

Development of 2.4 L i-VTEC Gasoline Engine for 2008 Model Year ACCORD

Ryota KAWAGUCHI*	Kazuya YAMAMOTO*	Takashi KAYABA*
Sadao KOJIMA*	Takahiro SHINKAI*	Koichiro ASAME*

ABSTRACT

A 2.4 L in-line 4-cylinder i-VTEC gasoline engine for the 2008 model year ACCORD was developed with the aim of balancing high output with low exhaust emissions.

The VTEC mechanism of this engine with the i-VTEC system was developed to switch between cams on the intake and exhaust valve sides at different engine rpms. On the exhaust side, at low speeds it operates with one exhaust valve inactive to increase the flow motion of the exhaust gas and promote after-burning. This raises the catalyst temperature. Operating with one valve inactive also reduces exhaust interference and increases higher low-speed torque. On the intake side, the variable camshaft phasing mechanism, together with the variable valve timing and lift, enable optimum valve timings to be set for the low-and high-speed engine rpm. In addition to this new VTEC mechanism, the developed engine also adopted a cylinder head with exhaust manifold, a close-coupled catalytic converter, and other new technology. The result is an engine that achieves maximum output of 142 kW, maximum torque of 220 Nm, and power performance at the top level in its class. At the same time, this engine also realizes a balance between low fuel consumption and low exhaust emissions for U.S. LEV II SULEV regulation on par with that of previous models.

1. Introduction

As engine development addresses the needs of global environmental protection and energy conservation, the enhancement of engine drive performance has become an important issue.

Honda has developed a new-generation engine employing such technologies as a variable cylinder management system that makes use of cylinder deactivation mode, a direct-injection lean burn system, a reduction in the total engine displacement through the addition of a turbocharger, and the like.

The previous engine had experienced issues in achieving a balance of high power performance and environmental performance at a high level.

The present engine achieves high engine performance by taking a previous 4-cylinder i-VTEC system⁽¹⁾ with a variable camshaft phasing mechanism (VTC) combined with VTEC as the base, then reducing the intake and exhaust resistance and increasing the compression ratio for

higher engine performance with a maximum output of 142 kW.

Exhaust emissions were reduced by the use of a cylinder head with exhaust manifold, a close-coupled catalytic converter, and high-precision air-fuel ratio control. A new VTEC mechanism, high-ignitability plugs, and a new fuel injector were also developed and the catalyst was enhanced to achieve high engine performance. The engine thus achieved reduced exhaust gas emissions for U.S. LEV II SULEV⁽²⁾ regulation as well as a high-level balance between power performance and environmental performance. This paper provides an overview of the structure and concept of this new model engine and of the technologies applied to it.

2. Development Goals

The aim of the engine for the new model ACCORD is to address advanced emissions requirements as a matter of social responsibility while also achieving outstanding

* Automobile R&D Center

Table 1 Engine specifications

Engine code	K24A (Developed model)		K24A (Previous model)	
Cylinder configuration	In-line 4-cylinder		In-line 4-cylinder	
Bore × stroke (mm)	87 × 99		87 × 99	
Displacement (cm ³)	2354		2354	
Compression ratio	10.5 : 1		9.7 : 1	
Valve train	DOHC i-VTEC		DOHC i-VTEC	
VTEC Type	Inlet	Low-speed / High-speed	1-valve operation	
	Exhaust	1-valve operation	N/A	
Number of valves	4 per cylinder		4 per cylinder	
Valve diameter (mm)	Inlet	36	35	
	Exhaust	31	30	
VTC angle (deg)	50		25	
Intake manifold	Resin with glass fiber		Aluminum alloy	
Exhaust manifold	Integrated with cylinder head		Double stainless steel pipe	
Oil pan	Aluminum		Steel plate	
Catalytic converter (L)	Close-coupled (1.0) + under-floor (1.0)		Under-floor (1.0 + 1.0)	
Recommended gas	Unleaded regular (RON 91)		Unleaded regular (RON 91)	
Max. power (kW[PS]/rpm)	142 [193] / 7000		125 [170] / 5800	
Max. torque (Nm[kgm]/rpm)	220 [22.4] / 4400		220 [22.4] / 4000	

power performance. The development concept of “The World’s BEST! Highest Output & Lowest EM L4 Engine” had the following objectives:

- (1) Output of 142 kW with regular gasoline
- (2) Compliance with U.S. LEV II SULEV exhaust emissions regulations
- (3) Fuel consumption at the top level in its class
- (4) Quieter operation

3. Overview of Engine and Major Specifications

Table 1 shows the specifications of the new model engine and the previous model. Figure 1 shows an exterior view of the new engine.

The developed engine was engineered to run at higher speed than the previous model. Various technologies were adopted for the purpose of high engine performance, including optimized valve timing, a higher compression ratio, higher diameter intake and exhaust valves, and the like.

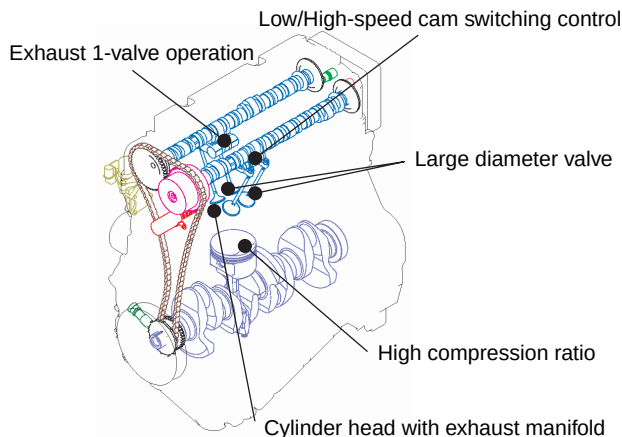


Fig. 1 New application technologies for developed K24A engine

4. Power Performance

4.1. Power Performance

The power characteristics of the new model engine are shown in Fig. 2.

Measures employed to give this engine enhanced performance include higher speed, optimized valve timing, a higher compression ratio, higher diameter intake and exhaust valves, and the like. The adoption of M12 long reach spark plugs and a piston oil jet also reduce knocking to enable 142 kW of output and 220 Nm of torque.

4.2. Technology for Higher Engine Performance

The previous 4-cylinder engines that used a cylinder head with exhaust manifold encountered obstacles to higher engine performance because of exhaust interference. Figure 3 shows the results of simulation analysis. The results from simulation of pressure distribution in the exhaust ports from the commencement of exhaust to intake in the No. 1 cylinder show that the pressure in the No. 1 cylinder ports increases again in the area of overlap between exhaust and intake strokes in that cylinder. An exhaust gas simulation conducted to analyze the causes of this showed that the exhaust from cylinder No. 3 moves to the side of cylinder No. 1. As a result, the pressure in the cylinder No. 1 exhaust port increases so that a scavenging effect is not obtained. A similar phenomenon was occurring in cylinder No. 4. This showed it would be necessary to give the exhaust ports shapes that would prevent the exhaust gas from cylinder Nos. 2 and 3 from interfering with the scavenging effect in cylinder Nos. 1 and 4.

The shape of the ports was optimized to help prevent interference with scavenging in cylinder Nos. 1 and 4 as

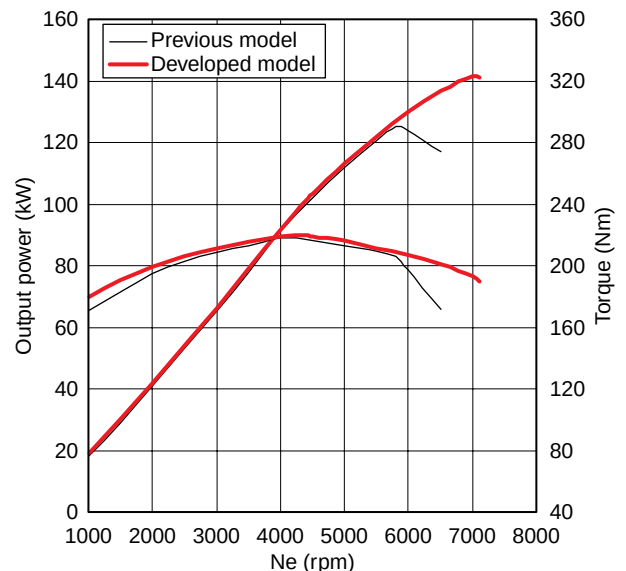


Fig. 2 Engine performance

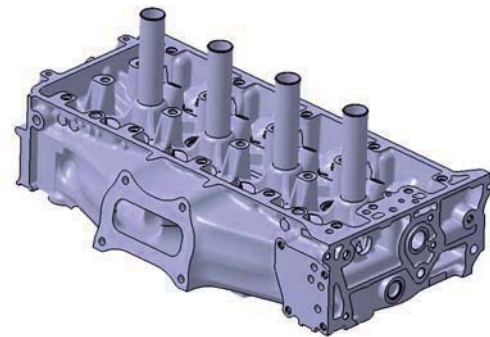
shown in Fig. 4. The angle θ was increased, L was reduced, and S was increased. Adoption of this shape achieved high engine performance.

The valve timing was handled in a similar manner so that the exhaust valves would close before the exhaust gas could move to the other side. This yielded higher engine performance even when a cylinder head with integrated exhaust manifold was used.

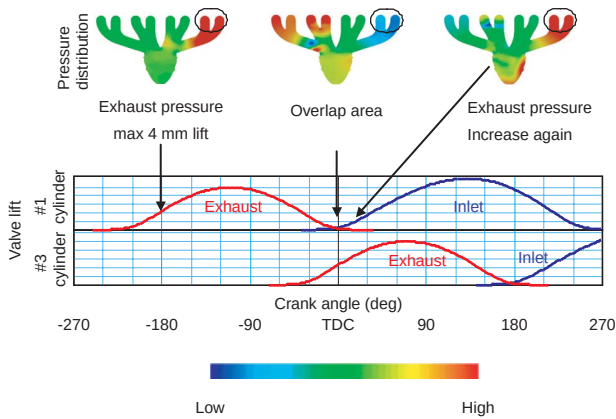
Previous measures to reduce exhaust emissions involved issues with passageway resistance in the exhaust system.

In order to support higher engine performance in this engine, however, a new catalyst that enables reduction of exhaust emissions with fewer cells was developed. The reduction in number of cells resulted in a reduction in the geometrical surface area, while the reduction in the amount of precious metals lowered the catalyst function. This was addressed by reducing the catalyst washcoat to increase the geometric surface area and controlling the pores in the catalyst layers to achieve greater dispersion of the reaction gases to the deep layers of the catalyst. Reduction of the catalyst washcoat reduced the heat mass

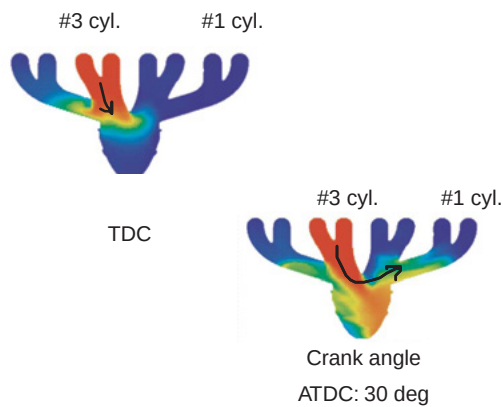
and enhanced catalyst light-off performance. As this introduces a possibility of reduced OSC performance by the catalyst, however, the Ce/Zr composite oxides were optimized, thus enhancing the heat resistance of the OSC material and raising OSC performance by the catalyst. The adoption of these technologies enabled the achievement of a high-level balance between reduced exhaust emissions and higher engine performance, and additionally enabled a 50% reduction in the amount of precious metals used compared to the previous catalyst.



(a) Overview

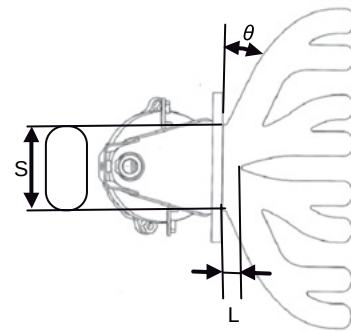


(a) Exhaust gas pressure distribution



(b) #3 Cylinder exhaust gas flow

Fig. 3 Exhaust gas flow and pressure distribution in exhaust port



(b) Section view

Fig. 4 Cylinder head exhaust port shape

5. i-VTEC System

This engine adopted the former low/high valve timing lift switching mechanism on the intake side and 1-valve operation on the exhaust side.

Figure 5 shows this engine's VTEC switching mechanism. The system needs to be able to switch between different engine speeds, with high-speed operation on the intake side and low-speed operation on the exhaust side. Their respective oil channels were therefore made independent and a new dual system of spool valves was developed to achieve three-stage switching.

For the low/high switch on the intake side, which is similar to the switch used in the previous model, Honda has for the first time employed aluminum for the three

rocker arms. A new high-strength material was developed in order to use aluminum for the three rocker arms. The newly developed material realizes a 0.21-kg weight reduction per vehicle, as well as a cost reduction.

The new engine also uses 1-valve operation on the exhaust side. Operating with one valve inactive causes a cross-flow in the exhaust gas, generating a powerful swirl. Figure 6 shows the results from exhaust gas simulation.

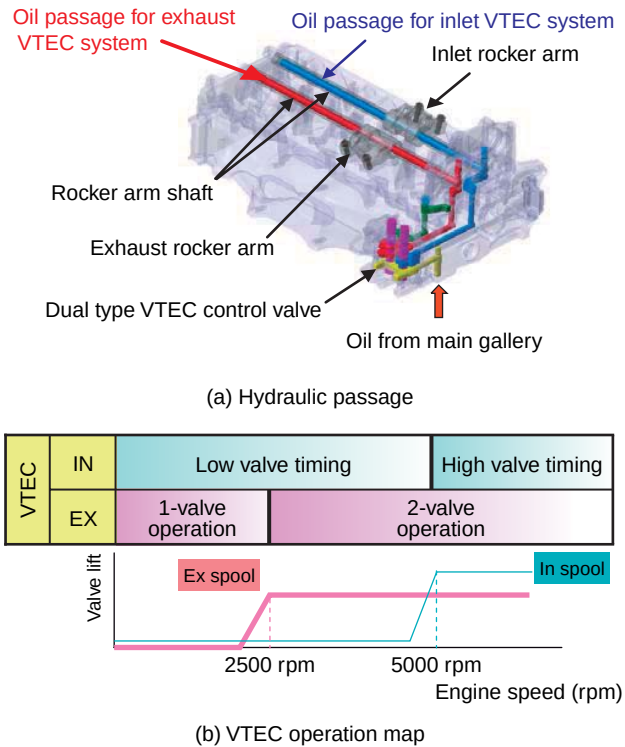


Fig. 5 VTEC unit and operation map

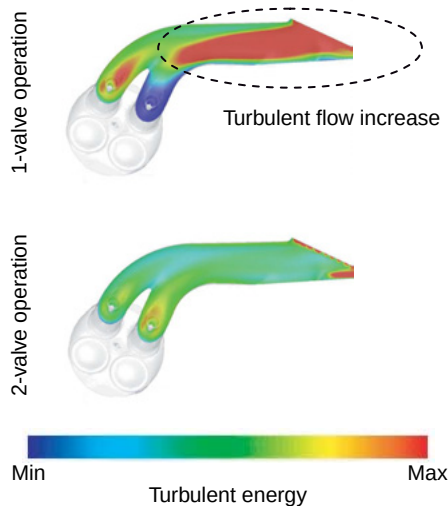


Fig. 6 Comparison of exhaust gas flow between 1-valve operation and 2-valve operation

These results indicate an increase in turbulent flow.

The results from verification of cold starting with an actual engine are shown in Fig. 7. There is an increase in the turbulent flow inside the port, promoting the oxidation reaction in the feed gases. As a result, reaction heat is generated for faster light-off of the catalyst, enabling a reduction in HC emissions.

One other effect of 1-valve operation on the exhaust side is an enhancement of volumetric efficiency in the low-speed range. Figure 8 shows a comparison of output characteristics with 2-valve operation. Operating with one valve inactive in the low-speed range reduces blowback of exhaust into the cylinder and enhances low-speed torque.

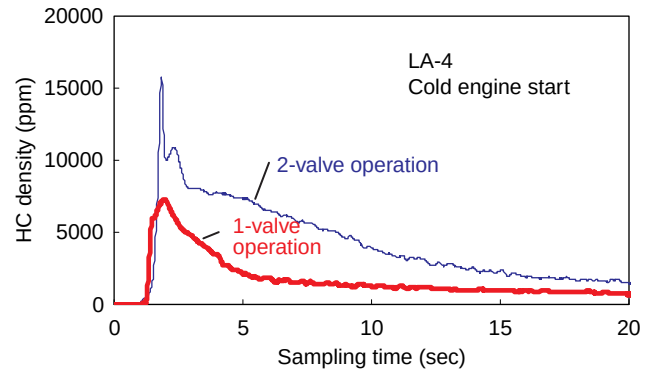


Fig. 7 Comparison of amount of HC emission between 1-valve operation and 2-valve operation

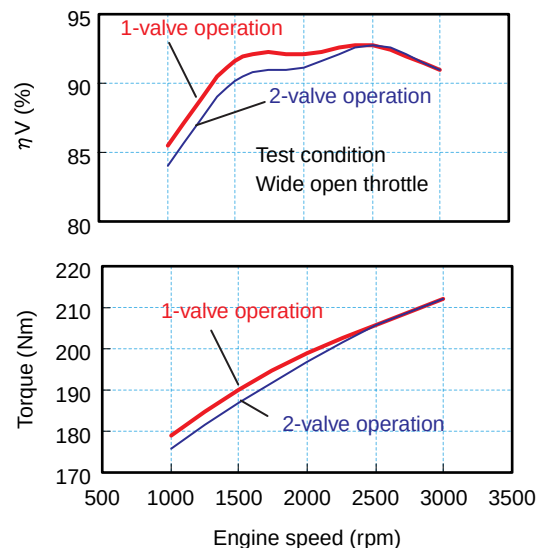


Fig. 8 Comparison of output performance

6. Low Exhaust Emissions

6.1. Exhaust Gas Treatment System

Figure 9 shows the exhaust gas purification system. One close-coupled catalytic converter is installed at the cylinder head with exhaust manifold and connected by the exhaust pipe to an under-floor converter with a three-way catalyst.

6.2. Exhaust Gas Reduction Technology

The exhaust emissions reduction technologies employed in this engine can be generally grouped into the following six categories:

(1) Reduction of heat mass for faster light-off of the catalyst

Use of the cylinder head with exhaust manifold and the close-coupled catalytic converter reduce the heat mass for faster light-off of the catalyst.

(2) More precise control of air-fuel ratio

In order to achieve more precise control of the air-fuel ratio, a universal exhaust gas oxygen (UEGO) sensor is installed upstream from the close-coupled catalytic converter and a heated exhaust gas oxygen (HEGO) sensor downstream from it. The system also employs prediction and identification-type sliding mode (PRISM)⁽²⁾ control like that of the previous model engine, thus realizing greater precision in the air-fuel ratio. The timing for fuel injection immediately after starting the engine was also optimized to reduce the amount of HCs before catalyst light-off takes place.

(3) Use of high-ignitability spark plugs for ignition timing control

This engine uses high-ignitability spark plugs, as shown in Fig. 10, that have a cylinder of precious metal welded onto the outer electrode. The ground electrode is given a needle-like shape to reduce quenching of the

flame core and enhance ignition stability. As shown in Fig. 11, this plug enables ignition retardation by 10° compared to the previous iridium plug, so that the exhaust gas temperature is 150°C higher and HCs are reduced 75%. Use of this spark plug yields a reduction in exhaust emissions amounting to a 13% NMOG reduction in LA-4 mode.

(4) More precise fuel injection

A new model injector was developed to enhance performance more than before in order to achieve a balance of greater output with lower exhaust emissions. The main goals were to enhance atomization performance and expand the possible area of injection (widen the range). Figure 12 shows the structure of this injector.

Effective means for promoting atomization include reducing pressure loss in the fuel passageway and keeping one spray from interfering with another. In order to reduce pressure loss, the fuel passageway shape and area were optimized. In order to reduce interference with the spray, a form control plate was employed and computer-aided engineering (CAE) was employed to optimize the fuel passageway and nozzle hole placement. As a result, the spray particle diameter was reduced 40% compared to the previous model and a particle diameter was achieved

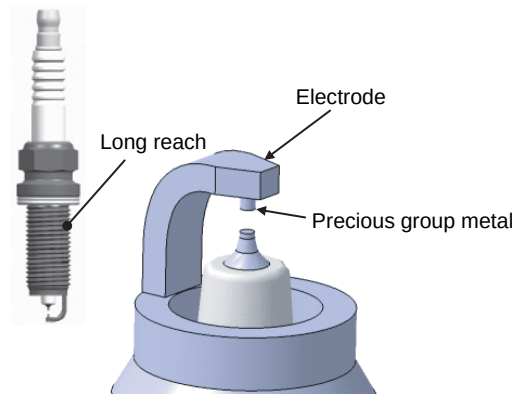


Fig. 10 High ignitability plug

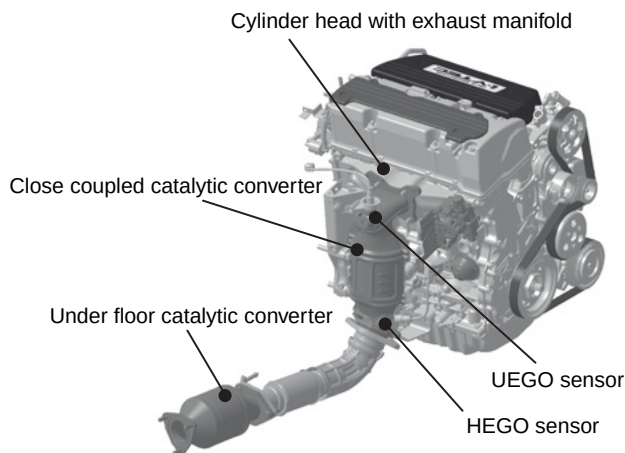


Fig. 9 Exhaust system arrangement

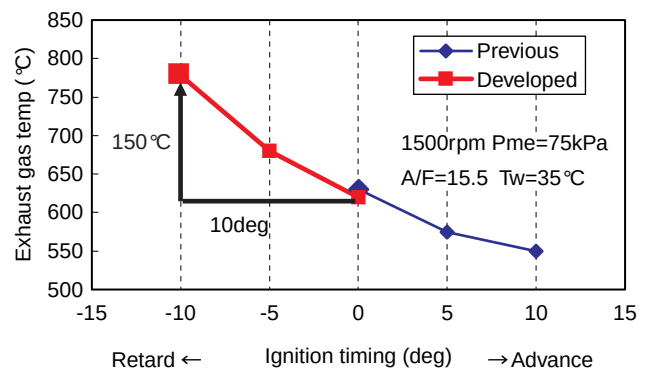


Fig. 11 Comparison of plug performance

equivalent to that formerly achieved by compressed air-assisted mechanisms.

Effective means for achieving a wider range include enhancing the valve opening and closing response. Reducing the weight of the needle valve, optimizing the stroke, and increasing the suction power yielded a 20% wider range compared to the previous model and contributed to higher engine performance.

(5) Exhaust gas flow enhancement effect

In order to maximize the purification performance and limit the deterioration of the catalyst, it is necessary to introduce exhaust gases to the catalyst in an even manner. This is also effective in raising output because it reduces loss of pressure in the exhaust gases. Figure 13 shows the shape of the front cone. The exhaust system of this engine has a catalytic converter placed immediately after the cylinder head with exhaust manifold. This layout produces a bend in the exhaust gases that emerge from the ports, making it more challenging for the exhaust gases to be introduced evenly.

Figure 14 shows an analysis of exhaust gas flow through the front cone. Exhaust gases from the No. 2 and

No. 3 ports tend to flow along the outer wall of the front cone because of an inertia force [Fig. 14 (a)]. Exhaust gases from the No. 1 and No. 4 ports pass through a sharply-angled passageway so that the gases form a spiral flow at the front cone collector section and remain in a spiral flow as they pass on to the outer edge of the converter [Fig. 14(b)].

The gas flow characteristics shown in Fig. 14 were therefore taken into consideration in optimizing the shape of the front cone. As shown in Fig. 15, the exhaust gases

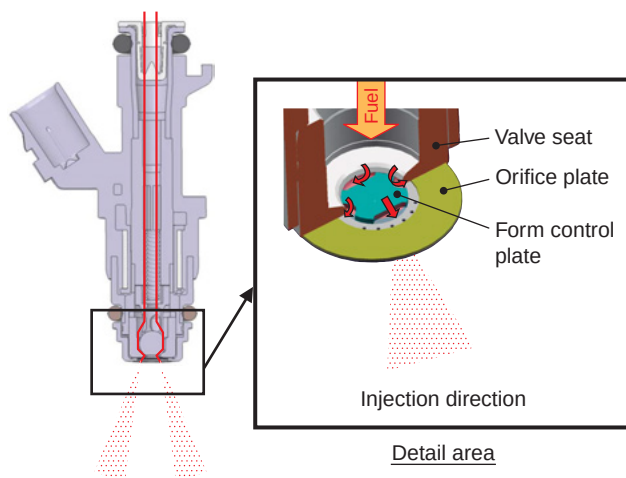


Fig. 12 Detailed structure of injector unit

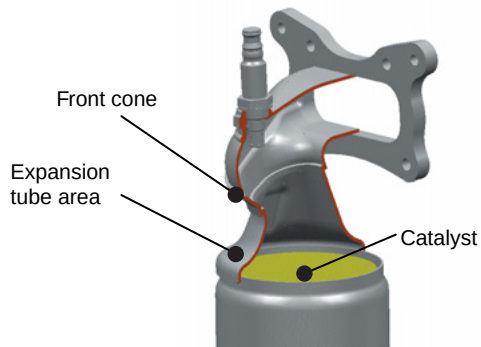
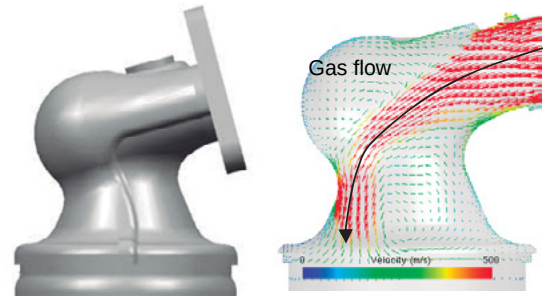
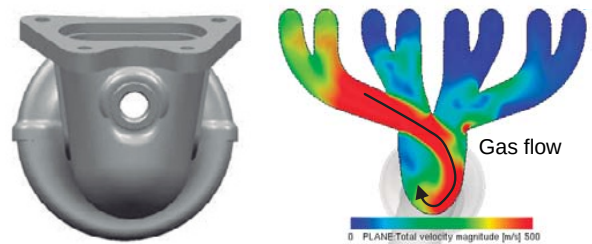


Fig. 13 Front cone section view



(a) #2, #3 port gas flow



(b) #1, #4 port gas flow

Fig. 14 Analysis of exhaust gas flow

	Start specification		Final specification	
Shape				
#1, #4				
#2, #3				

0 70
Velocity (m/sec)

Fig. 15 Optimized exhaust gas feed to catalyst

that had formerly collected at the outer edge now flowed instead through the central area so that the gases could be directed against the catalyst in an even manner.

The cone shape farther down the expansion tube area was also reshaped to be more like a bell mouth in order to reduce eddy loss at the wall surface⁽³⁾.

(6) Enhanced air-fuel ratio controllability

Figure 16 shows the state of gases from all cylinders on their exhaust stroke as they strike the UEGO sensor. It is necessary for the UEGO sensor to be able to detect the exhaust gases from every cylinder uniformly in order to enhance air-fuel ratio controllability. Computational fluid dynamics (CFD) simulations of the exhaust gases from each cylinder were conducted and analyzed in order to optimize the sensor location. The results enabled the sensor to receive exhaust gases from all cylinders uniformly, enabling more precise control of the air-fuel ratio.

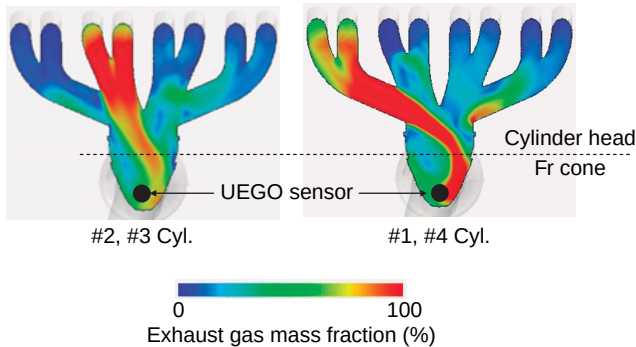


Fig. 16 UEGO Sensor arrangement optimization

7. Fuel Consumption

7.1. Engine Standalone Fuel Consumption

Figure 17 shows the brake specific fuel consumption (BSFC) for the total engine displacement. The VTC was widened from the previous 25° to 50° in order to obtain an internal exhaust gas recirculation (EGR) effect, reduce pumping loss, and enhance BSFC 4.1% in stoichiometric air-fuel ratio combustion, as compared to the previous model engine. This achieved a reduction in the engine's standalone fuel consumption.

7.2. Fuel Consumption Reduction Technology

This engine changed the operating angle of the VTC employed as before from 25° to 50°. The results of the change are shown in Fig. 18. It is apparent that the change from the previous VTC operating angle of 25° to the wider 50° causes an internal EGR effect that reduces pumping loss on the intake stroke.

Optimizing the VTC angle for every engine operating range produced the results shown in Fig. 19. Fuel

consumption was enhanced approximately 1% in U.S. LA-4 mode, which evaluates the low to medium-load operating range, and approximately 3% in highway mode. This places the engine at the top level in its class for fuel

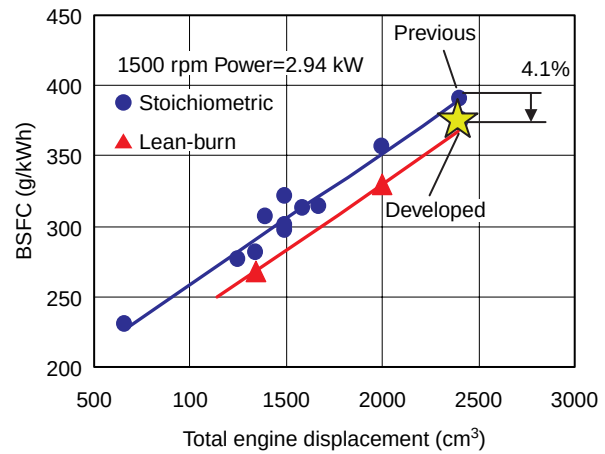


Fig. 17 Effect of BSFC decrease

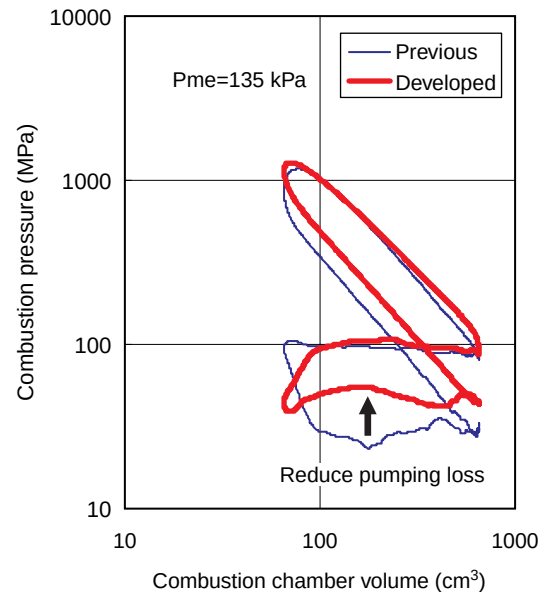


Fig. 18 Effect of new VTC angle

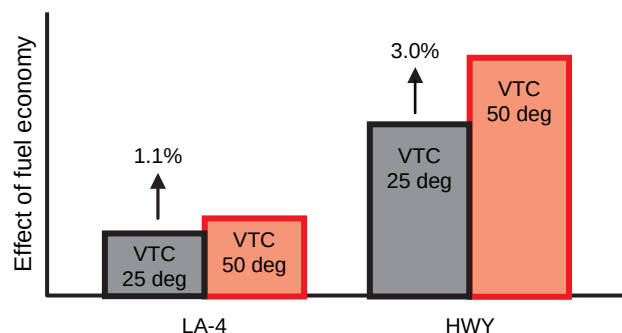


Fig. 19 Effect of fuel economy on VTC angle

consumption. The development of a new highly heat-resistant material for the converter mat in the close-coupled catalytic converter assured a stoichiometric air-fuel ratio combustion range equivalent to that of the previous under-floor converter.

8. Noise and Vibration Reduction Technology

Noise and vibration (NV) performance is a key factor in achieving enhanced comfort. Figure 20 shows how increasing single part sound radiation becomes a concern when the previous model engine is made to yield higher engine performance.

With this engine, however, an aluminum oil pan is employed and power plant rigidity is increased to achieve NV levels equivalent to those in previous models.

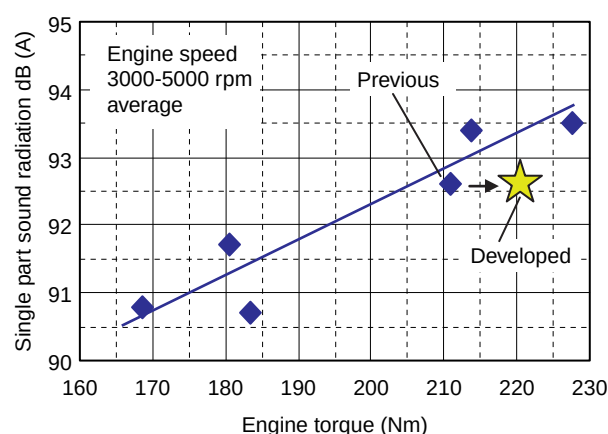


Fig. 20 Positioning of noise vibration

9. Conclusion

The below findings were obtained with the developed engine. The realization of these specific technologies enabled a high-level balance between better levels of emissions and outstanding power performance.

- (1) Analysis of the effects of exhaust interference in an in-line 4-cylinder engine enabled achievement of high power performance even with the cylinder head with exhaust manifold structure. The result was 142 kW of output and 220 Nm of torque, placing the engine at the top level in its class.
- (2) The adoption of operation with one exhaust valve inactive and optimization of the flow of exhaust gases for enhanced purification performance, the use of a high-ignitability plug, and other such technologies yielded higher engine performance than with the previous model, but still achieved U.S. LEV II SULEV regulation and reached low emissions levels equivalent to those of the previous model.
- (3) Changing the operating angle of the VTC from the

previous 25° to 50° enabled the internal EGR effect to function and reduced pumping loss, thus enhancing fuel consumption.

- (4) Increasing power plant rigidity secured quiet operation equivalent to previous levels even though higher engine performance than that of the previous model was achieved.

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■ Author ■



Ryota KAWAGUCHI



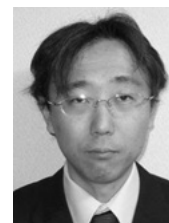
Kazuya YAMAMOTO



Takashi KAYABA



Sadao KOJIMA



Takahiro SHINKAI



Koichiro ASAME