

Development of New 2.0 L Gasoline Engine for Accord Hybrid

Akiyuki YONEKAWA*

Osamu WATANABE*

Noritaka SEKIYA*

Naohiro ISHIKAWA*

ABSTRACT

We developed a new 2.0 L gasoline engine for an Accord hybrid. This engine achieved remarkable fuel efficiency, and complied with the SULEV20 regulation for the first time in the world for an Accord plug-in hybrid in North America. The mechanical compression ratio was set to 13 and improvement in thermal efficiency was aimed at by adopting the Atkinson cycle and cooled EGR. Applying a VTEC system to the intake valve-train, we set up the output cam and the fuel economy cam. The output cam has narrow duration and is used as needed at the time of starting and high-output. The fuel economy cam has wide duration and is used during normal driving. By controlling air-intake closed-valve timing in combination with VTC, the fuel economy cam can acquire the maximum effect of the Atkinson cycle. The minimum specific fuel consumption attained was 214 g/kWh, equaling a 10% improvement in fuel consumption compared to the mass-production 2.0 L engine.

Moreover, we also aggressively tackled engine weight saving. A lightweight forged crankshaft was adopted, and the piston design was optimized, and lightweight press-type rocker arms were applied to the exhaust valve-train. As a result, the newly developed DOHC engine attained 4.7% weight savings over the mass-production 2.0 L SOHC engine.

1. Introduction

In the evolution of global motorization, providing products that are considerate of the environment is a responsibility of automobile companies. Each manufacturer performs various approaches for reduction of the CO₂ discharged from a car, such as fuel cell electric vehicles (FCV), electric vehicles (EV), hybrid electric vehicles (HEV), and the use of downsized turbocharged engines. Honda has been selling HEV that have Integrated Motor Assist (IMA) systems. This system has the advantages of being simple, compact and lightweight, and suitable for small cars. At the end of 2012, Honda announced the Accord plug-in hybrid, a vehicle fitted with a new two-motor hybrid system. This system increases motor power, and can be applied in medium-sized vehicles. A new 2.0 L gasoline engine was developed simultaneously in order to improve fuel efficiency⁽¹⁾. This paper will discuss the main technologies employed in the new engine, in addition to weight-saving measures and electric VTC.

2. Development Goals

The following aims were set for the development of an exclusive engine for a hybrid car.

- (1) Low fuel consumption: Improved fuel efficiency in the hybrid operating range
- (2) Reduced weight: Weight equivalent to or less than a mass-production SOHC 2.0 L engine despite changing to DOHC
- (3) Emission performance: Conformity with SULEV 20 standard of the plug-in hybrid (PHEV) specification for the North American market
- (4) Quietness: Equivalent NV performance to an upper-mid-class sedan

3. Main Specifications and Performance

3.1. Engine Specifications

Figure 1 shows an external view of the newly developed engine, and Table 1 compares its specifications with those of a mass-production 2.0 L engine. The new engine is DOHC, and has a VTEC system and electric valve timing control (EVTC) on the intake side. For the exhaust side, we adopted press-type rocker arms with Hydraulic Lash Adjusters (HLA). Since it is lightweight, it was possible to set high positive acceleration of the valve lift curve, thus reducing loss in the expansion stroke. A high-tumble port has been employed in order to realize stable EGR combustion, and the intake valves have been increased in diameter by 1 mm in order to make

* Automobile R&D Center

Table 1 Engine specifications

Engine Type	Developed	Current
Cylinder configuration	Inline 4	Inline 4
Bore x Stroke (mm)	81 × 96.7	81 × 96.9
Displacement (cm ³)	1993	1998
Valvetrain (intake)	VTEC and E-VTC	VTEC
Valvetrain (exhaust)	Finger rocker arm (with HLA)	Rocker arm (with rocker shaft)
Number of valves	4	4
Valve diameter (mm) Intake/exhaust	33/26	32/26
Cylinder offset (mm)	6	12
Crank journal diameter (mm)	50	55
Compression ratio	13.0	10.6
EGR system	Cooled	Hot
Water pump	Electric	Mechanical
Fuel injection type	Port injection	Port injection
Fuel	Regular	Regular
Maximum power	105 kW	115 kW
Maximum torque	165 Nm	192 Nm
Emission regulation	SULEV20	EURO5

up the decline in the flow coefficient. The cylinder offset has been modified, and the height of the cylinder block has been reduced in order to reduce weight. The diameter of the crank journal has been reduced in order to reduce friction and weight. The compression ratio was set to 13, and applied the Atkinson cycle and cooled EGR. The use of an electric water pump and the removal of the accessory belt have reduced friction loss. With consideration of a balance between cost and fuel efficiency, a port injection system was chosen.

3.2. Power Performance

Figure 2 shows the power performance of the engine. The engine realizes a maximum power of 105 kW at 6200 rpm and a maximum torque of 165 Nm at 4500 rpm.

3.3. Fuel Consumption Performance

Figure 3 shows the distribution of brake specific fuel consumption (BSFC). The yellow line shows operation in



Fig. 1 New 2.0 L gasoline engine for Accord Hybrid

hybrid drive mode, and the area surrounded by the white broken lines is the engine drive mode operation area⁽²⁾. The engine achieves a BSFC of 214 g/kWh at an operating point of 2500 rpm/120 Nm. In addition, in comparison of BSFC in equivalent horsepower to a mass-production 2.0 L engine, it increased by 10% across the entire operating range (Fig. 4).

3.4. Emissions Performance

Figure 5 shows the new engine's exhaust system. The engine uses a new control⁽¹⁾ that utilizes the characteristics of the hybrid system in order to efficiently warm up the two catalysts by adjusting the amount of power generated after engine start. Feed emissions are also reduced to a low level through the use of output cams with narrow opening angles at engine start. As a result, the PHEV specification for the North American market is the first vehicle to conform to the SULEV 20 standard (Fig. 6).

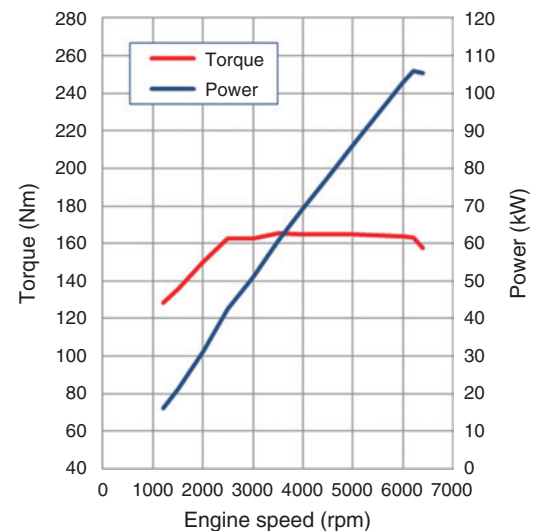


Fig. 2 Engine performance

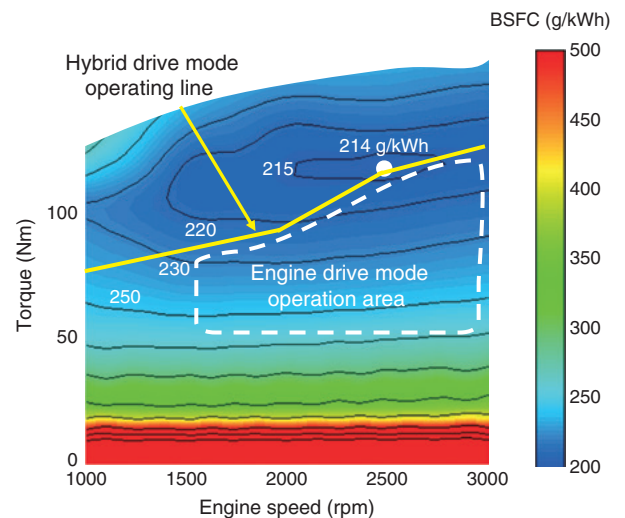


Fig. 3 Fuel consumption performance

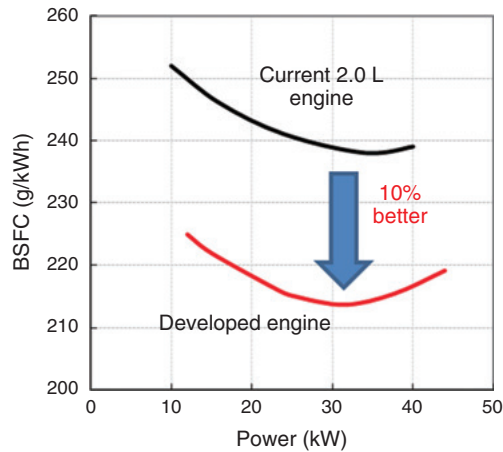


Fig. 4 Improvement of fuel consumption

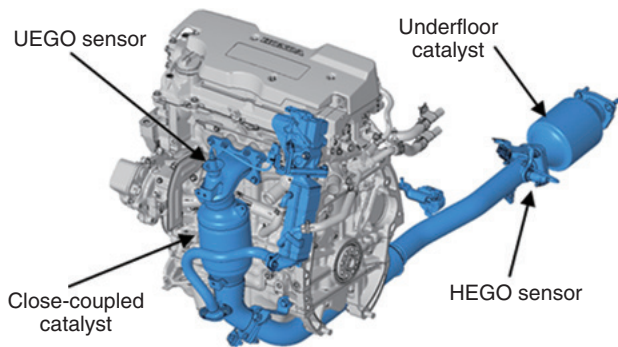


Fig. 5 Exhaust system

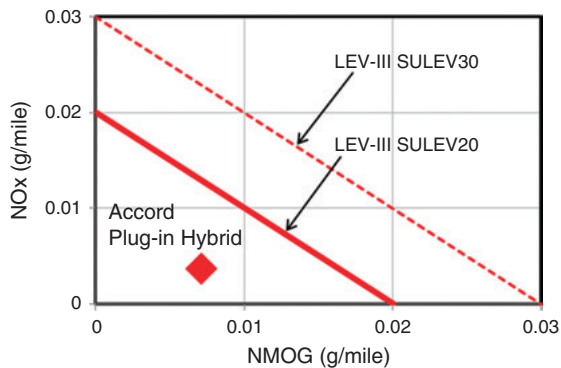


Fig. 6 SULEV20 regulation and emission performance

4. Main Engine Technologies

4.1. VTEC

Figure 7 shows the configuration of the VTEC system used in the intake-side valvetrain. The system uses three cams and three rocker arms for each cylinder. The two cams at the sides (shown as blue) are called output cams, and the center cam (shown as green) is called a fuel economy (FE) cam. When the output cams are in operation, the synchronized pins are not engaged, and the rocker arms

act independently. When the FE cams are in operation, the synchronized pins are engaged, and the rocker arms are coupled by the pins. In order to make it possible to switch between output and FE cam operation in the low-speed range, the system uses a form of VTEC in which both the engaged and non-engaged states of the synchronized pins are controlled by oil pressure⁽³⁾.

Figure 8 shows the valve lift curve when the output cams and the FE cam are in operation, and Fig. 9 shows the operating ranges of the cams. The opening angle of the output cams is narrow, 196° in the 1 mm and higher lift range, and these cams are used at loads close to wide-open throttle and at engine start. The opening angle of the FE cams is wide, 240° in the 1 mm and higher lift range, and these cams are used in operating states where fuel efficiency is demanded.

4.2. Cooled EGR

The high-load range, in which BSFC is low, is the main operating range for engines used in series hybrid vehicles. This makes it expedient to use cooled EGR,

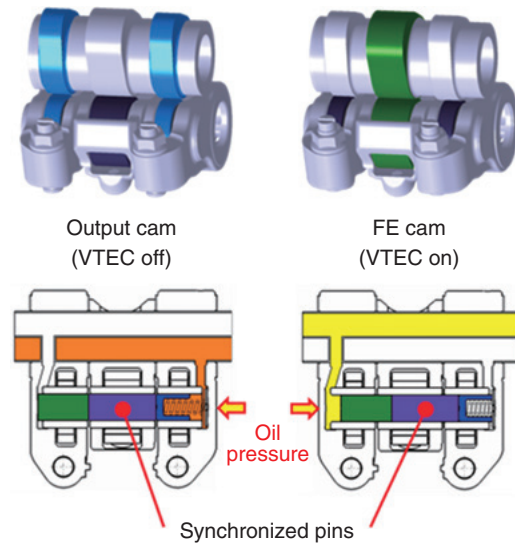


Fig. 7 VTEC structure and pin action

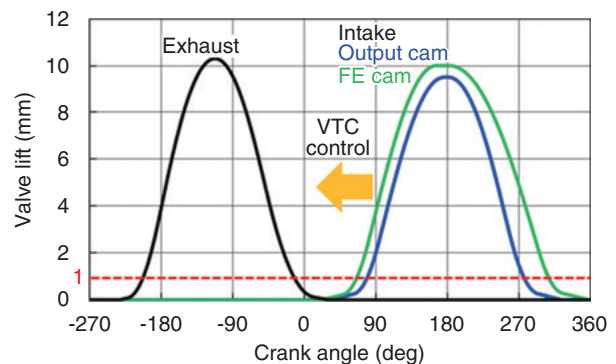


Fig. 8 Valve timing

which makes it possible to reduce knocking, in order to improve fuel efficiency⁽⁴⁾. However, cooled EGR slows down combustion, and can result in a decline in combustion stability. A high-tumble port was used in the new engine in order to increase combustion speed and assist in controlling these effects (Fig. 10). The shape of the side of the port was modified and an edge shape added to the lower section in order to strengthen tumble flow by helping to ensure that the main flow occurred on the exhaust side of the combustion chamber. Figure 11 shows simulation results

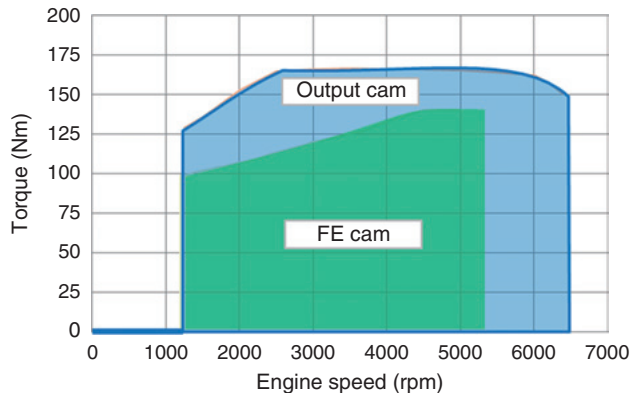


Fig. 9 VTEC operation

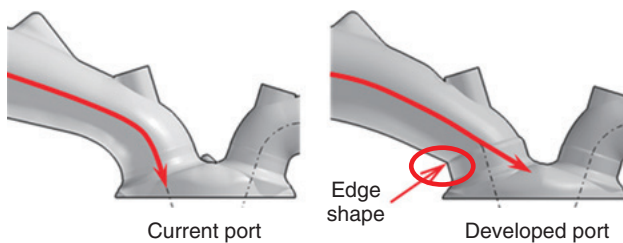


Fig. 10 High-tumble port shape

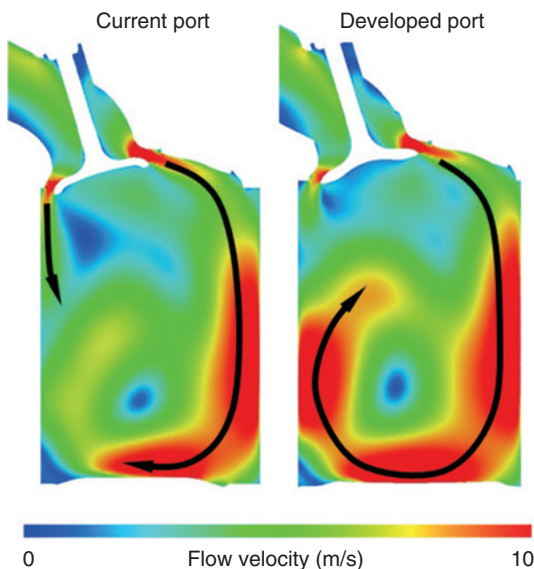


Fig. 11 Flow simulation result

for the flow in the cylinders. The results show that the flow from between the valves along the wall on the intake side has been reduced. In addition, the edge shape separates the flow, with the result that the main flow flows strongly along the exhaust side, creating a strong tumble flow within the cylinder. As a result, the tumble ratio has increased from 0.73 to 1.40. Figure 12 shows the results of tests to verify the effect of the new port. The increased combustion stability realized by means of the high-tumble port has resulted in reduced covariance in indicated mean effective pressure (IMEP). The innovations applied to the new port have helped to achieve a 5 g/kWh reduction in indicated specific fuel consumption (ISFC).

4.3. Weight Reduction Technologies

The reduction of weight is also an important element in increasing automotive fuel efficiency. Hybrid vehicles are fitted with heavy batteries, increasing the importance of reducing weight in other areas. The reduction of weight was therefore also focused on in the development of the new engine.

4.3.1. Crankshaft

As Fig. 13 shows, an extra angled forging process has been applied to the crank counterweights in order to form a dent shape. This is the first time this technology has been applied. This has realized a weight savings of 3.7 kg in combination with the reduction of the journal diameter from 55 mm to 50 mm and the reduction of the number of counterweights from eight to four.

4.3.2. Pistons

Since assistance by a motor can be used in a hybrid car, the output torque required of an engine could be low as that of the same displacement gasoline engine. As a

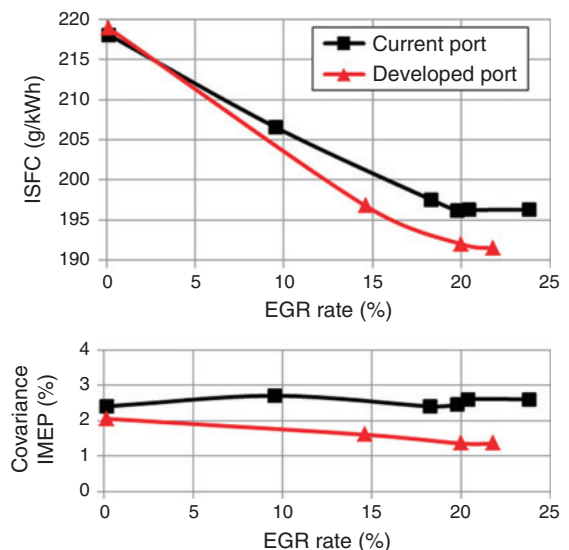


Fig. 12 Effect of high-tumble port

result, the maximum pressure in the cylinders can be set up lower. Pressure has been reduced from 7.9 MPa in the mass-production 2.0 L engine to 5.6 MPa in the developed engine. The compression height and piston pin diameter and length were newly set based on this characteristic, resulting in a weight savings of approximately 61 g per cylinder and 246 g for the entire engine (Fig. 14). The weight savings achieved in this section also contributed to improved fuel efficiency through reduced friction.

4.3.3. Exhaust-side sheet-metal rocker arms

To reduce weight and to assist in maximizing the effect of the Atkinson cycle achieved through lift curve settings, HLA and sheet-metal rocker arms were employed in the exhaust-side valvetrain (Fig. 15). This type of valve train is 1.3 kg lighter than Honda's conventional rocker shaft-type valve train.

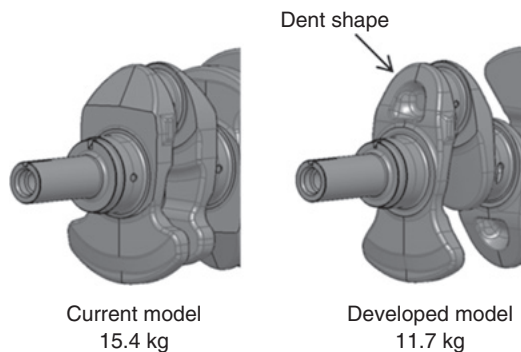


Fig. 13 Crankshaft design

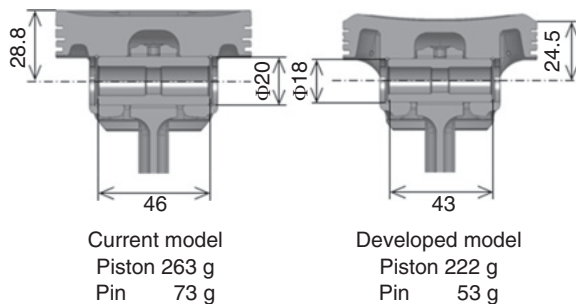


Fig. 14 Piston design

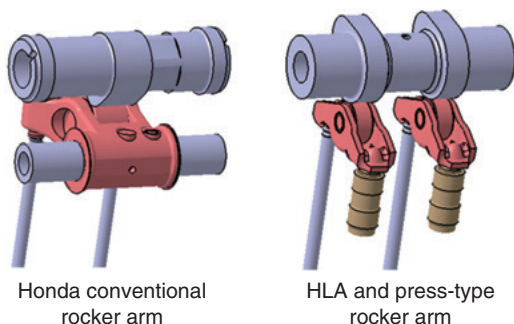


Fig. 15 HLA and rocker arm

4.3.4. Electric water pump

The use of an electric water pump (Fig. 16) has made it possible to do away with the accessory belt, reducing weight by 1.3 kg.

The technologies described above have reduced the weight of the engine by 4.7% against the previous engine, despite changing to DOHC.

4.4. Electric VTC

The developed engine employs idling-stop in order to improve fuel efficiency. However, because the mechanical compression ratio is high at 13, a significant amount of vibration was generated by compression pressure during cranking when the engine is restarted using the output cams, and this had a negative impact on NV performance. Retarding the intake valve close-timing (IVC) at engine start is an effective means of addressing this issue, therefore electric VTC was applied in the new engine. Figure 17 shows the operation and effect of electric VTC.

Figure 17 shows the rise in engine speed at IVC 76 deg (red) and IVC 96 deg (blue). At IVC 76 deg, vibration generated in the resonance range at under 600 rpm continues over 600 rpm. By contrast, at IVC 96 deg, engine speed increases smoothly. This indicates that the cause of the decline in NV performance at engine start is the powertrain torsional mode that occurs under 600 rpm. Modifying the resonance frequency by means of structural measures is too difficult, so the source of the vibration was controlled by means of decompression through retardation of the IVC. Next, the details of the method are described.

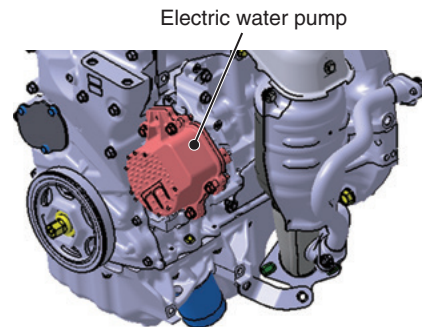


Fig. 16 Electric water pump

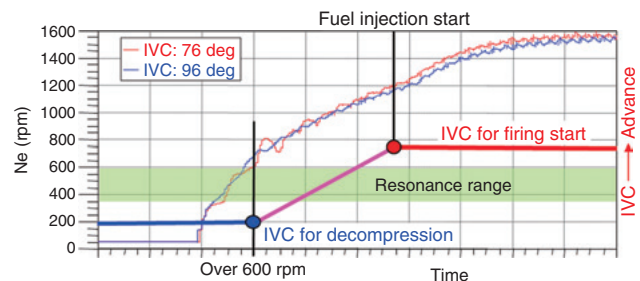


Fig. 17 Effect of electric VTC

When the engine is stopped, VTC maximally retards the IVC (96 deg) and waits for engine restart. When the engine exceeds 600 rpm, which is beyond the resonance range, VTC advances the IVC to 76 degrees for the initiation of fuel injection. These operations control the source of vibration, making it possible to realize the necessary NV performance.

Because this series of operations takes place before the increase in engine speed, it would be challenging to realize using a standard oil pressure-type VTC. The application of electric VTC has made it possible to realize the high level of NV performance demanded from an upper-mid-class sedan, without sacrificing power or emissions performance.

5. Conclusion

The application of the technologies discussed above has resulted in the development of a competitive engine for use in a hybrid system. The development can be summarized as follows:

- (1) The application of the Atkinson cycle and cooled EGR, in combination with VTEC, has made it possible to realize a maximum power of 105 kW and a BSFC of 214 g/kWh (a 10% improvement over the previous engine).
- (2) The application of weight-saving technologies including a forged crankshaft has reduced the weight of the developed engine by 4.7% against the previous engine despite changing to DOHC.
- (3) The PHEV specification for the North American market is the first vehicle to conform to the SULEV 20 standard.
- (4) The application of electric VTC and the retardation of IVC in order to reduce vibration at engine start made it possible to realize the high level of NV performance demanded from an upper-mid-class sedan, without sacrificing power or emissions performance.

References

- (1) Yonekawa, A., Ueno, M., Watanabe, O., Ishikawa, N.: Development of New Gasoline Engine for ACCORD Plug-in Hybrid, SAE Technical Paper 2013-01-1738 (2013)
- (2) Higuchi, N., Sunaga, Y., Tanaka, M., Shimada, H.: Development of a New Two-Motor Plug-In Hybrid System, SAE Technical Paper 2013-01-1476 (2013)
- (3) Okui, S., Kishi, T., Ishikawa, N., Hanada, K.: Development of 3-stage i-VTEC VCM Engine for CIVIC Hybrid, Honda R&D Technical Review, Vol. 18, No. 2, p. 44-51
- (4) Kawamoto, N., Naiki, K., Kawai, T., Shikida, T., Tomatsuri, M.: Development of New 1.8-Liter Engine for Hybrid Vehicles, SAE Technical Paper 2009-01-1061 (2009)

■ Author ■



Akiyuki YONEKAWA



Osamu WATANABE



Noritaka SEKIYA



Naohiro ISHIKAWA