New Concepts for Individual Cylinder Control

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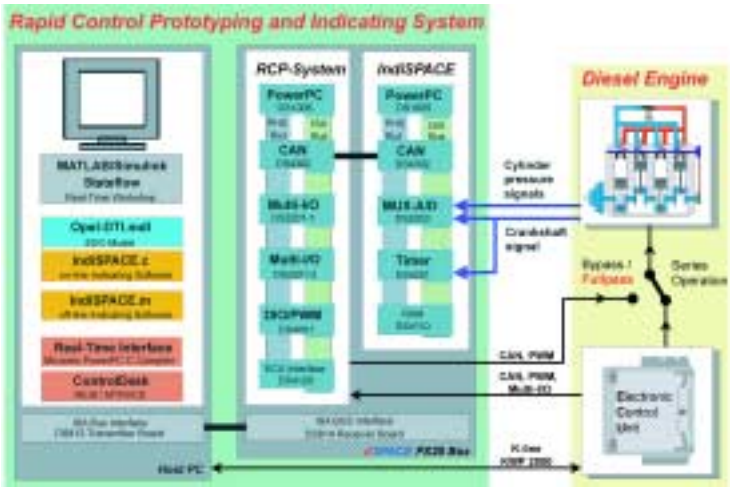
- **Direct download of Simulink models to dSPACE Protoyper**
- **ControlDesk for on-line adjustment of experiment parameters**
- **Development system for broad use, e.g., at Bosch/Germany**

When it comes to diesels, engine developers are looking for new approaches to fulfill increasing requirements on fuel consumption or emission levels. One example is the application of cylinder pressure based diesel engine management. With the advent of new piezoresistive and optical sensors, closed-loop engine control can be achieved. A dedicated development system was set up at the Institute of Automatic Control at the Darmstadt University of Technology . This system comprised dSPACE Prototyper, dSPACE modular hardware, the indicating software and Simulink models.



System configuration.

Our diesel engine management is based on the pressure of the combustion chamber measured against the crankshaft angle. This gives us vital information on the combustion process. The subsequent design and optimization of diesel engines along with the development of the electronic control unit (ECU) is based on this data. Thanks to new miniaturized sensors, the pressure measurements do not require additional drillings in the cylinder, as they can be mounted as add-on devices to the glow plugs or the injection valves. This enables cylinder pressure based engine management featuring a torque based engine control. Within the scope of a special research program of the German research society, "Deutsche Forschungsgemeinschaft, SFB 241: Innovative Mechatronic Systems", we developed such a management system and tested it using a 2.0 liter, 75 kW Opel-DTI diesel engine. To do so, we set up a test stand with dSPACE Prototyper. From this arrangement we derived an online indicating system which already reached product level and is commercially available. Bosch has acquired this indicating system for use with dSPACE AutoBox, to name just one example. The featured test stand consists partly of dSPACE Prototyper and partly of modular dSPACE hardware, which we customized.

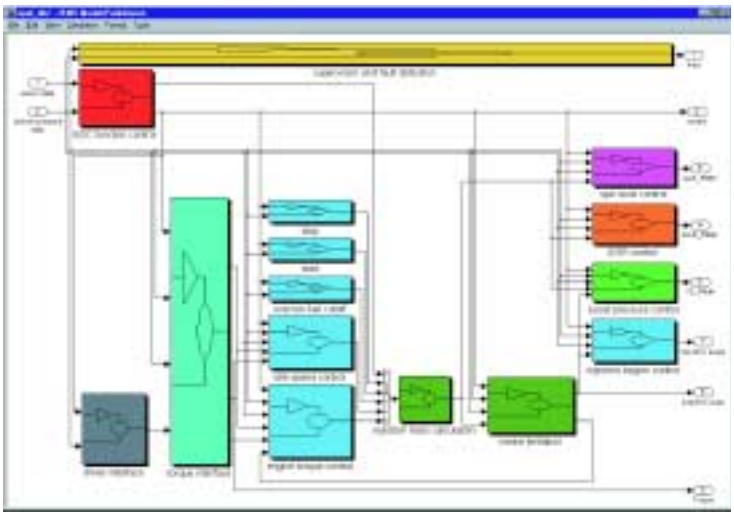
Engine test stand: Opel-DTI diesel engine and asynchronous machine.

Multiple Components of the Development System

The indicating system used to measure cylinder pressure and trace additional dynamic engine signals enables real-time data capturing and processing with a resolution of 0.75°, 1°, 3° and 6° crank angle. This data is evaluated and transferred via CAN to dSPACE Prototyper, where the engine control is performed. The control functions on dSPACE Prototyper are implemented graphically via Simulink blocks. To connect the dSPACE hardware with the Simulink environment, we use Real-Time Interface (RTI). For experiment control and visualization, we have the latest version of ControlDesk. We also make use of the test automation feature integrated within ControlDesk. The information obtained can then be processed offline with MATLAB and dSPACE's MLIB/MTRACE.

Engine Management

By evaluating the series CAN messages, PWM signals and actuator control, the diesel engine can be operated with dSPACE Prototyper in three different modes:



ECU function level of Simulink model.

- Series Operation: The series parameters are applied.
- Bypass: Extracted ECU functionalities are performed on dSPACE Prototyper.
- Fullpass: All engine control functions are performed on dSPACE Prototyper.

As a result, a suitable engine management system can be developed step-by-step. We examined the series production ECU's functionality and mapped the relevant data on dSPACE Prototyper accordingly. The function design for the cylinder pressure based diesel engine management is performed completely in fullpass mode. The substantial new functions implemented so far:

- Cylinder-selective calculation: the indicated torque and the friction torque are calculated in real time with a resolution of 1° crankshaft angle
- Engine torque interface: enables the driver's torque demand in relation to engine speed and accelerator pedal position with reference to external torque demands
- Global feedback control: the engine's output torque is fully controlled in compliance with the exhaust behavior of the series production engine
- Adaptive cylinder torque balancing feedback control: enables the compensation of cylinder torque differences to the mean indicated cylinder torque, in compliance with the exhaust behavior of the series production engine
- Providing characteristic cylinder pressure values: real-time calculation of the thermodynamic and signal-based cylinder pressure values with a resolution of 1° crankshaft angle for future functions
- Diagnosis interface: the integrated diagnosis interface features supervision and fault detection functions

The functions based on Simulink models are calculated with a sample time of 1 ms. In addition to the new cylinder-pressure based functions, we also implemented the standard ECU control functions on dSPACE Prototyper. This includes the control of the injection mass and the injection timing for all cylinders, boost pressure and spin level control. The similarity to the series production ECUs can be validated by switching the test stand from fullpass to series mode.

Conclusion

For diesel engines, both a torque control system and a torque balancing system running on dSPACE Prototyper, in conjunction with our implemented online indicating system, were evaluated. The compensation of mean torque inequalities of 10-15 Nm is possible, reducing mean torque differences to values around 0.1 Nm. The implemented algorithms proved the considerable potential of cylinder pressure based diesel engine management systems for meeting and maintaining future engine specifications and requirements. Since the ECU is part of a fully structured vehicle model including vehicle dynamics and engine, it is ideally suited to perform hardware-in-the-loop simulation (HIL), which is also based on dSPACE technology.

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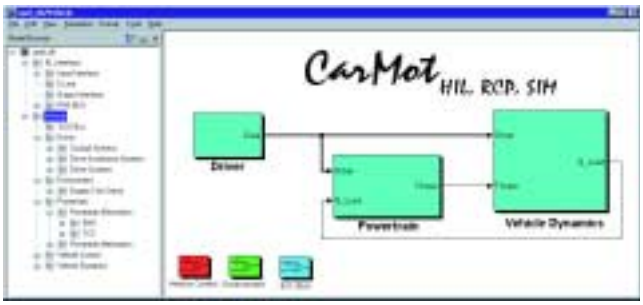
The unveiled online indicating system is a ready-to-go solution and available either as a single processor (IndiRCP for in-vehicle experiments) or multiprocessor version (IndiRCP-MP for lab-based experiments).
Please inquire at the Institute of Automatic Control/Darmstadt University of Technology/Germany, www.tu-darmstadt.de/iat



Structured overall model with all relevant vehicle components.