Environmentally Friendly Engine Control Systems

Minoru Osuga
Takuya Mayuzumi
Hiromu Kakuya

OVERVIEW: Vehicle CO_2 (and fuel consumption) and exhaust emissions standards as environmental regulations that have been led by the countries of North America and Europe are likely to become even more stringent in 2010 and beyond with stricter controls also anticipated in China and other Asian countries. Improving engine efficiency through new systems capable of even lower fuel consumption and exhaust emissions is essential to reducing vehicle CO_2. Systems that are effective for improving engine efficiency include downsizing systems that reduce friction and weight by moving to smaller engines with higher output, systems that reduce pumping loss to almost zero through precise control of valve operation, and idling stop systems. Further advances in these areas are anticipated. Hitachi is engaged in the development of the control systems and equipment that support these new systems.

INTRODUCTION

AGAINST a backdrop of strengthening environment regulation, including CO_2 (carbon dioxide) and exhaust emissions standards, Hitachi supplies engine control systems and various control components that meet the needs to the future (see Fig. 1).

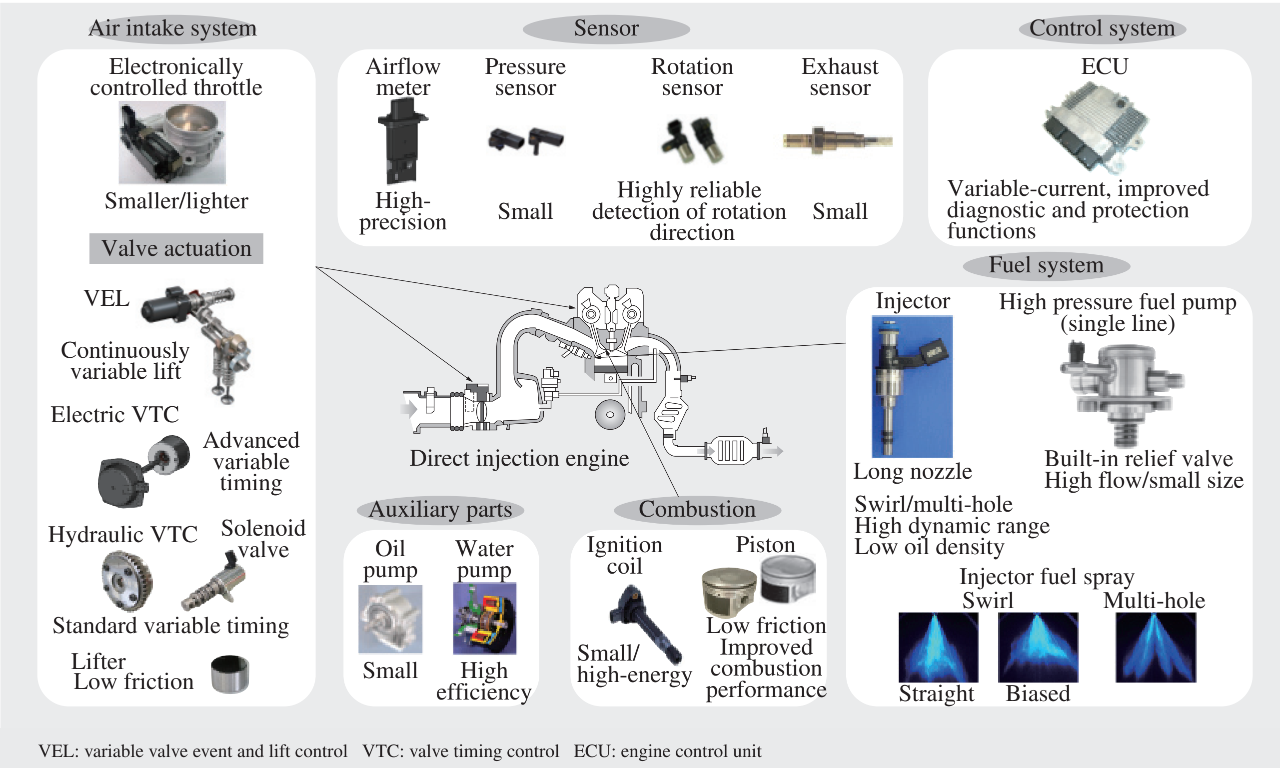

Fig. 1—Key Components of Environmentally Friendly Engine Systems.
Hitachi supplies engine control systems and components for complying with future environmental regulations. Key products include electronically controlled throttles, air intake systems operated from the valve train, airflow meters and other sensors, fuel and combustion systems that influence engine combustion, pumps and other auxiliary components, and ECUs that control these components.

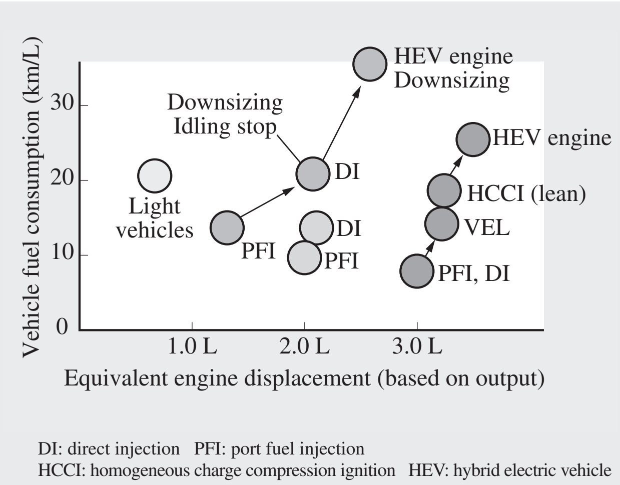

Fig. 2—Trends in Environmentally Friendly Engine Control Systems.
Advances are being made in engine downsizing, idling stop, and VEL, and work is underway on applying these to HEVs. New HCCI combustion techniques are also being developed.

TABLE 1. Main Components and Control Techniques Used by Each System
Hitachi is developing key components and high-precision control techniques for each type of system.

System	Key component	System control
Downsizing (supercharged DI system)	· Injectors with wide dynamic range · High pressure fuel pump · ECU (DI) · Airflow meter with fast response	· Variable fuel pressure control · Multi-stage injection control · Fast-pulse intake volume detection · Torque-based control
Idling stop system	· Quiet starter with high durability · Electric oil pumps (for AT, CVT) · Lead-acid battery for idling stop	· Engine shutdown and restart control · Energy regeneration control
VEL system	· VEL · Fast-response VTC	· VEL drive control · Torque-based control
HCCI (lean) system	· DI fuel control system · VEL · Fast-response VTC	· Driving mode switching control · HCCI combustion control · Torque-based control

AT: automatic transmission CVT: continuously variable transmission

Fig. 2 shows the future trend in engine control systems.

One developing trend is toward the downsizing of car engines by using supercharging to boost the output of small engines in the 1-L class. The low friction and low weight of these engines mean they can achieve better fuel consumption.

In 3-L class engines, progress is being made on VEL (variable valve event and lift control) systems that use intake valve lift to control the air intake with the aim of reducing pumping loss. For the future, HCCI (homogeneous charge compression ignition) systems that can achieve lean combustion with low NO*x* are also in development. Work is also ongoing on making these engines suitable for use in HEVs (hybrid electric vehicles).

This article describes the main areas where Hitachi is active in this field of environmentally friendly engine control systems.

KEY COMPONENTS AND TECHNIQUES USED IN ENGINE CONTROL SYSTEMS

Table 1 lists the main components and control techniques for environmentally friendly engine control systems supplied by Hitachi.

Supercharged DI (direct injection) systems capable of boosting engine output are used to facilitate downsizing. In the fuel system, Hitachi also supplies injectors with wide dynamic range designed for higher engine output through the use of supercharged DI, and high-pressure fuel pumps and the associated drive control.

The key technologies for idling stop systems are engine shutdown and restart control and quiet and highly durable starters that can withstand frequent starting and stopping. For the VEL systems that perform continuous control of intake valve lift and open/close timing, Hitachi supplies fast-response valve actuation and drive control. For the HCCI systems that use compression self-ignition to achieve lean combustion with low NO*x* (nitrogen oxide) levels, Hitachi is developing combustion control techniques and DI fuel systems that control compression self-ignition. Hitachi has also developed torque-based control that uses torque as the basis for engine management to perform integrated control of supercharging, valve actuation, and combustion. The following sections describe each of these systems in turn, while VEL is covered by a separate article in this issue entitled “Variable Valve Actuation Systems for Environmentally Friendly Engines.”

CONTROL SYSTEMS FOR DIRECT INJECTION ENGINES

High-pressure Fuel System for Direct Injection Engines

Fig. 3 shows a high-pressure fuel system for direct injection engines.

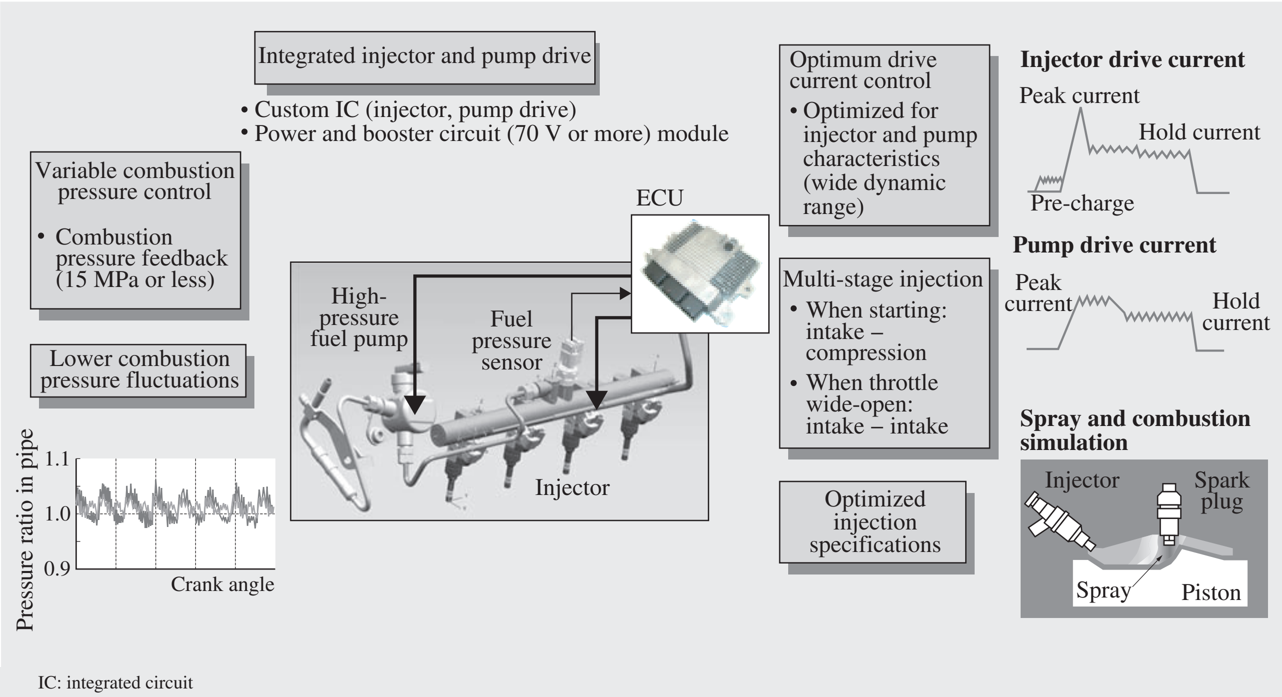

Fig. 3—High-pressure Fuel System for Direct Injection Engine.
Direct injection engines inject fuel directly into the cylinder at high pressure (15 MPa). Hitachi supplies control components for high-pressure fuel along with drive control techniques and equipment that can obtain the maximum performance from these components.

The key elements of the system are a high-pressure (15 MPa) fuel pump, the injectors that inject the fuel into the cylinder, and the engine control unit which incorporates a custom IC (integrated circuit) that drives the other components. The injectors and high-pressure pump drive feature a drive current that is optimized to obtain the maximum available performance resulting in fuel injection that has a wide dynamic range and is also used on supercharged DI engines. The system also supports multi-stage injection whereby injection is performed a number of times during each cycle to achieve both low exhaust emissions at cold starting and high torque at full load [WOT (wide open throttle)].

Hitachi also supplies technology for combustion system design. The shape and other characteristics of the fuel spray injected into the cylinder can be determined using a combustion simulation technique developed by Hitachi. Hitachi also supplies high-pressure pump control and fuel pipe designs that reduce pressure fluctuations in the fuel pipe.

Engine Control Unit

Fig. 4 shows an engine control unit for direct injection.

Because the drive waveform settings (peak and hold currents) for the high-pressure pump can be modified on the control unit from a microcomputer, the drive can be optimized to suit the engine operating conditions. The drive circuit also features advanced self-diagnosis and self-protection functions which improve the safety of the direct injection system comprising the drive circuit, injectors, high-pressure pump, and harness. Also enhanced fail-safe operation is achieved by monitoring the temperature of the drive circuit so that, in the event

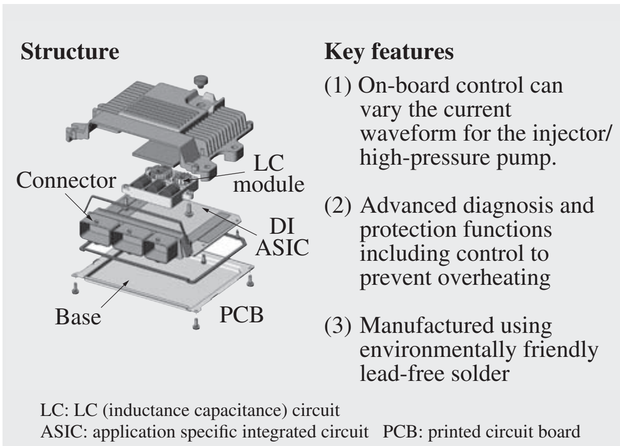

Fig. 4—Engine Control Unit for Direct Injection Engine.
An on-board control system can vary the current waveform for the injector and high-pressure pump and optimize the waveform for the operating conditions.

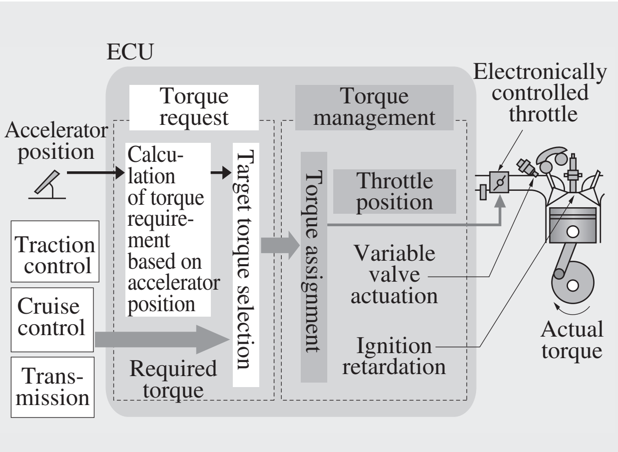

Fig. 5—Basic Structure of Torque-based Control.
The various different engine output requirements are combined to obtain a single value for the torque required at each instant, and the various actuators are controlled to achieve this target torque.

of overheating, the control operation can be modified to reduce heat generation rather than shutting down the entire engine.

To implement these functions in a way that minimizes the load on the microcomputer, Hitachi has developed a new ASIC (application specific integrated circuit) that integrates the current control, diagnosis, protection, and booster circuit control functions.

Torque-based Control

Fig. 5 shows the structure of torque-based control which will be the main technique used in future engine control.

The system is separated into a torque request unit and torque management unit between which torque parameters are exchanged. Although the electronically controlled throttle is the main actuator involved in setting the torque, the system also comprises the ignition coil, valve actuation systems [VEL and VTC (valve timing control)] and supercharger.

The torque request unit calculates the target torque by taking into account the requirements from the accelerator position, traction control (which prevents wheel slip), cruise control, and reducing the shock on the transmission.

The torque management unit calculates the control values to apply to each actuator in order to achieve the target torque.

With respect to the dynamic response, the target torque is achieved not only by the electronically controlled throttle but also by compensating with fast-acting actuators during ignition operation and similar.

IDLING STOP SYSTEM

Fig. 6 shows the structure of the idling stop system and its benefits in terms of improved fuel consumption.

The idling stop system works by turning off the engine while the vehicle is stationary instead of leaving it idling. It is a reliable way of improving fuel consumption with benefits that are expected to be as good if not better than other such techniques.

The key criterion for an idling stop system is that it be able to restart the engine and drive off smoothly and quietly. Achieving this requires that the pistons be halted in positions that do not hinder restarting when the engine is stopped, and that this position be taken into account in the control operation when the time comes to restart the engine. This is achieved by the piston position detection sensor and engine load control.

To ensure that the vehicle moves off smoothly, an electric oil pump system is being developed to maintain the oil pressure in the transmission while the engine is stopped.

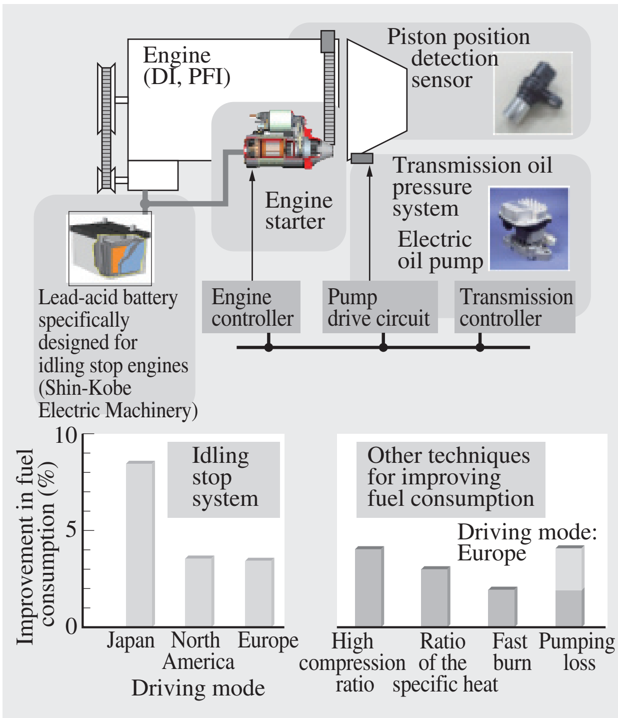

Fig. 6—Idling Stop System.
Idling stop systems deliver a greater improvement in fuel consumption than other fuel economy techniques and are likely to be adopted widely in the future.

Improving the durability and quietness of the starter is another important requirement if the engine is to be stopped and restarted frequently. Hitachi has improved the durability of starter parts subject to wear and introduced changes that make the starter quieter and were developed using an acoustic vibration analysis technique that is unique to Hitachi. Another product specially designed for vehicles with an idling stop system is a lead-acid battery that can cope with the inflow and outflow of current associated with the frequent operation of the starter drive and which is supplied by Shin-Kobe Electric Machinery Co., Ltd., a company in the Hitachi Group.

HCCI SYSTEM FOR GASOLINE ENGINES

An HCCI system for gasoline engines is under development at Hitachi Research Laboratory, Hitachi, Ltd. This new combustion system for future engines has significant benefits for fuel consumption (see Fig. 7).

The system adds a self-ignition (lean combustion) mode to the existing combustion and driving modes based on spark ignition. Although NO*x* is a problem for lean combustion, the low combustion temperature associated with self-ignition significantly reduces the quantity of NO*x* produced.

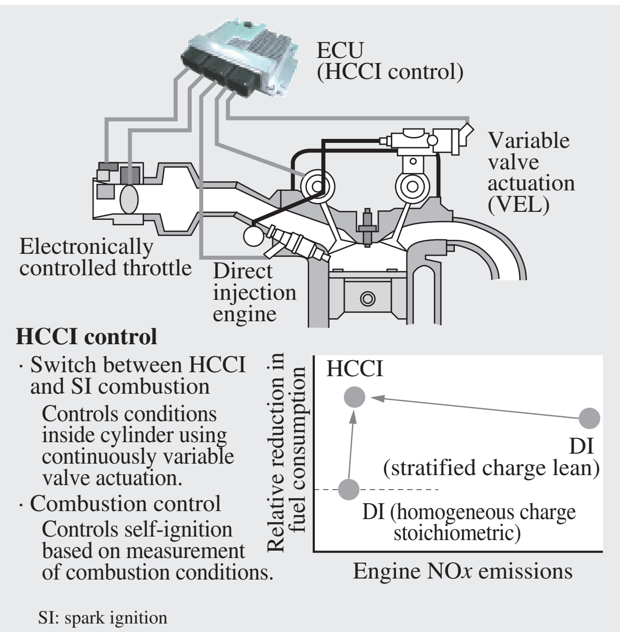

Fig. 7—HCCI System for Gasoline Engines.
Overview of a gasoline HCCI system for a direct injection engine with VEL is shown. Better fuel consumption is achieved with low NOx.

This makes it a worthwhile option for reducing CO_2 emissions because it reduces pumping loss and improves the efficiency of lean combustion.

The key elements of the system are the control of temperature inside the cylinder and the direct injection technology that injects fuel at the optimum temperature range. This is achieved by using the VEL valve actuation system described earlier to confine the distribution of air and fuel gas in the cylinder and control the temperature.

Implementing HCCI requires use of continuously variable valve actuation (VEL) to select the driving mode together with detection and control of the ignition and combustion conditions, and Hitachi is also involved in developing these control techniques.

CONCLUSIONS

This article has described the main areas where Hitachi is active in the field of environmentally friendly engine control systems.

The performance of this control equipment and the associated control techniques have a large impact on fuel consumption, emissions, and other aspects of engine performance. Hitachi will continue to supply products for use in these systems that are based on an adequate understanding of the trends, driving conditions, and other aspects of vehicle engines.

REFERENCES

(1) M. Osuga et al., "New Direct Fuel Injection Engine Control Systems for Meeting Future Fuel Economy Requirements and Emission Standards," Hitachi Review **53**, pp. 193-199 (Nov. 2004).
(2) J. Ishii et al., "Reduction of CO_2 Emissions for Automotive Systems," Hitachi Review **57**, pp. 184-191 (Sep. 2008).
(3) S. Yamaoka et al., "A Study of Controlling the Auto-Ignition and Combustion in a Gasoline HCCI Engine," SAE Paper 2004-01-0942, 2004.

ABOUT THE AUTHORS

Minoru Osuga

Joined Hitachi, Ltd. in 1979, and now works at the Control System Design Department, Powertrain Design Division, Powertrain & Electronic System Division, Hitachi Automotive Systems, Ltd. He is currently engaged in the development of control systems for direct injection engines. Mr. Osuga is a member of the Society of Automotive Engineers of Japan (JSAE) and The Japan Society of Mechanical Engineers (JSME).

Hiromu Kakuya

Joined Hitachi, Ltd. in 2002, and now works at the Third Department of Systems Research, Hitachi Research Laboratory. He is currently engaged in the development of engine control systems for automobiles. Mr. Kakuya is a member of the JSAE.

Takuya Mayuzumi

Joined Hitachi, Ltd. in 1993, and now works at the ECU Design Department, Electronic Device Design Division, Powertrain & Electronic System Division, Hitachi Automotive Systems, Ltd. He is currently engaged in the development of engine control units for direct injection engines.