

Development of V6 Engine with New Variable Cylinder Management

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ABSTRACT

A new V6 3.5-L i-VTEC variable cylinder management (VCM) engine was developed with the goals of high output, low fuel consumption, and low exhaust emissions. This engine employs a cylinder deactivation mechanism that uses variable valve timing and lift electric control (VTEC) that enable operation with three, four, or six cylinders according to operating conditions. With the addition of 4-cylinder operation, this realizes three-mode control over the number of cylinders, one mode more than previous cylinder deactivation engines. The increase in the number of cylinder deactivation modes was combined with the new development of hydraulic circuits, a hydraulic switching mechanism, and switching control. This has enabled the instantaneous switching of operating cylinders without losses of drivability, as in previous models. This engine is being installed in the new model ACCORD, giving this vehicle output and fuel economy at the top of its class, and at the same time complying with Partial Zero Emission Vehicle (PZEV) regulations in the U.S. state of California.

1. Introduction

Increasing demands for low fuel consumption and low exhaust emissions are being placed on automobiles from the aspects of the environment and economy. An automobile engine should be able to meet these demands while also exhibiting enhanced driving performance. In order to satisfy these demands, Honda announced a V6 engine that uses a variable cylinder management system (hereafter called “VCM” system)⁽¹⁾, which was first installed in the 2003 model INSPIRE. This system is used to switch the engine between the 6-cylinder and the 3-cylinder modes. Recently, a system that has an additional 4-cylinder mode was developed so as to increase the range over which the engine could be used in a cylinder deactivation condition, and thus additionally enhance the fuel economy.

This paper describes the enhanced fuel economy of the newly developed V6 3.5-L i-VTEC VCM engine (hereafter called “VCM engine”) and the method of achieving this enhancement.

2. Development Goals

The development goal of the VCM engine is to realize low fuel consumption and low emissions on a par with

that of a small displacement engine, without impairing the output of the large displacement engine. The goals of developing environmentally friendly technology that can be used throughout the world to make next generation large displacement engines are as follows.

- (1) High output performance that is appropriate for a V6 engine
- (2) Higher fuel economy exceeding the level of this vehicle class
- (3) Compliance with PZEV regulations of the U.S. state of California

3. Engine Outline and Specifications

Table 1 shows the main specifications of this engine.

3.1. Outline of the VCM System

The VCM system employs technology that deactivates the intake and exhaust valves and simultaneously stops the fuel injection process, and, when the intake and exhaust valves are in a closed condition, puts the inside of the cylinders into a hermetically sealed state, thus reducing both pumping losses in the engine and the brake specific fuel consumption. (Fig. 1)

Compared to the conventional 3-cylinder and 6-cylinder modes, the newly developed VCM system has an

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Table 1 Engine specifications

Engine code		J30A8	J35Z2
Cylinder configuration		60° V-6 cylinder	60° V-6 cylinder
Bore × stroke (mm)		86 × 86	89 × 93
Displacement (cm ³)		2997	3471
Compression ratio		10.0	10.5
Valve train		SOHC VTEC	SOHC i-VTEC VCM
Number of valves		4 per cylinder	4 per cylinder
Valve diameter (mm)	Inlet	35	36
	Exhaust	30	30
Fuel		Regular	Regular
Maximum power (kW/rpm)		182 / 6250	200 / 6200
Maximum torque (Nm/rpm)		286 / 5000	336 / 5000
Fuel economy (CITY/HWY)		18/26	19/29

additional 4-cylinder mode to permit switchover between 3-cylinder, 4-cylinder, and 6-cylinder operation, thus realizing enhanced fuel economy.

The driving conditions for switchover are as follows: When the load on the engine is small, such as when the vehicle is cruising, the 3-cylinder mode is selected. In 3-cylinder mode, if the allowance drive force is insufficient, such as when driving in the gradual acceleration range or in the high vehicle speed range, the 4-cylinder mode is selected. When further drive force is necessary, the 6-cylinder mode is selected. In this way, this system selects the number of cylinders that results in the best fuel economy according to the drive force.

The VCM system utilizes the conventional Variable valve Timing and lift Electric Control (VTEC) technology. In addition, a new hydraulic passage, a hydraulic switchover mechanism, and switchover control were developed to cope with the increased number of cylinder deactivation switchover patterns.

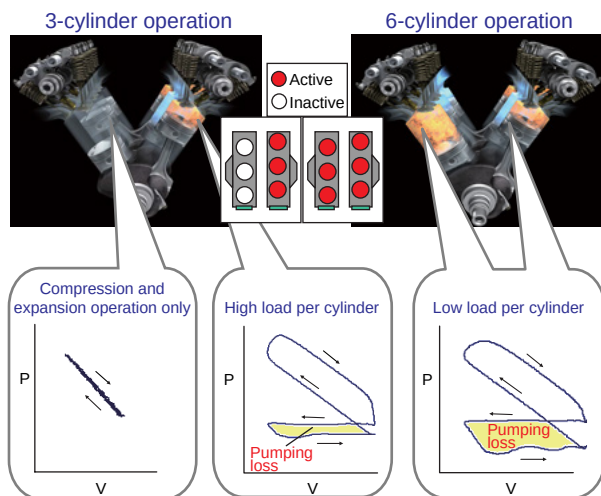


Fig. 1 Pumping loss

3.2. Basic Construction

Figure 2 shows an outline of the valve train mechanism.

The valve operation and deactivation switchover mechanism is the same two-loop hydraulic switching system as that of the conventional VCM system (Fig. 3). Each rocker arm has two hydraulic pistons. When hydraulic pressure is applied to the hydraulic piston A side, the hydraulic pistons are coupled to each other, and when hydraulic pressure is applied to the hydraulic piston B side, the pistons are decoupled.

Figure 4 shows the deactivation condition of the cylinders for each driving mode. At the bank 1 side, only one cylinder needs to be deactivating when the engine is in 4-cylinder mode, and all three cylinders need to be deactivating when the engine is in 3-cylinder mode. Consequently, an independent switching hydraulic passage for each cylinder group is necessary. For this reason, a total of four hydraulic passages, consisting of two sets of two-loop hydraulic switching passages, each consisting of two systems, are used. At the bank 2 side, only one

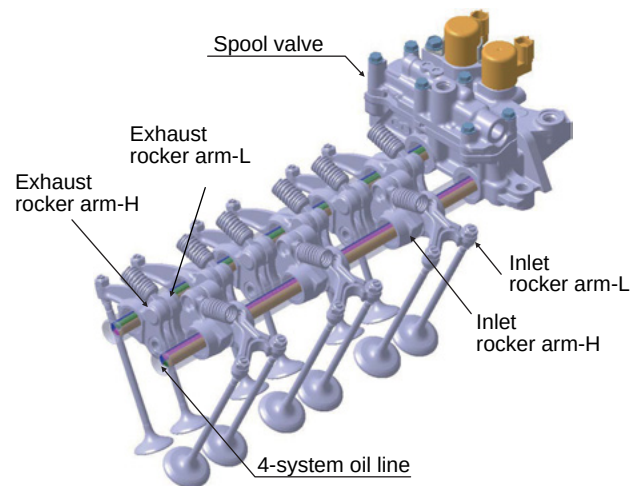


Fig. 2 VTEC VCM valve train

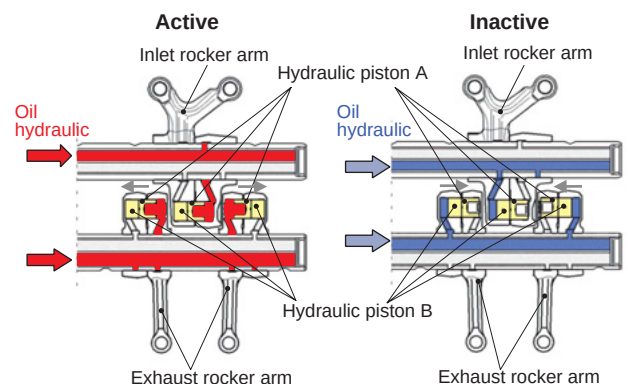


Fig. 3 2-way hydraulic passage VTEC mechanism

cylinder is switched over when the engine is in 4-cylinder mode, hence one 2-system switchover hydraulic passage is used.

In order to configure these switchover hydraulic passages, the inside of the rocker shaft at the bank 1 side is of a 4-chamber construction. Figure 5 shows the hydraulic passage.

The spool valves that controls the hydraulic pressure of this passage is installed on the end of each rocker shaft of banks 1 and 2. The spool valves installed on the bank 1 side consists of two spool valves that independently perform control of the two sets of two-loop hydraulic switching passages. If the concept of the conventional VCM were to have been simply extended, two sets of independent hydraulic passages would have been used. However, in this development, two spool valves were arranged in series as a hydraulic passage. The use of this passage configuration enables a single fault detection hydraulic switch to be used instead of two, which would have been required if independent passages had been used. Also, a 2-way solenoid valve was used as the spool valve on the downstream side. Because the 4-cylinder mode was limited to the high vehicle speed range, it could be used only in the engine speed range in which the hydraulic pressure is high, enabling a 2-way valve of simpler

construction to be used. In addition, efforts are being made toward increased compactness and lightness by partially installing the spool valve into the head cover, integrating the spool valve with the holder, rationalizing the hydraulic passage, and the like.

Furthermore, the shape of the pipes inside the 4-chamber rocker shaft was also changed so that the chambers can be sealed using only two pipes. This reduced the number of parts, which simplified the construction compared to that with four internal pipes, and also reduced the weight and cost.

3.3. Switching Control

The operating conditions of the spool valve at the bank 1 side in 6-cylinder mode, 4-cylinder mode, and 3-cylinder mode are shown in Figs.6 through 8. The passage indicated in red indicates the condition in which hydraulic pressure is applied.

To activate 6-cylinder mode, SPL-A-SOL (spool valve A solenoid) and SPL-B-SOL are switched OFF (Fig. 6).

To switch from 6-cylinder mode to 4-cylinder mode (Fig. 7), SPL-B-SOL is switched ON (1). As a result, hydraulic pressure is applied to SPOOL-VLV-B (spool valve B) (2), initiating movement in SPOOL-VLV-B. SPOOL-VLV-A applies hydraulic pressure to the operating side of the hydraulic piston of the rocker arms of the two cylinders (3). SPOOL-VLV-B applies hydraulic pressure (4), which arrived via SPOOL-VLV-A, to the deactivating side of the rocker arm of the rocker arm hydraulic piston of the remaining cylinder (5). Hydraulic pressure was applied to these cylinders when the engine was in 6-cylinder mode, but the hydraulic oil is discharged from (6). As a result, the rocker arm hydraulic piston moves to the deactivating side, and the valve deactivates. At the same time, the bank 2 side switches SPOOL-VLV-C ON, deactivation cylinder 1, and the engine goes into 4-cylinder mode.

When the engine returns from 4-cylinder mode to 6-cylinder mode (Fig. 6), SPL-B-SOL is switched OFF (1). The application of hydraulic pressure to SPOOL-VLV-B is stopped, and the hydraulic oil is discharged from (2). When the hydraulic pressure in SPOOL-VLV-B decreases, SPOOL-VLV-B is returned by spring force. As a result, the hydraulic passage of SPOOL-VLV-B switches over. Hydraulic pressure is applied to the operating side (3) and the hydraulic pressure on the deactivating side is applied from (4) to SPOOL-VLV-B, then the hydraulic oil flows through (5) and is discharged from SPOOL-VLV-A (6). As a result, the rocker arm hydraulic pressure piston moves to the operating side, and the valve operates. At the same time, the bank 2 side switches SPOOL-VLV-C OFF, and the engine returns to 6-cylinder mode.

To switch over from 6-cylinder to 3-cylinder mode (Fig. 8), SPL-A-SOL is switched ON (1). As a result, hydraulic pressure is applied to SPOOL-VLV-A (2), initiating movement in SPOOL-VLV-A. SPOOL-VLV-A

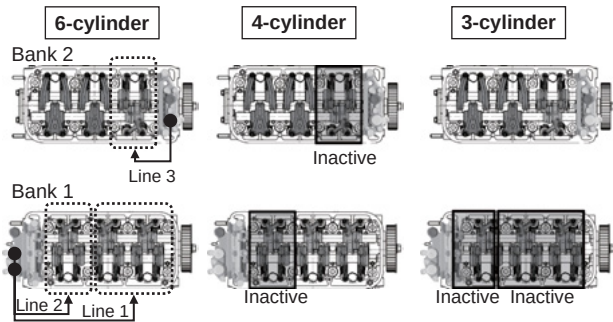


Fig. 4 State in each mode

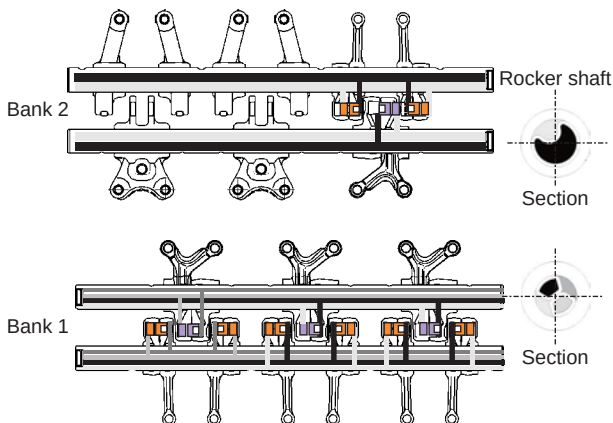


Fig. 5 View of valve train and hydraulic passage

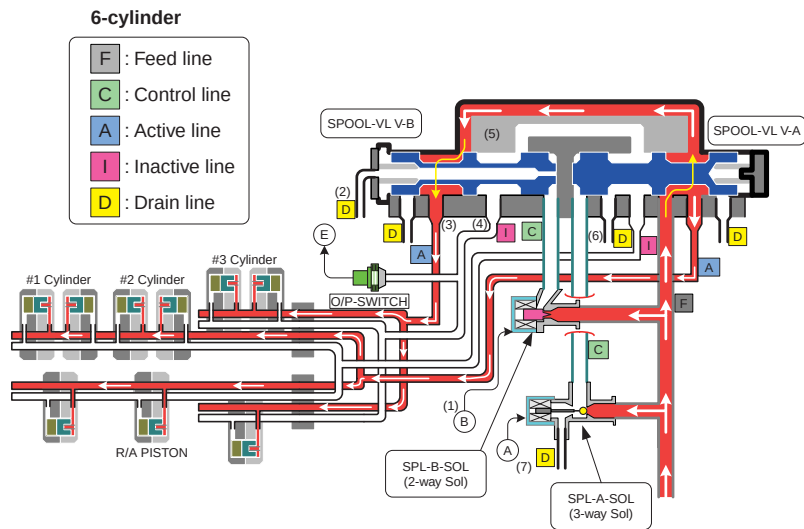


Fig. 6 6-cylinder oil-hydraulics control

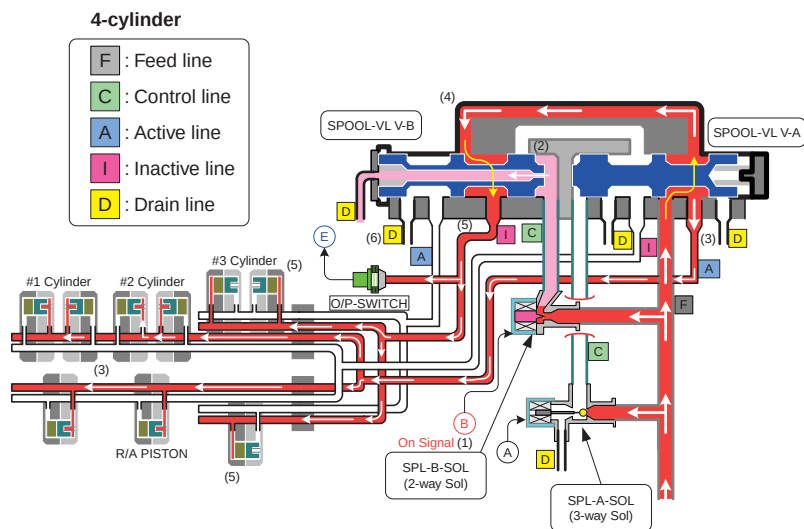


Fig. 7 4-cylinder oil-hydraulics control

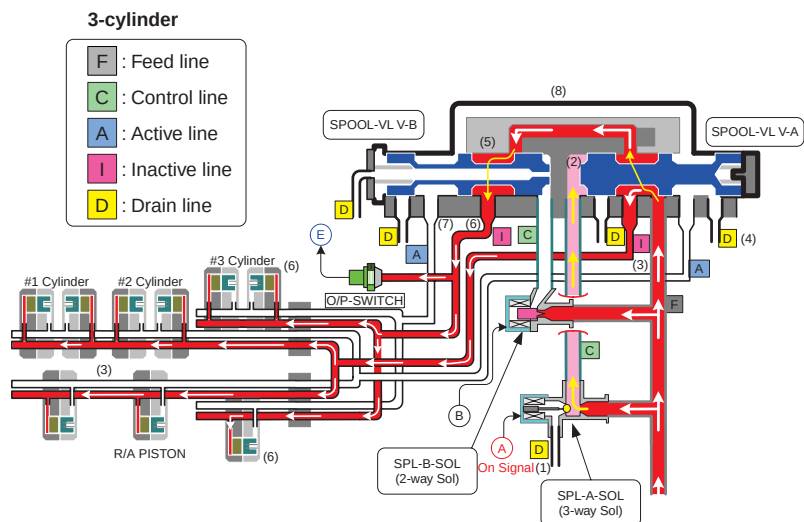


Fig. 8 3-cylinder oil-hydraulics control

applies pressure to the deactivating side of the rocker arm hydraulic piston of the two cylinders (3). The hydraulic pressure applied to the operating side of this cylinder is relieved from (4). As a result, the rocker arm hydraulic piston moves to the deactivating side, and the valve deactivates. SPOOL-VLV-B applies the hydraulic pressure (5) that arrived via SPOOL-VLV-A, to the deactivating side of the hydraulic piston on the remaining cylinder (6). The operating side hydraulic pressure applied to this cylinder enters SPOOL-VLV-B from (7), passes through (8), and is discharged from SPOOL-VLV-A (4). As a result, the rocker arm hydraulic piston moves to the deactivating side, and the valve deactivates.

To switch over from 3-cylinder to 6-cylinder mode (Fig. 6), SPL-A-SOL is switched OFF. The hydraulic pressure applied to SPOOL-VLV-A is stopped, and the hydraulic oil is discharged from SPL-A-SOL (7). When the pressure at SPOOL-VLV-A decreases, SPOOL-VLV-A is returned by spring force. As a result, the hydraulic passage of SPOOL-VLV-A switches over. In this way, SPL-A-SOL, SPL-B-SOL, and SPL-C-SOL, as well as the operation and deactivation of the applicable cylinders are controlled, thus enabling switchover between the three modes.

The functions of SPOOL-VLV-A and SPOOL-VLV-B differ according to whether the discharge of the hydraulic oil in the valve is controlled (SPOOL-VLV-A) or not controlled (SPOOL-VLV-B) by SPL-A-SOL. Controlling the discharge helps eliminate leakage of hydraulic oil when hydraulic pressure is applied, enabling switchover from low pressure to be realized. Because 4-cylinder mode is limited to the high engine speed range, SPOOL-VLV-B, which has a simple construction, can be used. The method of selecting the optimum number of cylinders and the method of controlling the switchover between the different cylinder modes are basically the same as those of the conventional VCM system. Figure 9 shows an outline of engine control.

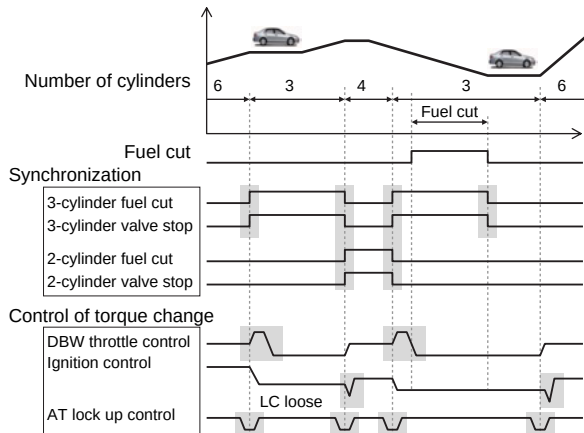


Fig. 9 Pattern of VCM operation

3.4. Output Performance

Figure 10 shows the output characteristics of the new VCM engine. When regular gasoline is specified, the output obtained is 200 kW at 6200 rpm, and 336 Nm at 5000 rpm.

The method of obtaining the above performance is as follows. In order to enhance the cooling performance, the coolant circulation passage between the cylinder block and the cylinder head was modified, and the thread dimensions of the spark plugs were changed from M14 to M12 and long reach plugs were used, enabling the thickness of the water jacket around the combustion chamber to be reduced. Also, a piston oil jet was used to reduce the piston temperature, enabling knocking to be suppressed, and the compression ratio to be set to 10.5. In addition, the valve timing and the shape of the intake system and intake manifold were restudied, the suction efficiency was increased by widening the valve head diameter, for example, and the exhaust efficiency was increased by changing the construction of the exhaust pipe, thus enabling the above performance to be obtained.

3.5. Fuel Economy Performance

With this system, in order to operate the engine on a number of cylinders that conforms to the driving condition, the valve operation of the applicable cylinders is momentarily interrupted, realizing reduced engine friction due to reduced pumping losses and reduced valve operation losses. In addition, the fuel economy is increased due to enhanced thermal efficiency resulting from the use of a load zone in which the combustion form

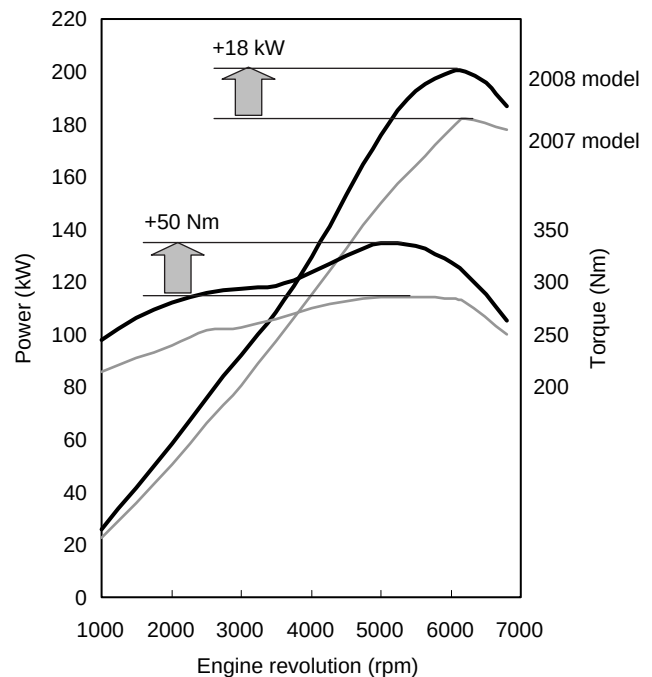


Fig. 10 Output performance

is satisfactory, and by increasing the fuel cut time.

Figure 11 shows the relationship between the total engine displacement and the brake specific fuel consumption (BSFC) when the engine speed is 1500 rpm and the output is 2.94 kW. By switching from 6-cylinder to 3-cylinder mode, BSFC of the stand-alone engine was reduced by about 30%, and despite the fact that the total engine displacement was 3.5 L, the BSFC obtained was equivalent to that of an engine with a total displacement of 2.0 L.

Figure 12 shows the cruising fuel economy effectiveness and the load zone in which cylinder deactivation driving can be performed. A cruising fuel economy exceeding that of the 3.0-L engine of the previous year's model was achieved by driving in 3-cylinder mode in the low-speed range, and in the added 4-cylinder mode in the high-speed range. Figure 13 shows the relationship between the load and the BSFC at

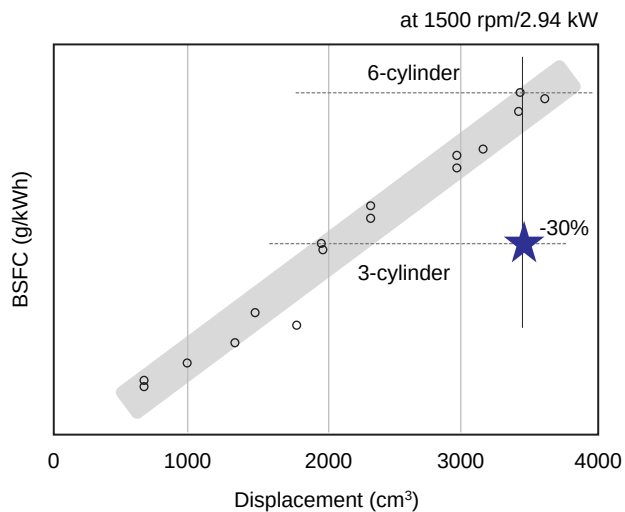


Fig. 11 VCM effect on BSFC

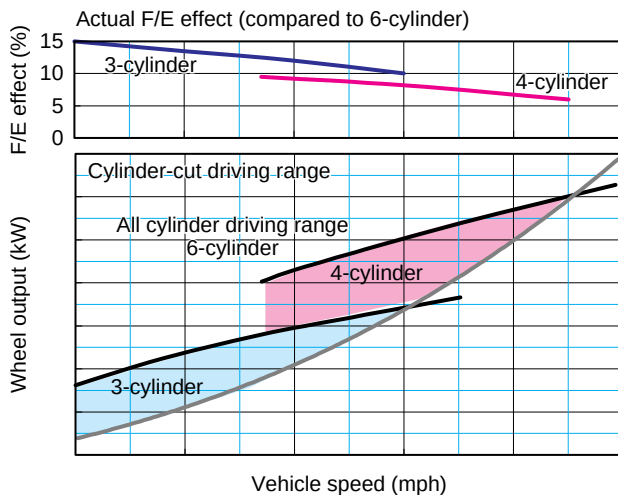


Fig. 12 Effect of VCM on fuel economy

a vehicle speed of 70 mph. The number of cylinders changes according to the required drive force, affecting the fuel economy. While the vehicle is cruising, higher fuel economy can be obtained by selecting the 3-cylinder mode. Under running conditions where additional drive force is needed, higher fuel economy can be obtained by selecting the 4-cylinder mode.

Fuel economy enhancing technology that suppresses knocking, increases the compression ratio, realizes precision control of active lockup in the automatic transmission, and the like, was adopted in addition to the newly developed VCM system. Consequently, as shown in Fig. 14, the fuel economy was higher than that of the 3.0-L engine of the previous year's model despite the fact that the actual engine displacement was 3.5 L. A 10%

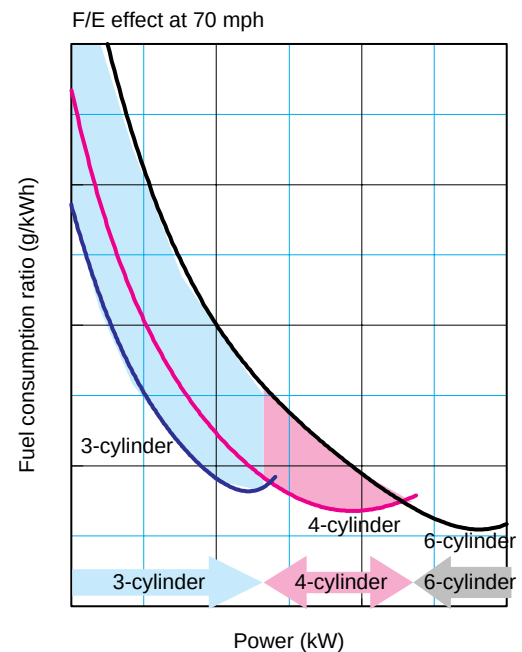


Fig. 13 Fuel consumption comparison

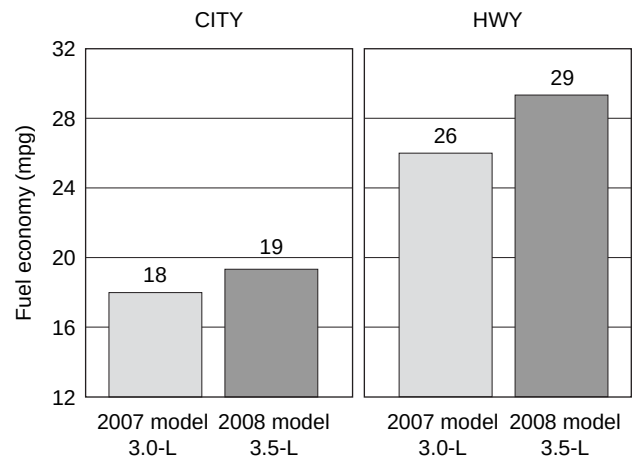


Fig. 14 Fuel economy effect

increase in fuel economy was obtained in EPA highway mode, resulting in top level output and fuel economy for this class of vehicle (Fig. 15).

3.6. Exhaust Gas Performance

The new VCM system complies with the PZEV regulations of the U.S. state of California. Its specifications are shown below.

A high density 900 CPI three-way catalyst was installed immediately behind the cylinder head of each bank. As a result, the thermal capacity was reduced, the temperature rise characteristics in the cold range, for example, were enhanced, and the cleaning performance

was increased. Also, an LAF (linear A/F) sensor and an O_2 sensor were installed at each bank in order to increase the response, and precision feedback control of each bank can be performed. In addition, from the 2008 model, an air flow meter will be used, in order to increase the accuracy of air-fuel ratio control (Fig. 16).

In addition to the abovementioned low emission technology, precision control of the electrically operated EGR valve has been employed, and the starting HC reduced by means of dual probe electrode spark plugs, thus complying with the PZEV regulations of the U.S. state of California and realizing environmental friendliness and low fuel consumption.

4. Comfort

NV (noise and vibration) performance is one important factor for offering comfort worthy of a high-grade automobile. As a result of the addition of 4-cylinder mode, the combustion intervals are unequal, so vibration increases. As a countermeasure, the performance of the NV device used with the conventional VCM was enhanced, and the use of 4-cylinder mode was limited to the high vehicle speed range, thus enabling the NV performance to be satisfied.

The performance enhancements realized by the NV device are as follows.

- (1) Reduction of the long torsion spring constant
As with the conventional VCM system, a long torsion spring is used as the lockup damper. The spring constant of this spring was reduced, resulting in further reduction of vibration in the drive system.
- (2) Increased drive force of the active control engine mount (ACM) and measures for the 4-cylinder order
As with the conventional VCM system, an ACM is used to reduce vibration when the cylinders are deactivating. Four-cylinder order control was added to suppress vibration in 4-cylinder mode, and the drive force was increased in order to suppress vibration when cylinders are deactivating, including when the engine is running in 3-cylinder mode.

5. Conclusion

- (1) A new V6 variable cylinder system to which a 4-cylinder mode was added was developed, with high output, low fuel consumption, and low emissions set as the study objectives.
- (2) Compared to the previous year's model 3.0-L SOHC VETC, a 10% increase in fuel economy was achieved during EPA highway mode driving despite the fact that displacement was increased to 3.5 L.
- (3) While achieving the above level of fuel economy, the output when regular gasoline was used reached 200 kW at 6200 rpm, and 336 Nm at 5000 rpm, which is the top level for this class of vehicle.

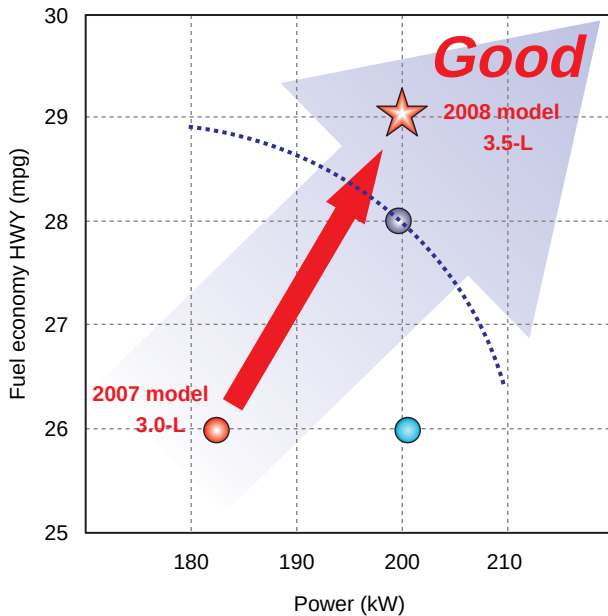


Fig. 15 Performance of 2008 model year ACCORD on fuel economy and power

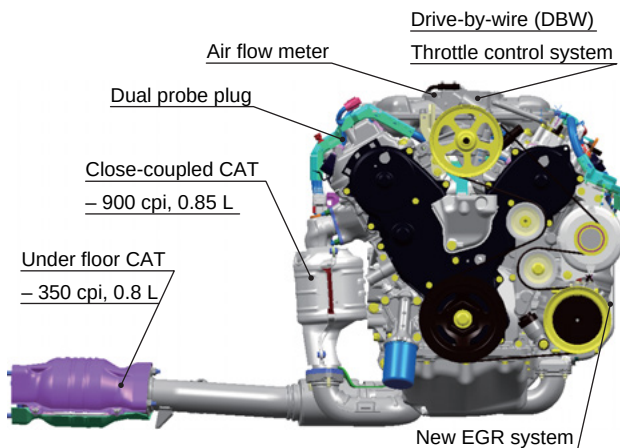


Fig. 16 Engine configuration and control system

Reference

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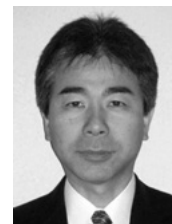
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