Testing Steering Systems

Real-time-based testing at ZF TRW Steering Development

Developing and validating safety-critical mechatronic systems such as power steering requires a suitable test environment. ZF TRW Tech Center in Duesseldorf uses test instances with increasing hardware content.

Also entire ZF TRW steering systems are tested in a real-time environment.

The demands on the functional performance and safety of today's steering systems are continuously increasing – namely, functional performance in the context of autonomous driving and safety in relation to the stricter requirements for steering support availability. Both aspects have to be integrated into a validation process that complies with ISO 26262. Furthermore, a comprehensive validation procedure also needs to consider aspects arising from the high number of vehicle platform variants. Proof of series maturity has to be delivered as soon as possible and at competitive costs.

> "The openness of the dSPACE environment gives us decisive advantages for implementing our own models and using self-developed test bench components."
>
> *Dr. Michael Moczala, ZF TRW*

Virtualization as the Solution

To tackle these challenges the ZF TRW Tech Center in Duesseldorf uses virtualization technology and Hardware-in-the-Loop simulators. This means that real components (hardware) are used in a control loop that is closed by virtual components. In particular, these virtual components include precise models of the steering sensor, the steering gear, the driver's arms and vehicle communication. These specialized submodels can easily be combined with the components of the Automotive Simulation Models (ASM) Library from dSPACE. This lets you simulate vehicle dynamics realistically and in real time. The real-time capability of ASM enables the testing of ECU hardware in a virtual vehicle environment. This makes it possible to perform model-based testing when the real systems or components are not available yet. Errors and failures can be simulated without any risk or damage to the product, and automating tests becomes both easier and more efficient. A further benefit is that tests are easy to reproduce and are independent of weather conditions, which is important for in-vehicle tests.

Three Test Instances

On the basis of the system integration strategy, ZF TRW set up three HiL test instances with different hardware-to-model ratios: ECUiL, EPPiL and EPSiL. The three abbreviations stand for: Electronic-Control-Unit-in-the-Loop, Electric-Power-Pack-in-the-Loop and Electrically-Powered-Steering-in-the-Loop. In the EPP, the ECU and the electric motor together form a functional unit. The EPS then combines the ECU, the motor, a steering sensor, and mechanical power transmission elements to form one steering system. The amount of hardware used in the tests increases from one test bench to the next, while the amount of modeled components decreases. The test benches are then used successively according to the ISO 26262 test phases (figure 1). This means that the extensive tests of the early validation phases are carried out cost-effectively on the ECUiL simulators, of which there are several. The test benches dedicated to higher integration levels have higher acquisition and operating costs.

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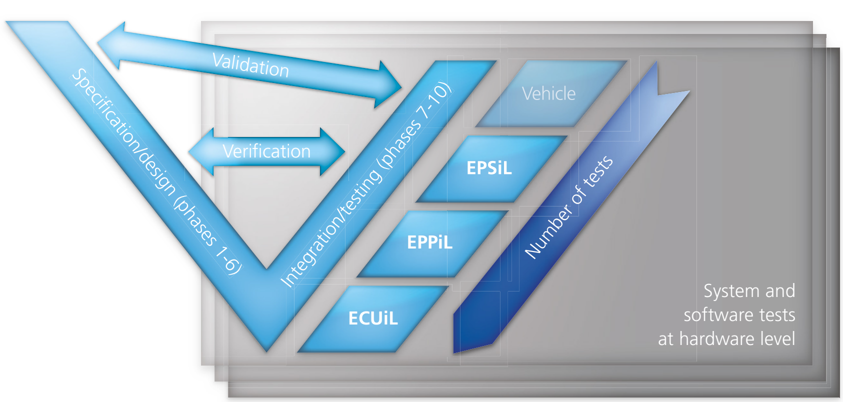
Figure 1: The three test benches are used for the ISO-26262-compliant functional validation of the steering algorithms at the hardware level – verification via bidirectional traceability. The validation steps require additional information from superordinate specification phases.



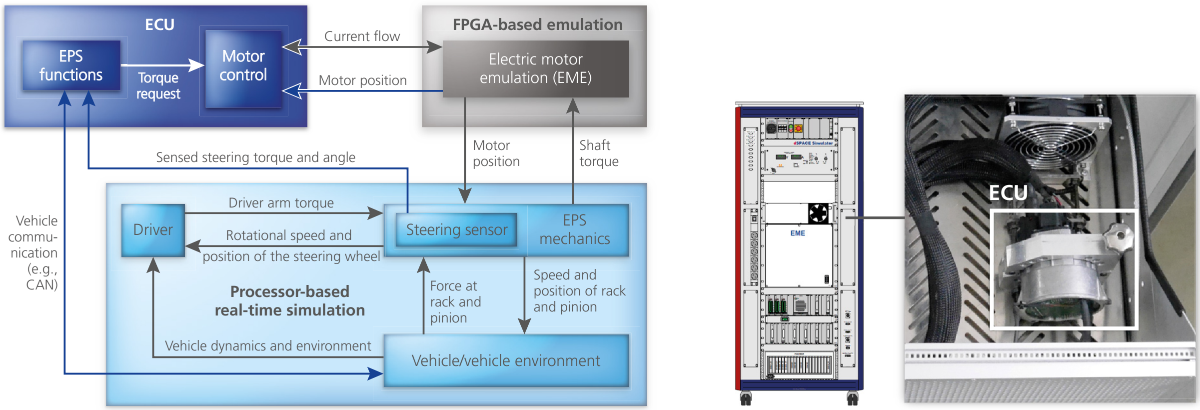


Figure 2: The number of virtual components is largest in the ECUiL systems. The ECU under test is electrically connected to the simulation environment.

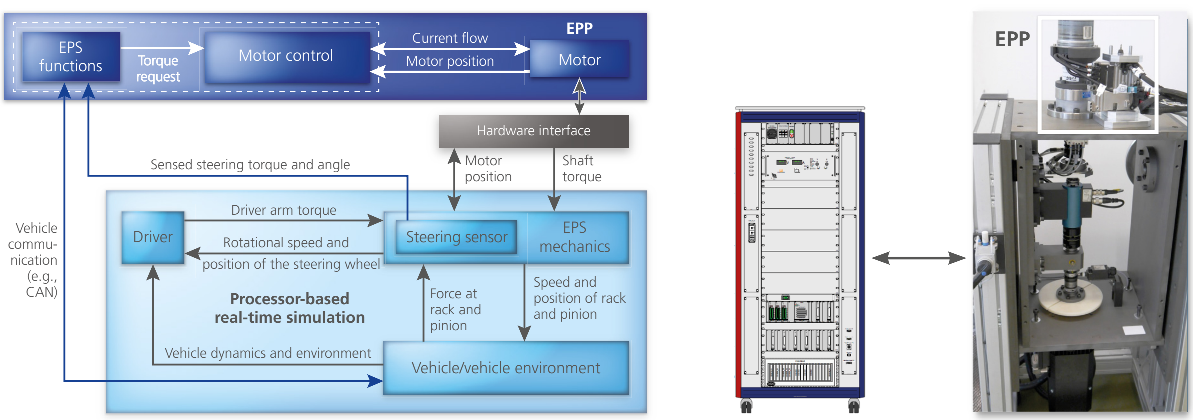


Figure 3: The EPPiL system contains the ECU and the steering motor as hardware. An actuator and sensors are used to integrate the motor into the simulation environment.

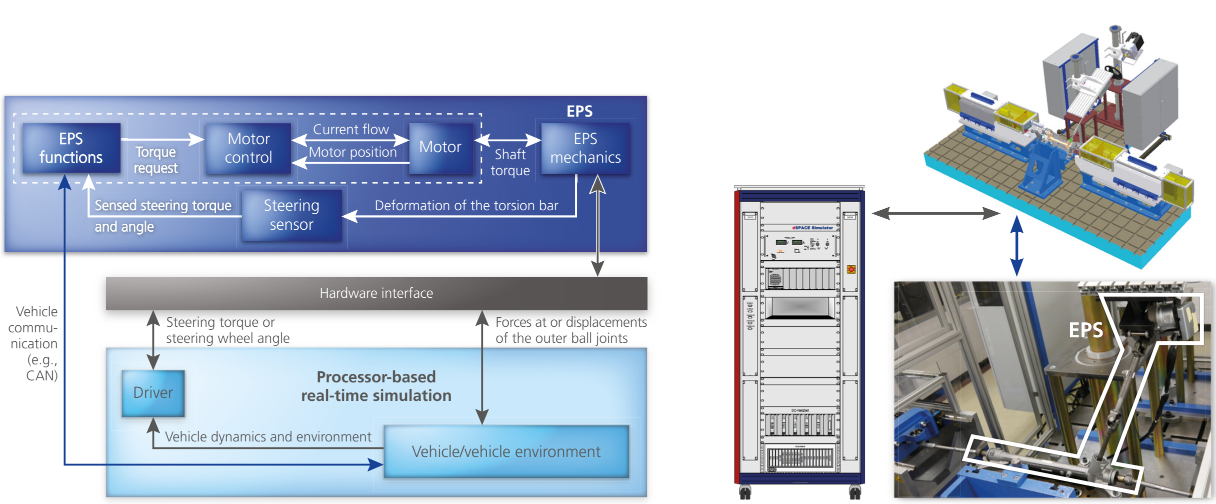


Figure 4: The EPSiL simulator tests the entire steering system. The mechanical interface to the model is therefore complex.

> "The flexibility of dSPACE's real-time systems is impressive. We use our HiL infrastructure for application projects and predevelopment."
>
> *Dr. Michael Moczala, ZF TRW*

On the other hand, the higher the degree of integration, the lower the amount of testing.

Instance 1: Electronic-Control-Unit-in-the-Loop

The ECU used in the steering system contains the numeric algorithms of the steering functions and the actual controller of the electric motor (figure 2). The motor generates a torque that is adjusted to the driving situations and to the driver requests. Simulating this interaction requires the electrically precise emulation of the motor in such an ECUiL test environment. The required precision can be achieved by the electric motor emulator (EME), which is integrated into the dSPACE real-time system. With this solution, the developers and testers also have the ability to adjust the motor characteristics. They can access the motor parameters, the measured signals, and all other data of the control model via integrative dSPACE software.

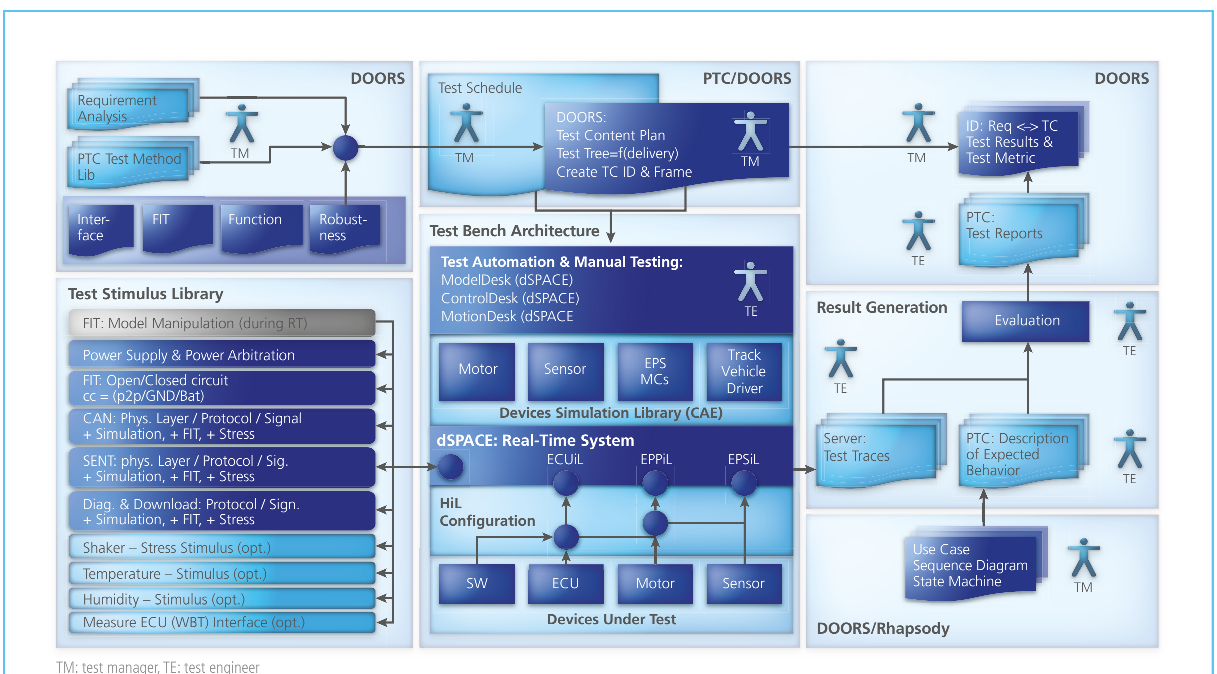
Instance 2: Electric-Power-Pack-in-the-Loop

For EPPiL testing, the ECU is connected to the real steering motor (figure 3). The motor interacts with a rotary actuator according to the simulated load case. The matching sensors, which are a part of the hardware interface, provide the actual state, and the actuator's inverter receives the target values generated in the control model. The HiL loop is then closed by virtual components, similar to the ECUiL systems.

Instance 3: Electrically-Powered-Steering-in-the-Loop

The EPSiL simulator contains the fewest virtual components (figure 4). However, providing the mechanical interfaces of a complete steering system to the model requires a large number of active elements and measurement devices. For example, the driver torque and the rotational angle of the steering wheel are controlled by a direct rotary actuator. The linear actuators, which are connected to the two tie rods, are used as direct electric drives as well. The close connection between real-time hardware and drive controllers via the TWINsync protocol guarantees the high-precision and dynamic transfer of the control variables to the steering hardware under test. Measurement values from several force, torque, position and acceleration sensors feed the steering states back into the real-time model and close the control loop. The EPSiL simulator is a one-stop solution from dSPACE.

Figure 5: EPS HiL tool architecture using dSPACE tools that provide a complete solution for editing and managing test artifacts.



> "The open dSPACE architecture – real-time hardware and software tools – enabled us to map our integration strategy to the HiL infrastructure."
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> *Thomas Maur, ZF TRW*

Flexible Test Environment

The control environment of all three HiL test benches is designed so that it simulates not only complex interactions between driver, vehicle and road in a virtual environment, but also offers the possibility for simple force and trajectory specifications at the related hardware interfaces. Synthetic stimuli or recorded measurement data can be fed to the unit under test via the hardware interface. The modular character of the real-time systems creates a flexible environment. For example, only little effort is required to connect the real-time systems to existing test benches.

Summary and Evaluation

To validate the electrically powered steering (EPS) systems, ZF TRW uses a test concept that consists of several HiL instances, from ECU testing (ECU-in-the-Loop) to testing the entire steering system on a test bench (EPS-in-the-Loop). In combination with the HiL simulators' hardware, the Tech Center in Duesseldorf created a complete data and software infrastructure that can be accessed by all HiL test benches. Models, user layouts and test automation scripts are developed with the entire system in mind. One great advantage at this place is the seamlessness and flexibility of the dSPACE products. The combination of the dSPACE hardware with tools such as ControlDesk® Next Generation, AutomationDesk, ASM or ModelDesk gives developers and users maximum flexibility. The open setup of the real-time application, which is described in MATLAB®/Simulink®, makes it possible to extend it with specialized submodels. These detailed models let developers master the demanding development and test tasks of the EPS systems. The data management system SYNECT® completes the software infrastructure and provides the required interfaces to the test management in PTC® Integrity and the requirements management in DOORS® (figure 5). The HiL infrastructure makes it possible to develop and test EPS systems according to the ISO standard for the functional safety of road vehicles efficiently and reliably. The test instances (ECUiL, EPPiL, and EPSiL) reflect the integration strategy defined by ISO 26262. ■

Dr. Michael Moczala,
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> "By integrating SYNECT in our dSPACE-based HiL setups we closed the gap between requirements management and testing. 'Testing between DOORS & DOORS' is our new motto."
>
> *Thomas Maur, ZF TRW*

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