vehicle lifting bars of the steerable function test bench (SFT). The calibration gauge is measured with a certified coordinate measuring machine, equipped with measuring surfaces, and aligned lasers for calibration and adjustment of the following components:

- The chassis geometry measurement system of the SFT, which detects the symmetry axis of the vehicle among other things.
- The light collection box of the SEP,
- The 10m wall,
- The RTS antennas,
- The monitor

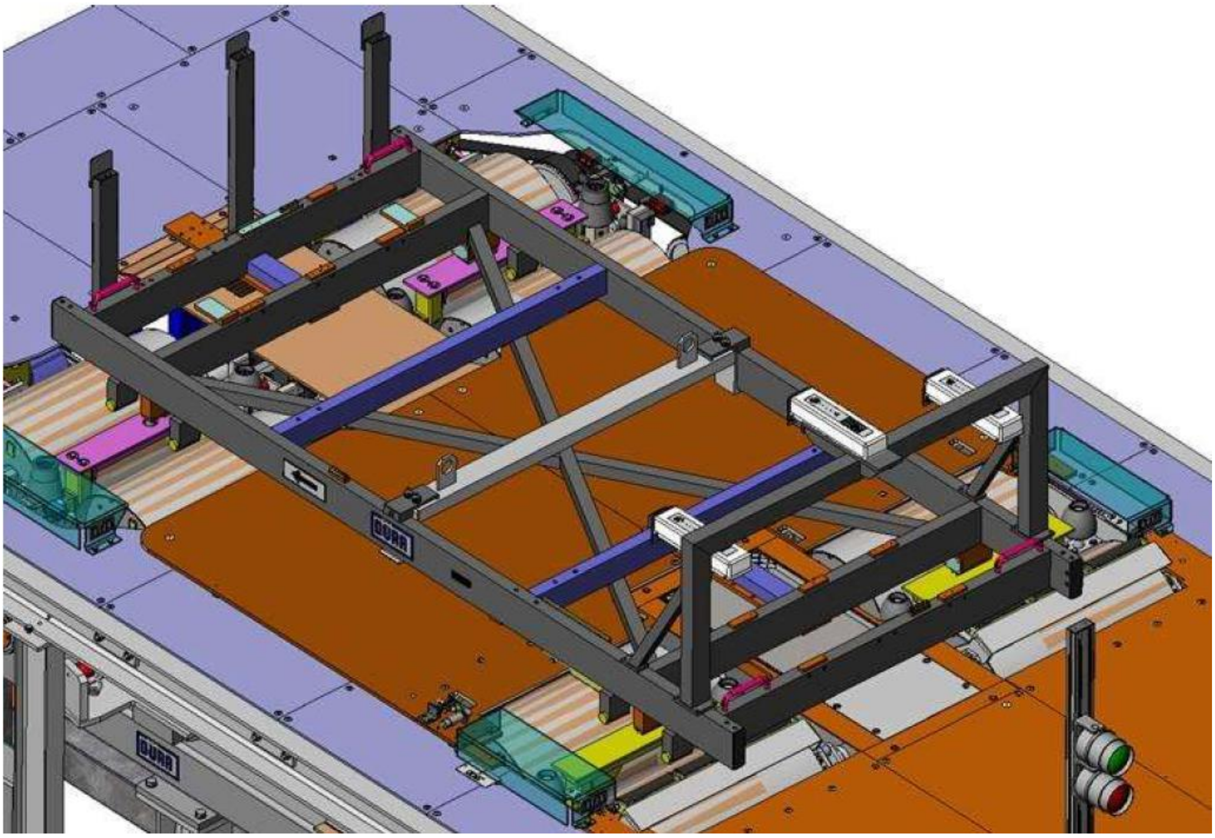


Figure 3: Calibration gauge on the SFT for calibration and adjustment of all test equipment. (Source: Dürr)

During the static and dynamic headlight adjustment test, height adjustment and the lateral adjustment in relation to the direction of the symmetry axis of the vehicle must be checked.

ADAS only works without errors if the ADAS sensors are precisely set within the tolerance to the geometric driving axis specified by the manufacturer (OEM) and the software is executed correctly. Thus, it is also necessary to check the lateral adjustment of the ADAS sensors in particular.

5.2 Static and dynamic headlamp adjustment tests (SEP)

For the **static SEP**, the vehicle is stopped and lifted out of the double rollers of the SFT by means of a vehicle lift. The vehicle lifting bares are leveled according to the current 2018 HU SEP guideline. The light collection box is positioned left and right in front of the headlights on the gantry system. The light image of the low beam is digitally measured in the light box with the aid of image processing and evaluated based on the position of the bending point. It should be noted in particular that the lateral setting (azimuth angle with respect to the axis of symmetry of the vehicle) is recorded independently of the tester and based on an accurate measurement of the axis of symmetry of the vehicle.

In **dynamic SEP**, the vehicle is lowered into the dual rollers of the SFT and driven at a constant speed greater than 50 km/h. The monitor is positioned in front of the camera in the windshield. The 10 m wall is lowered and the hall is completely darkened. When the automatic light system is switched on, the adapted high beam is activated and the corresponding "hot spots" can be seen on the 10 m wall. The camera in the windshield controls the function of the adaptive high beam. Therefore, the monitor is used to simulate night driving in the following three basic scenes:

1. Vehicle driving in front
2. Oncoming vehicle in the left lane
3. Vehicle in front and oncoming vehicle

According to these scenes, the lasers of the *LaserVisiWall* system project the outlines of the dark target areas in green to scale on the 10 m wall. These outlines can be those of geometrical objects (vertical lines, rectangles, etc.) as well as those of vehicles. If these outlines are centrally located in the dark ‘gap’ of the adaptive high beam (see Figs. 4, 5), the correct function is present.

Furthermore, the corresponding scenes can also be generated as dynamic scenes via the environment simulation (see chapter 5.3).

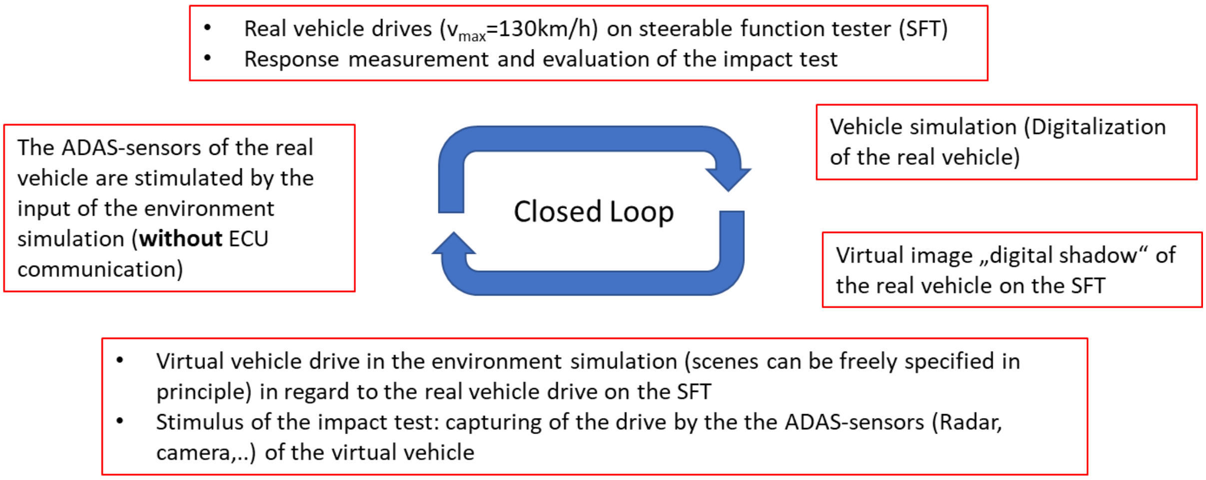
Figure 4: Functional illustration of the adaptive high beam (Source: Opel Media/Stellantis)

Figure 5: Testing adaptive high beams in KÜS DRIVE (source: KÜS)

5.3 Principle of scene-based ADAS impact testing

For scene based ADAS impact testing, a digital image of the real vehicle to be tested, driving on the SFT, is first generated. This digital image consists of the geometric data that is important for the test, which originates from a database (e.g. **K**raftfahrzeug**b**undes**a**mt (KBA) type data) or the measurement on the SFT, and of the dynamic data of the vehicle's trajectory measured on the SFT. This dynamic data is the current position, current speed, and current steering angle of the vehicle. The geometric and dynamic data of the vehicle is combined in a vehicle simulation to create a dynamic, digital vehicle. This digital vehicle is now moved in an environment simulation along the same trajectory as the real vehicle on the SFT. In principle, the environment simulation can be freely specified, but is designed in such a way that the vehicle runs through scenarios relevant to the test. The scenes that are captured by the digital vehicle's camera and radar sensor are fed into the real vehicle's camera and radar sensor on the SFT via the monitor and radar target simulator (RTS).

This input is the defined stimulation in the impact test. The response of the real vehicle is measured by the SFT and can be compared with a specified target response. This closed loop between SFT and vehicle model/environment simulation is implemented in cooperation between dSPACE [4] and Dürr (scheme see below).



Due to the exact alignment of the monitor and the RTS to the camera and radar sensor of the real vehicle and the measurement of the tangential forces of the vehicle tires on the dual rollers of the SFT, an ADAS impact test is performed that evaluates the following:

- The quality of the adjustment of the ADAS sensors.
- The quality of the functionality of the ADAS software.
- The quality of the execution by the ADAS actuators.

5.4 LDW, LKA impact testing

The **LDW impact test** is performed according to the above principle with the vehicle driving on the SFT and the monitor positioned in front of the windshield. The monitor shows an empty, straight road with a median strip and hard shoulder. The vehicle on the SFT is driven in such a way that the digital image is located between the centerline and the sideline on the right lane. In the cockpit, two green lines are usually shown on the left and right as lane boundaries. Depending on the implementation, the visualization may differ. 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 of the outer wall of the left tire from the centerline is measured accordingly. The same procedure is performed with the sideline by steering to the right.

The **LKA impact test** is performed under the same boundary conditions as the LDW impact test, but now a curved road course is simulated. The test engineer releases the steering wheel and the steering wheel rotation, controlled by the LKA system, then follows the course of the road in such a way that both lines in the cockpit display remain green.

Figure 6: Impact testing of LKA in KÜS DRIVE (source: KÜS)

5.5 ACC, AEB impact testing

For the **ACC and AEB** impact testing, in addition to the monitor in front of the windshield, the radar target simulator (RTS) is positioned in front of the vehicle's radar sensor so that the two antennas are exactly facing the direction of the radar beam emitted by the radar sensor. Now, one antenna can receive the transmitted radar signal from the vehicle and the other antenna can send back a modified signal, generated by driving the digital image of the vehicle in the environment simulation.

The test engineer drives on the SFT at a speed of approx. 60 km/h. The monitor display a vehicle to the engineer and the camera. The engineer accelerates to reduce the distance from the indicated vehicle. The ACC has to detect the vehicle and display it in the cockpit display when the vehicle is closer than a specified distance. The ACC, which was activated again when the driver stopped intervening, now ensures that the distance to the vehicle in front remains constant without the driver operating the accelerator pedal.

The function of the AEB is tested by a simulated emergency braking of the vehicle in front. As soon as this simulated emergency braking is detected by the camera and/or radar sensor, the vehicle under test must initiate emergency braking on its own. If this is not initiated in time and if the tested vehicle does not come to a halt with sufficient distance to the simulated vehicle, the AEB is evaluated as defective.

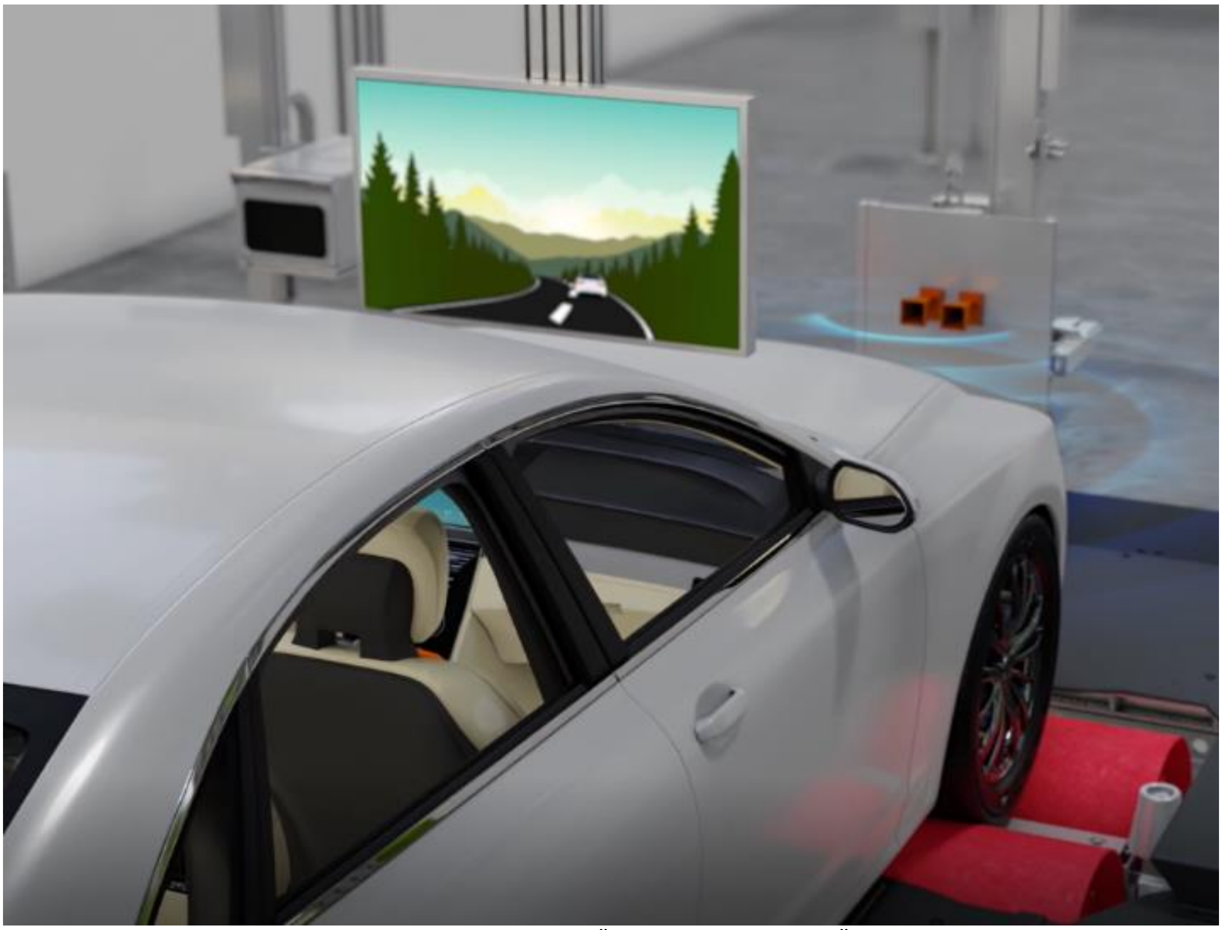


Figure 7a: Impact testing of ACC and ABE in KÜS DRIVE (source: KÜS)

Figure 7b: Impact testing of ACC and ABE in KÜS DRIVE (source: KÜS)

6 Outlook

Together with the new buildings of the KÜS Academy, the research hall will be completed by the end of 2022, when the *KÜS* DRIVE test benches are installed and commissioned. This will be followed by a research and testing phase in which we will apply the innovative tests to vehicles from a wide range of manufacturers. This will allow us to gain practical experience with the impact tests and make adjustments if necessary.

Regarding the level of investment for such a test lane, it should be noted that a monitoring organization such as KÜS has the legal mandate to ensure a high level of road safety by checking the technical condition of vehicles. Therefore, the general inspections prevent accidents and increase road safety. The 'classic' DAS and especially the 'advanced' driver assistance systems (ADAS) are capable of significantly reducing accidents caused by human error or incapacity. For this, they must function correctly over the entire life cycle of the vehicle. This correct function must be checked by independent, periodic testing. For example, ACC and AEB can prevent rear-end collisions, especially at high speeds, and therefore significantly reduce such accidents. It is precisely in accidents of this kind that many deaths and serious injuries occur, in addition to the high amount of property damage. Therefore, the investment made in avoiding accidents by using ADAS must always be viewed in the context of the financial damages as well as deaths and injuries incurred by accidents as those described above.

In addition, it should be noted that the importance of driver assistance systems is changing. While these are currently largely convenience systems designed to make driving more convenient for the driver, they are increasingly developing into safety systems. Due to this development step, in the future they will inevitably fall into the area for which a periodic inspection is necessary as part of the main inspection

7 Expressions of Thanks

We would like to thank the companies Dürr Assembly Products, VisiCon Automatisierungstechnik and dSPACE for their cooperation and for providing us with 3D CAD data of their systems.

8 Summary

The *KÜS* DRIVE test lane is an innovative machine for the independent testing of adaptive lighting systems and driver assistance systems in addition to the current scope of testing as part of an advanced periodic general inspection. For advanced driver assistance systems (ADAS), this is done via impact tests, the stimuli for which are scenarios that are fed from an environment simulation into the sensor system of an approved vehicle on a steerable function test bench (SFT). No ECU communication is required for this. The modular nature of the setup and the flexibility of the environment simulations ensure that the test scope of *KÜS* DRIVE can easily be adapted to foreseeable vehicle technologies up to autonomous driving.

9 References

[1] e.g. VDA 5, Mess- und Prüfprozesse, ISSN 0943-9412, 3. Auflage, Juli 2021

[2] Dr. rer. nat. T. Tentrup & al., VDI Mechatroniktagung 2019

[3] Patent specification DE 10 2018 121 144 B3

[4] Dr.-Ing. A. Himmler, Dr. rer. nat. A. Trapp, www.elektronikpraxis.vogel.de/wie-sich-4d-bildgebende-radarsensoren-validieren-lassen-a-1026076/, ID:47373389, 2021

This paper based on a German publication in the frame of "VDI Mechatroniktagung 2022".