

## Abstract

### **Modelling and Hardware-in-the-Loop Simulation of Diesel Engines for Development and Test of Future Engine Management Systems**

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#### **Introduction**

To fulfil future emission limits the combination of exhaust gas aftertreatment and in-engine measures will become necessary. The latter includes cylinder pressure based control functions and variable valve trains. The increasing number of degrees of freedom involves a rise in complexity of electronic control units. To reduce development time and costs different simulation methods like model-in-the-loop (MIL) simulation, software-in-the-loop (SIL) simulation and rapid control prototyping (RCP) have been established for ECU function development and control design. The hardware-in-the-loop (HIL) simulation has become state-of-the-art for ECU testing.

At present, simple mean value models are used for these applications which are often based on look-up tables experimentally obtained. For the development and test of future control units for engines with integrated cylinder pressure sensors or with variable valve trains these cycle-averaged models don't suffice. Here the crank-angle synchronous calculation of the cylinder pressure and respectively the air-mass flow through the inlet and outlet valves is necessary. The design of cylinder individual control functions (e.g. cylinder-to-cylinder imbalance control) as well as diagnosis functions demands not only a crank-angle resolution but a cylinder-by-cylinder engine model.

#### **Process model and simulator test bench**

The contribution presents the development of a crank-angle synchronous, cylinder-by-cylinder engine model (CCEM) for real-time simulation. It focuses on future cylinder pressure based engine management systems and is intended to support all kinds of simulation methods (MIL, SIL, HIL) as well as rapid control prototyping. The modelling is carried out for a common rail diesel engine equipped with exhaust turbocharger and exhaust gas recirculation.

The physics based model is divided into submodels for the air and exhaust path, the exhaust turbocharger and the cylinders. As distributed models are computationally still too time-consuming for real-time applications a lumped parameter approach is used for modelling the air and exhaust path.

The turbocharger is described by basic thermodynamic and mechanical equations supplemented by characteristic maps measured at the engine test bed of the Institute of Automatic Control. Contrary to common approaches the heat exchange between the turbine and the compressor via the turbocharger housing is explicitly taken into account. With this extension the model quality for very low turbocharger speeds and mass flows can be significantly increased.

The state variables within the cylinders are calculated by a single-zone engine model. The heat release of the combustion process is approximated by an empirical model. Pilot and main injection are treated separately.

The overall engine model is implemented into a hardware-in-the-loop simulator consisting of a dSPACE real-time system, real actuator components and dummy loads. After introducing the

setup of the simulator the distribution of the model on two processors as well as further possibilities of reducing the calculation time are presented. A calculation step size of three degrees crank shaft can be achieved for a rotational speed of 3000 rpm. The successful closed loop interaction of the engine model with a production-type ECU (Bosch EDC16) is demonstrated.

For the parameterization of the model a methodic approach starting with the test planning and ending with the model validation is introduced. By means of a quasi-stationary measurement strategy the measurement effort and time can be considerably reduced.

### **Simulation results**

The engine model is validated using measurements of an Opel 1,9L common rail diesel engine. Emphasis is placed on the representation of cylinder pressure characteristics (e.g. peak pressure, location of mass fraction burned 50%). Furthermore simulation results of a standardized test cycle are opposed to measured data of the engine test bed.

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### **Conference topic**

Simulation & testing – New methodologies and tools

### **Previous papers published on this subject**

- Zahn, Sebastian; Isermann, Rolf: Development of a Crank Angle Based Engine Model for Realtime Simulation. 2nd Conference on Engine Process Simulation and Supercharging, Berlin, Germany, 2007