The Cutting Edge

The new TS500i cut-off machine with STIHL Injection is the first-ever battery-less, completely electronically controlled injection system for handheld power tools with a two-stroke engine on the market. STIHL used TargetLink and dSPACE real-time hardware to develop a flexible control unit that ensures easy startup and optimum engine control under rough conditions.

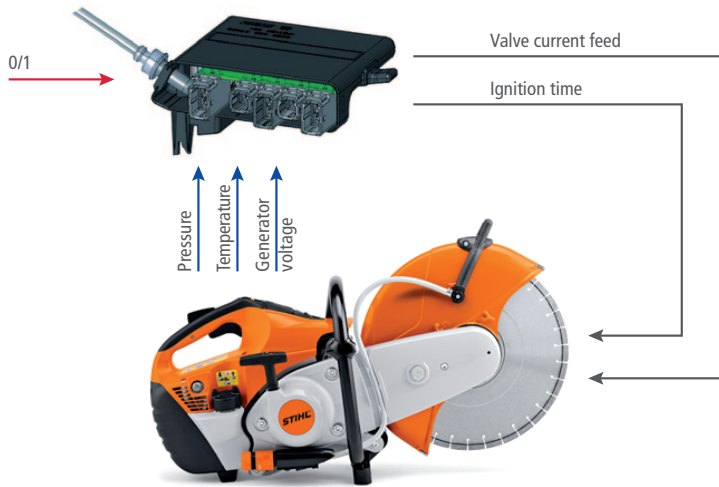Completely electronically controlled injection for two-stroke engines

Figure 1: With STIHL Injection, the ignition timing is determined not only by engine speed, but for the first time ever by the load as well.
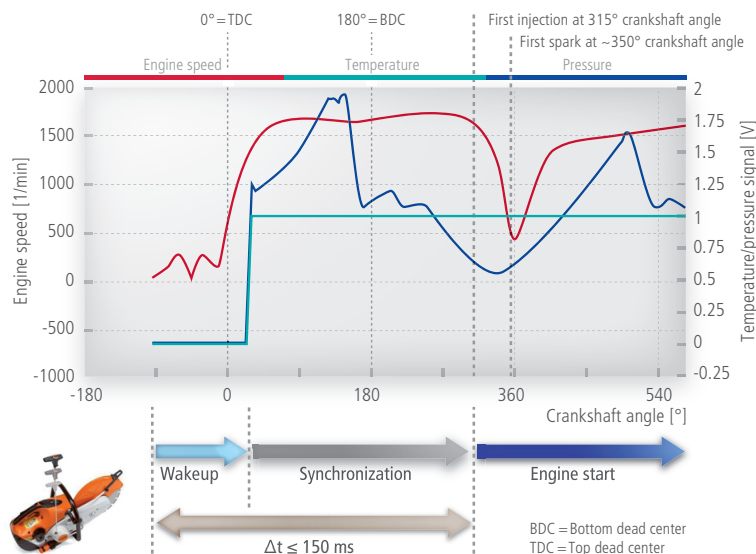
- The quality and constituents of the fuel used (e.g., biofuel/ethanol content) can vary enormously in practical use.
- The tool has only very limited space for system components – and where the ignition and the microcontroller are close together, interference is an additional concern.
- The performance and fuel consumption of the two-stroke engine must be optimal in all operating modes without manual intervention by the user.
- Compliance with the applicable emission standards is essential.
- The system has to be batteryless – which is ideal for startup when the tool has not been used for some time – and must also have automatic diagnostics.
- Maintenance effort has to be as low as possible.
- In addition, the tool frequently changes position during operation, and strong vibrations result. The engine must run smoothly despite this.

Coping with Extremes

Handheld engine-powered tools – like those used in construction, civil engineering and forestry – have to satisfy tough requirements. Robustness and safety are the top priorities, but comfort also plays a role in the endeavor to make working in rough conditions as convenient and efficient as possible. There are special requirements for integrating a completely electronic engine control, which makes things like a choke and manual settings unnecessary:

To meet all these requirements, STIHL used dSPACE tools to develop a completely electronically controlled injection system especially for handheld power tools with two-stroke engines. The new system first went into operation in the new TS500i cut-off machine. The ECU and software in STIHL Injection are generic in design so that they can be used in other STIHL products. The system was therefore designed for very high engine speeds of up to 16,000 rpm, which can occur in power saws.

System Design and Function

The components of the new STIHL Injection system are the power generator, the temperature and pressure sensors, the ECU, and the injection pump and injection valve. As soon as the crankshaft is started by the

Figure 2: Less than 150 ms are available for the batteryless startup.

> "With TargetLink, we were able to perform fast iterations and try out changes in the model directly on the target."

Heiko Däschner, ANDREAS STIHL AG & Co. KG

starter cord, the generator constantly supplies not only electricity but also the crankshaft position, and therefore the engine speed, to the ECU. The ECU is based on a 16-bit microcontroller with 64 KB flash ROM, 8 KB RAM and a 32 MHz clock rate, and uses the machine's load state to compute the required quantity of fuel, the injection duration and the ignition time. It also electronically controls the water supply for dust suppression. While the injection pump holds fuel pressure at a constant 100 mbar, the injection valve injects the optimum fuel amount directly into the crankcase synchronously to the cycle. The ECU has to perform complete engine manage-
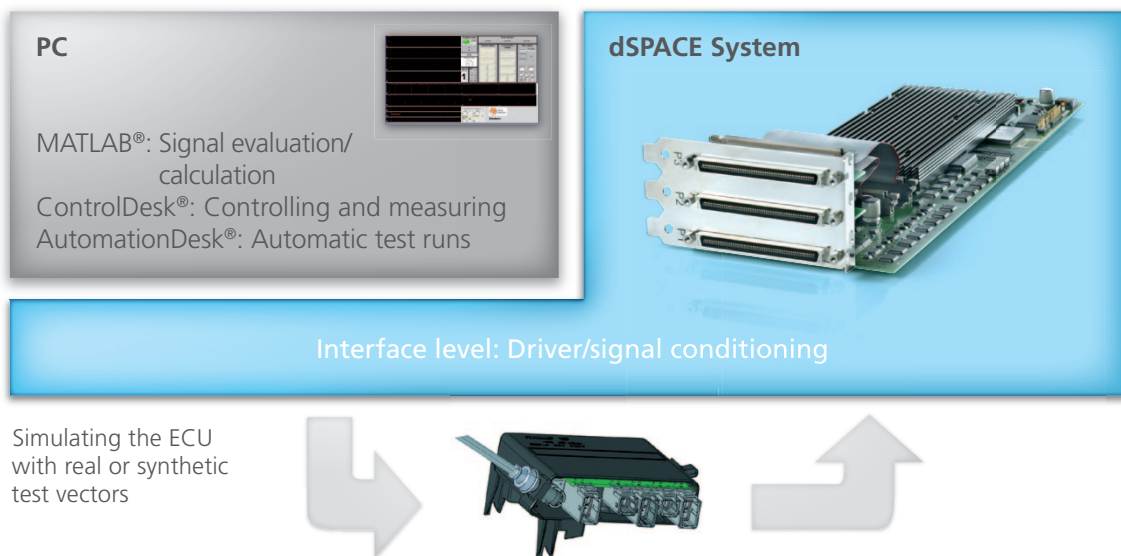
ment computation with each crankshaft rotation. The objective is to achieve a permanently high torque with minimum emissions. One particular challenge is the batteryless start-up process initiated when the starter cord is pulled. The startup process must be completed within less than 150 ms, including powering up the ECU, synchronizing the system components, and performing injection.

Model-Based Development
For flexibility and fast iterations in the development of the software for STIHL Injection, STIHL used the model-based development approach throughout the entire project, combined with automatic production

code generation. The mechatronic components were developed in parallel to the algorithms and the ECU. While the ECU and its operating system come from a supplier, STIHL itself developed the entire function model with the real-time concept for engine control, converted it to ECU code, performed system tests on the hardware and software, and calibrated and validated the control on the final device in parallel to development. The software was integrated on the ECU in close consultation with the ECU supplier. TargetLink was used to generate the ECU code from the function model and perform the associated SIL, MIL and PIL tests, supported by dSPACE Model

Figure 3: Error simulation for targeted debugging.

PC
MATLAB®: Signal evaluation/ calculation
ControlDesk®: Controlling and measuring
AutomationDesk®: Automatic test runs

dSPACE System

Interface level: Driver/signal conditioning

Simulating the ECU with real or synthetic test vectors

Compare for comparing different model variants. This let developers try out new ideas and changes quickly on the target processor. The final model of STIHL Injection comprises about 1500 TargetLink blocks. During development, STIHL reproduced the control deficiencies that were found, and performed targeted debugging by reproducing the error cases on a dSPACE real-time system (DS1103 plus ControlDesk) combined with extensive test automation via AutomationDesk. The system automatically compared the relevant parameters and checked the diagnostic functions. Static test vectors that had been recorded previously with the real machine were used for stimulation in the tests. Because the system has no battery, a special focus of the test runs was on close synchronization between the hardware and the software.

Objective Achieved
With this combination of model-based development, automatic ECU code generation and error simulation for

targeted debugging, STIHL ensured both high software quality and a fast rate of development for the STIHL Injection innovation project, with fast iterations and immediate feedback on the target. Further development of the control will be based on the same development process and dSPACE tools to ensure that new functions can be implemented quickly while preserving maturity. Another STIHL control that will be further developed with the aid of the new development process is M-Tronic, which has been available since 2006. With the successful launch of the TS500i in early 2012, STIHL succeeded in implementing the world's first two-stroke injection engine for handheld power tools in large-scale production. The technology facilitates handling while at the same time boosting performance, and setting new technological standards. ∎

Dipl.-Ing. (FH) Heiko Däschner
Dr.-Ing. Georg Maier
Dipl.-Ing. Robert Böker
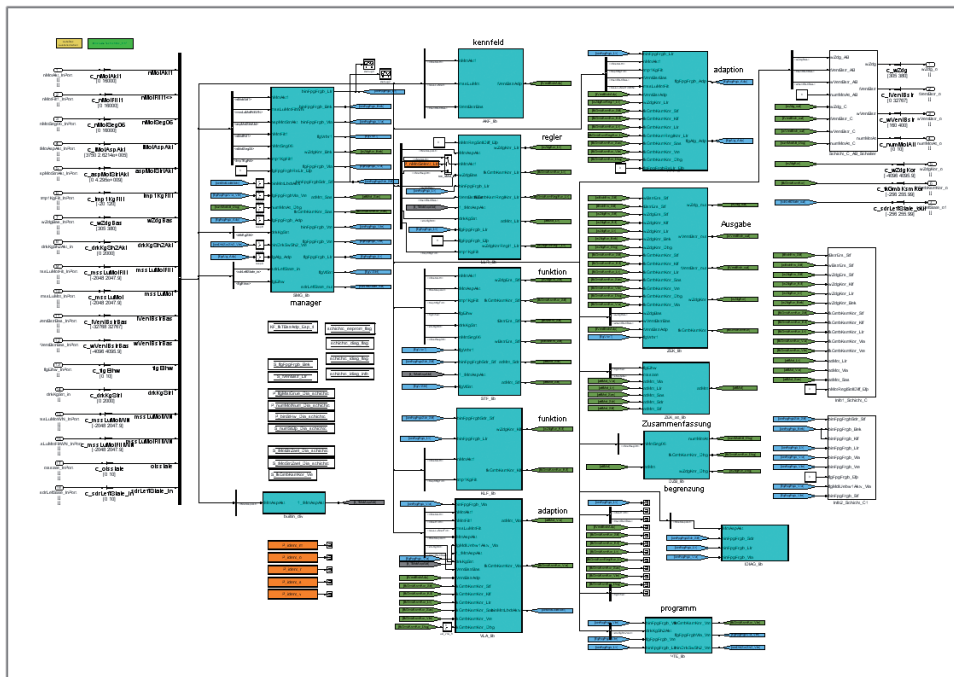*ANDREAS STIHL AG & Co. KG*

Figure 4: The ECU code from the function model was generated with TargetLink.

Dipl.-Ing. (FH) Heiko Däschner
Dipl.-Ing. (FH) Heiko Däschner heads up the group developing integrated electronic systems at STIHL in Waiblingen, Germany.

Dr.-Ing. Georg Maier
Dr.-Ing. Georg Maier is head of the Engine Management and Mechatronics department at STIHL in Waiblingen, Germany.

Dipl.-Ing. Robert Böker
Dipl.-Ing. Robert Böker is responsible for service and diagnostic tools at STIHL in Waiblingen, Germany.