Smooth
Success

Developing an infinitely variable transmission for tractors

Source: © CLAAS

Before they developed their new tractor transmission, CLAAS Industrietechnik (CIT) did not have any experience in model-based software development. In the end, the product surpassed even their highest expectations. Part of this success story: the powerful tools from dSPACE.

Frontloading

Mowing

Tilling

Municipal work

The heavy tractor starts on a hill without a single jolt, accelerates evenly and reaches its maximum speed without any noticeable loss in tractive force. The only thing the driver does is use the accelerator. The clutch and gearshift are obsolete. A new tractor transmission from CLAAS Industrietechnik GmbH (CIT) makes this possible. The infinitely variable transmission EQ 200 reliably keeps the tractor in an active idle state, even on a slope, and promptly reacts to accelerator commands. It is designed so that the tractor drives with a very low engine torque of 1,500 revolutions per minute even at the maximum speed of 50 km/h. This saves valuable fuel on the road. CIT developed their own transmission to increase efficiency and comfort. "The transmissions on the market did not satisfy our demands," states Jan-Willem Verhorst, head of the CIT product division.

Tractors as Mobile Energy Sources
One main feature of tractors is that they drive working tools, such as hay tedders, via a power take-off (PTO). "That's why we should think of tractors not only as vehicles, but also as mobile power sources," explains Helmut Konrad, head of electronics development at CIT. "Of course, this entails new challenges." He particularly focuses on the process speed of the attached farm implements, which have to be controlled independently of the tractor's propulsion. The decisive challenges for the CIT team are efficient processes and a consistently optimum efficiency over the entire speed range.

Technical Requirements
To ensure ideal operation for the diverse use cases of tractors, CIT uses drive controls that automatically identify the best strategies for driving and operating the implements. Furthermore, the controller realizes the manufacturer-specific drive philosophy, which Verhorst explains as follows: "In general, we try to achieve a low torque and thus low fuel consumption. At the same time, we want to make the tractor highly dynamic." What is more, there are strict requirements in agricultural engineering concerning fail-safe functioning, because a vehicle that cannot be used due to a technical defect can significantly reduce production or even cause the loss of the entire harvest.

Development Task: Infinitely Variable Transmission
The overall goal of harmonizing all of these requirements was the decisive factor for CIT to develop the infinitely variable transmission (IVT) EQ 200 themselves, including the transmission ECU and drive controller. "Because we did not have a predecessor project in this performance class at CIT that we could have built on, our developers started out with a blank sheet of paper," recalls Thomas Gohde, system engineer for R&D Tractor Powertrain. "That's why our visions were unlimited at first." The initial drafts resulted in a specification whose requirements were so high that it went down in company history as "A Driver's Dreamland". At the same time, the developers also had to consistently adhere to common requirements,

TargetLink generates efficient production code from the controller model and implements it on the ECU.

Controller model

.C
Production code

.A2L
Description files for internal ECU parameters

ECU
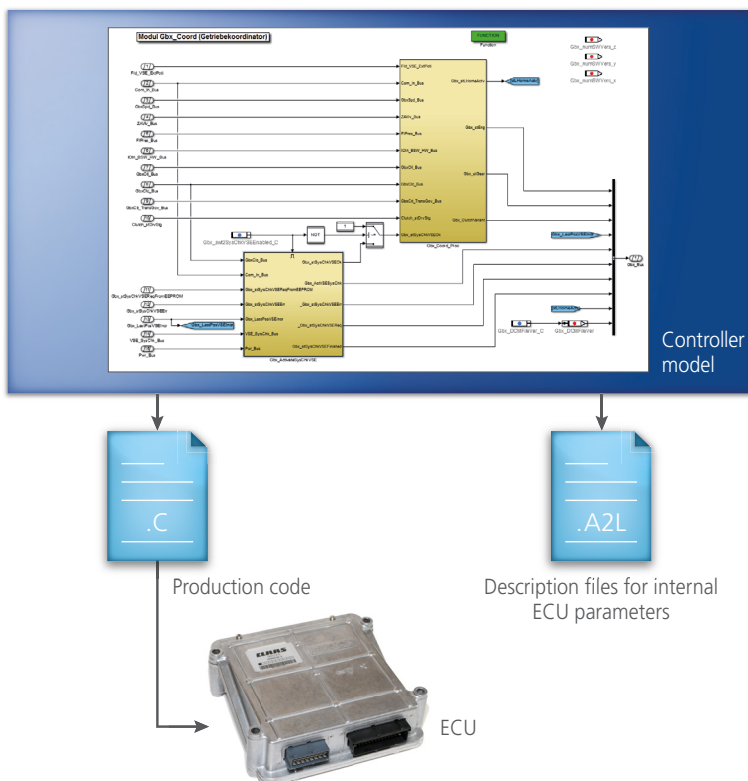
Winter maintenance

Operating at night   Source: © CLAAS

> "MicroAutoBox enabled us to test and assess our control strategies easily and quickly in the vehicle."
>
> *Jan-Willem Verhorst, head of R&D Drivetrain, CLAAS Industrietechnik GmbH*

such as automotive standards and the ISO 25119 standard, which defines the functional safety of electronic control units (ECUs) for agricultural vehicles.

Choosing a Tool Chain

For the drive control and the EQ 200's ECU, for the very first time CIT opted for a model-based software development process (MBD). But because they were very new to this field, they wanted to use only standard, industry-proven tools. That's why Simulink® was quickly chosen as the development environment. But how was CIT to generate the target code for the two ECUs? After consulting previous research from other departments at CLAAS, they chose dSPACE's production code generator, TargetLink®. Another well-established dSPACE tool for vehicle development – MicroAuto-Box® – was selected to test the algorithms in the tractor prototype. In a later development phase, two dSPACE hardware-in-the-loop (HIL) simulators were added for ECU testing.

Developing the Functions

At the outset of the project, CIT had a team of four, but the team soon grew to work on additional tasks. However, the truth was that the specifications were just too high – even for the

rapidly growing team. A revised specification document, called "Down to Earth", set a new, more realistic course. Despite the initial lack of experience in model-based development, the first successes were soon apparent, not least because of the dSPACE products. "The tool chain we used improved the communication with the mechanics in the transmission development, because we were able to focus on function development without having to tackle too many coding tasks," says Gohde. CIT was even able to take the project for the transmission ECU, which was carried out by a development partner at first, and continue it themselves.

Implementing the Functions

CIT uses the TargetLink Blockset to develop the function models. "In addition to the native TargetLink blocks, we created our own library for often-used functionalities, such as filters," Gohde explains. The development team also benefitted from the distributed development via model referencing. In model referencing, partial functions are created, generated, and tested individually. Then they are included in a superordinate integration model, from which TargetLink generates the glue code for software integration. Furthermore, the team used

Infinitely Variable Transmission EQ 200

The components of the EQ 200 include a multiple-ratio planetary transmission, a hydrostatic transmission unit, and two multi-plate clutches. The transmission parts were combined in such a way that the transmission has a particularly high and nearly constant efficiency at all speeds. When gears are shifted automatically, not only the gear ratio but also the overall power flow through the transmission changes. The torques of the two clutch shafts approach each other as speed increases until they both have the same torque. When the two torques are exactly synchronous, the multi-plate clutches change gears. The gears therefore switch without a jump in rotational speed or torque, even under load, which enables a smooth acceleration behavior.

Learn more about how the EQ 200 transmission works in this video.
www.dspace.com/go/ dMag_20161_CLAAS_E
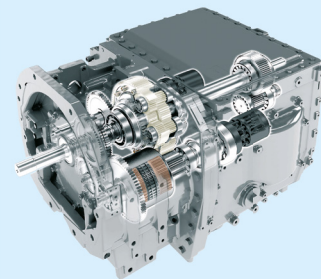
The EQ 200 transmission convinces with its jolt-free gear changes and smooth performance.

>>

Turning

Plowing

Cultivating

Transporting

> "By using TargetLink, we saved an entire development step and always generated reliable production code."
>
> *Thomas Gohde, system engineer for R&D Tractor Powertrain, CLAAS Industrietechnik GmbH*

the page-switching technique to reserve storage areas for easy switching between parameterization variables, and for the A2L files generated by Target-Link for calibration and measurement tools. CIT was able to thoroughly test the code with TargetLink's own features and BTC EmbeddedTester, enabling them to detect and eliminate errors early on. The efficient production code generated with TargetLink was then implemented on the control units.

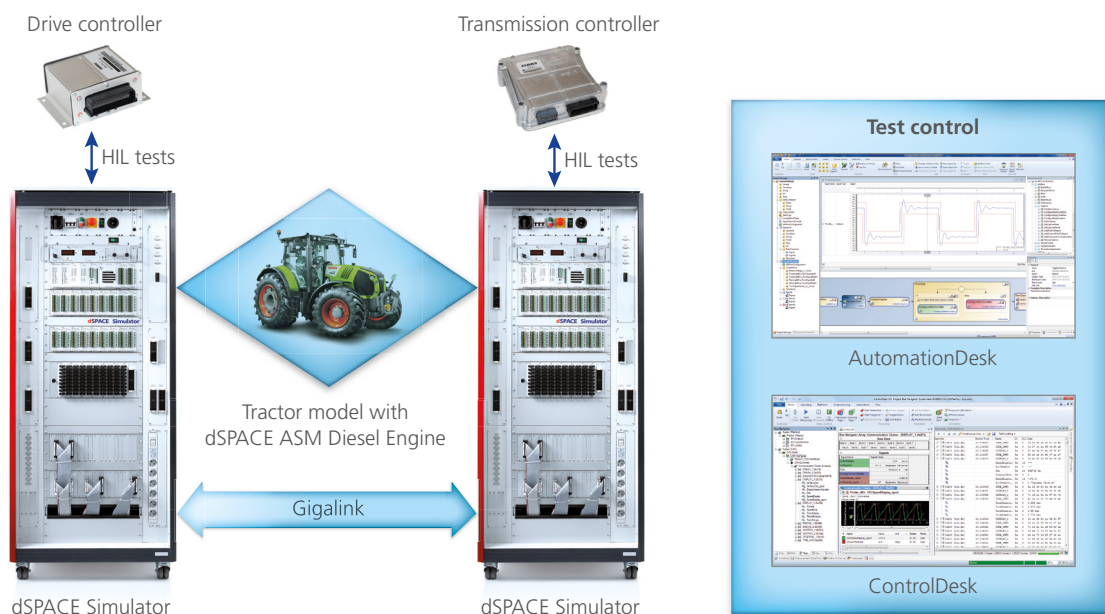**Validating the ECU Software**
"Even at the very beginning of the

project, we knew that testing the ECUs would entail just as much effort as developing the ECU software," Konrad recalls. "This is why we built two equally strong teams for development and testing, and separated them so each team maintained its own vantage point." The HIL tests started with the drive control ECU. CIT developed most of the simulation models needed for this task themselves, while they used the ASM Diesel Engine model from dSPACE for engine simulation. Throughout the development process, the developers

built a test library in AutomationDesk to execute the many tests automatically. This enabled them to test new software versions overnight and evaluate the results on the very next day.

Verifying and Validating via System Tests
Once the component tests are complete, i.e., the ECUs for drive and transmission control were tested on their own, integration tests of the two networked ECUs were performed. CIT extended the developed test libraries to be able to test the interaction of

Setup of the HIL test bench, which can run overnight thanks to test automation.

Drive controller

Transmission controller

↕ HIL tests

↕ HIL tests

dSPACE Simulator

Tractor model with dSPACE ASM Diesel Engine

Gigalink

dSPACE Simulator

Test control

AutomationDesk

ControlDesk

Clearing

Spreading   Source: © CLAAS

the two ECUs in the restbus-simulated vehicle. The two dSPACE Simulators and AutomationDesk made it possible to perform a complete system test, with two test engineers, in just three weeks. The depth of the tests helped certify the ECUs according to ISO 25119. The subsequent field tests demonstrated the high software maturity achieved in the lab: While similar projects required approximately 11,500 hours for testing the electronics system, the new, model-based method required only 3,500 test hours.

Successful Start of Production
In 2014, the infinitely variable transmission EQ 200 and the drive control were successfully brought to market. They are used in tractors of the ARION 500/600 series, whose efficiency and convenience immediately convinced many customers. In the meantime, CIT has sold more units of this series than forecast in the business plan, so customers have to be patient and wait approximately one year for their tractor to be delivered. But the commercial success is not all. The development team around Verhorst, Konrad, and Gohde is even more thrilled about the positive customer feedback concerning the tractors' driving behavior and fuel consumption: "What made this project the largest and most successful project at CIT is not just our determined effort, but also our efficient and easy-to-operate tool chain. Even though our developers started

out without any special MBD knowledge, we were able to deliver the right product at the right time, a product that has been in the fields for a whole year and has yet to produce a software error." ∎

With the kind permission of CLAAS Industrietechnik GmbH, Paderborn, Germany.

The Project

The Task
Developing a drive control and transmission ECU for tractors.

The Challenge
Introducing the model-based development method and an appropriate tool chain for function development and validation of ECU software according to ISO 25119.

The Solution
Setting up a model-based ECU development process. Efficiently using MicroAutoBox for rapid control prototyping, TargetLink for software implementation, and the dSPACE Simulator with AutomationDesk for validating the ECUs. For future projects, CIT plans to manage and evaluate the comprehensive test cases and test data with the data management software dSPACE SYNECT®.

"The dSPACE Simulators helped us considerably increase software and hardware quality."

Helmut Konrad, head of Electronics Development, CLAAS Industrietechnik GmbH