

Development of i-VTEC Gasoline Engine for 2008 Model Year Honda FIT

Ryutaro TAGISHI*

Tsutomu SATO*

Hiroshi KAWAGUCHI*

Yoshiharu HAGIWARA*

ABSTRACT

Lightweight, compact 1.3-L and 1.5-L 4-cylinder SOHC i-VTEC gasoline engines were developed that achieve a balance of environmental performance (low fuel consumption, low exhaust emissions) and high output. The 1.3-L model employs a 4-valve cylinder head, VTEC that operates with one intake valve inactive for rapid combustion, and friction reduction technology. As a result, it achieves 24-km/L fuel consumption in 10-15 mode as well as high power with 73 kW of maximum output and 127 Nm of maximum torque. The 1.5-L model has a high-output VTEC for a maximum output of 88 kW and maximum torque of 145 Nm, the same friction reduction technology as that of the 1.3-L model, and achieves 19.6 km/L fuel consumption in 10-15 mode. The technology for low exhaust emissions includes a close-coupled catalyst, high-accuracy adaptive air-fuel control, and a cylinder head with integrated exhaust manifold, the same as that employed in the CIVIC. As a result, using the 10-15 and JC08C mode, the engines to be used in all 2008 FIT models have achieved an emissions level 75% below the level required by Japanese 2005 regulations.

1. Introduction

The development of technology to lower exhaust emissions in order to protect the environment and the development of technology to lower fuel consumption in order to reduce CO₂, which is a causal factor in global warming, have taken on growing importance in recent years. The technology adopted to address these requirements was the L13A 1.3-L 4-cylinder SOHC 2-valve dual and sequential ignition (i-DSI).⁽¹⁾ Installed on the engine for the 2002 model year Fit, this uses two spark plugs for each cylinder and controls the timing of the spark according to the engine operating conditions in order to achieve rapid combustion. The 1.5-L model added in 2003 adopted the L15A 1.5-L 4-cylinder SOHC 4-valve VTEC (VTEC that operates with one intake valve inactive), which controls the amount of lift on one intake valve in the low-speed range to achieve rapid combustion. The 1.3-L i-DSI is a 2-valve type, however, and although it provides lower fuel consumption through rapid combustion, there was demand for higher output for greater appeal as a product. There was also demand for still better drive performance in the 1.5-L model. These demands were met by the development of a new model

engine for the 2008 model year FIT with a 4-valve head common to the 1.3-L and 1.5-L versions to achieve higher output. The new engine also balances that with low fuel consumption by the application of friction reduction technology and combustion enhancement technology. The following report describes the technology adopted for the new model engine, with a focus on the 1.3-L version.

2. Development Goals

The distinctive characteristics of this engine were clearly identified in terms of the engine displacement as 1.3-L for fuel consumption and 1.5-L for driving, and the specific development objectives were set as follows:

1.3-L development objectives

- (1) Fuel consumption of 24-km/L in 10-15 mode to put it at the top of its class
- (2) High output and high torque at the top level in its class

1.5-L development objectives

- (1) High output at the top level in its class
- (2) Higher performance in fuel consumption of 19.6 km/L in 10-15 mode

* Automobile R&D Center

Table 1 1.3L engine specification

	2008 model FIT	2002 model Fit
Engine code	L13A (Developed)	L13A (Conventional)
Cylinder configuration	In-line 4-cylinder	In-line 4-cylinder
Bore × stroke (mm)	73.0 × 80.0	73.0 × 80.0
Displacement (cm ³)	1339	1339
Compression ratio	10.5 : 1	10.8 : 1
Valve train	SOHC i-VTEC 1 intake valve inactive	SOHC i-DSI
Number of valves	4 per cylinder	2 per cylinder
Valve diameter (mm)	In. 28 × 2	32 × 1
	Ex. 23 × 2	28 × 1
Gasoline	Regular (RON91)	Regular (RON91)
Max. power (kW/rpm)	73 / 6000	63 / 5700
Max. torque (Nm/rpm)	127 / 4800	119 / 2800

3. 1.3-L i-VTEC

3.1. Overview of Engine and Major Specifications

Table 1 shows the major specifications of the 1.3-L engine in comparison with the previous model.

The distinctive features of this engine are the higher output that has been achieved by adopting a 4-valve cylinder head as opposed to the 2-valve i-DSI, and the lower fuel consumption achieved by adopting enhanced combustion technology, including VTEC that operates with one intake valve inactive, and friction reduction technology.

3.1.1. Cylinder head

The new model engine adopted a 4-valve cylinder head to raise intake efficiency at high speeds in order to achieve higher output. Figure 1 shows a section view of the cylinder head. The cylinder head is of the exhaust manifold-integrated type that is intended to yield faster light-off of the catalyst by reducing the heat mass of the exhaust system up to the catalyst. This structure constitutes technology that was applied to the 2006 model year CIVIC.⁽²⁾

The basic structure of the valve assembly is as shown in Fig. 2. Like the previous model, this engine has one rocker shaft, and that single shaft supports two aluminum rocker arms on the intake side and two on the exhaust side.

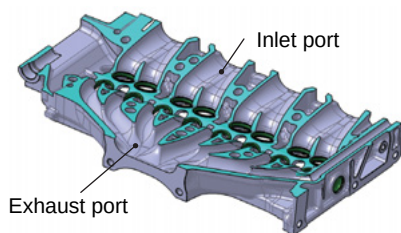


Fig. 1 Section view of exhaust manifold-integrated cylinder head

3.1.2. Intake system and exhaust system

The configuration of the intake system is shown in Fig. 3. It is equipped with an electronically controlled throttle (drive by wire: DBW) and an air flow meter (AFM) to implement highly precise torque control and air-fuel ratio control when the intake air volume fluctuates, such as, for example, when the engine shifts from operation with one intake valve inactive to operation with two valves. The engine also has an intake manifold chamber made of plastic that has been integrated with a resonator for better torque, as well as an intake manifold made of aluminum with a built-in EGR passage, contributing to a reduction in weight.

Figure 4 shows the configuration of the exhaust system. This employs an exhaust manifold-integrated cylinder head with one catalytic converter containing a three-way catalyst located directly under the cylinder head, thus reducing the heat mass of the exhaust system up to the catalyst in order to yield faster light-off of the catalyst. The air-fuel ratio controllability has also been enhanced by placing a universal exhaust gas oxygen (UEGO) sensor

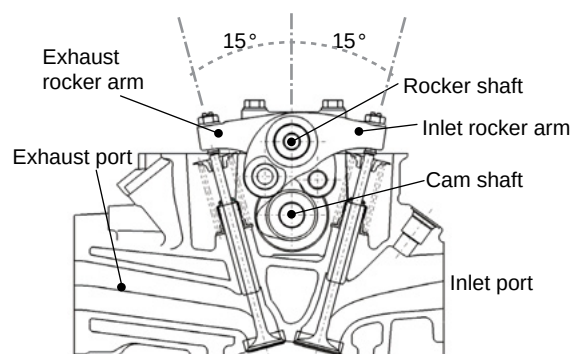


Fig. 2 Section view of exhaust manifold-integrated cylinder head

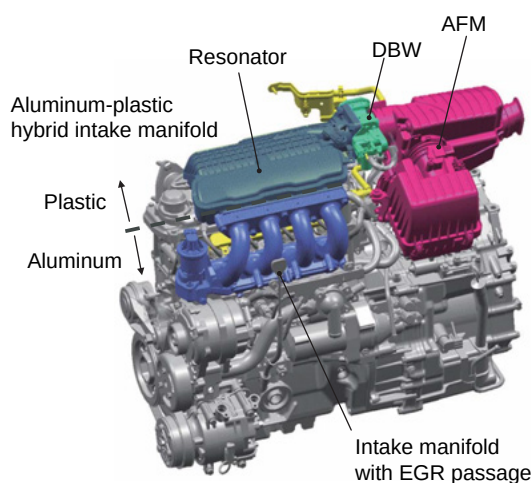


Fig. 3 Configuration of air intake system

upstream from the close-coupled catalyst and a heated exhaust gas oxygen (HEGO) sensor upstream from the under-floor catalytic converter. This provides more precise control of air-fuel ratio, which has reduced exhaust emissions.

3.2. Fuel Consumption Enhancement Technology

The application of combustion enhancement technology, friction reduction technology, and knocking reduction technology have resulted in a reduction of approximately 5% in engine standalone fuel consumption relative to the previous model.

3.2.1. Combustion enhancement technology

Adoption of the combustion enhancement technologies shown below resulted in a reduction of approximately 2% in engine standalone fuel consumption relative to the previous model.

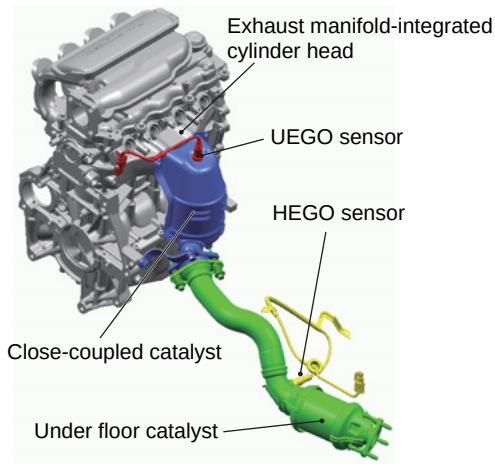


Fig. 4 Configuration of exhaust system

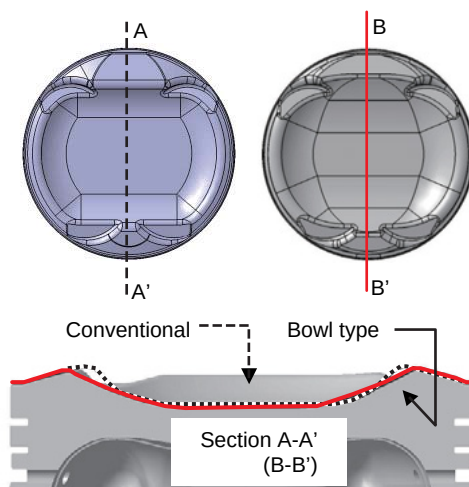


Fig. 5 Comparison of conventional and modified top form of piston

- Optimization of piston top shape
- Adoption of VTEC that operates with one intake valve inactive
- High-ignitability spark plugs

- (1) Optimization of piston top shape: The combustion chamber was made more compact and the in-cylinder flow was strengthened in order to enhance combustion. The shape of the piston top was optimized for this purpose. Figure 5 shows the piston top shape compared with the previous model. The top of the piston has been given a more bowl-type shape than the piston in the previous model. This shape provides an advantage in generating a tumbling flow while simultaneously reducing the surface area of the combustion chamber. Figure 6 shows the heat balance resulting from different piston top shapes with the engine at 1500 rpm and BMEP of 175 kPa. The adoption of a bowl-type shape has brought about a reduction in time loss and heat loss, and enabled a decrease of approximately 0.7% in fuel consumption.
- (2) VTEC that operates with one intake valve inactive: Intensifying the swirling flow is effective in enhancing combustion stability and ignitability during EGR. The adoption of four valves, however, reduces the swirling flow relative to the previous two-valve model, and this reduces the EGR flow volume that can be recirculated. This engine employs VTEC that operates with one intake valve inactive to reinforce swirling, thus assuring combustion stability during EGR. Figure 7 shows the valve timing characteristics and the calculated results for turbulence energy inside the cylinder resulting from differences in valve timing characteristics with the engine operating at 1500 rpm and intake manifold pressure of -45 kPa. The previous 1.5-L model already employed

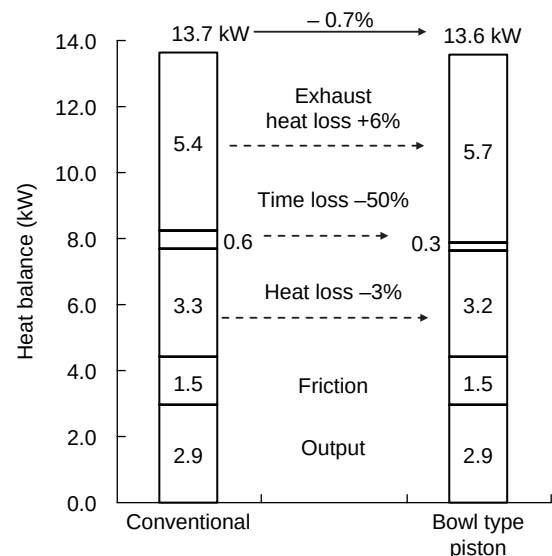


Fig. 6 Comparison of heat balance at partial load

VTEC that operates with one intake valve inactive, but in the new model engine, the inactive valve cam phase was retarded 20° relative to the previous model in order to strengthen the in-cylinder flow. The amount of lift in the inactive valve is reduced at a crank angle of around 90° , when the piston speed is at a maximum, and this increased turbulence energy inside the cylinder. An increase of approximately 5% in turbulence energy was also obtained at a crank angle of around 320° , where ignition occurs. Figure 8 shows the results of testing for fuel consumption and combustion stability during EGR with the engine operating at 1500 rpm and BMEP of 175 kPa. Combustion stability during EGR was enhanced, and a reduction of approximately 1% in fuel consumption was attained.

The switch between operating with one valve inactive and operating with four valves is controlled by the engine speed and load. In the normal operating range, the engine will operate with one valve inactive and EGR will be used to lower fuel consumption. In a range where torque is needed, it will switch over to four-valve operation.

3.2.2. Friction reduction technology

The following technologies were adopted for friction reduction, yielding a reduction in friction of approximately 7% relative to the previous model.

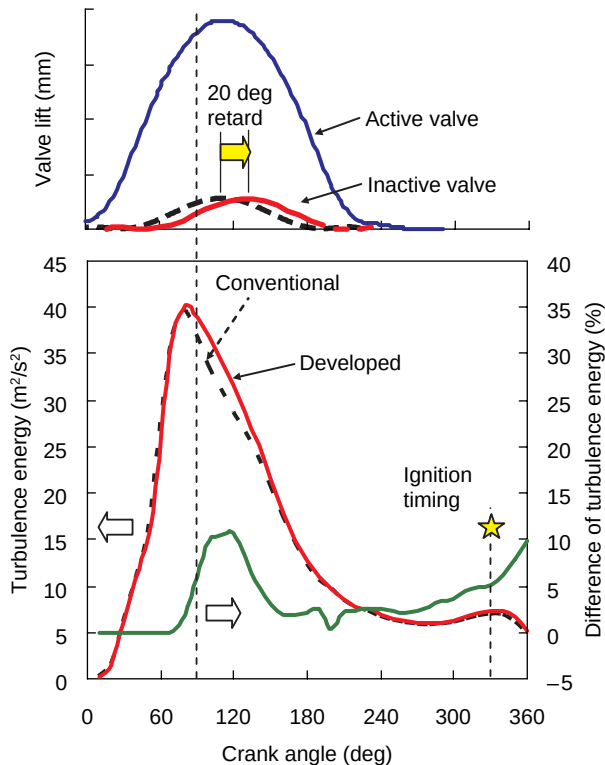


Fig. 7 Effect of inactive valve timing on turbulence energy in combustion chamber

- Pattern coating of molybdenum disulfide on the piston skirts
- Optimization of the piston skirt shape
- Reduction of piston ring tension
- Crank journal bearing metal treated by shot peening and application of molybdenum disulfide
- Plateau honing of cylinder liners
- Cam chain width made narrower
- Cam journal surface roughness reduced
- Accessory belt auto-tensioner

Figure 9 shows the side view of a piston that has had pattern coating applied to the piston skirt portion. Pattern coating is a technique for creating circular pits and bumps in a lattice pattern when applying a molybdenum disulfide coating to the piston skirt. This increases oil retention and reduces piston sliding resistance. The pits are distributed with reference to pit diameter and intervals in order to reduce the coefficient of friction. Figure 10 shows the results of friction testing with the engine operating at 1500 rpm and intake manifold pressure of -45 kPa. A friction reduction of 2% was obtained relative to molybdenum disulfide coating without patterning, and a friction reduction of 1% relative to shot peening and application of molybdenum disulfide, as used on the previous model.

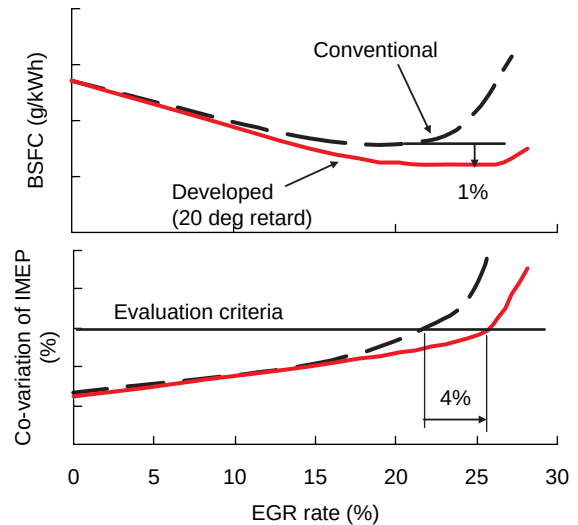


Fig. 8 Effect of inactive valve timing for BSFC and co-variation of IMEP

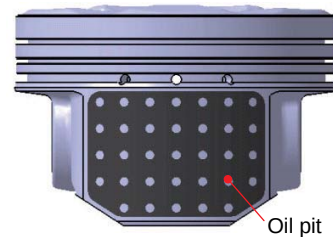


Fig. 9 Pattern coating for piston skirt

3.2.3. Knocking control technology

The frequency of operation in the high-load range becomes higher for smaller displacement engines, for which control of knocking therefore becomes an important concern associated with the reduction of fuel consumption. The previous model used i-DSI with two spark plugs per cylinder to control knocking. With the adoption of four valves, however, the number of spark plugs was reduced to one, so that control of knocking increased in importance. The following knocking control technologies were applied:

- Bowl-type piston
 - Optimization of coolant circulation path
- (1) Piston top shape: The use of a bowl-type shape on pistons to strengthen the in-cylinder flow is also effective for knocking control. Figure 11 shows the calculated results from simulation of turbulence energy inside the cylinder due to differences in the piston top shape with the engine

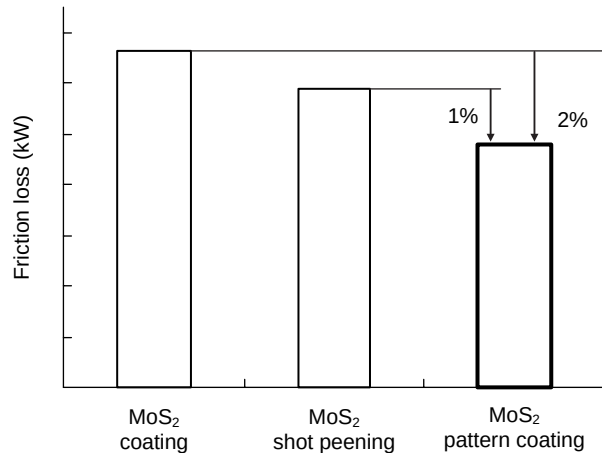


Fig. 10 Effect of pattern coating on friction loss

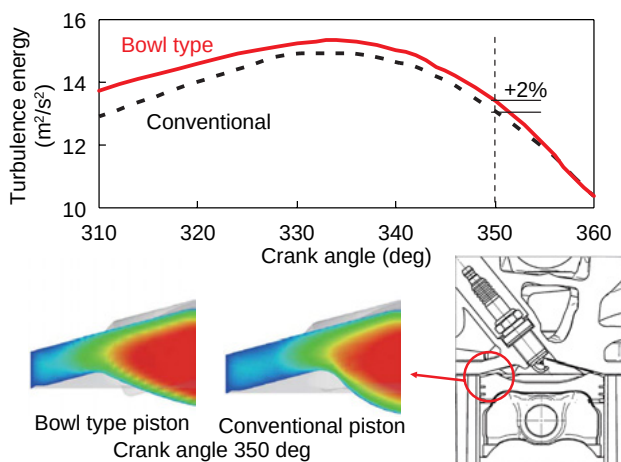


Fig. 11 Effect of piston top form on turbulence energy in combustion chamber

operating at 6000 rpm, or wide open throttle (WOT). This indicates that turbulence energy inside the combustion chamber as a whole has been strengthened by approximately 2%, with a strengthening of the flow in the end gas zone, which is a location particularly associated with knocking. Figure 12 shows the amount of knock retard resulting from differences in piston top shape. The vertical axis of the graph shows the ignition timing for knocking with the MBT at 0°. The amount of ignition retard from knocking is reduced by 1–3° across the entire range of engine speed for the “bowl-in” type relative to the previous model.

- (2) Coolant circulation system: Optimization of the coolant circulation path increased the flow velocity in every part, enhanced the cooling effect in the combustion chamber, and acted to control knocking. Figure 13 shows the coolant circulation path in comparison with the previous model. In the previous model, the coolant went from the water pump into the cylinder head, where the main flow divided into two parts, one going through the cylinder head and the other through the cylinder block. The coolant then followed a path taking it along the cylinder sides on the intake side and the exhaust side, following the same direction in both. This system limited the flow into the cylinder block when the engine was cold, thus enhancing the quick warming effect. When the engine was warm, coolant that had been warmed in the cylinder head could be directed to the cylinder block to maintain the high temperature there and reduce friction. Since the

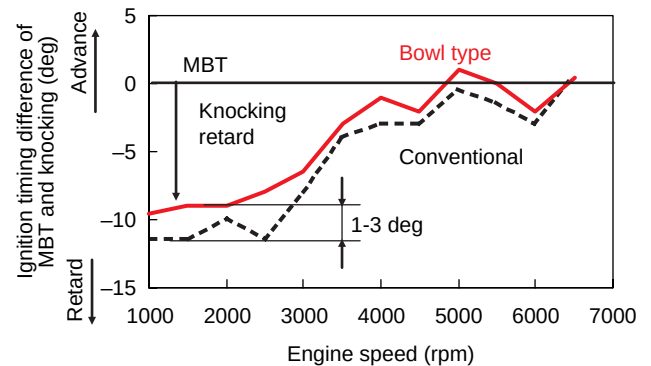


Fig. 12 Effect of piston top shape on ignition timing

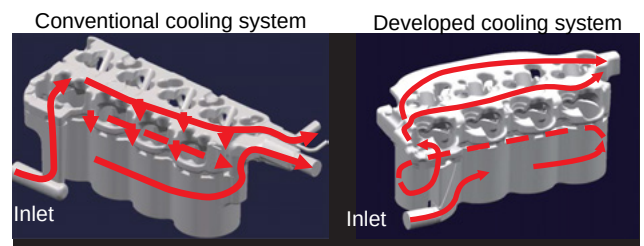


Fig. 13 Cooling circulation system

coolant followed multiple paths, however, the flow velocity in each part tended to decrease. Therefore, a method was adopted to keep the main flow of coolant entering the cylinder block from the water pump in a single flow, as though drawn in a single stroke, thereby raising the flow velocity in the various parts. Figure 14 shows the results from a simulation of the coolant flow velocity distribution with the engine operating at 6000 rpm. Figure 15 shows the results from testing the knocking ignition timing at WOT using the coolant circulation system. The change in the circulation system increased the flow velocity around the combustion chamber and through the upper part of the cylinder block, enabling enhancement of the cooling effect and control of knocking at high speeds.

3.3. Full Throttle Output Characteristics

Figure 16 shows the engine performance curve at wide open throttle. Adoption of the below intake efficiency enhancement technology and knocking reduction technology achieved 73 kW of maximum output and 127 Nm of maximum torque. This yielded an

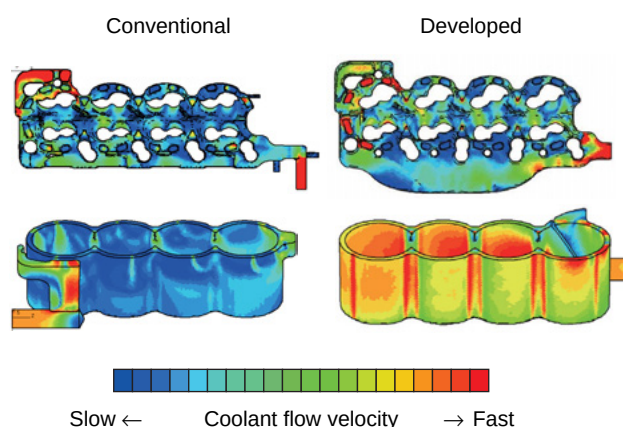


Fig. 14 Comparison of coolant flow velocity between conventional and developed flow

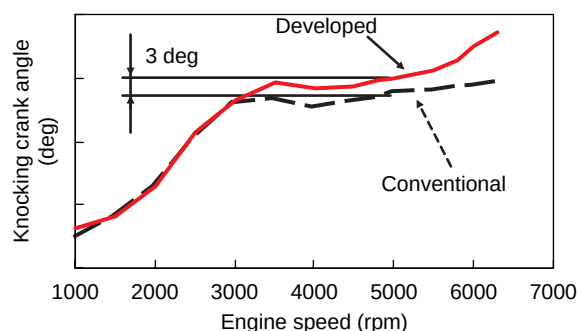


Fig. 15 Comparison of knocking between conventional cooling system and modified cooling system

enhancement of approximately 20% in maximum output and approximately 7% in maximum torque, relative to the previous model.

Intake efficiency enhancement

- 4-valve cylinder head and optimization of port shape
- Reduction in air cleaner air-flow resistance
- Reduction in knocking by means of intake manifold with integrated torque-up resonator
- “Bowl-in” piston
- Optimization of coolant circulation path

3.4. Noise and Vibration Reduction Technology

3.4.1. Engine sound radiation

Measures were taken to reduce engine noise radiation in the 770–2000-Hz range for the developed engine in order to reduce engine noise transmission from the engine compartment at wide open throttle. The method of transfer path analysis was applied to the engine as a standalone unit in the course of implementing efficient measures to

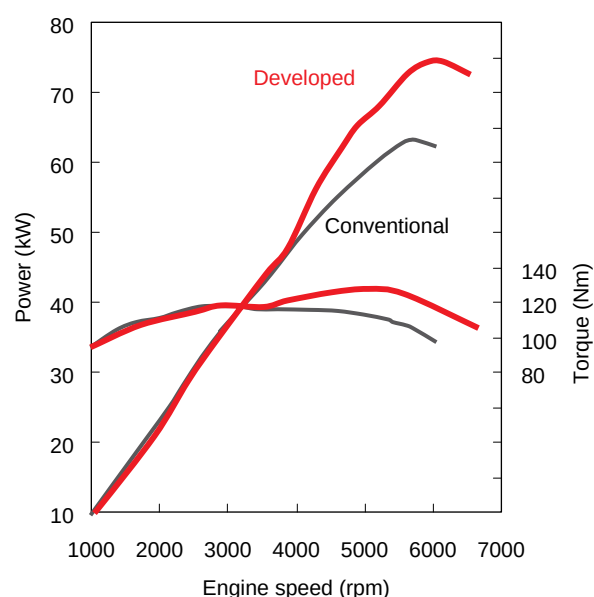


Fig. 16 Engine performance of 1.3L engine

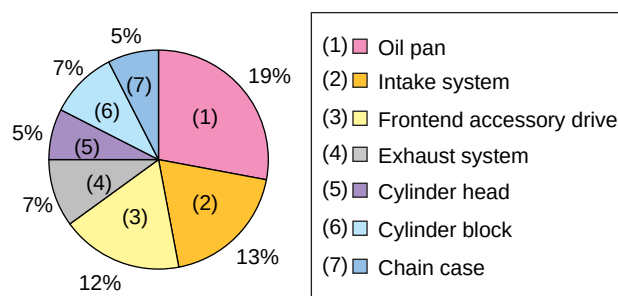


Fig. 17 Contribution to powertrain noise

counter engine noise radiation.⁽³⁾ The results were used to calculate the energy contribution to noise generation by part (Fig. 17). It was found, as a result, that the largest contribution was from the oil pan. Computer-aided engineering (CAE) was utilized to examine the possibility of increasing the rigidity of the oil pan, and the results were applied to the actual engine. A 2.5-dB reduction in engine noise radiation was achieved as a result. Figure 18 shows engine noise radiation with the throttle wide open and on a sweep of engine speeds gradually rising from idle. The adoption of a head cover made of plastic, and other such measures, achieved a reduction of 2–6 dB relative to the previous engine.

3.4.2. Piston slap noise

Figure 19 shows cylinder liner vibration with the engine operating with no load and on a sweep of engine speeds gradually rising from idle. A piston behavior simulation was utilized to achieve a balance in the reduction of piston slap noise and friction.^{(4),(5)} Optimization of the piston offset and of the piston skirt shape realized a 13-dB reduction in cylinder liner vibration, compared to the previous engine, while at the same time enabling a 0.3% reduction in friction.

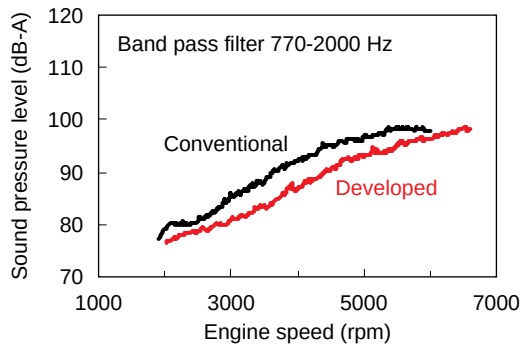


Fig. 18 Comparison of engine noise

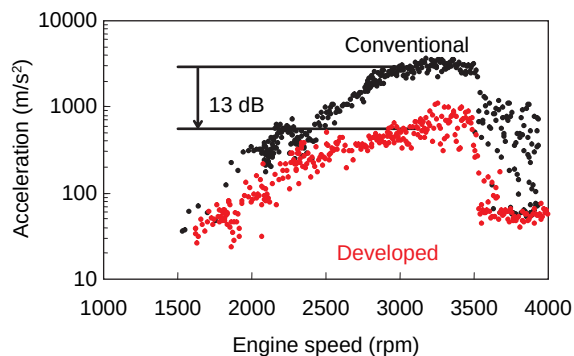


Fig. 19 Comparison of piston shape for cylinder liner acceleration

Table 2 1.5L engine specification

	2008 model FIT	2003 model Fit
Engine code	L15A (Developed)	L15A (Conventional)
Cylinder configuration	In-line 4-cylinder	In-line 4-cylinder
Bore × stroke (mm)	73 × 89.4	73 × 89.4
Displacement (cm³)	1497	1497
Compression ratio	10.4 : 1	10.4 : 1
Valve train	SOHC i-VTEC High-output VTEC	SOHC VTEC 1 intake valve inactive
Number of valves	4 per cylinder	4 per cylinder
Valve diameter (mm)	In. 28 × 2	27.5 × 1
	Ex. 23 × 2	23 × 1
Gasoline	Regular (RON91)	Regular (RON91)
Max. power (kW/rpm)	88 / 6500	81 / 5800
Max. torque (Nm/rpm)	145 / 4800	143 / 4800

4. 1.5-L i-VTEC

4.1. Overview of Engine and Major Specifications

Table 2 shows the major specifications of the 1.5-L engine compared with the previous model engine. Where the previous 1.5-L model employed VTEC that operates with one intake valve inactive, the new model employs high-output VTEC that is intended to enhance driving performance. The major point of difference from the new 1.3-L model is utilization of the high-output VTEC. Otherwise, the two versions share the same basic configuration. There are two valve assembly types, one in the VTEC that operates with one intake valve inactive, utilized in the 1.3-L engine, and the other in the high-output VTEC. However, the two share the same cylinder head, and the differences were addressed by changes in the rocker arm, cam shaft, and rocker shaft holder. Figure 20 shows the rocker arm shapes. The valve assembly is discussed in detail below.

The output enhancement technology, other than the valve assembly, and the friction reduction technology are shared with the 1.3-L version. They yielded a maximum output approximately 9% higher than that of the previous model, with maximum torque approximately 1% greater.

4.2. Full Throttle Output Characteristics

Figure 21 shows a conceptual view of the high-output VTEC operation in comparison with the previous system. The high-output VTEC constitutes technology for opening the intake valves wider at high speed and increasing the amount of valve lift. When the previous model of high-

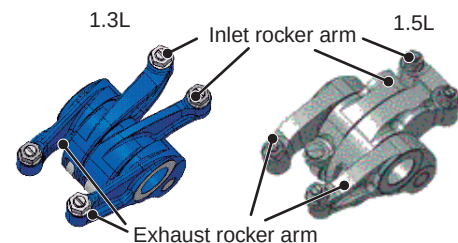


Fig. 20 Comparison of rocker arm shape

output VTEC utilized four valves, it used three rocker arms on the intake side. The new model engine has L-shaped rocker arms that enable one rocker arm to lift two intake valves. This has enabled the engine to realize functionality equivalent to the previous system with a total of just two rocker arms while making the valve assembly compact. The determination of when to switch between the low-speed cam and high-output cam is made according to the engine speed.

Figure 22 shows the performance curve. By adopting high-output VTEC and output enhancement technology held in common with the 1.3-L version, this engine achieves 88 kW of maximum output and 145 Nm of maximum torque. This maximum output is approximately 9% higher than that of the previous model, with maximum torque approximately 1% greater.

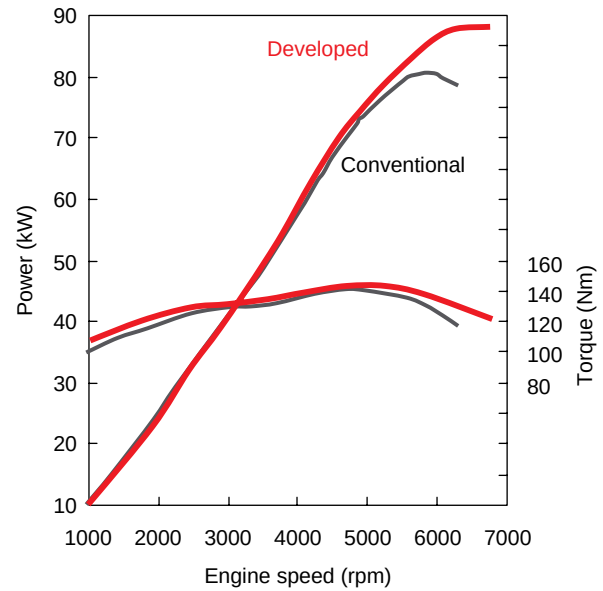


Fig. 22 Engine performance of 1.5 L engine

5. Completed Vehicle Fuel Consumption

Vehicles with the new model i-VTEC engine installed also utilize a newly developed highly efficient continuous variable automatic transmission (CVT) equipped with torque converter that achieve 10-15 mode fuel consumption of 24 km/L for the 1.3-L version and 19.6 km/L for the 1.5-L version. At the same time, they have also successfully realized higher dynamic performance by means of higher output. Figure 23 shows the positioning of mid-range acceleration performance and 10-15 mode fuel consumption for the previous model engine, the new engine, and vehicles sold in Japan.

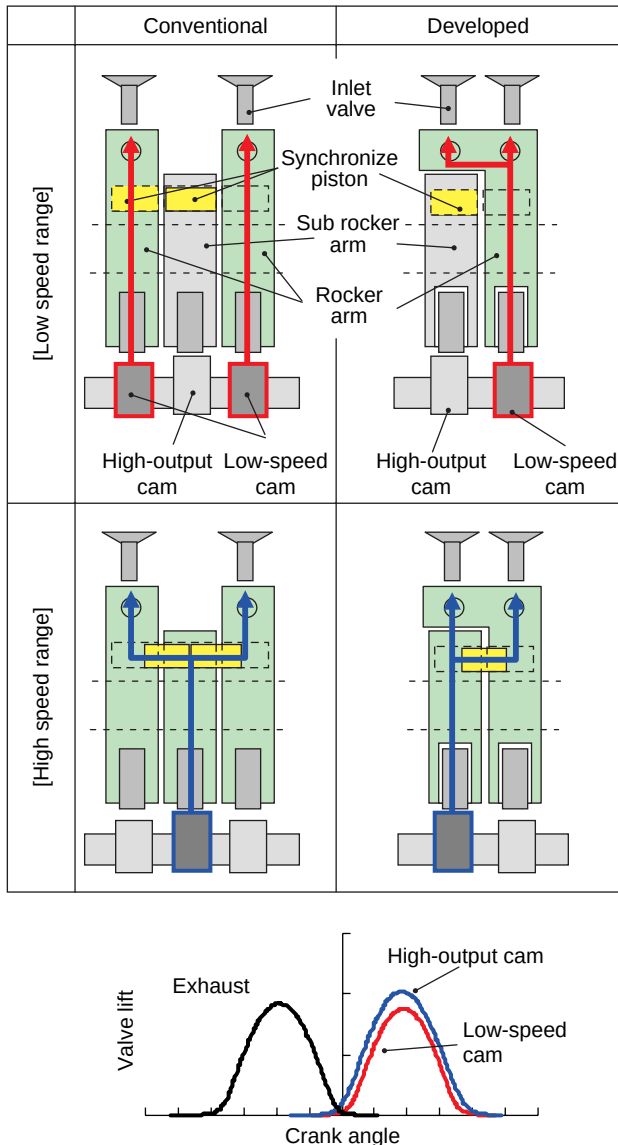


Fig. 21 Valve system operation image and cam profile

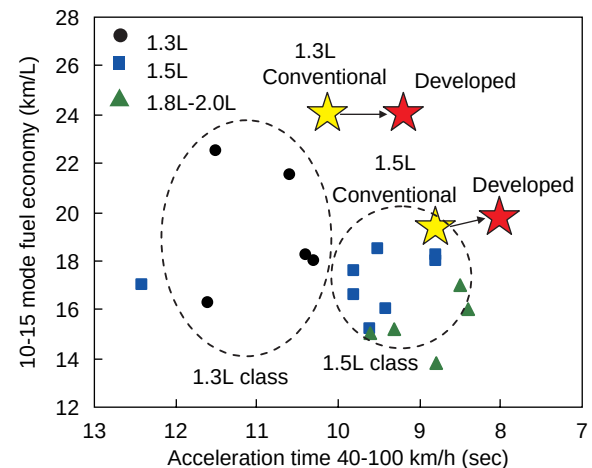


Fig. 23 Positioning of 10-15 mode fuel economy and dynamic performance

6. Low Exhaust Emissions Technology

Technologies adopted for low exhaust emissions include faster light-off of the catalyst by the utilization of a cylinder head with integrated exhaust manifold and a close-coupled catalyst, placement of a UEGO sensor upstream from the close-coupled catalyst and a HEGO sensor upstream from the under-floor catalytic converter, utilization of DBW and AFM for highly precise adaptive control of the air-fuel ratio, and the like. These technologies have achieved a 70% or greater reduction in the amount of precious metal used relative to the previous model engine, while also realizing exhaust emissions at a level 75% lower than required by fiscal year 2005 exhaust emissions regulations.

7. Conclusion

The development of an engine that utilizes 4-valve i-VTEC technology, friction reduction technology, and combustion enhancement technology has realized a balance between lower fuel consumption and high output. The results obtained were as follows:

- (1) The 1.3-L engine achieved maximum output approximately 20% higher and maximum torque approximately 7% greater than those of the previous model, and its use in vehicles incorporating the highly efficient CVT has realized 10-15 mode fuel consumption of 24 km/L.
- (2) The 1.5-L engine achieved maximum output approximately 9% higher and maximum torque approximately 1% greater than those of the previous model while also realizing 10-15 mode fuel consumption of 19.6 km/L.
- (3) Through utilization of the exhaust manifold-integrated cylinder head, close-coupled catalyst, and high-accuracy adaptive air-fuel control, both the 1.3-L and 1.5-L engines have achieved an emissions level 75% below the level required by Japanese 2005 regulations in 10-15 and JC08C mode.

References

- (1) Nakayama, Y., Suzuki, M., Iwata, Y., Yamano, J.: Development of a 1.5L 2PLUG Engine for the 2002 year Model Fit, Honda R&D Technical Review, Vol. 13, No. 2, p. 43-52
- (2) Seko, K., Taga, W., Torii, K., Nakamura, S., Akima, K., Sekiya, N.: Development of 1.8L i-VTEC Gasoline Engine for 2006 Model Year Honda CIVIC, Honda R&D Technical Review, Vol. 18, No. 1, p. 8-15
- (3) Noumura, K., Yoshida, J.: Method of Transfer Path Analysis for Interior Vehicle Sound Using Principal Component Regression Method, Honda R&D Technical Review, Vol. 18, No. 1, p. 136-141
- (4) Kobayashi, T., Take, K., Kamiya, M., Takahashi, Y.:

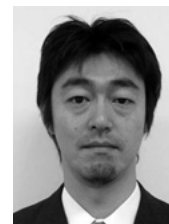
Piston Slap-noise Prediction Using 3-dimensional Piston Secondary Motion Simulation, Honda R&D Technical Review, April 2007, p. 163-169

- (5) Sato, K., Fujii, K., Ito, M., Koda, S.: Friction Analysis by Piston Secondary Motion Simulation in Consideration of Cylinder Block Bore Distortion, Honda R&D Technical Review, Vol. 18, No. 1, p. 94-100

■ Author ■



Ryutaro TAGISHI



Tsutomu SATO



Hiroshi KAWAGUCHI



Yoshiharu HAGIWARA