Optimizing diesel engine controls for extremely low emissions

Less Is More

ISUZU is developing an electro-hydraulically actuated variable valve system as an engine device to simultaneously reduce exhaust gases and fuel consumption. One development goal is to undercut the limits of the Japanese exhaust emission standard. The prototype controller has to cope with numerous valves and actuators and deliver high computing performance.

Stricter than the Emission Regulations

Together with the National Institute of Advanced Industrial Science and Technology (AIST), Japan, ISUZU participated in the project 'Comprehensive Technological Development of Innovative, Next-Generation, Low-Pollution Vehicles' promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO) from 2004 to 2009. The development target values for this project were NO_x (nitrogen oxides) 0.2 g/kWh and PM (particulate matter) 0.01 g/kWh, even stricter than Japan's domestic Post New Long-Term Emission Regulations. The fuel consumption target was set at the extremely rigorous level of a 10 % improvement over the current standard (figure 1).

The Engine Concept: Camless Valve System with Hydraulic Actuation

To meet these tough project targets, ISUZU developed a concept for a future engine that simultaneously reduces emissions and fuel consumption. The concept includes a hydraulic variable valve actuation (camless) system that improves the trade-off between exhaust gas, especially NO_x, and fuel – the most crucial issue in achieving reductions.

System-Specific Requirements

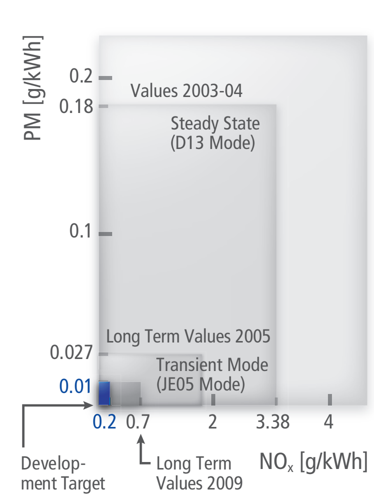
In the camless system, supplying high-pressure actuation fluid opens the valves, and draining the fluid closes them. By controlling the timing of fluid supply and discharge, and the volume of fluid supplied, this system allows the intake/exhaust valve to be set to any opening-closing timing and any amount of lift (figure 2).
However, the system requires actuators for supplying and discharging the fluid, and each valve needs two actuators.
The development system will be applied to a large inline six-cylinder diesel engine. A total of 24 intake/exhaust valves and 48 actuators are needed. In addition, if control of the fuel injection and air systems is included, the system needs sufficient driver capacity to operate a total of 56 actuators, and the controllers and drivers require the following capabilities:

- Ability to support high-speed, precise pulse output synchronized with the crank angle
- Ability to control the current peak/hold time and current values

System Design Outline

To reliably control all 56 actuators and allow flexible system changes, a rapid control prototyping (RCP) system based on modular dSPACE hardware and RapidPro was chosen. This control system uses one proces-

Figure 1: Emission Regulations in Japan.



> "In the future, creating control logic systems that are highly precise and diverse will increase loads on systems. However, the high level of expansibility and flexibility of dSPACE products should avoid any problems."

Kikutaro Udagawa, ISUZU Advanced Engineering Center

Figure 2: Schematic diagram of the intake/exhaust valve opening-closing method in conventional cam actuation (left) and in the hydraulic camless actuation system (right).

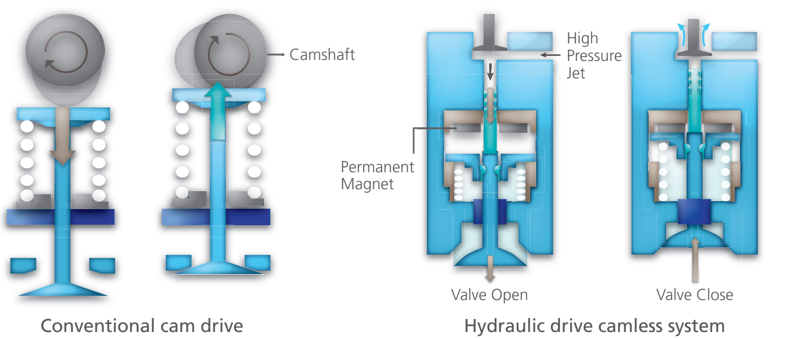
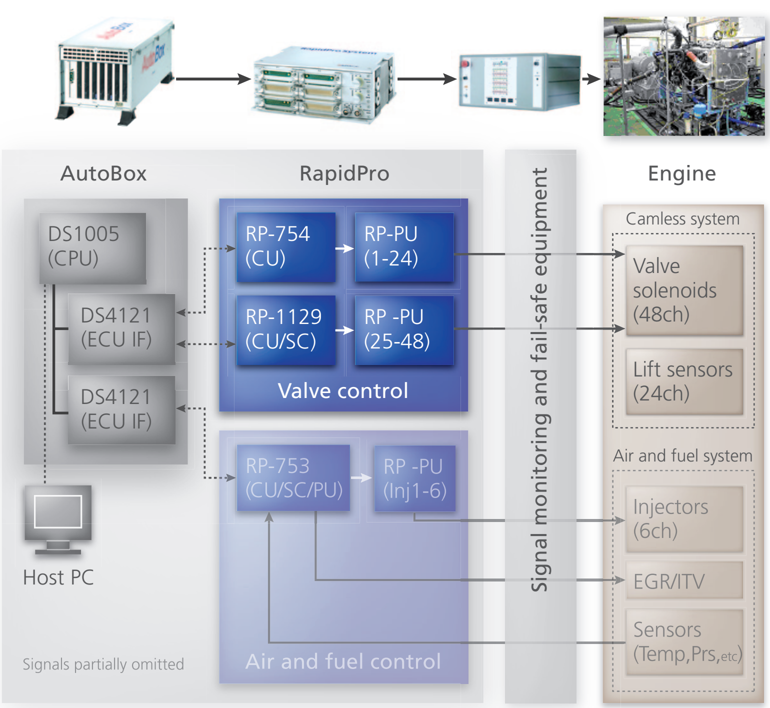


Figure 3: Schematics of the control system.



sor board as a controller and, because of constraints on the number of control unit TPU channels, uses three RapidPro units as drivers for intake/exhaust valve control and for control of the air and fuel injection systems (figure 3).

Fail-safe Requirements and Solutions

While the camless system intake/exhaust valves can operate without any constraints on the positions of the pistons, a control abnormality or inappropriate target instruction can cause valves and pistons to collide, resulting in serious damage to the engine. Therefore, from a fail-safe perspective, it is essential that the quality of the control software be improved to protect the engine, and that protection measures be devised for the case of control abnormalities. This leads to the following basic requirements for the development tools:

- *High-precision signal processing*
  Use a RCP system supporting high sampling rates and high I/O performance.
- *Measures to protect the engine during control abnormalities*
  Adopt a software-based abnormality monitoring function plus a hardware-based protection system. Accordingly, insert a fail-safe device between the control unit and the power unit to protect the engine by forcibly closing the intake/exhaust valves.
- *Securing control software reliability*
  Use hardware-in-the-loop (HIL) simulation to simulate a camless engine and run software evaluation tests before running the actual engine. To further verify operation in the actual engine, use the control system and actual camless system installed in the engine to actuate the valves, and also perform rig evaluation tests.

Role of Development Tools in Resolving the Issues and Expectations

As explained above, the controllers for the camless system require high performance and high reliability. And because this is a system under development, the controller and driver hardware configuration must also be modified by additional actuators and sensors in response to frequent model changes, or to specification modifications to the engine itself and any auxiliary components. Responding flexibly to these kinds of structural changes in the model and the controller hardware demanded flexible dSPACE products rather than in-house controllers and drivers.

Evaluating dSPACE Products after Development

The hardware (DS1005, RapidPro) is highly reliable and has the flexibility to fit new I/O specifications and upgrades in computing performance. Also, ControlDesk and other development tools operate visually and intuitively, allowing parameters to be visualized. First-time users can use the tools with ease. The reliability, operability and flexibility of the development tools are balanced to a high level. dSPACE products were successful in controlling the camless system – that is, in dealing with the difficult issue of accurately controlling an extraordinary number of actuators at high speed.

Results and Outlook

Multi-cylinder engine tests confirmed a fuel consumption improvement effect under the same NO_x emission conditions in steady-state operation. Furthermore, partially transient operation resulted in a proposal for a next-generation control system for stable valve control. These ideas are being implemented with the next generation of engine management. This consists of a multiprocessor configuration, and contains a DS1005 and the DS1006 Processor Board for model-based control. The two processors are interconnected via Gigalink to provide even more processing power for the extended controller software. ■

> "Using dSPACE RapidPro allows I/O of almost any signal, and cuts the time and effort needed to design and build external interface circuits."
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> *Ryo Kitabatake, ISUZU Advanced Engineering Center*

Figure 4: dSPACE hardware in the test rig. Parts of the wiring harness were removed for this photo.

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