

Development of IMA System for New CIVIC Hybrid

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ABSTRACT

The 2006 year model CIVIC Hybrid was developed to surpass its former model in both fuel economy and acceleration performance.

The combination of an advanced variable cylinder management system employing 3-stage i-VTEC technology and an IMA motor has resulted in enhanced fuel economy through increased regenerative energy and motor-only operation. A variety of modifications have been made to the IMA components to increase fuel economy and power: Flat wire coils for superior motor torque, modification of current collecting plates in the battery for reduced resistance, and an increased CVT pulley diameter for enhanced capacity and reduced energy loss.

The application of these technologies has achieved both a fuel economy of 31.0 km/L in the 10-15 mode and an acceleration performance of 0-100 km/h in 12.1 seconds.

1. Introduction

Fuel-efficient, low-emission vehicles are attracting increasing attention while the importance of environmental protection increases. Honda has responded by developing hybrid systems in order to increase fuel economy: The ultra-low fuel consumption Insight⁽¹⁾ reached the market in 1999, followed by the CIVIC Hybrid small sedan⁽²⁾ in 2001, and the ACCORD Hybrid⁽³⁾, a medium-size sedan for the US market, in 2004.

With the model change of the CIVIC base vehicle, a new IMA system was also developed for the CIVIC Hybrid. The goals behind the new development were to achieve even higher levels of fuel economy, an important selling point of the CIVIC Hybrid, while also pursuing superb driving performance. This paper discusses the technologies employed to achieve these increases in fuel economy and power.

2. Development Goals

With the aim of balancing fuel economy and driving performance, the targets for the development of the new system were to achieve a fuel economy of more than 30 km/L in the 10-15 mode and an acceleration performance of 0-100 km/h in 12 seconds.

3. System Configuration

The configuration of the complete hybrid system is shown in Fig. 1. Figure 2 shows an external view of the power plant.

The layout of the main components is identical to that of the 2003 year model CIVIC Hybrid ("former model" below): The engine compartment features a thin IMA motor to supply drive power and conduct power regeneration. This IMA motor is sandwiched between the engine and the CVT, while an Integrated Power Unit (IPU), containing high voltage electrical components, including the inverter unit used to drive the motor, a high-voltage battery pack, and an air-cooling system, all which are located in the trunk behind the rear seatbacks. A cable to transmit drive power

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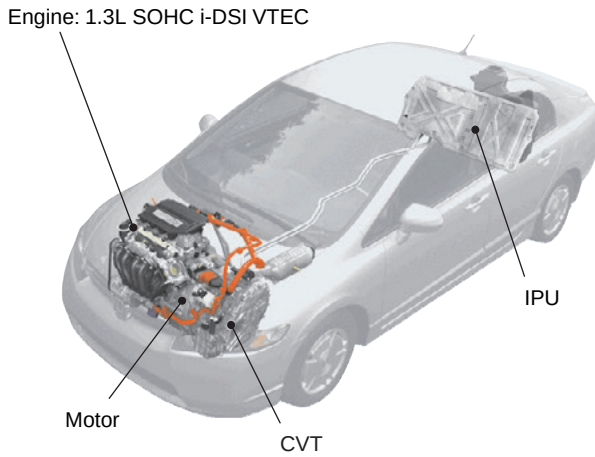


Fig. 1 IMA system configuration

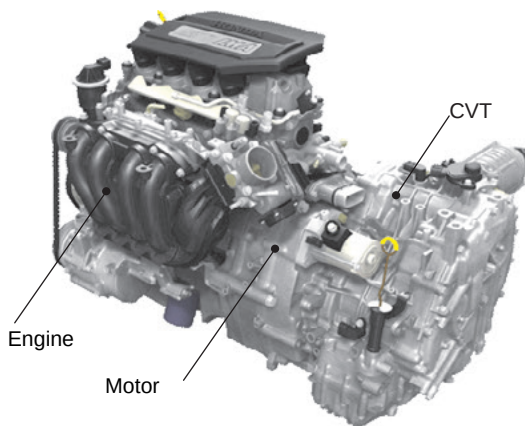


Fig. 2 View of IMA power train

and regenerated energy between the motor and the inverter runs underneath the floor of the vehicle, outside the cabin space.

4. Technologies Employed to Balance Fuel Economy with Driving Performance

4.1. Engine

The assist provided by the motor enables an engine of lower displacement to be used in the CIVIC Hybrid than in the base gasoline vehicle to reduce fuel consumption. The 1.3L SOHC i-DSI engine, with the modified Variable Cylinder Management (VCM) system has been employed in the 2006 year model CIVIC Hybrid.

This system previously deactivated valves in three cylinders to increase the amount of regenerative energy during deceleration, but the new CIVIC Hybrid has been redesigned to deactivate valves in all four cylinders to further reduce pumping loss.

3-stage i-VTEC has been employed to achieve higher power output. The rest of this section will discuss the functioning of the 3-stage i-VTEC mechanism, which an overview is shown in Fig. 3.

The new mechanism features three rocker arms on the intake side (low-speed, high-speed and idling) and two rocker arms on the exhaust side (operation and idling). Three hydraulic channels are used to switch these rocker arms. These enable valve timing and lift to be varied in order to achieve excellent power characteristics from low to high engine speeds, and enable valves

to deactivate as required to provide the optimum engine operating mode. In the new system a high-speed cam has also been employed and the valve diameter has been increased to achieve higher power.

The number of spool valves employed has been increased to two, and the hydraulic channels used for inactive valves have been separated to increase the reliability of reactivation, enabling valves in all the cylinders to be deactivated.

Deactivation of valves in all four cylinders reduces pumping loss as compared to figures when valves are active in all cylinders, and reduces engine friction by a maximum of 66%, as shown in Fig. 4.

4.2. Driving Mode and System Operation

The combination of the 3-stage i-VTEC mechanism and IMA motor in the 2006 year model CIVIC Hybrid enables a variety of operating modes. The optimum deployment of these operating modes in actual driving patterns has enabled engine operation (and thus fuel consumption) to be reduced, it increases the amount of power regenerated during deceleration, and increases the power of the entire power plant, enabling high fuel economy to be reconciled with excellent dynamic performance.

The rest of this section will discuss the operating modes of the

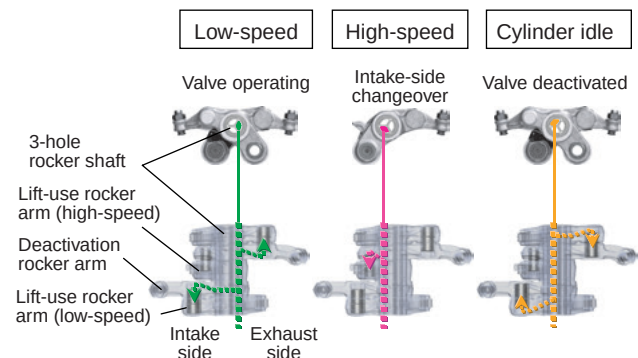


Fig. 3 3-stage i-VTEC mechanism

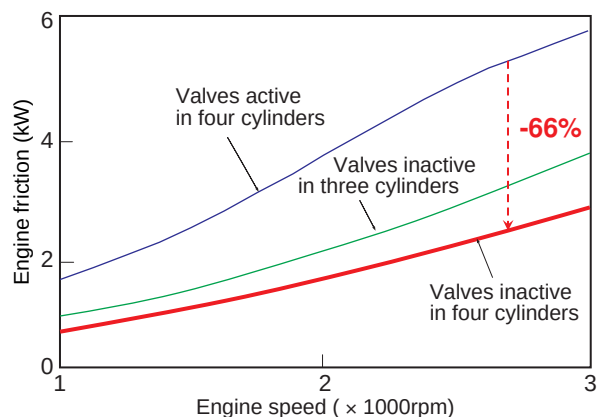


Fig. 4 Engine friction

system, as shown in Fig. 5.

When the vehicle goes from a stationary state (Mode 1) to start-up and acceleration (Mode 2), the IMA motor starts the engine from an idle stop state, and both the engine and the motor supply power to provide sufficient acceleration. When gentle acceleration is sufficient, the system uses Mode 3, and the vehicle accelerates using only the engine. In this mode the motor does not provide or regenerate power, but conducts flux weakening control to reduce running resistance.

When the vehicle has stopped accelerating and is cruising at a low speed, the system enters Mode 4. In this mode, only the motor operates the vehicle, using energy stored in the batteries. The valves in all cylinders are closed and all cylinders become idle, which stops the fuel supply and reduces pumping loss. This reduces running resistance, enabling vehicle operation using the motor only.

When the vehicle accelerates again, the system enters Mode 5, in which the valves become active and both the engine and the motor provide power for acceleration. When rapid acceleration is required at high engine speeds, Mode 6 switches valve operation from the low/medium speed-cam to the high-speed cam, enabling more power to be provided by the engine.

When the vehicle is cruising at high speed, Mode 7 is engaged, and the vehicle is operated using power from the engine only (low-speed cam). In this mode, the motor conducts flux weakening control to reduce running resistance.

When the vehicle decelerates, Mode 8 is engaged. In this mode, the motor regenerates energy, converting kinetic energy into electrical energy to be stored in the battery and employed as a power source when the vehicle is ready for the next accelerating or cruising cycle. Valves of all the cylinders become inactive at this time to reduce pumping loss and increase the amount of energy able to be regenerated.

When the vehicle is stationary (Mode 1), auto idle stop is engaged in order to stop fuel consumption when idling.

This dual combination of an engine which is able to provide

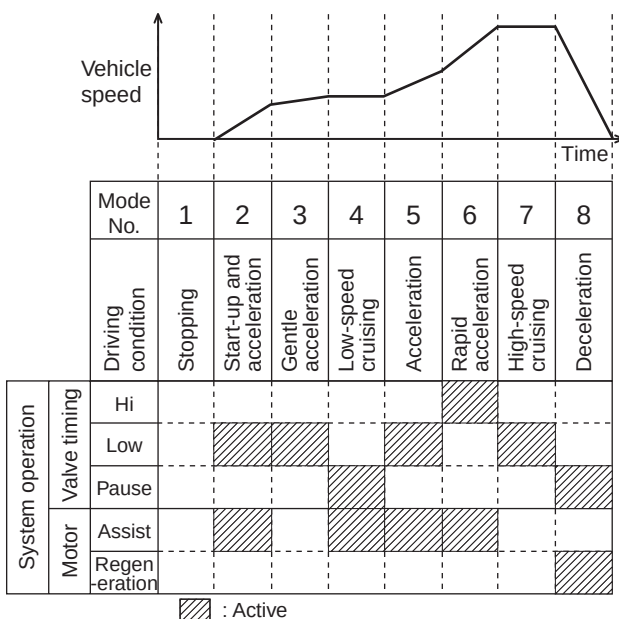


Fig. 5 Characteristics of 3-stage i-VTEC+IMA operation

high power and stable torque from the low-to-high engine speed ranges, and a motor which is able to recover kinetic energy as regenerated power and provide large torque from the ultra-low speed, enables highly efficient and high-power driving modes. These contribute to the balance of fuel efficiency and excellent acceleration achieved by the new CIVIC Hybrid.

4.3. Cooperative Regeneration Brake System

The cooperative regeneration brake system shown in Fig. 6 has been employed in the new CIVIC Hybrid to increase the amount of regenerative energy. This system is composed of a power unit that generates hydraulic pressure to ensure that stable hydraulic pressure is maintained even when the valves of cylinders are inactive, a hydraulic servo and a master cylinder that amplify and transmit the braking pressure applied by the driver, a solenoid valve and a hydraulic pressure sensor to control hydraulic braking power, and an ECU to calculate the required braking force. Apart from the power unit, these components are bundled together as a servo unit and positioned in the engine compartment.

Formerly, only a fixed amount of energy was regenerated with respect to the required braking force as determined by the pressure applied by the driver to the brake pedal, and hydraulic pressure control was employed to enable the shortfall in braking force to be supplemented by the hydraulic brakes. In the new system, control is applied to ensure that the maximum energy regenerated against the required deceleration force is always within the limit of the remaining storage capacity of the battery, and the hydraulic pressure of the brakes is controlled to ensure that the shortfall is made up by the brakes.

The application of this form of control has increased the vehicle energy recovery rate from 38% to 64%.

4.4. High Power Motor

The motor employed in the new CIVIC Hybrid is the same thin DC brushless type⁽⁴⁾ used in the previous model, but with modifications added to the rotor and stator to increase power and torque.

Torque has been increased by replacing the previous surface

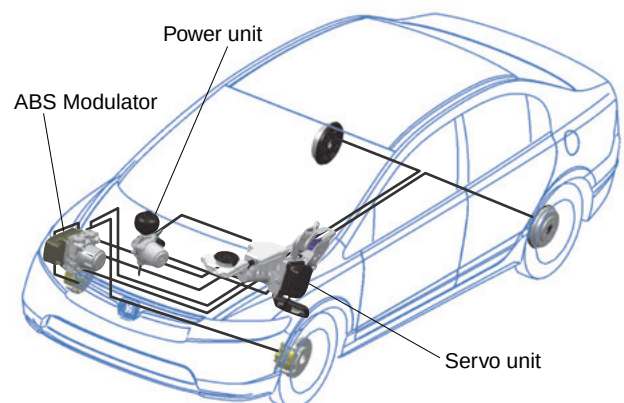


Fig. 6 Cooperative regeneration brake system

permanent magnet (SPM) with an interior permanent magnet (IPM) as shown in Fig. 7, reducing the size of the magnetic air gap and employing a high-performance magnet with high residual flux density.

In the stator, as shown in Fig. 8, the previous round wire coils have been replaced by flat wire coils to increase the space factor, the number of turns has been increased to increase the torque constant and the cross-sectional area of the wire coil has been increased to increase the allowable current. These modifications have resulted in higher torque.

The innovations discussed above have enabled the achievement of a 22% increase in regenerated power and a 14% increase in torque against the previous model with no change in the shape or dimensions of the motor. This has not only enhanced acceleration performance, but has increased the amount of energy that can be regenerated, contributing to increased fuel economy.

4.5. Technology for High Power Battery

The shapes of the current collecting plates in the battery module were modified (Fig. 9). The number of welding points to the electrodes was increased, the size and thickness of the electrodes were optimized and the amount of electrolyte in the electrolytic solution was increased. The reduction in resistance achieved by these methods has increased power density by 25%.

In addition, the number of modules in the battery pack has been increased from twenty to twenty-two. All of these modifications have been made to increase motor power and accommodate increased power regeneration. The use of a staggered module arrangement rather than the previous lattice arrangement has ensured cooling performance in addition to enabling the new model to be as easily installed as the previous model, despite the increase in the number of modules (Fig. 10).

4.6. CVT for High Power

A number of changes were made to the CVT in order to increase fuel economy and power.

The shift ratio range was expanded, and the ratio of the final gear was set high to reduce fuel consumption.

The distance between the axes of the drive and driven pulleys was increased from 143 mm to 156 mm and the diameter of the pulleys was increased to respond to increased power. The drive radius was also increased to enable the pulley clamp hydraulic pressure to be reduced, increasing CVT efficiency and contributing to increased fuel economy.

As a further measure in response to the increased power, the number of plates in the start clutch was increased from four to five to increase torque capacity (Fig. 11).

4.7. Air-conditioning System

Like the 2005 model year ACCORD Hybrid, the air-conditioning system in the new CIVIC Hybrid employs a dual scroll hybrid compressor driven by a DC brushless motor using power supplied by the high-voltage power source in addition to a conventional belt drive. This enables the idle stopping range to be increased for greater fuel economy while maintaining passenger comfort.

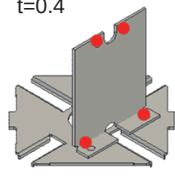
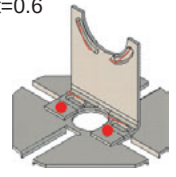
	Conventional	Developed
Collecting plate		
Internal resistance	39.24mΩ	25.2mΩ

Fig. 9 Comparison of battery collecting plates

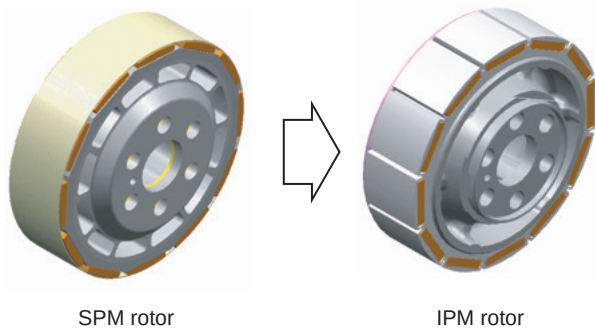


Fig. 7 Electric motor rotor

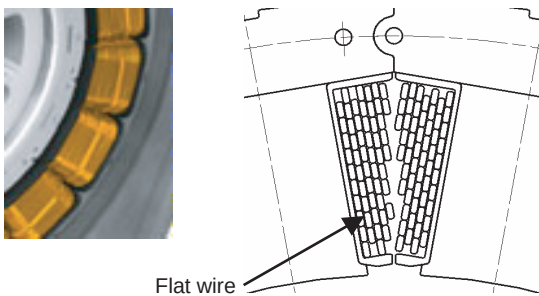


Fig. 8 Electric motor stator

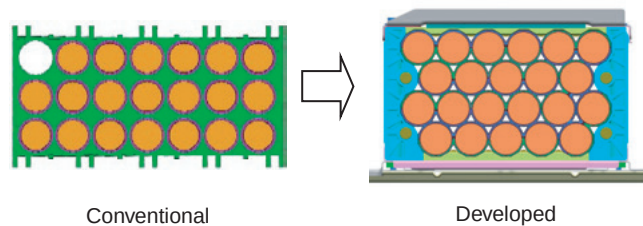


Fig. 10 Comparison of module arrangement

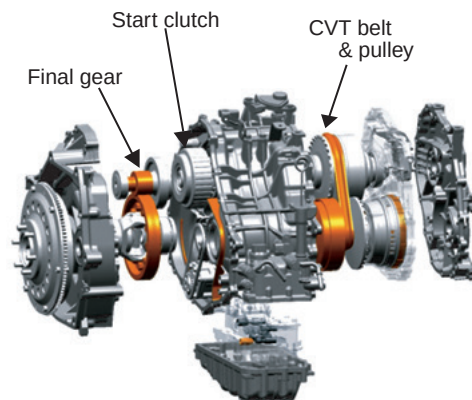


Fig. 11 CVT construction

In addition, an integrated thermo and humidity sensor (Fig. 12) has been used in-cabin, to enable the air-conditioning to be stopped when the temperature is high but humidity is low enough for no discomfort to be felt, or when there is a balance of temperature and humidity inside and outside the vehicle that will not cause the windows to fog, ensuring that passenger comfort is maintained while further increasing fuel economy (Fig. 13).

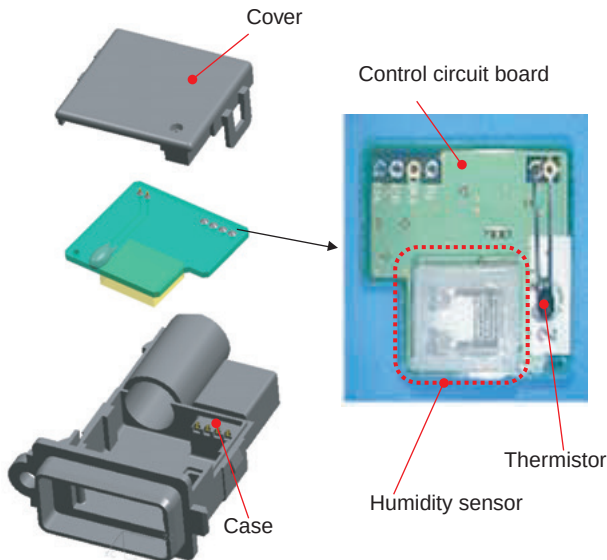


Fig. 12 Thermo & humidity sensor

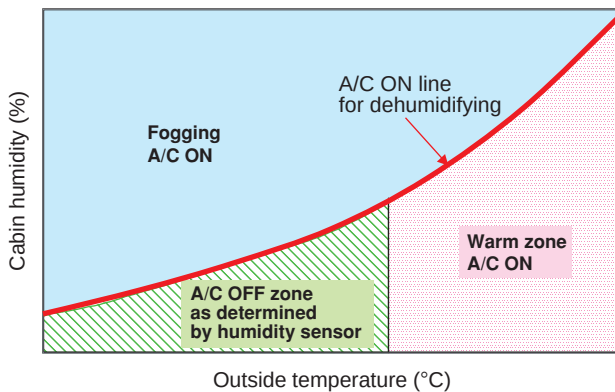


Fig. 13 Air conditioner operational chart

5. Fuel Economy and Driving Performance

The application of the technologies discussed above has resulted in the achievement of a 10-15 mode fuel economy of 31.0 km/L, representing a 5% increase against that of the previous model.

In addition, engine power and torque have been increased to 70 kW (+11%) and 123 Nm (+4%) respectively, and motor power and torque have been increased to 15.5 kW (+50%) and 123 Nm (+14%) respectively, when regenerating. These increases have resulted in the achievement of 0-100 km/h acceleration in 12.1 seconds (Figs. 14, 15).

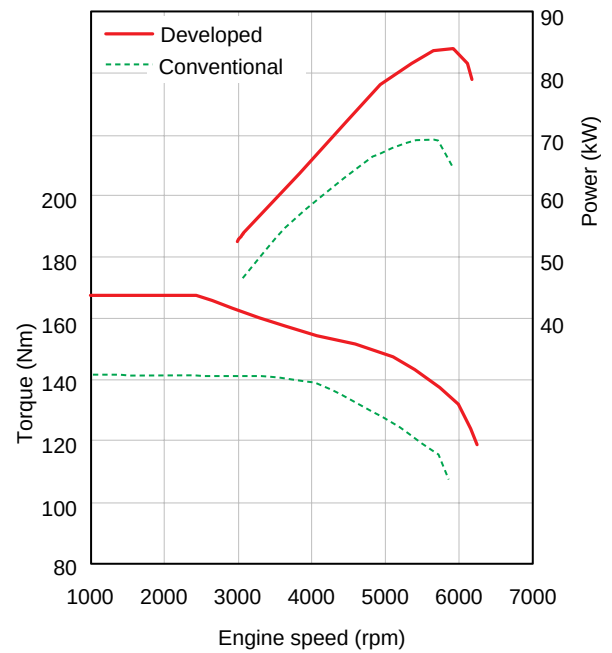


Fig. 14 Output performance of IMA system

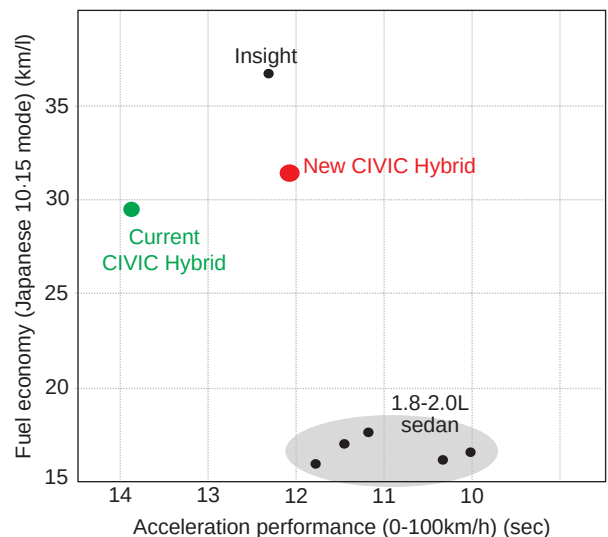


Fig. 15 0-100km/h performance/Fuel economy

6. Conclusion

The following technologies have been employed in the development of the 2006 year model CIVIC Hybrid in order to balance fuel economy and driving performance:

- (1) 3-stage i-VTEC has reduced pumping loss and increased engine power in the high-speed range.
- (2) Valves deactivation in all 4-cylinders has increased the amount of energy regenerated and enabled cruising on motor power.
- (3) A cooperative regeneration brake system has increased the amount of energy that is regenerated.
- (4) Modifications have been made to the components of the motor, battery and CVT to increase power and to respond to an increase in the amount of regenerated energy.
- (5) The use of a hybrid air-conditioner has enabled the range of the idle stop mechanism to be increased, and by adding air-conditioner control, employing a humidity sensor, the range in which the air-conditioner can be stopped has been increased.

As a result of the application of these technologies, the new CIVIC Hybrid has achieved an excellent balance between fuel economy and driving performance, with 31.0 km/L fuel economy in 10-15 mode (+5% against the previous model) and 0-100 km/h acceleration in 12.1 seconds (-1.8 seconds against the previous model).

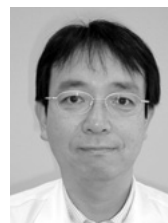
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