Port-injection Engine-control System for Environmental Protection

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OVERVIEW: Over recent years, problems such as global warming, atmospheric pollution, and natural-resource depletion have become ever more obvious. In accordance with these circumstances, the vehicle industry is having to deal with the tightening of emission and fuel-consumption regulations around the whole world. Aiming to meet these emission and fuel-consumption regulations while contributing to the evolution of the vehicle-oriented society and offering various solutions to vehicle manufacturers, Hitachi Group has applied its collective strength in developing and commercializing a port-injection engine control system. This system — which ensures crisp driveability — uses various kinds of sensors and actuators in its cutting-edge main components, namely, an air-flow sensor and injector, a variable-valve-control system, and a control unit.

INTRODUCTION

HITACHI, LTD. commercialized a port-injection engine-control system — based on a digital format and using a microcomputer — in 1982. After that, owing to the demands of various emission regulations imposed on both Japanese and non-Japanese vehicle manufacturers, we have striven to expand the main parts of this system while offering new technologies.

From now onwards, it will be necessary not only to meet the projected tougher standards for emission [such as new long-term regulations in Japan, SULEV (super-ultra-low emission vehicle) regulations in the USA, and Euro-5 regulations in Europe] and for fuel consumption (new 2010 regulations in Japan and CO_2 regulations in Europe), but also to satisfy demands concerning vehicle “driveability.”

The challenge common to all these concerns is to improve fuel combustion. In regards to this combustion

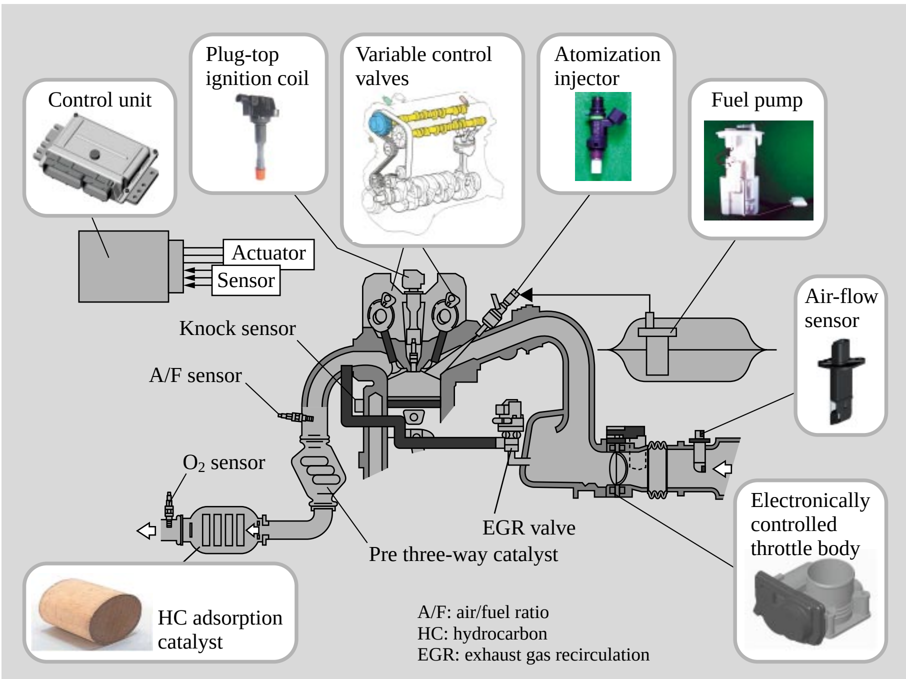

Fig. 1—Components of Port-injection Engine-control System Developed through Collective Strength of Hitachi Group.
Applying simulation technologies for nuclear-power plants and shinkansen bullet trains to the development of engine-control systems and parts has enabled Hitachi Group to commercialize high-quality, high-reliability systems and parts — with superior performance in a shorter development time — and offer these products as combined system solutions.

improvement, it is necessary to optimize the constitution of the fuel-air mixture in the cylinders of an automobile combustion engine. Accordingly, Hitachi Group is developing technologies for producing optimum air flow for efficient atomization and evaporation, as well as feeding, of fuel. In addition, as regards the harmful components in exhaust from engines, it is necessary that catalysts are activated promptly and can perform adsorption and decontamination of HC (hydrocarbon). To meet these needs, we are making efforts to develop post-treatment technology, including that for early activation of catalysts and that for controlling HC adsorption and combustion catalysts. Furthermore, as for improving fuel consumption and vehicle "driveability," we are developing technologies for introducing variable-valve-control systems and for optimizing intake/exhaust valve systems from both the hardware and the software sides.

In the remainder of this paper, we introduce the port-injection engine-control system developed by Hitachi Group in response to the latest environmental-control regulations (see Fig. 1).

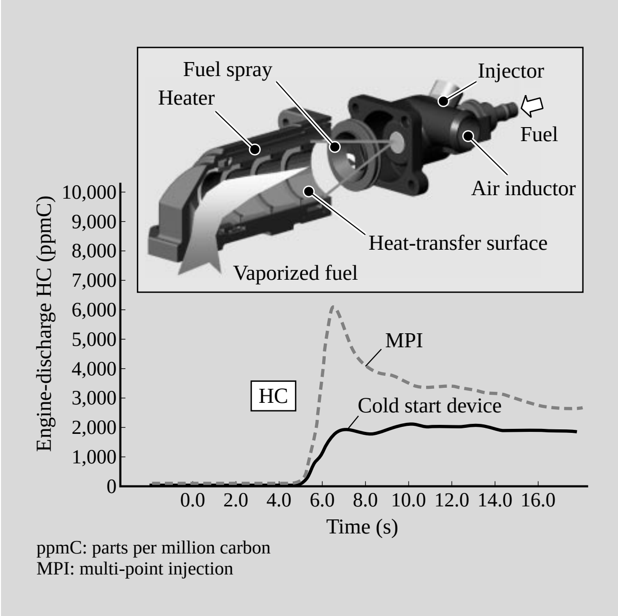

Fig. 2—Cold Start Device Structure and Test Results on Real Vehicle.
Applying the PTC (positive temperature coefficient) heater resulted in minimization from the viewpoints of reduction in power consumption and installability.

TECHNOLOGY FOR EXHAUST CONTROL

Aiming at improving combustion in the period between engine start-up to just after and at reducing emission of harmful exhaust components, we have developed a so-called cold start device that atomizes fuel before supplying it to the engine.

In the cold start device, as shown in Fig. 2, fuel sprayed from the injector is atomized by air supplied from the air inductor. And while the atomized fuel is swirling around, it is fed into the heater. From there, the fine fuel particles ride on the carrier air flow directly into the intake manifold. At the same time, large fuel particles are swirled around and come close to the heater wall surface, where they are vaporized and also fed into the intake manifold. The fuel vaporized in the cold start device (fitted to the plenum of the intake manifold) is supplied to the cylinders through each of the manifolds downstream of the plenum. After a predetermined time after its operation, the cold start device reverts back to normal port injection. Under a start-up ambient temperature of 25°C, as shown by the graph in the lower part of Fig. 2, the amount of HC discharged from the engine in a short time after ignition is reduced by two thirds in the case of cold start device injection (2,000 ppmC) compared to that in the case of port injection (6,000 ppmC).

In addition, under US FTP (federal test procedure) mode, the cold start device injection achieved a 52% reduction in HC emission.

Applying the cold start device assures good start-up performance — regardless of the properties of the gasoline used (i.e. light or heavy grades). Additionally, since the amount of fuel compensation (i.e. increase the fuel amount) during the start-up time does not have to accommodate heavy-grade gasoline, actual fuel consumption is improved.

TECHNOLOGY FOR REDUCING FUEL CONSUMPTION

In regards to reducing fuel consumption, it is necessary to accommodate the engine-control system, the engine itself, auxiliary parts, and drive-train systems (transmission) in a comprehensive manner.

As for the method used by the variable-valve-control system (which is part of the engine-control system), for example, fuel consumption, exhaust discharge, and output power are improved by controlling the timing of the opening and closing of the inlet and exhaust valves. The optimum timing for improving fuel consumption, however, differs according to the operating conditions. That is to say, in the case of idling operation, residual gas is decreased, and to improve combustion, the inlet valve

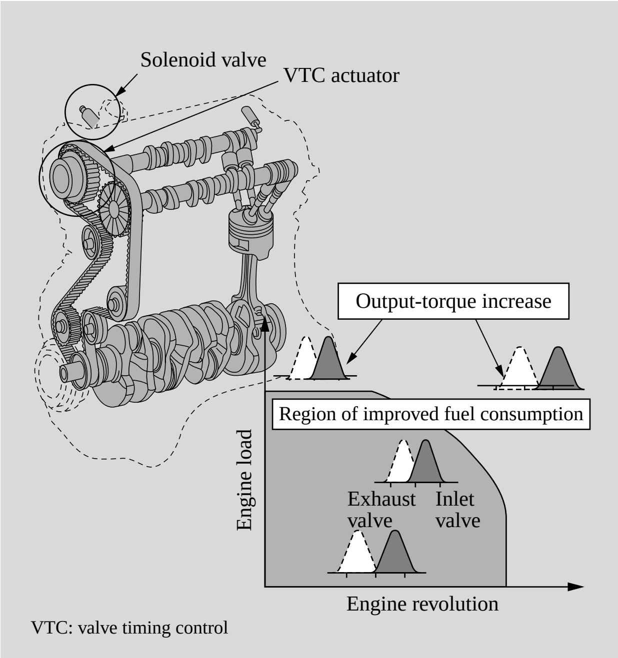

Fig. 3—Design Features and Structure of Variable-valve-control System.
The system is designed to optimize the target engine by means of various kinds of actuators and mechanisms.

is opened slowly and the exhaust valve is closed quickly. On the other hand, in the case of partial operation (partial loading), to reduce the pumping loss, the inlet valve is opened quickly and the exhaust valve is closed slowly. In this way, for a 3,000-cc engine vehicle with an automatic transmission operating under FTP testing mode, fuel consumption is improved by 5.7%.

Furthermore, regarding this variable-valve-control system developed by Hitachi as well as handling various phase, lift, and timing combinations, it is designed for optimum fit with various types of actuators and mechanisms used in different engines (see Fig. 3).

TECHNOLOGY FOR IMPROVED "DRIVEABILITY"

In recent years, on top of demands regarding fuel consumption and exhaust emissions becoming a matter of course, from the viewpoint of product improvement, crisp, precise driveability and quietness have also become much sought-after features. Accordingly, these demands must be dealt with from both the hardware side and the software side. Such hardware includes the previously mentioned variable-valve-control system and electronically controlled throttle body; software includes torque-based control methods. For example, as regards the development of torque-based control technology, improvement of driveability — such as reducing shock during speeding up and slowing down and improving quietness during cruising — and strengthening the interface with other control units (e.g. coordination with automatic-transmission systems) have been attempted. As for this acceleration/ deceleration shock and vibration generated during load

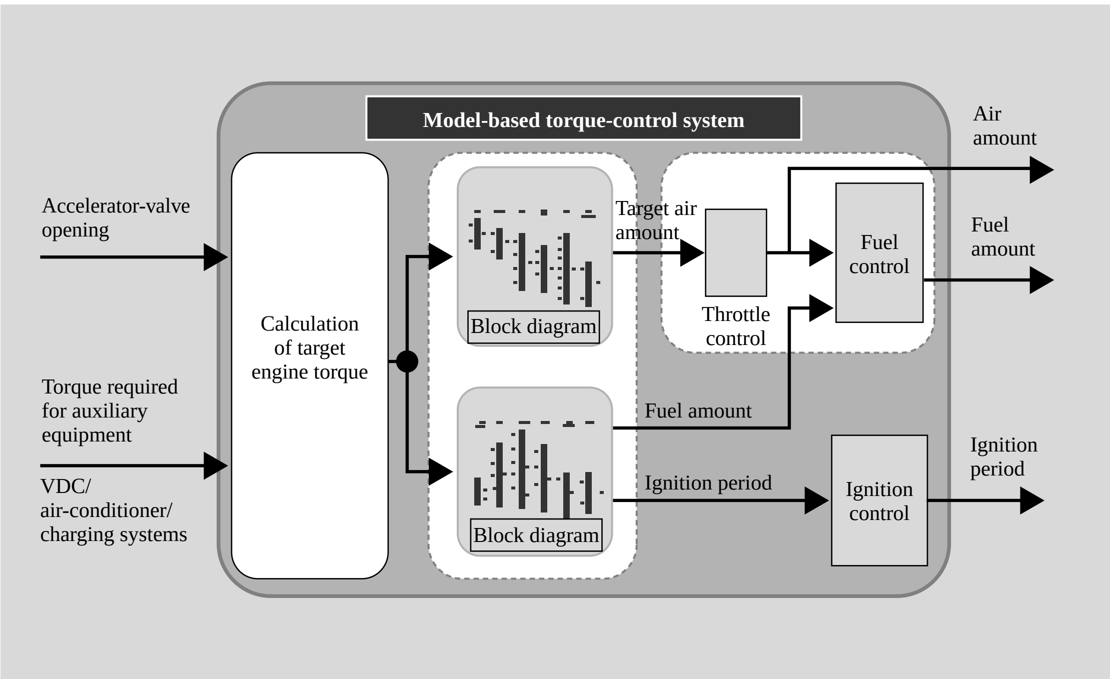

Fig. 4—Block Diagram of Torque-based Control.
The torque-based control system enables precise cooperation between the drive-train and chassis systems.

fluctuation due to auxiliary equipment like air conditioners, these issues are dealt with by controlling the variation per unit time of the torque generated by the engine. In the case of conventional engine control, the intake airflow volume is determined by the opening of the accelerator, and since the combustion volume and ignition timing adjustment depend on the intake air-flow volume, it was not possible to control the torque. Accordingly, in our new torque-based control system, a target engine torque covering the required torque for the accelerator opening and that for other equipment is pre-set, and the airflow volume, combustion volume, and ignition timing are determined according to that target.

Taking acceleration as an example, in its initial stage, the torque rises gently so that the excitation force exerted on the vehicle body is weakened. After that, by turning up the torque rapidly — without loss of acceleration performance — shock can be reduced (see Fig. 4).

MAIN STRUCTURAL PARTS OF SYSTEM

Control Unit

The control unit uses the latest implementation technologies — namely, our own high-performance microcomputer series and a custom IC (integrated circuit) chip for miniaturization — to carry out OBD (on-board diagnosis), electronic throttle control, digital-noise control, etc. All these parts are compatible with any kind of gasoline engine, and they are commercially available as three types of products for installation inside the engine, in the engine compartment, and in the vehicle interior.

Electronically Controlled Throttle Body

Quick throttle response (i.e. the actuation time from idling to fully open is reduced to less than 150 ms) as a result of an improved transfer mechanism, low power consumption, and idling control by means of a high-precision valve system have enabled the minimum flow rate to be lowered. In addition, with a compact, lightweight design (under 1 kg), the throttle control module can be produced as a single unit. Owing to its robust structure against vibration, the module is also being applied to diesel engines. As for its use, system support is being provided by means of development of control logic, fault diagnosis, and fail-safe operation.

Injector

Through various efforts regarding the design of the injector’s components, the number of parts is cut and the weight is reduced to 29 g. A flow simulation carried out for different combinations of passage configuration and hole/vent/valve placement showed that the best fuel particle size is 60 μm. And the dynamic range of the injector (i.e. the standard measure) has been increased to ± 5%, namely 25 times that of a conventional injector.

SIMULATION AND EVALUATION METHODS

For efficient development of the port-injection engine control system, it was necessary to quantitatively and accurately understand the behavior and combustion response of fuel as well as to understand what factors influence the engine performance. To perform these investigations, computer-simulation methods were applied.

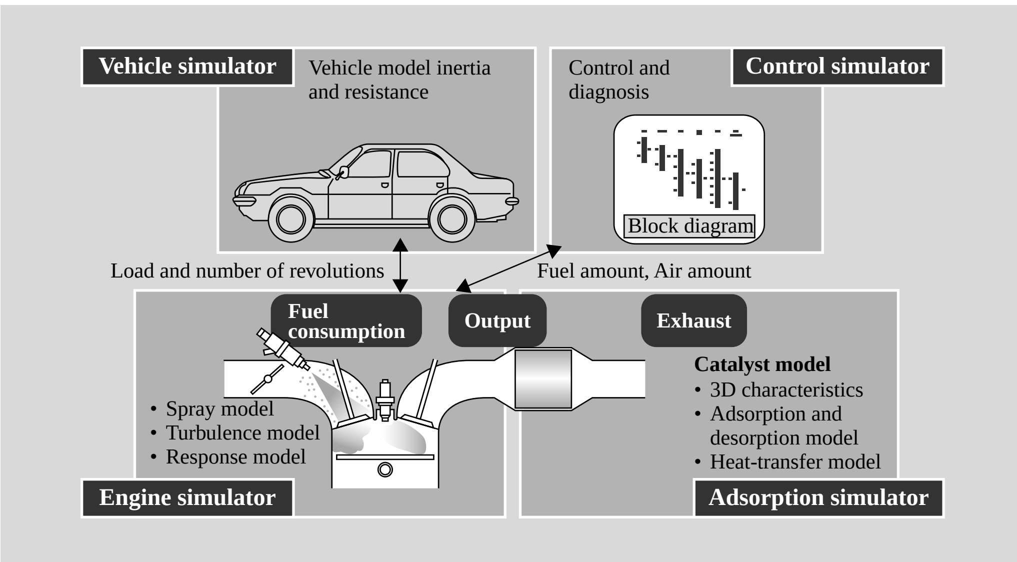

Fig. 5—Integrated Simulation Environment for Development of Engine-control Technologies.
Establishing an integrated simulation environment — covering atomization behavior within the engine up to vehicle driveability — has resulted in reduced development times and improved system performance and reliability.

By applying an in-house two-phase-flow chemical-reaction simulation acquired through development of nuclear power plants, Hitachi developed an engine simulator that can calculate and analyze fuel-spray and combustion behavior for different fuel-air mixtures within an engine. Moreover, by linking this simulator with other simulators — such as a simulator for evaluating mobility, mode mileage, and emission, a control-system simulator for evaluating engine control and diagnosis, and a simulator for evaluating catalyst cleansability and burnability — an integrated analysis environment ranging from engine-system behavior up to vehicle characteristics was established (see Fig. 5).

Exploiting these simulation technologies enables us to significantly reduce the manpower needed for trial production, and to assess and verify system performance at the early development stage. This means that development periods for engine-control technologies can be shortened, yet high-quality, high-reliability systems can still be developed.

CONCLUSIONS

This paper introduced the developed technologies of Hitachi Group's port-injection engine-control system and described the main products that make up this system.

From now onwards, Hitachi Group will, as a matter of course, continue to shoulder our social responsibility in terms of meeting emission and fuel-consumption regulations, and we will strive to develop highly practical systems aimed at crisp vehicle driveability and quiet operation. Furthermore, by commercializing systems and parts that will reduce lifetime costs while maintaining high quality, incorporating IT systems produced through the collective strength of Hitachi Group, and promoting cooperation between drive-train and chassis systems, we will provide new technologies and solutions that will contribute to the evolution of the vehicle-oriented society.

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