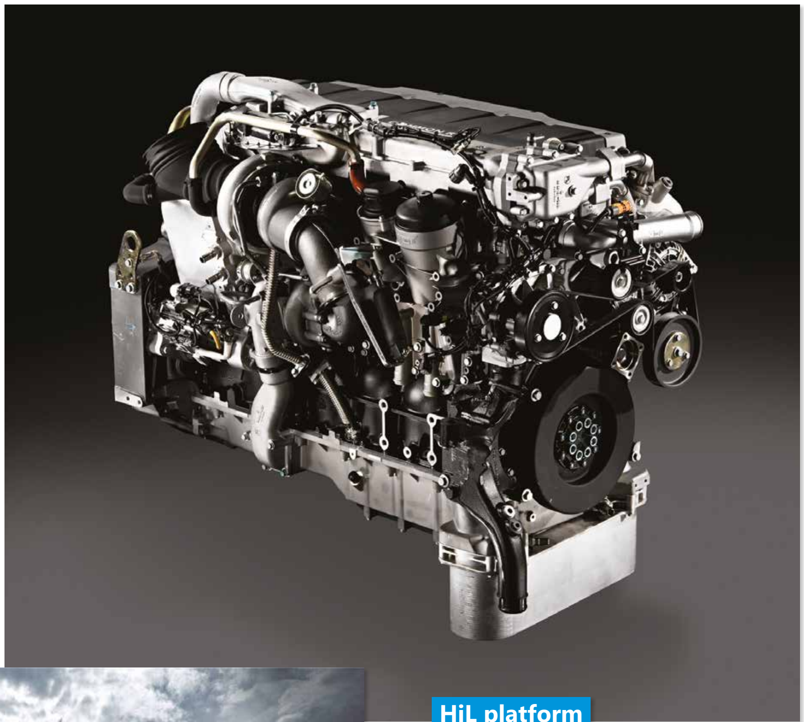
Processors for Trucks

Real-time thermodynamic simulation of combustion engines

TEXT: Editorial Staff PICTURES: © MAN Nutzfahrzeuge

Model accuracy and real-time capability play a crucial role in the simulation of combustion engines. Real-time simulation is subject to the tight time constraints of the cylinder cycle. To meet these requirements, MicroNova HiL systems distribute the simulation work over several processors.

The German commercial vehicle manufacturer MAN Truck and Bus decided to use MicroNova's HiL platform NovaCarts to simulate diesel engines with up to twelve cylinders. In this use case, a multiprocessor system with four processors was used in conjunction with a thermodynamic simulation model.

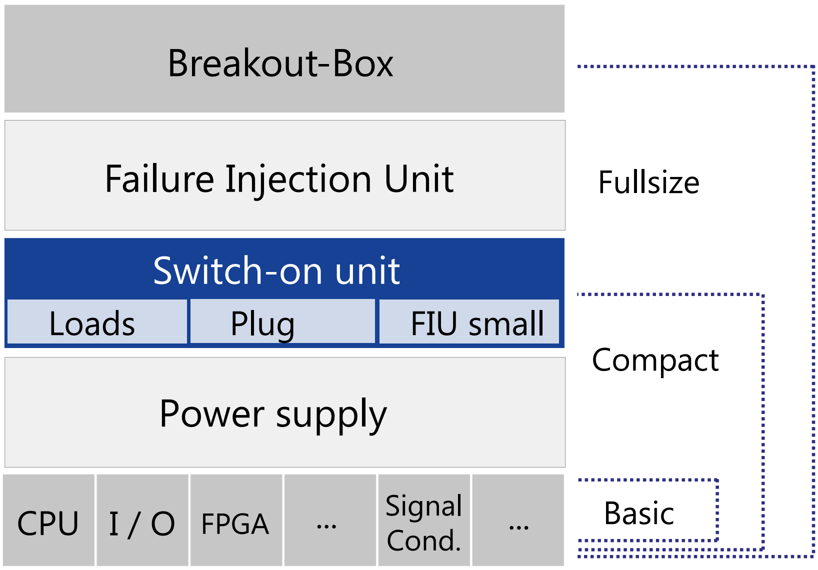


HiL platform

MicroNova's scalable real-time platform covers the range from simple simulation to distributed multiprocessor systems with distributed I/O, making the following possible:

- I/O pin count up to several thousand I/Os
- Computing power from power PC up to coupled, distributed real-time systems with up to 16 processors each
- Can be used from simulation to operation of distributed, high-performance Hi models
- Simulation without load as well as high-precision simulation of real loads such as high-pressure solenoid injectors

An overview of the scaling possibilities of the HiL platform is given in figure 1.



1 The HiL platform from MicroNova

MAN Nutzfahrzeuge AG

MAN Nutzfahrzeuge AG's products range from six-cylinder truck engines to twelve-cylinder marine engines. A realistic simulation of the engine behavior is essential to the development of the appropriate control units for these engines. Characteristic map-based mean value models reached their limits here, as they could not reproduce all the required effects without an excessively high parameterization outlay. Using a real-time thermodynamic engine model enabled the required high accuracies. The HiL multiprocessor platform provides a powerful runtime environment for these requirements. A typical engine to be simulated is shown on the left. For higher cylinder counts, two identical electronic control units (ECU) are used. The HiL system used is capable of handling the large number of I/Os (several hundred) in real time.

enDYNA Themos

TESIS DYNAware GmbH, with which MicroNova AG collaborates, is a provider of real-time simulation models that can run on the MicroNova HiL platform.

The enDYNA Themos is a software package for the simulation of combustion engines. The thermodynamic model approach allows for detailed mapping of physical dependencies in the engine. enDYNA Themos provides a high-quality basis for the development and testing of diesel and petrol engine ECUs. The performance of these models makes them ideally suited for real-time operation on the MicroNova platform. The engine model's high degree of accuracy allows ECU developers to make accurate and reliable statements about the behavior of engines and the associated ECUs. It is even possible to perform extensive pre-calibration of the ECUs on the HiL system. Applications for the simulation models include:

- Hardware-in-the-loop tests of ECUs with monitoring of the cylinder pressure curve
- Concept and control design for, among other things, two-stage turbocharging, fully variable valve timing and exhaust gas recirculation
- Testing and development of functions for exhaust gas aftertreatment and onboard diagnostics.

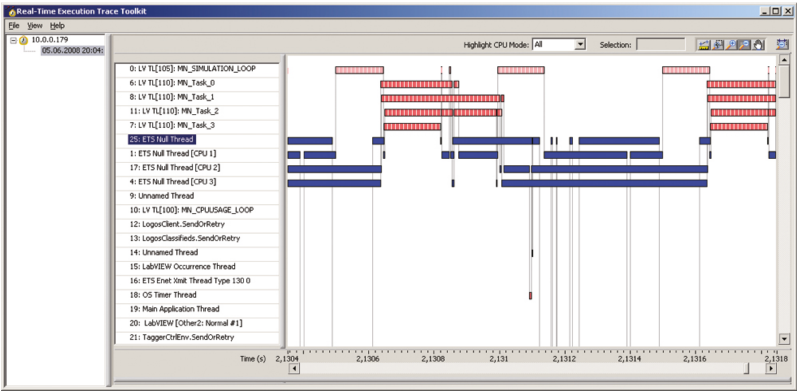
enDYNA Themos calculates the temporally resolved pressure curve in the cylinder based on a zero-dimensional combustion model, the wall heat loss across the cylinders and the piston kinematics.

With the physical model approach, it was possible by definition to replicate coupled effects such as the impact of charge dilution through exhaust gas recirculation on torque development and exhaust gas. The high level of detail of the models with simultaneous real-time requirements necessitated powerful hardware and HiL software that enabled parallelization of the calculation process. MicroNova solved these challenges with a quad-core CPU and a high-performance Simulink blockset.

HiL hardware

A twelve-cylinder diesel HiL system houses the following components from top to bottom:

- Fault switching for 160 pins. The injectors have separate fault switching
- Breakout boxes for 360 I/O pins
- Simulated loads for 16 high-pressure solenoid injectors with current measurement. LEDs are provided for the injectors to indicate their control status
- ECU connection with further simulated loads
- Quad-core CPU with 2.4 GHz clock frequency
- PXI rack with I/O cards and signal conditioning



2 Four processors at work

The tried-and-tested MicroNova HiL construction kit was used to build the HiL simulator, with components such as the simulation of lambda sensors. The dimensioning of the simulation of the high-pressure solenoid injectors used was adapted to the physical conditions in the truck sector.

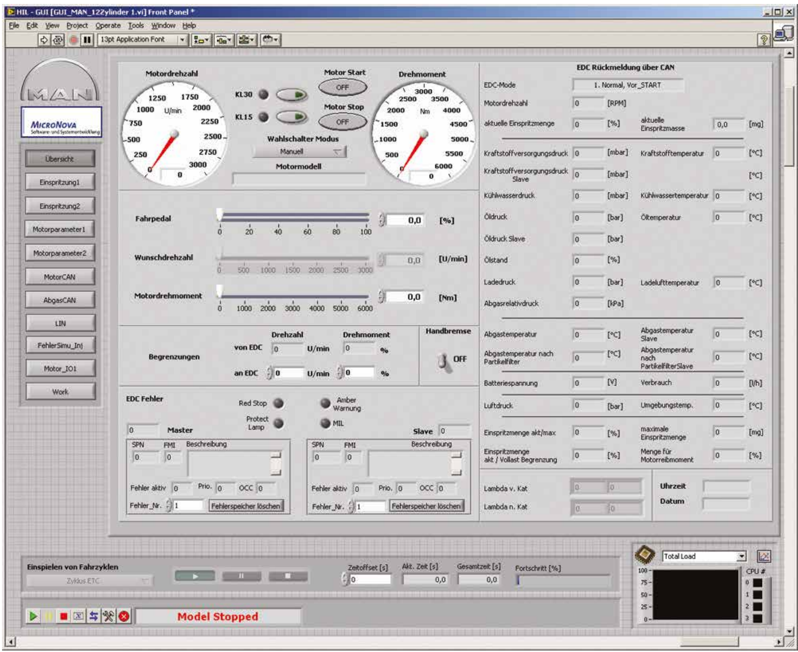
HiL software

The successful use of models for the simulation of combustion engines is based on the simple connection of engine-specific inputs and outputs. The basis for this is a series of easy-to-configure Simulink blocksets. These include:

- Analog input and output
- Digital input and output
- PWM input and output
- Table-controlled generation of crankshaft and camshaft signals
- Injection and ignition detection (including multiple injection and ignition detection)
- Simulink blocksets for CAN
- Simulink blocksets for LIN

These blocksets are used in numerous MicroNova HiL simulators. Multi-rate models, i.e. models that contain parts with different cycle times, are also supported and use the high processing power of multi-processor platforms. In the application described here, parts of the model compute in parallel on multiple processors, so that the time requirements of the simulation were met. Simulink blocks allow individual calculations to be assigned graphically to different processors. The model parts running on the individual processors merely have to be placed in corresponding subsystems by the user. The software ensures efficient allocation of calculations to individual processors and synchronization of the individual parallel calculations. This makes the use of multiple processors a piece of cake for the user.

Figure 2 shows a model step with a cycle time of one millisecond. The main loop is shown in light pink, the combustion processes in the individual cylinders are shown in red. The calculation for each of the four cylinders is summarized in a thread. The processing times for the individual cylinders are different because a combustion process, for example, requires more processing time than the ejection of



3 The user interface

exhaust gases. The threads shown in blue are the idle threads. These represent the processing time reserve on the HiL simulator. Moreover, there is still sufficient room for future expansions.

The HiL simulator can be operated in two ways:

» Firstly, there is a user-friendly interface implemented in LabVIEW.
» Secondly, fully automatic operation of the simulator is possible via Python-based test automation.

The user interface for the HiL system is shown in figure 3. For easy operation of the HiL simulator, all inputs and outputs, along with key model variables and parameters are available on the user interface. The HiL system was supplied to MAN Nutzfahrzeuge AG with a fully parameterized model.

Summary

By using tried-and-tested components from the modular product system, MicroNova was able to realize a custom, standards-based HiL system in no time at all. This meant that the real engine could be simulated realistically, eliminating entries in the ECU's fault memories. The ECU could not tell that it was not controlling a real engine.

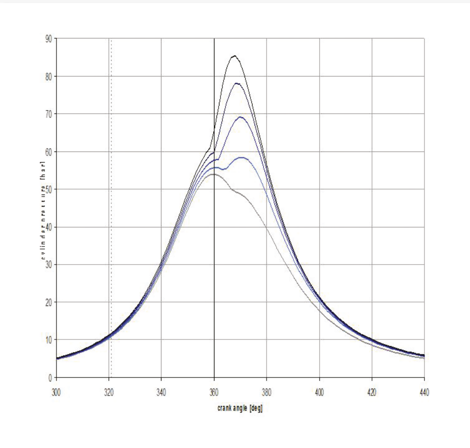
Achieving such simulation quality was possible because:

» MAN provided very high quality engine data.
» The enDYNA engine model enables simulation at the required level of detail. Only a thermodynamic model approach reproduces the engine behavior with the required accuracy.
» MicroNova provides the necessary powerful hardware and software environment.

For the customer, there is a major cost advantage because tests can now be carried out on the Hi simulator that previously had to be performed on expensive engine test benches, requiring more time to complete and under less reproducible conditions. Tests can even be started before a real engine is actually available.

The MicroNova HiL platform is also suitable for other complex applications such as vehicle dynamics models in conjunction with driver assistance systems. By supporting almost any number of processors in multiprocessor systems, it is possible to realize numerous new HiL applications.

Excursus: Thermodynamic engine model



4 Curve of the internal cylinder pressure

The core of a thermodynamic engine model is the engine process simulation. Here, the combustion process and the energy flows arising as a result are calculated in a temporally resolved manner using a physics-based approach. The crucial advantage compared to conventional mean value models, in which the steady-state engine behavior is usually stored in characteristic maps, is the representation of complex interrelationships according to physical principles and the higher accuracy that is achieved at the same time.

As a result, for example, the direct effects of reduced air flow on exhaust gas temperature and boost pressure can be depicted to very high levels of precision. The temporally resolved calculation of the combustion process also shows the influence of injection angle and multiple injections on the internal cylinder pressure curve over the entire working range of the engine. Figure 4 shows simulated cylinder pressure curves at different load points and injection patterns. A thermodynamic engine model is therefore indispensable for the testing and development of increasingly complex controllers such as exhaust gas temperature management, two-stage turbocharging, fully variable valve train, EGR, and for checking onboard diagnostic functionality.