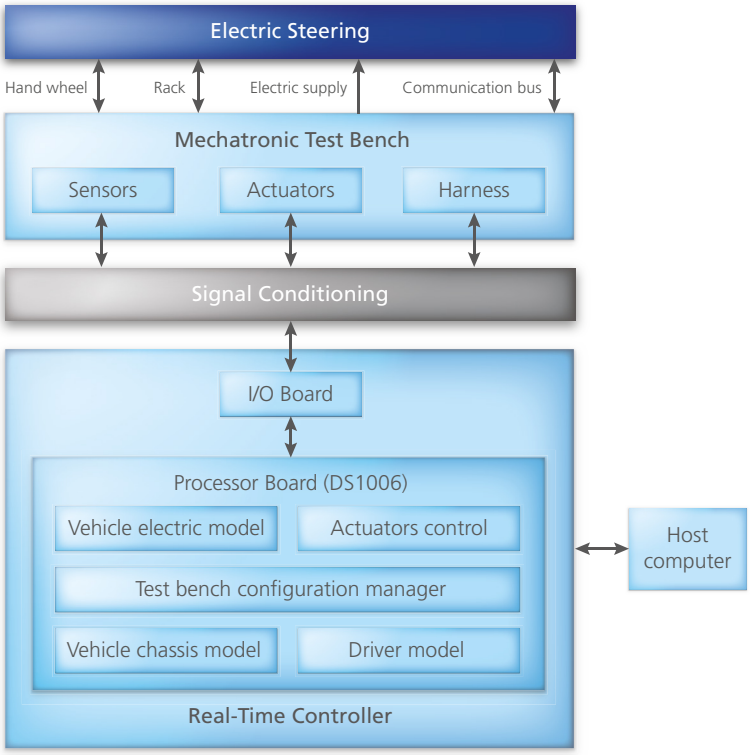
Automated fault injection tests for JTEKT steering systems

Inspect the unexpected

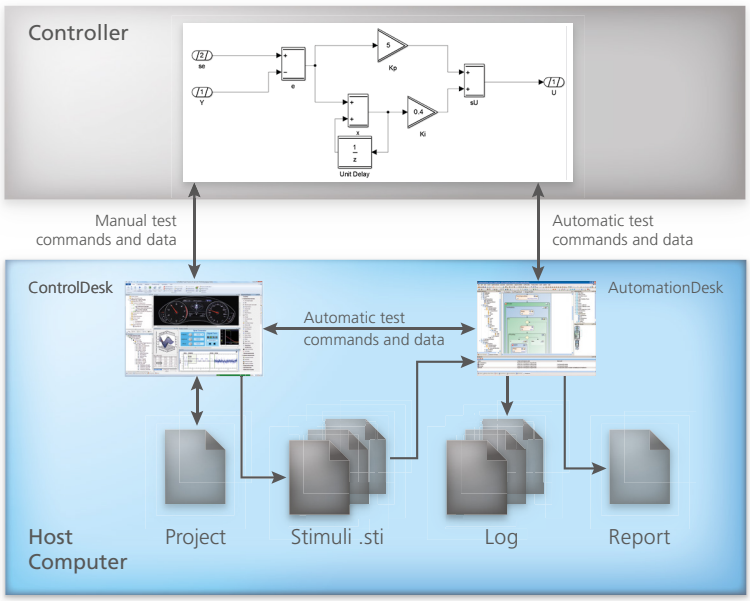
The steering control of a passenger car is a safety-critical component. Therefore, its fault tolerance has to be checked according to ISO 26262. Thanks to a dSPACE HIL simulator with automated fault injection, JTEKT can eliminate a large portion of potential inconsistencies long before a vehicle under test enters the proving ground.

Expect the unexpected? Complex controls in electric power steering systems often assist the driver noticeably in steering the vehicle. However, if these controls suddenly show unexpected behavior, the vehicle may quickly run off track. To avoid this and to demonstrate the required robustness, steering systems and their controls must be subjected to numerous fault injection tests before their market introduction. Generally, this means test drives on a proving ground. At the same time, the sharp increase in vehicle and function variants translates into a high number of test cases and rising expenses for real test drives. Due to the necessary safety precautions and the natural inhibitions of human test drivers, real road tests cannot cover the entire vehicle dynamics range. >>



Intelligent work division: The quad-core architecture of the DS1006 Processor Board enables JTEKT to distribute different calculation models of the test bench simulation to the individual processor cores and thus optimize real-time execution.

Perfect addition: The experiment and visualization software ControlDesk® not only enables JTEKT to manually control the steering test bench. With AutomationDesk in the background, ControlDesk also lets engineers configure and control all automation processes, such as fault injection.



ISO 26262 on the Rise

Another driving force for JTEKT is compliance with ISO 26262, the international standard for the functional safety of road vehicles. The standard includes several regulations for fault injection tests at system level. Among other regulations, it calls for a regression strategy of repeating test cases to ensure that modifications of previously tested software parts do not cause new failures. Tests that are not or only partially regressive are allowed only in exceptional cases and detailed reasons must be given as part of the certification process. For Automotive Safety Integrity Level D (ASIL D), ISO 26262 requires back-to-back testing during which the results of the tests at software level are compared to the test results at model level. These and other requirements of the safety standard, for example, for requirements management, software design, and the documentation of different work products throughout the development and verification process, lead to significant formal efforts in the development project.

Test Bench Testing for More Safety and Efficiency

To meet all these current requirements, manage the increased effort, and conduct the fault injection tests in compliance with ISO 26262, JTEKT Europe in Irigny, France decided to use a real-time-capable hardware-in-the-loop (HIL) test bench with integrated automated fault injection from dSPACE. This means that developers can frontload a large portion of their real road test program to a high-precision, reproducible simulation that also uses real components. As a result, the system is already very mature before the steering control is approved for further tests in a real vehicle under test. On the one hand, this reduces the risks for the test drivers. On the other hand, the HIL test bench also

> "The HIL simulator from dSPACE gives us a powerful system that can be continuously enhanced thanks to its open architecture."
>
> *Loic Bastien, JTEKT*

allows for the simulation of test drives in extreme situations, called boundary conditions in ISO 26262, that a human driver could never reproduce because of natural inhibitions. Therefore, the test bench provides a significantly higher test coverage. Another benefit is the ability to efficiently test different variants of the steering system without having to make time-consuming and expensive modifications to the vehicle under test.

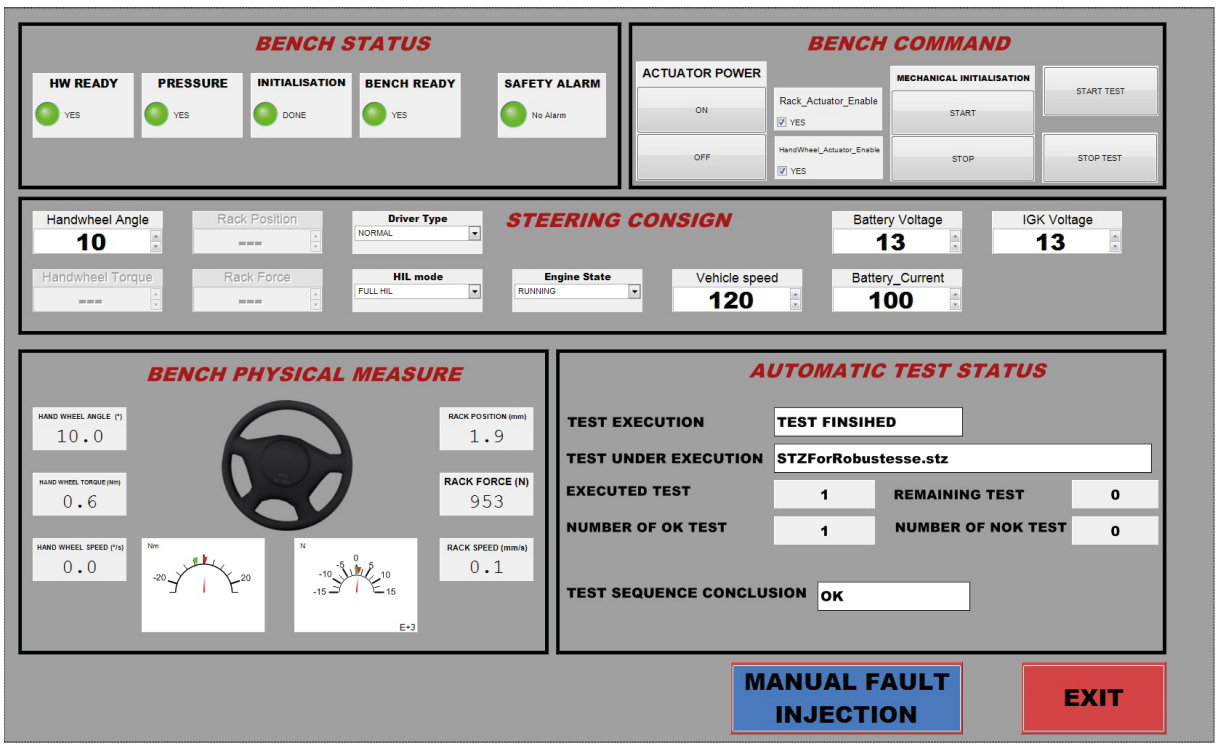
Components of the Test Bench

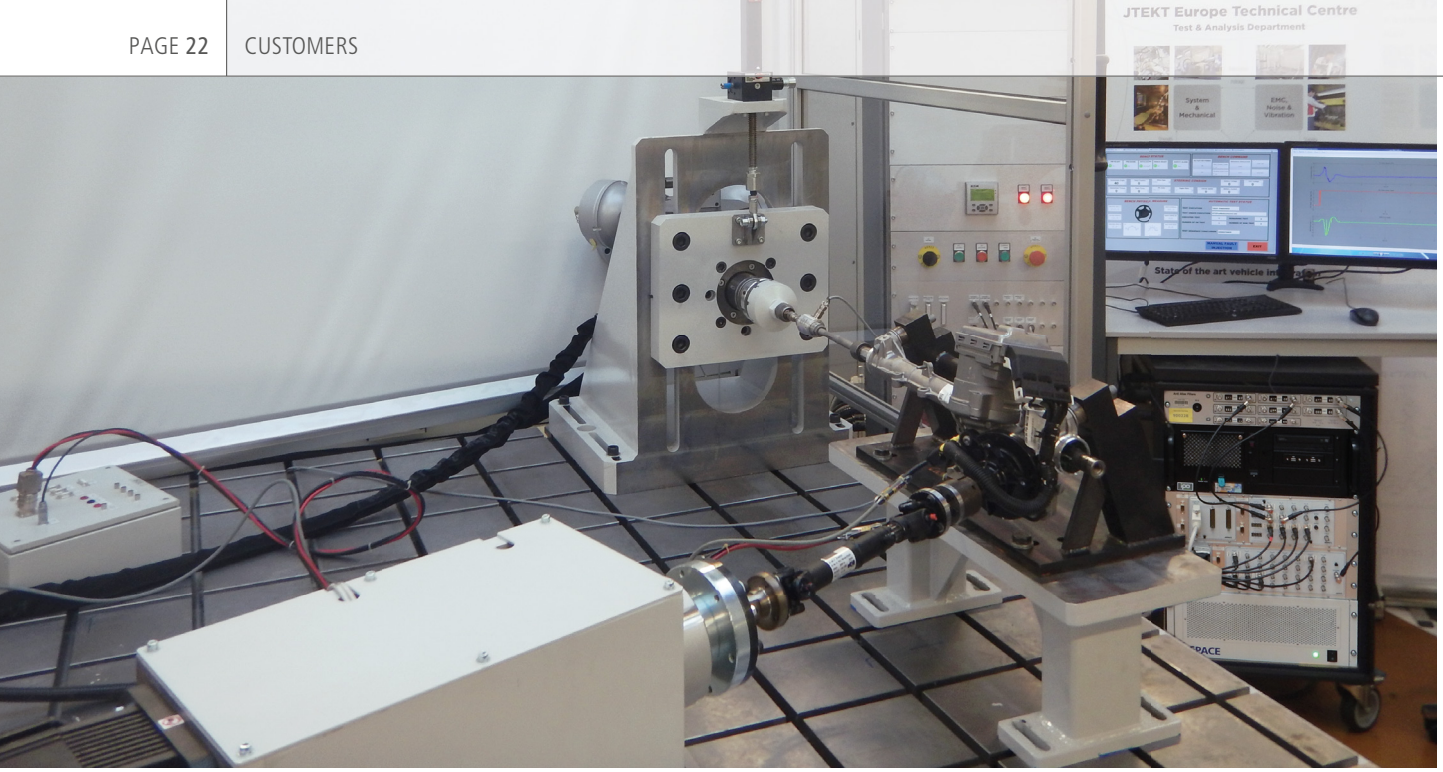
The test bench for JTEKT Europe consists of a mechanical setup, a HIL simulator, actuators for the steering wheel and the rack, sensors for angles, forces and displacement of the rack as well as a signal conditioning interface and a host computer for the user interface. The HIL simulator uses a DS1006 Processor Board that executes a vehicle model to calculate how the force is applied to the rack and a driver model to simulate human behavior in certain situations. Aside from pure HIL operation, the handwheel and the rack actuators can be controlled independently. The respective changes in angle or torque and in force or displacement allow for the execution of very specific system testing.

Fault injection and Debugging

Because of its real-time capability and its powerful multiprocessor architecture, the dSPACE HIL simulator offers JTEKT a perfect tool for time-synchronous fault injection via the XCP protocol. The dSPACE tools can be included in a test automation, which means that the tests can be repeated at any given time. This minimizes the effort for repeated full tests, hence the regression strategy required by ISO 26262 can be comfortably put into practice at all times. As a result, JTEKT no longer has to invest time and effort into justifying excluded or incomplete regression tests. >>

Virtual control center that is easy to configure: ControlDesk allows developers and test engineers to always fully focus on their current task.





Hardware-in-the-loop steering test bench from JTEKT: A large portion of their test program for fault tolerance can be frontloaded to a high-precision simulation with real components even before conducting real road tests.

Moreover, the fault injection tests are now simulation-based and carried out directly during the system test. Back-to-back testing as required by ISO 26262 can now be conducted in a simple manner: The same stimuli that were used for the model-based development of the functions can now be reused on the HIL test bench. The test bench uses the XCP protocol to also read internal data of the electronic control unit. This data can be used for debugging, for example. For a correct evaluation, it is very important that in both cases the data that is added on the basis of the XCP protocol is absolutely synchronous with the analog measurement data from the test bench sensors. For this, JTEKT uses the dSPACE RTI Bypass Blockset to easily carry out the complex data synchronization.

Automation Helps Control Variant Diversity

The test plan JTEKT uses to qualify a newly developed steering system for test drives in the real world consists of a variety of tests, all of which must be conducted for all planned variants of a platform. To meet the tight deadlines for delivering new software versions despite the high number of variants, JTEKT uses dSPACE AutomationDesk. This test automation software processes the test program in a reproducible manner and records the resulting measurement data.

Afterwards, AutomationDesk uses the recorded data and the evaluation blocks that contain the predefined test criteria and the respective fulfillment criteria to calculate the results of the fault injection tests and summarizes them in a detailed report for test engineers. Aside from the information on the passing or failing of a test required by ISO 26262, the report also provides details to specifically compare individual measurement data with the applied test criteria and to analyze potential deviations. AutomationDesk's ISO 26262 certification thereby drastically reduces the effort for classifying and qualifying the tools that are used in the context of functional safety for road vehicles.

Easily Configuring the User Interface

Test bench engineers can control all their tasks in one user interface created with dSPACE ControlDesk. This experimentation and visualization software lets engineers send individual actuator commands to the test bench, monitor their effects, and record them. It also lets them configure and control automation functions up to the final evaluation of the test results. In these cases, AutomationDesk always works in the background while ControlDesk permanently provides full transparency and control over the related operations in progress. ControlDesk is easy to con-

> "The efficient test automation with AutomationDesk has considerably increased the productivity of test operations that comply with ISO 26262."
>
> *Jean Michel Trebuchon, JTEKT*

Test Center of JTEKT Europe in Irigny: The HIL test bench is the perfect addition to the test drives with new steering systems that are conducted here. The safety of the test drivers is increased because many inconsistencies of the steering control can already be eliminated during the simulation.

figure and provides intuitive visualization options. This allows developers and test engineers to always fully focus on their respective task.

Summary and Next Steps

The HIL test bench and the tool chain from dSPACE helped JTEKT reach their primary goal, which was the automation of fault injection tests in the laboratory and compliance with ISO 26262.

As a result, the number of road tests with real vehicles was considerably reduced, which in turn saved significant amounts of time and resources. Moreover, test drivers are now using a system that has already been thoroughly tested, making their job much easier. In the future, the simulator might be used for even more tests, such as additional requirements-based HIL tests at system level. JTEKT is also planning to use recorded measurement data from real test drives on the HIL test bench instead of synthetic stimuli. This is easily possible because of the existing infrastructure and the seamless dSPACE tool chain. Developers can even use the 3-D visualization software MotionDesk early on to visualize how much a failure in the steering control lets the vehicle deviate from its planned track. This results in even higher test efficiency. Thanks to the dSPACE tool chain, JTEKT no longer has to worry about "expecting the unexpected". They can now thoroughly "inspect the unexpected". ■

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