

Development of 1.8L i-VTEC Gasoline Engine for 2006 Model Year Honda CIVIC

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ABSTRACT

Honda has developed a lightweight and compact next-generation 1.8L i-VTEC 4-cylinder gasoline engine that offers a superb balance of power and environmental performance (high fuel economy and low emissions). The i-VTEC system in the new engine provides high power when the vehicle is accelerating by operating the valves with a cam that produces maximum power. When the engine is operating under a low load, e.g. when cruising, the system switches to a cam with delayed valve closure timing and simultaneously opens the electronically-controlled throttle in order to reduce pumping losses and increase fuel economy. The 2006 CIVIC in which the new engine is fitted has achieved a high level of fuel economy, obtaining 17.0 km/l in Japanese 10-15 mode, a 5% increase over the level required by Japanese 2010 fuel economy standards. The use of a variable-length intake manifold has balanced low- to medium-speed torque with high power. The integration of the cylinder head with the exhaust manifold and the employment of a high-density close-coupled two-bed catalyst and high-accuracy adaptive air-fuel control has enabled the achievement of an emissions level 75% below the level required by Japanese 2005 regulations. In addition, noise and vibration have been reduced by employing a lower block structure that increases the rigidity of the crankshaft support structure.

1. Introduction

The reduction of exhaust emissions is an ongoing requirement of the engine development process. More recently, additional issues have become increasingly important focal points of engine development: conserving energy resources by reducing fuel consumption and enhancing environmental performance by reducing CO₂ greenhouse gas emissions. Honda has continued to enhance environmental performance by developing a series of next-generation engines, including 2.0L and 2.4L 4-cylinder i-VTEC

engines⁽¹⁾ that combine VTEC with a VTC mechanism to provide continuous camshaft phase variations, and a 3.0L V6 i-VTEC engine⁽²⁾ that comes equipped with a variable cylinder system that allows cylinder idling.

Honda has now developed an R18A 1.8L 4-cylinder i-VTEC gasoline engine that has a new mechanism enabling delayed closure of the intake valves to balance enhanced fuel economy with high power and low emissions. This paper will discuss the innovative technologies that have been used in the new engine.

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2. Development Aims

The development concept for the new engine is the achievement of a superb balance between the environmental performance (high fuel economy and low emissions) and the increased torque performance required of Honda next-generation engines. The following were established as specific development aims:

- (1) Fuel economy of 17 km/L in 10-15 mode
- (2) Emissions levels 75% lower than required by 2005 exhaust gas standards
- (3) Low- to medium-speed torque allowing smooth driving under standard usage
- (4) Balance between increased quietness and weight savings

3. Overview of Engine and Main Specifications

Figure 1 shows an external view of the R18A i-VTEC engine and Table 1 shows its main specifications as compared to those of a D17A engine. The reduction of pumping loss by delaying closure of the intake valves is known to be an effective means of increasing fuel economy in gasoline engines⁽³⁾. The new engine discussed in this paper has been provided with a new variable valve mechanism that switches cams depending on engine load, enabling increased fuel economy under low engine loads through delayed closure of the intake valves, and increased power under high loads.

The new engine has also been made more lightweight and compact, with a 5 kg weight reduction and 13 mm shortening in length compared to the former D17A engine.

Figure 2 shows a cross-section of the cylinder head. As in the D17A engine, the intake and exhaust rocker arms are supported by a single rocker shaft. The valve-included angle of the cylinder head has been reduced from 46° to 34° to make the combustion chamber more compact.

In addition, integration of the cylinder head with the exhaust manifold, as shown in Fig. 3, has reduced the heat-radiating surface area, thus allowing faster activation of the catalyst.

Hydraulic-hydraulic switching continues to be used in the valve system, however, an aluminum alloy rocker arm was used for the first time in a VTEC engine. The new rocker arm weighs approximately 35% less than the former cast iron rocker arm.

Table 1 Engine specifications

Engine code	R18A	D17A
Cylinder configuration	In-line 4-cylinder	In-line 4-cylinder
Bore × stroke (mm)	81 × 87.3	75 × 94.4
Displacement (cm ³)	1799	1668
Compression ratio	10.5 : 1	9.9 : 1
Valve train	SOHC i-VTEC Inlet delayed closure	SOHC VTEC-E 1 intake valve inactive
Number of valves	4 per cylinder	4 per cylinder
Valve diameter (mm)	In. 32 Ex. 26	30 26
Cylinder offset (mm)	12	0
Intake manifold	Variable intake system	Conventional
Gasoline	Regular (RON91)	Regular (RON91)
Max. power (kW/rpm)	103/6300	96/6300
Max. torque (Nm/rpm)	174/4300	155/4800

The lightweight alloys (aluminum, magnesium) formerly used to manufacture the head cover have been replaced by plastic, which has contributed to reducing the sound level radiated from the valve system and achieved a weight reduction of approximately 40%.

In order to reduce weight as well as to cope with the increased power, hot-forged, high-strength cracked connecting rods, as shown in Fig. 4, have been used in the drive system. The use of a material with approximately 50% higher fatigue strength than that of the former material has enabled the cross-sectional area of the connecting rods to be reduced by approximately 20%. Integrating the rod and the cap and manufacturing the connecting rods by cracking after forging allows the rods to be fitted together by means of the concavities and convexities of the cracked surface, eliminating the requirement for a locating dowel pin. This has enabled the bolt pitch to be reduced by 1 mm, resulting in the weight reduction of approximately 13% in the connecting rod unit.

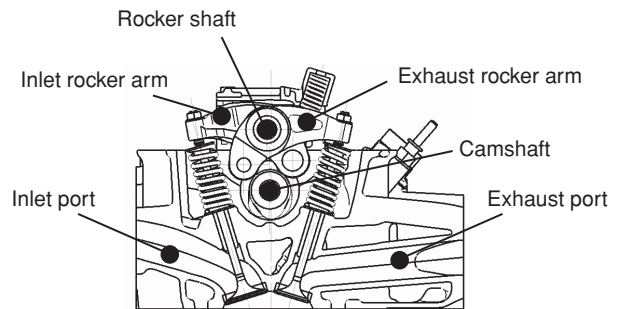


Fig. 2 Configuration of cylinder head



Fig. 1 R18A i-VTEC gasoline engine

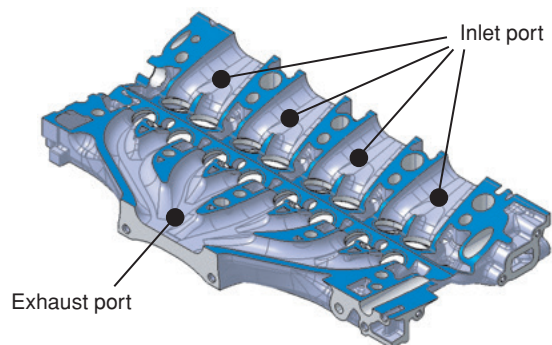


Fig. 3 Section view of exhaust manifold-integrated cylinder head

Figure 5 shows the camshaft drive system. Optimizing the positioning of the chain has enabled its width to be reduced by 1.9 mm, as compared to the former model. The chain guide and chain tensioner arm are entirely manufactured from plastic and aluminum alloy has been used for the tensioner body, resulting in a weight reduction of approximately 35% in the drive system.

Figure 6 shows the configuration of the variable-length intake manifold, and Fig. 7 shows the open and closed position of the bypass valves and illustrates the change in the effective length of the intake manifold. This plastic variable-length intake manifold has allowed an increase in torque at low to medium speeds and higher power at high speeds. In addition, the new circular cross-section of the surge tank has reduced radiated noise and allowed the thickness of the tank walls to be reduced by 30% against those of the former model.

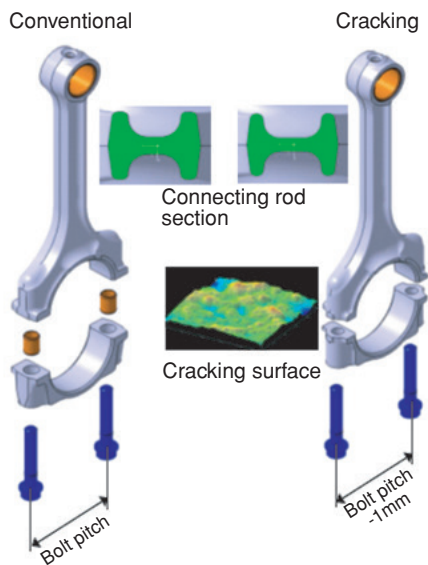


Fig. 4 Comparison of conventional and cracking connecting rod

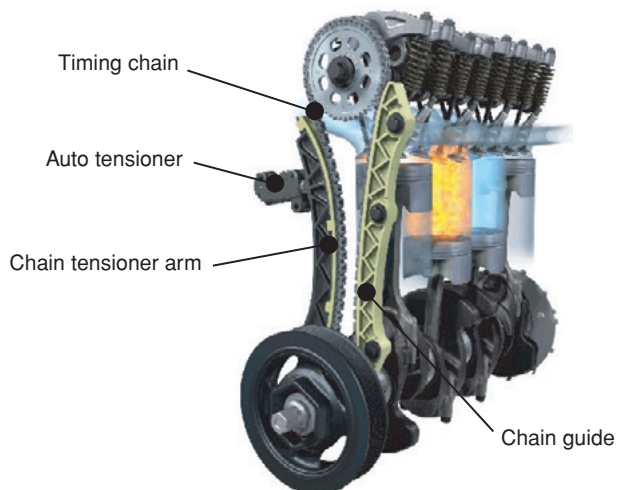


Fig. 5 Camshaft drive system

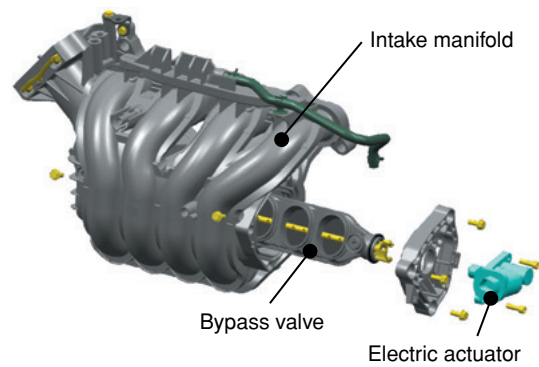


Fig. 6 Configuration of variable intake manifold

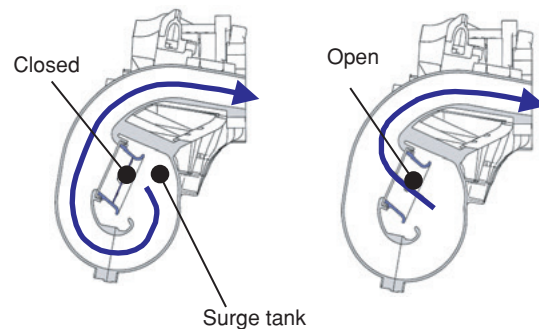


Fig. 7 Motion of bypass valves

4. Power Performance

Figure 8 shows the engine's power characteristic. A variety of technologies have been used to increase power: Use of the variable-length intake manifold has increased filling efficiency, the shapes of the intake and exhaust ports have been optimized, the compression ratio has been increased, knocking performance has been enhanced by making the combustion chamber more compact and by using a piston oil jet, and friction has been reduced. These measures have increased the ratio of torque to displacement by 4% against that in the former engine.

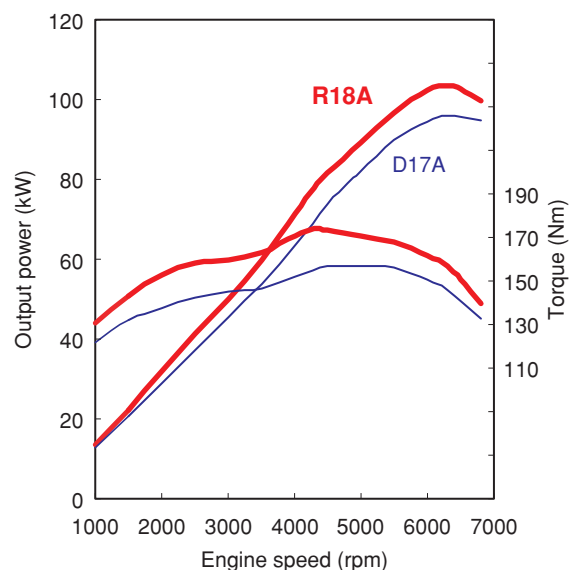


Fig. 8 Engine performance

5. i-VTEC Mechanism

5.1. i-VTEC Intake Valve Closure Delay Mechanism

At high load (acceleration) conditions, the i-VTEC system used in the new engine controls the intake valves by a cam designed to produce maximum power (high output cam, below). When the engine is under low loads (when the vehicle is cruising, etc.), the system switches to another cam (delayed closure cam, below) that delays the closure of one bank of intake valves, and at the same time opens the electronically controlled throttle. This reduces pumping loss and increases fuel economy⁽⁴⁾. The delayed closure cam has effectively reduced the compression cycle and essentially is able to increase the expansion ratio versus the effective compression ratio. A high expansion cycle has long been known to be effective in increasing fuel economy, but also causes filling efficiency and the effective compression ratio to decline, resulting in reduced power. The mechanism proposed to resolve this issue in the new engine was optimal switching between the high output cam and the delayed closure cam in response to driving conditions by means of the i-VTEC system.

Valve switching in the i-VTEC system is conducted by means of the connection and disconnection of the rocker arms via the hydraulic pressure exerted on the synchro pistons built into the arms. In the new engine, this switching mechanism has only been applied to one rocker arm of the two intake valves.

Figure 9 shows the basic configuration of the valve train and the hydraulic passages. Figure 10 shows the configuration of the rocker arms and the cam profile. This is a hydraulic-hydraulic switching mechanism that employs two hydraulic passages and is identical to the mechanism used in the CIVIC Hybrid cylinder idling system⁽⁵⁾.

When the high output cam is operating, synchro piston A is disconnected by the hydraulic pressure exerted on synchro piston B, and the intake valves are operated according to cam profile A (Fig. 10(a)).

As shown in Fig. 10(b), when the delayed closure cam is in operation, the hydraulic pressure that is exerted on synchro piston A links rocker arms A and B, and the intake valves are operated according to cam profile B.

A three-way solenoid spool valve has been used to ensure responsiveness in switching between the two hydraulic passages. This hydraulic-hydraulic switching mechanism enables i-VTEC switching in the low engine speed/low hydraulic pressure range,

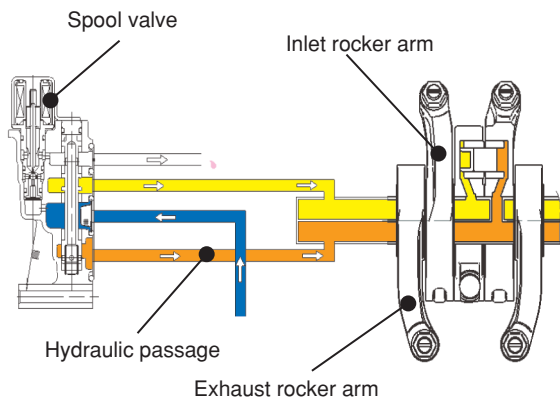


Fig. 9 Valve train and hydraulic passage

thus making it possible to receive the fuel economy benefits of the delayed closure cam at low vehicle speeds. To reduce weight, an aluminum alloy rocker arm has been used for the first time in the hydraulic-hydraulic switching system in the new engine.

5.2. i-VTEC Switching Control

Figure 11 shows the operational range of the delayed closure cam. Switching to the delayed closure cam is conducted at low engine speeds and low loads, which are the normal vehicle cruising conditions. Apart from this – at engine start, when the engine is idling, and when the engine is operating under high loads and at high speeds – the high output cam operates. The necessity for switching is judged on the basis of a variety of data, including engine speed, degree of throttle opening, vehicle speed and the engine's water temperature.

As Fig. 12 shows, control of the degree of throttle opening and the ignition timing ensures that this load-dependent switching is smooth, with no torque steps. This has enabled the operational range of the delayed closure cam to be extended to approximately 90% of WOT torque.

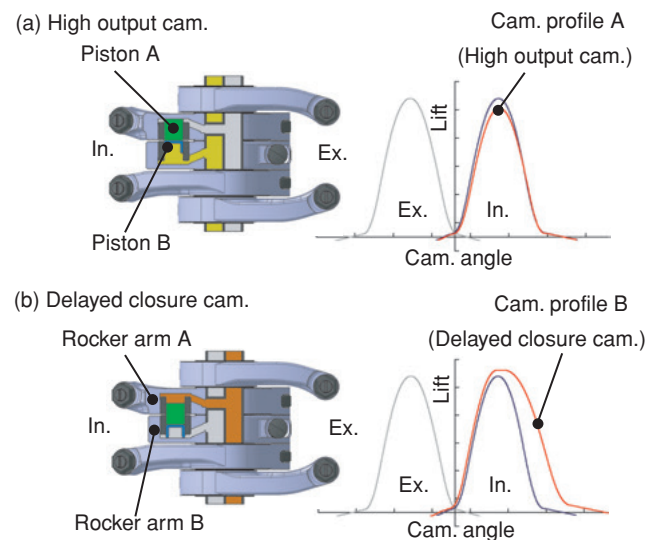


Fig. 10 Rocker arm and cam. profile

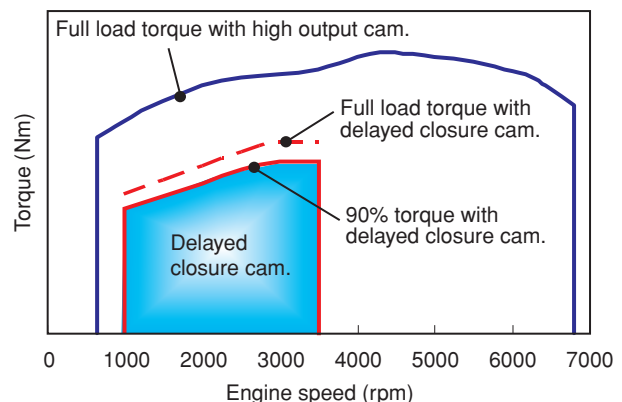


Fig. 11 Operational region of delayed closure cam.

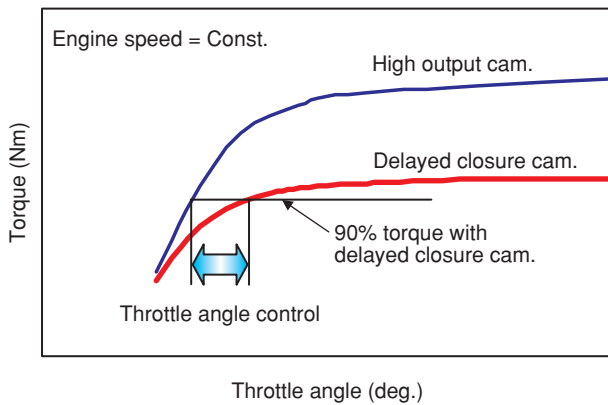


Fig. 12 Throttle angle control at i-VTEC switching

6. Friction Reduction Technologies

In addition to the use of delayed closure of the intake valves to increase fuel economy, the new engine incorporates the technologies that have been employed in the i-VTEC series to date to reduce friction: An offset cylinder configuration, roller-follower rocker arms, ion-plated piston rings and shot peening of the piston skirts⁽⁶⁾, followed by a molybdenum disulfate coating. Further technologies applied to reduce friction include a reduced cam chain width, reduced chain tensioner spring load, reduced cam journal surface roughness and reduced piston ring tension.

The application of these technologies has reduced friction in the new engine by 10% against that of the D17A engine.

7. Engine Fuel Economy and Vehicle Fuel Economy

Figure 13 shows brake-specific fuel consumption (BSFC) against total engine displacement. The reduction in pumping loss, brought about by delayed closure of the intake valves and the usage of technologies to reduce friction, have reduced BSFC by 6% against that in the former engine. This has resulted in the achievement of an engine fuel economy equivalent to that of a lean-burn engine even though it operates at a stoichiometric air-fuel ratio.

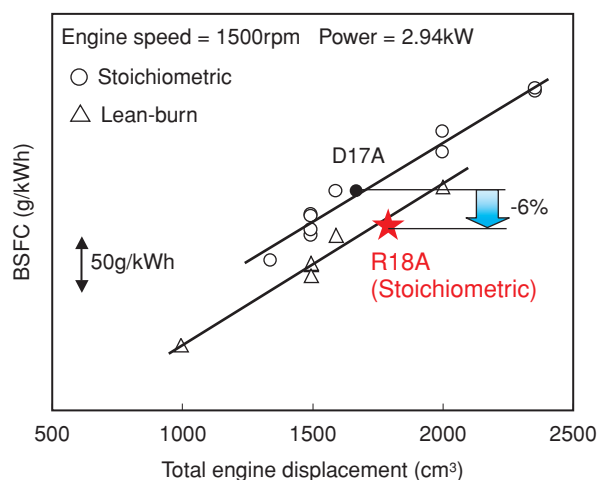


Fig. 13 Enhancement of BSFC

Other techniques have been used to reduce fuel consumption in the vehicle in which the engine is fitted, including expanding the AT lock-up clutch's operational range, which has resulted in the achievement of a 17 km/l fuel consumption rate in the Japanese 10-15 mode, representing a 5% improvement of 2010 fuel consumption standards (Fig. 14).

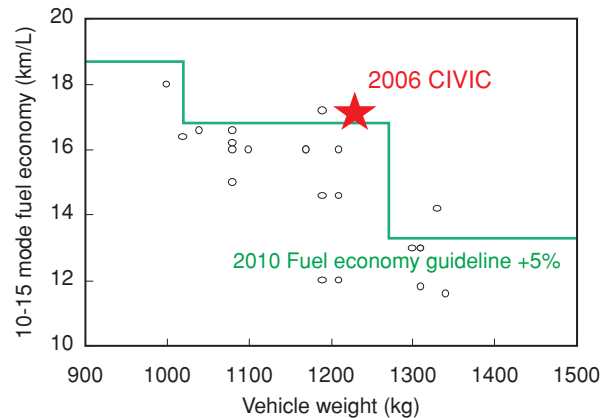


Fig. 14 Relationship between vehicle weight and 10-15 mode fuel economy in production stoichiometric gasoline vehicles

8. Technologies to Reduce Exhaust Emissions

8.1. Emissions Processing System

The exhaust system of the new engine is shown in Fig. 15. A closed coupled, two-bed, three-way catalyst has been fitted to the cylinder head, which has an integrated exhaust manifold. This has reduced heat mass and enabled rapid activation of the catalyst. In addition, a universal exhaust gas oxygen sensor (UEGO) has been positioned upstream and a heated exhaust gas oxygen sensor (HEGO) downstream from the front bed of the catalyst to allow highly accurate adaptive control of the air-fuel ratio, thereby achieving excellent purification performance. This has allowed significantly reduced amounts of precious metals to be used in the new engine, compared to the former engine.

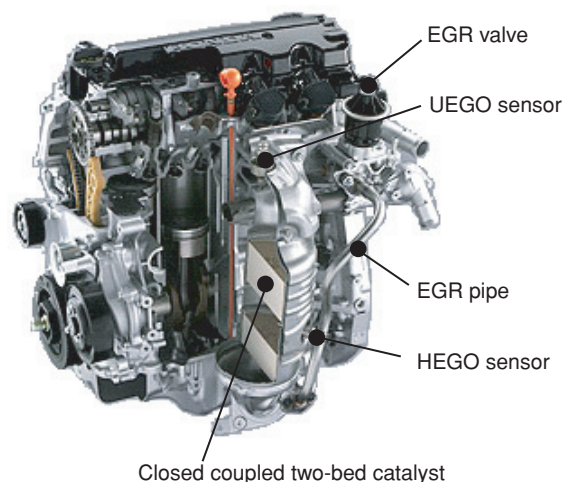


Fig. 15 Exhaust system

As shown in Fig. 16, the cone shape at the front of the catalyst has been optimized using computational fluid dynamics (CFD) to ensure that the exhaust gas strikes the catalyst uniformly, to maximize the catalyst's purification capability and to limit catalyst degradation. The channel has been restricted immediately after the cylinder head outlet. A bell mouth shape has been used to make the passage between the restriction and the catalyst smooth to ensure the exhaust gasses take an optimal flow direction, reducing vortex loss on the walls and resulting in excellent gas flow.

Figure 17 shows images of exhaust gas from each cylinder striking the UEGO during the exhaust stroke. To enhance air-fuel ratio control, the positioning of the UEGO sensor has been optimized to allow uniform detection of the exhaust gas from each cylinder.

8.2. EGR System

Figure 18 shows the configuration of the EGR system. To eliminate unburnt hydrocarbons from the EGR passage in the new R18A engine, EGR gas is removed after passing through the catalyst.

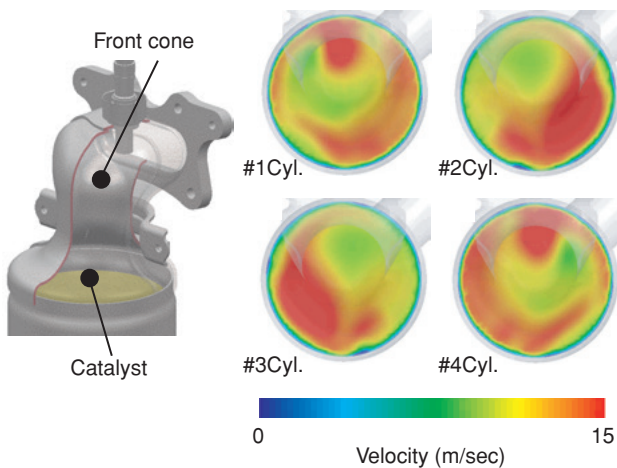


Fig. 16 Optimized exhaust gas feed to catalyst

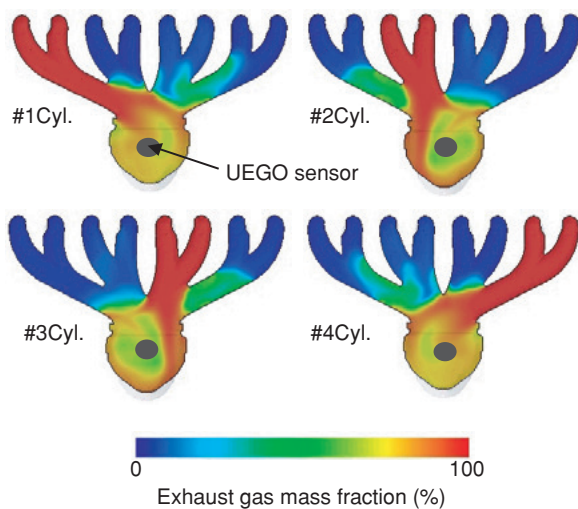


Fig. 17 Optimized UEGO sensor positioning

Figure 19 shows the results of an analysis of the EGR gas flow in the intake manifold around the area where the gas is introduced. The results indicate that a counterflow is generated downstream from the throttle valve when the opening angle of the valve is low. This counterflow carries EGR gas to the throttle valve and causes it to become dirty. The positioning of the EGR introduction joint in the intake manifold and the direction of the EGR gasses' introduction have therefore been optimized to prevent EGR gas from directly striking the throttle valve.

Figure 20 shows CFD results for sudden closure of the throttle. Optimizing the shape, length and orientation of the EGR

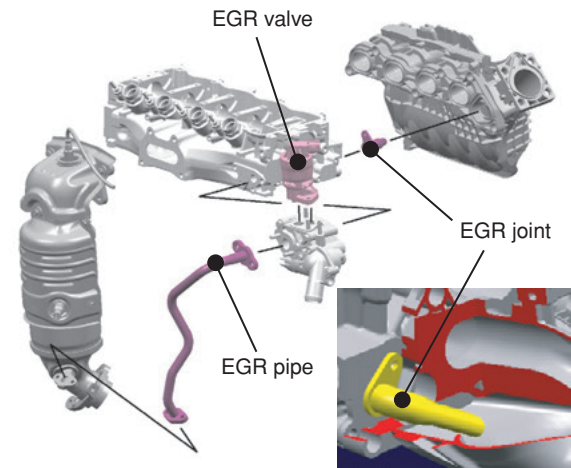


Fig. 18 Configuration of EGR system

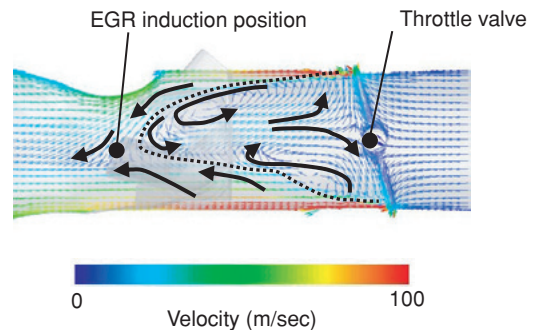


Fig. 19 Analysis of EGR gas flow around throttle valve

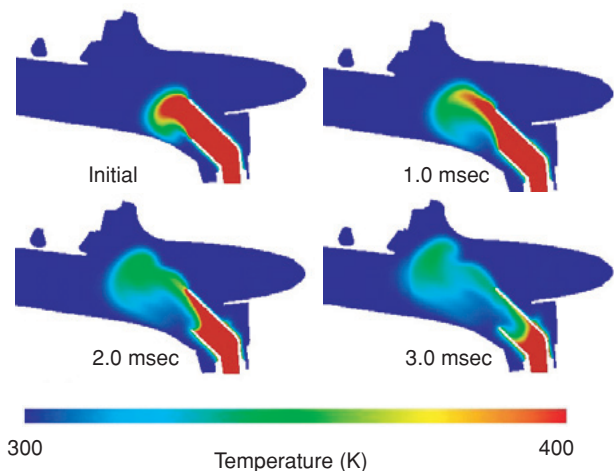


Fig. 20 Analysis of EGR gas flow at sudden throttle closing

introduction joint has prevented EGR gas from directly striking the intake manifold wall, reducing the effect of heat on the plastic manifold. In addition, the mixing of EGR gas and new gas has been promoted and EGR distribution to each cylinder has been optimized.

A 6-hole injector has been used to enhance the fuel spray droplet characteristics in order to reduce the amount of fuel that adheres to the intake port and combustion chamber walls, and to reduce unburnt hydrocarbon emissions at engine start and when the catalyst is being heated. The new engine has also been provided with highly accurate electronic EGR valve control and air-fuel control using air flow sensors, map sensors and an electronically controlled throttle. These various technologies have reduced emissions to a level 75% below 2005 standard levels.

9. Technologies to Reduce Noise and Vibration

A frequent issue in in-line 4-cylinder engines is a muddy sound (rumble) occurring between 2000 and 4000 rpm when the vehicle is accelerating. Measures were taken to resolve this issue in the new engine.

Rumble is mainly caused by structure-borne sound from cyclic engine vibration originating from the motion of the crankshaft, which is transmitted to the vehicle body via the engine mounts. The primary components of this sound are between 200 and 800 Hz⁽⁷⁾⁻⁽⁹⁾. To reduce this sound, the measures listed below were implemented to reduce the vibration originating in the crankshaft and the vibration transmitted from the crankshaft to the engine mounts.

- (1) Control of the crankshaft's primary bending deformation caused by the inertia of reciprocating parts
- (2) Increased rigidity of the area around the crankshaft bearings
- (3) Increased bending rigidity of the engine-transmission assembly
- (4) Reduction of the oil clearance of the crankshaft bearings

Figure 21 shows the relationship between the crankshaft's bending stiffness and the bending moment exerted on the crankshaft.

To reduce the crankshafts primary bending deformation, a

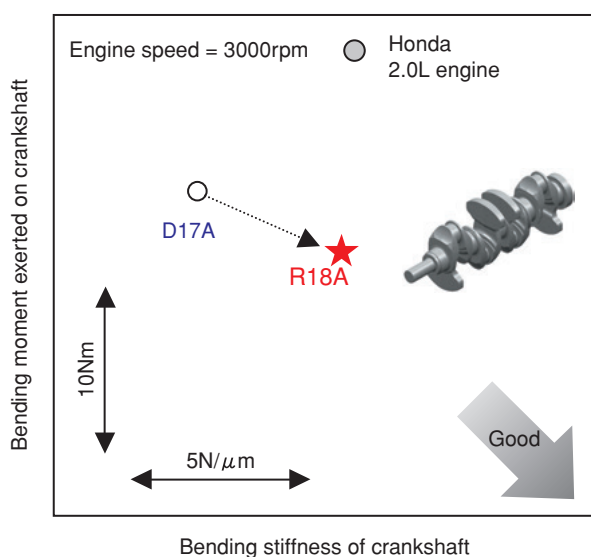


Fig. 21 Bending stiffness of crankshaft and bending moment exerted on crankshaft

counterweight was fitted to reduce the bending moment to a level less than or equivalent to that of the former engine. In addition, the pin width was reduced and the area around the web was reinforced, resulting in the achievement of a level of bending stiffness equivalent to that of a Honda 2L engine.

Increasing the stiffness of the crankshaft bearings was achieved by using a lower block that integrates the crankshaft's bearings and external wall into a ladder frame configuration. Figure 22 shows the cylinder block and lower block.

To enhance the bending rigidity of the engine-transmission assembly, the coupling between the engine and the transmission, the major factor in the bending mode of the power plant, was reinforced, while still keeping in mind the goal of weight reduction. As a result, the power plant's bending resonance frequency has been increased by approximately 20% against that of the former engine.

To reduce the oil clearance of the crankshaft bearings, although the bearing sections of the lower block usually use FC (Cast iron), FC casting has been eliminated in the R18A engine to reduce weight. This has increased the rate of change of oil clearance in relation to engine temperature, but adjusting the crank bearings' range of tolerance has allowed crank vibration to be reduced.

Figure 23 shows mid-frequency engine vibration against engine speed. By implementing measures (1) to (4), mid-frequency engine vibration at medium engine speeds has been reduced by approximately 10 dB against that of the former engine, and weight reduction has been balanced against reduced rumble.

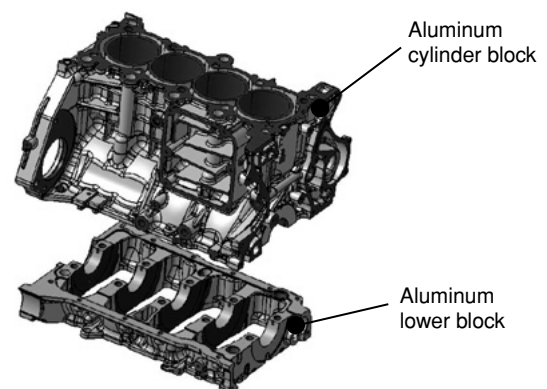


Fig. 22 Cylinder block and lower block

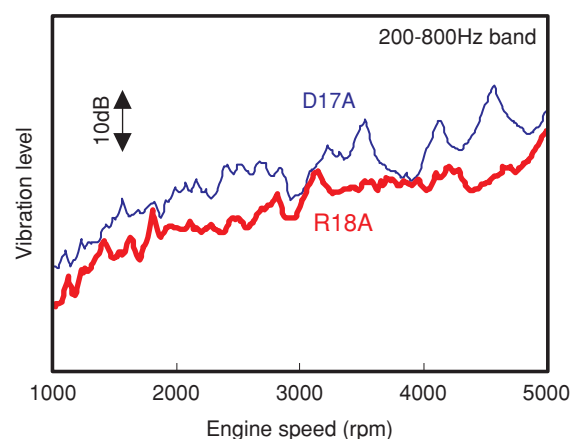


Fig. 23 Vibration level at the engine mount bracket end under full load

10. Conclusion

An i-VTEC mechanism allowing switching between a high output cam and a delayed closure cam in response to driving conditions has been developed. The following are significant findings in the development:

- (1) The torque versus displacement ratio has been increased by 4% and the unit fuel economy by 6% against that of the former engine.
- (2) The vehicle in which the new R18A engine is fitted has achieved a best-in-its-class fuel economy of 17 km/L in the Japanese 10-15 mode (an improvement of 5% against 2010 fuel economy standards).
- (3) The integration of the cylinder head with the exhaust manifold and the use of a closed coupled two-bed catalyst and highly accurate adaptive air-fuel ratio control have allowed the achievement of an emissions level 75% below that required in the 2005 standards.
- (4) The new engine is lighter, quieter and more compact than the former engine.

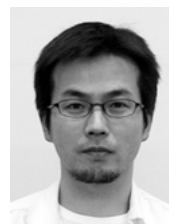
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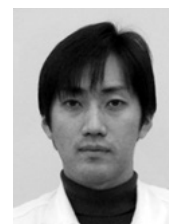
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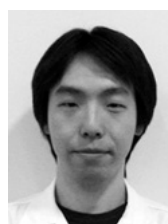
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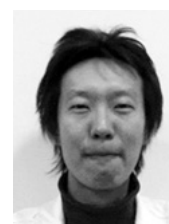
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