

Development of New V6 3.5 L Gasoline Engine

Nobuo SUZUKI*

Yasutaka HAYASHI**

Kazuya ISHIKI*

Atsushi SATO*

Tatsuhito ESAKI**

Satoshi WATANABE*

ABSTRACT

A new V6 3.5 L gasoline engine was developed with the goal of simultaneously reducing CO₂ emissions and achieving the driving enjoyment inherent to vehicles. The DI VTEC VCM system that is the key technology of this engine integrates variable valve timing lift and a variable cylinder system with a direct injection system. This increased the maximum output by 3.3% and reduced the fuel consumption rate by 20.1% compared to the previous model. A 2014 model year ACURA RLX equipped with this new engine, enhanced NV performance that expands the 3-cylinder drive area, and vehicle body technologies that increase fuel economy achieved fuel economy enhancement of 29% in Environmental Protection Agency highway mode and 18% in city mode compared to the previous model.

1. Introduction

As expectations increase for enhanced environmental performance of automobiles, Honda is aiming to reduce CO₂ emissions of its products sold around the world by 30% compared with 2000 levels, by the year 2020. The domains of new next-generation technology that pursue driving enjoyment characteristic of Honda products with a base of good environmental performance, and achieve a high balance of both driving quality and fuel economy have been designated EARTH DREAMS TECHNOLOGY. Figure 1 shows the EARTH DREAMS TECHNOLOGY domain lineup, which includes 0.66 L to 3.5 L-class gasoline engines, a small diesel engine, K-Car to medium vehicle-class CVT, an electric vehicle (EV) powertrain, and a hybrid series of powertrains. The gasoline engines achieve

both high output performance and low power consumption by further advancing Honda's original VTEC technology, increasing thermal efficiency, and reducing friction.

The newly developed V6 3.5 L engine achieves both enhanced fuel economy and high output by integrating a high-output type Variable valve Timing and lift Electronic Control (VTEC) system that has been used according to the concepts of the vehicles in which it has been mounted thus far, with a Variable Cylinder Management (VCM) system⁽¹⁾ that enables 3-cylinder drive, and also by adopting cylinder Direct Injection (DI). This paper reports on the new technology used in this new V6 3.5 L engine.

2. Development Goals

The new engine was developed with the following goals to achieve both the high product appeal and environmental performance enabling use in a mid-size luxury sedan.

- (1) Securing top-class output competitiveness
- (2) Achieving top-class Environmental Protection Agency (EPA) mode fuel economy
- (3) NV performance befitting a mid-size luxury sedan

3. Overview of Engine and Applied Technology

The VCM system is a technology for reducing the fuel consumption of V6 engines. The VCM system treats a V6 engine as two 3-cylinder engines, and instantly stops



Fig. 1 Domains of EARTH DREAMS TECHNOLOGY

* Automobile R&D Center

** HONDA R&D AMERICAS, INC.

Table 1 Engine specifications

Engine code	J35Y4 (new)	J37A
Displacement (cm ³)	3471	3664
Bore x stroke (mm)	89 x 93	90 x 96
Valve train	SOHC VTEC with VCM	SOHC VTEC
Compression ratio	11.5:1	11.2:1
Fuel system	Direct injection	Port injection
Max. power (kW/rpm)	231 / 6500	224 / 6300
Max. torque (Nm/rpm)	369 / 4500	368 / 5000
Redline (rpm)	6800	6800
Fuel grade	Premium recommended	Premium mandatory

inlet and exhaust valve drive for one bank consisting of three of the six cylinders in accordance with the driving status, propelling the vehicle with only the remaining three cylinders. Then, when the accelerator is pressed or a high load is otherwise applied, the engine instantly returns to 6-cylinder drive. This simultaneously achieves a high balance of both the power of large displacement and the low fuel consumption of small displacement.

The new engine uses a newly designed valvetrain and combustion chamber shape to accommodate DI VTEC VCM adoption. Intake efficiency is secured by adopting VTEC and DI, and low-speed torque is secured by reducing knock, which increases the torque. The V6 layout with a bank angle of 60° that is advantageous in terms of first-order rotational vibration, and the compact and lightweight framework structure are carried over from the previous model. Figure 2 shows the external appearance of the engine, and Table 1 lists the major engine specifications.

This paper describes the VTEC VCM system and DI system that are the key technology of this engine. In addition, it also describes the friction reduction technology



Fig. 2 J35Y4 engine

and VCM applied technology that contribute to enhancing fuel economy, and the mode fuel economy enhancement effects.

4. Key DI VTEC VCM Technology

4.1. VTEC VCM System

Figure 3 shows the VTEC VCM system used in this engine. Three-cylinder drive is supported by locating VTEC rocker arms in the V-engine's front bank that constantly performs driving [Fig. 3(a)], and VTEC VCM rocker arms with a new structure in the rear bank [Fig. 3(b)].

The drive mode is switched according to information such as the engine speed, load, vehicle speed, and throttle opening. Figure 4 shows a diagram of the rear bank oil circuit. The newly developed system consists of two different spool valves: spool valve A that controls the hydraulic pressure for VCM switching; and spool valve B

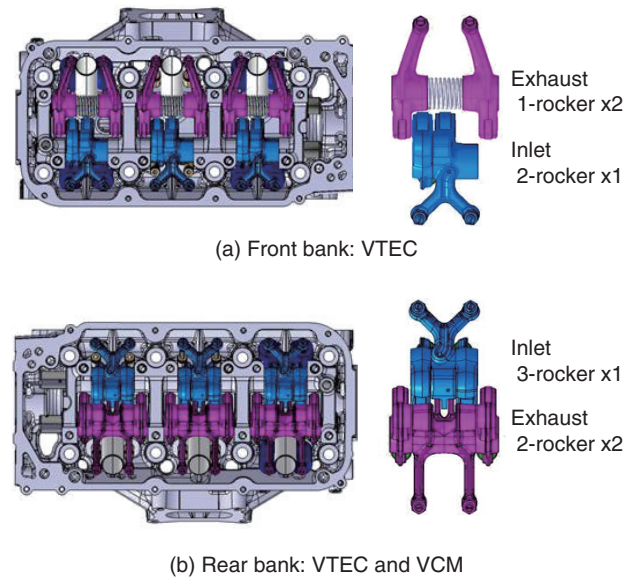


Fig. 3 VTEC VCM structure

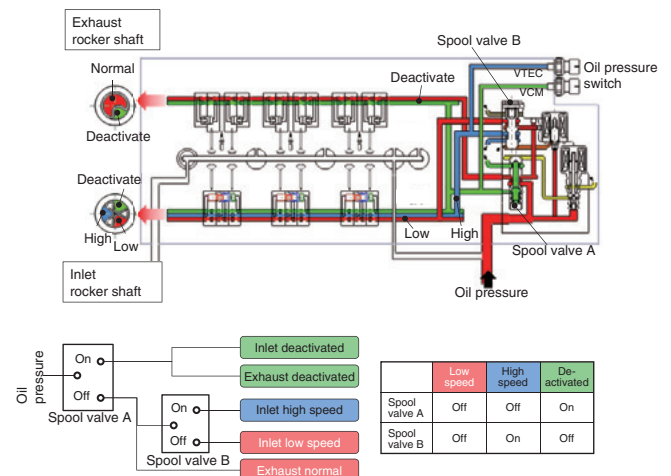


Fig. 4 VTEC VCM oil path system

that controls the hydraulic pressure for VTEC switching between low-speed and high-speed operation. Hydraulic pressure is supplied to the rocker arms, the synchronizing piston pins move, and the rocker arms connect and disconnect according to the switching of these spool valves.

4.1.1. Coaxial synchronizing piston pin structure

Figure 5 shows the differences between the newly developed VTEC coaxial synchronizing piston pin structure and the conventional structure. The conventional structure located the synchronizing piston pin for VTEC switching and the synchronizing piston pin for VCM switching on different axes⁽²⁾. However, the increase in inertia weight due to locating the synchronizing piston pins on different axes increases the friction loss, which affects fuel economy, so a newly developed 3-stage coaxial synchronizing piston pin structure was adopted that uses hydraulic-hydraulic switching. This was done by incorporating a hollow outer pin and solid inner pin into the mid rocker, and realizes three different types of valve lift by extending and sliding these pins using hydraulic pressure.

Figure 6 shows an overview of VTEC VCM lift change-over. In the initial state, hydraulic pressure is applied to path 2 and the outer and inner pins of the mid rocker are pressed apart, so the low-speed rocker and mid rocker are connected and low-speed cam drive results. During cylinder

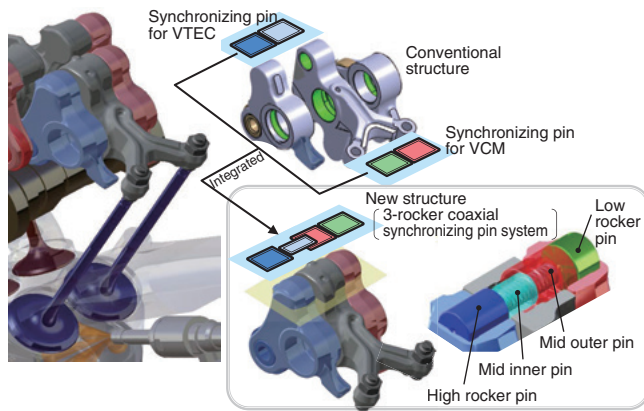


Fig. 5 Synchronizing pin structure

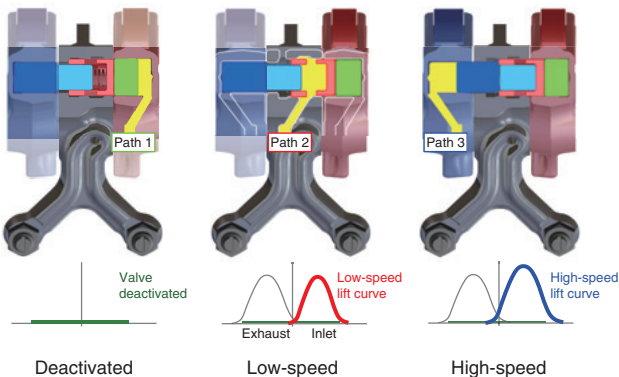


Fig. 6 Valve lift change over

deactivation, hydraulic pressure is applied to path 1 and the low-speed rocker pin is pushed out, so the low-speed rocker and the mid rocker are disconnected and valve drive stops. When a request to switch to the high-speed cam is issued, hydraulic pressure is applied to path 3 to push out the high-speed rocker pin, so all three high-speed, mid and low-speed rockers are connected and high-speed cam drive results.

Figure 7 shows the results of measuring valve bounce behavior relative to engine speed. Adoption of the new synchronizing piston pin structure suppressed the increase in weight and enabled stabilizing of valvetrain behavior up to 7000 rpm without increasing the valve spring load.

The adoption of a structure that connects all three rockers even when driving with the high-speed cam enabled stabilizing of the low-speed cam behavior during high-speed operation without adding a new lost motion spring.

The conventional structure in which the three rockers are always connected requires that hydraulic pressure be applied to two paths. In contrast, this coaxial synchronizing piston pin mechanism requires that hydraulic pressure be applied to only one of three paths, which reduces the oil path volume and oil leak amount compared to the conventional mechanism.

4.1.2. Switching responsiveness

The switching responsiveness of the VCM system is an important factor for realizing a linear drive feeling. The volume, diameter and length of the oil path, the introducibility of hydraulic pressure to the synchronizing piston pin, the oil leakage amount, and other factors that affect the switching responsiveness were optimized with the aim of immediately boosting the pressure in each part of the oil path to the supplied hydraulic pressure or returning to low pressure in accordance with the VCM switching signal.

Figure 8 shows an example of the results of measuring the pressure-receiving characteristics of the synchronizing piston pin and optimizing the oil channels. In the initial development stages, a delay occurred in the pin load relative to the rise in hydraulic pressure in the oil path (black line in Fig. 8). Therefore, the introducibility of oil to the

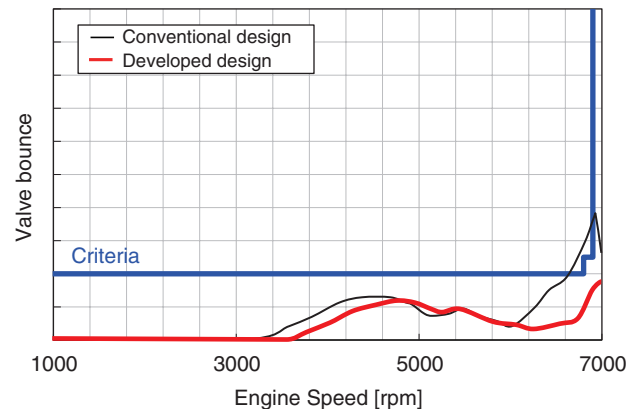


Fig. 7 Valve bounce behavior

pin was enhanced by expanding the inflow area and adding a cross groove to the synchronizing piston pin. This enabled shortening of the reaction time (red line in Fig. 8).

Figure 9 shows the structure of the 3-way spool valve. Use of a 3-way valve enabled lowering of the hydraulic pressure applied in the valve deactivation state by leading the oil to the drain, and to immediately raise the hydraulic pressure on the operating side when switching from the valve deactivation state to the normal operating state. This system achieved high switching responsiveness by reviewing the detailed drain path and spool valve structures, and realized control that stops fuel injection in sync with the inlet and exhaust valve operation stop timings.

4.2. DI System

The combustion chamber shape, head port shape and intake manifold were specially designed to accommodate DI system adoption.

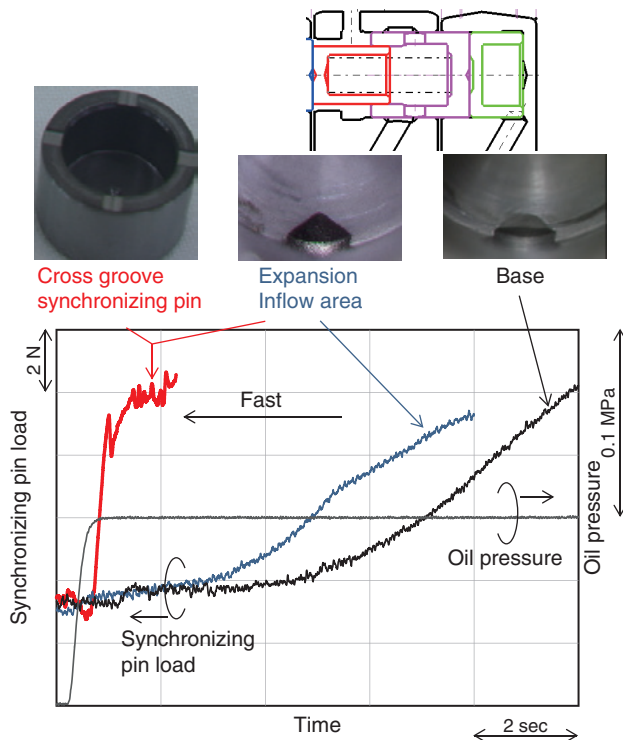


Fig. 8 Decrease of reaction time

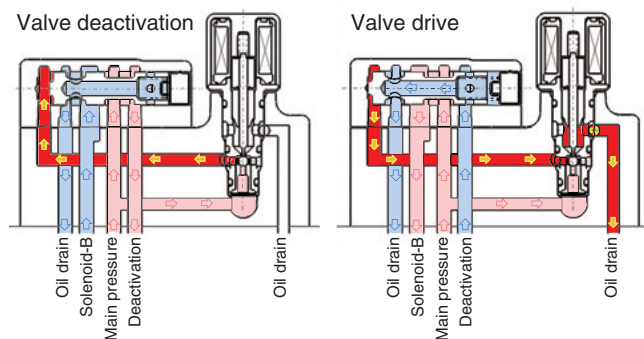


Fig. 9 3-way spool valve drain system

Figure 10 shows the DI combustion system that uses technical elements shared with the new 2.4 L engine. A multi-hole DI injector is located on the intake side of the combustion chamber, and produces strong tumble flow that forms a homogenous air fuel mixture for homogenous combustion. The shallow cavity in the piston crown is used together with split injection to stabilize combustion when warming up the catalyst.

The fuel system uses a compact package that fits between the V banks as shown in Fig. 11 in consideration of collision safety and reduction of noise to the outside of the vehicle. Fuel supply to the front and rear banks was integrated to a single plunger-type pump located at the end of the camshaft on the rear head side to minimize friction loss when driving the high-pressure fuel pump.

The sizes and positions of the orifices inside the fuel pipe were optimized to suppress the fuel pressure fluctuation when the drive mode switches. Figure 12 shows the fluctuation inside the fuel pipe when switched between 6-cylinder drive and 3-cylinder drive. Optimization of the orifice positions and sizes suppressed the fuel pressure fluctuation before and after switching, with the result that A/F control could be rationalized by equalizing the fuel injection amount.

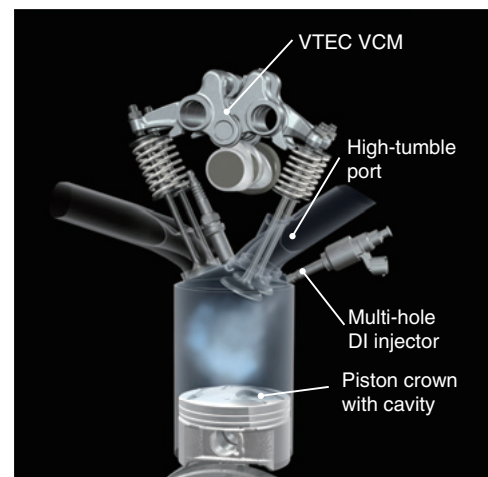


Fig. 10 DI combustion system

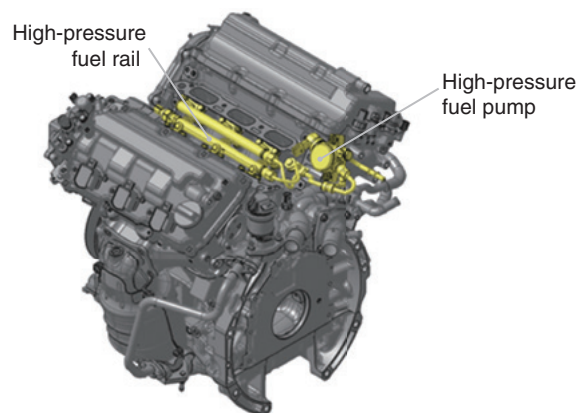


Fig. 11 DI system layout

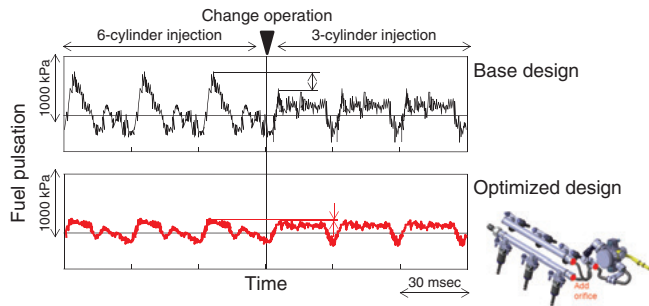


Fig. 12 Reduced fuel pressure fluctuation

5. Power Output

Figure 13 shows the output characteristics of the new V6 3.5 L engine. Adoption of new technology such as the DI VTEC VCM system and reduction of the intake and exhaust pipe resistance achieved a maximum output of 231 kW, which is 3.3% higher than that of the previous model, while downsizing the displacement. Torque characteristics equal to those of the 3.7 L engine of the previous model could also be achieved.

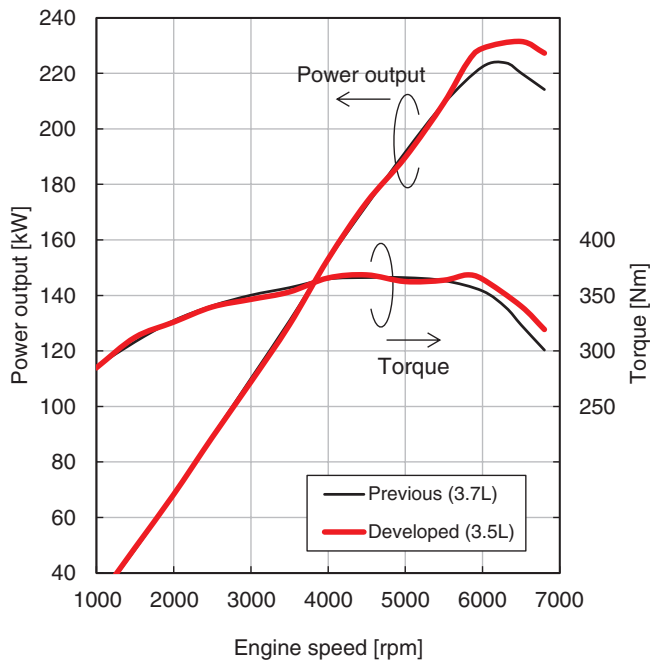


Fig. 13 Engine performance

6. Fuel Economy Enhancement Technology

6.1. Friction Reduction Technology

The cooling control spacers (CCS) and 2-stage relief structure of the oil pump shown in Fig. 14 are the key friction reduction technology used in this engine, and are described below.

First, the CCS are described. CCS are mounted in

locations subject to high piston thrust force inside the cylinder water jacket with the aim of reducing friction by optimizing the water flow and expanding the cylinder inner diameter. Figure 15 shows the results of calculating and analyzing the water flow inside the cylinder block water jacket with and without CCS. These results show that CCS reduce the cooling water flow speed in the lower part of the sleeve, and increase the head cooling water distribution ratio and flow speed in the area near the combustion chamber, which requires active cooling due to the heat generated by combustion.

Figure 16 shows the change in the cylinder wall

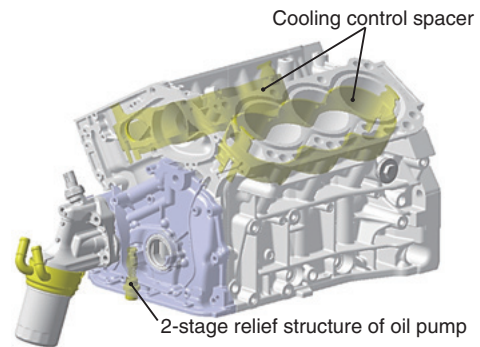


Fig. 14 Friction reduction technology

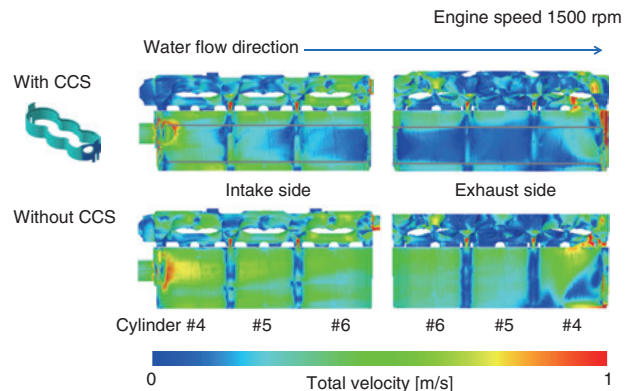


Fig. 15 Water flow speed distribution

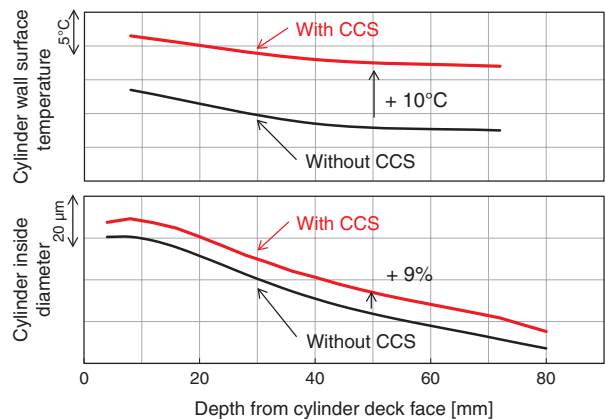


Fig. 16 Effect of CCS on cylinder wall temperature and cylinder inner diameter

temperature and cylinder inner diameter with and without CCS. Rationalization of the water flow inside the cylinder block water jacket increased the cylinder wall surface temperature by approximately 10°C and expanded the cylinder inner diameter by 9%. This reduced the sliding friction of the piston and piston ring, and achieved Brake Specific Fuel Consumption (BSFC) enhancement effects of 0.8%.

Next, the 2-stage relief structure of the oil pump is described. This structure is intended to reduce the oil pump drive torque by optimizing the hydraulic pressure characteristics at slow and mid-engine speed.

Figure 17 describes the relief structure. The conventional relief structure (1-stage relief) has a structure where the relief valve strokes and oil is discharged from a relief hole in the housing when hydraulic pressure of the set valve pressure or more is applied [Fig. 17(a)].

In contrast, the 2-stage relief structure enables 2-stage relief by adding a lubrication groove in the upper part of the relief valve and the housing upstream from the relief hole. Two-stage relief operates as follows. First, the relief valve begins its stroke when hydraulic pressure of the set valve pressure or more is applied. Oil passes through the lubrication groove formed by the valve and housing upstream from the relief hole, and is discharged from the relief hole. As the hydraulic pressure rises and the valve stroke progresses, the lubrication groove is blocked and the 1st-stage relief stops. When the hydraulic pressure rises further to the 2nd-stage valve pressure or more, oil is discharged from the 2nd-stage relief hole [Fig. 17(b)].

Figure 18 shows the hydraulic pressure characteristics at slow and mid-engine speed and the effect due to adoption of the 2-stage relief oil pump relief structure. As a result of optimizing the hydraulic pressure characteristics, hydraulic pressure reduction effects of 25% and oil pump drive torque reduction effects of 35% could be obtained.

Other friction reduction technology included thorough

measures to reduce mechanical friction such as application of a molybdenum pattern coat to the piston skirts, reduction of piston ring tension, use of low-torque oil seals and low-viscosity engine oil, and reduction of auxiliary belt tension. These measures achieved BSFC enhancement effects of 4% at 1500 rpm.

6.2. Fuel Consumption

Figure 19 shows the BSFC measurement results. Enhancement of thermal efficiency due to adoption of the DI system, together with the above-mentioned friction reduction technology, achieved BSFC enhancement effects of 5.2% during all-cylinder drive at the mode center of gravity of 1500 rpm, compared with the previous model. Furthermore, the pumping loss reduction effects yielded BSFC enhancement effects of 20.1% during 3-cylinder drive.

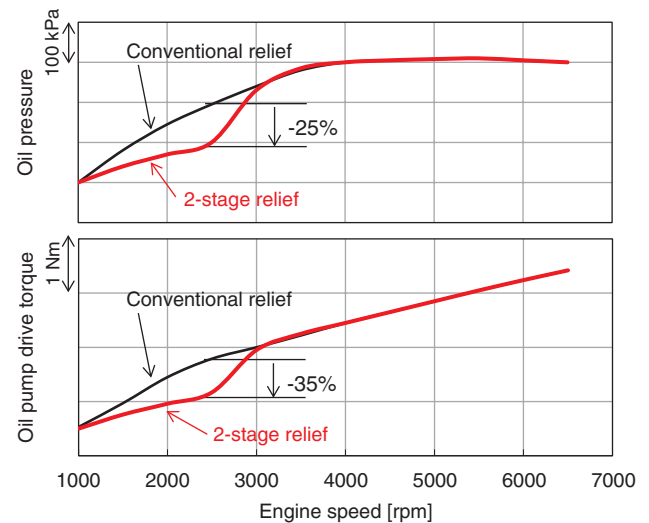


Fig. 18 Effect of 2-stage relief structure

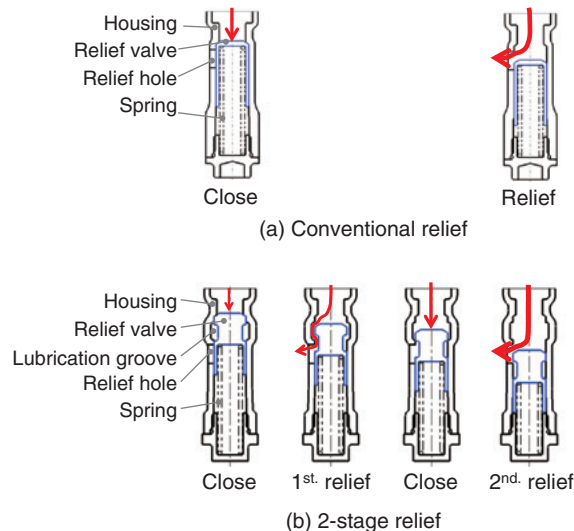


Fig. 17 Relief structure of oil pump

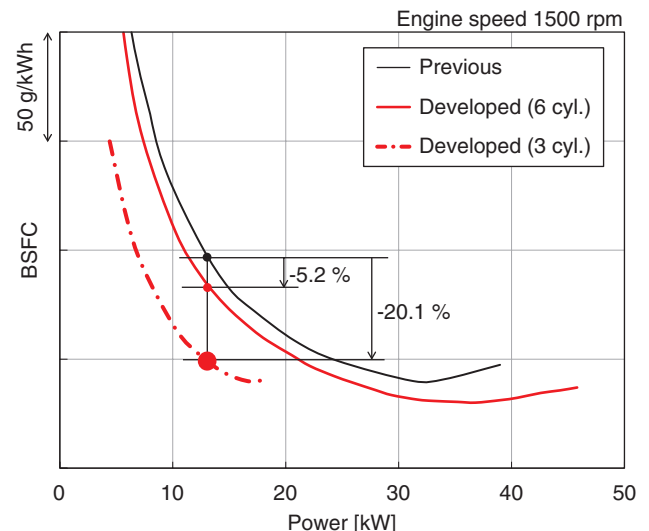


Fig. 19 BSFC characteristics

7. VCM Applied Technology

7.1. Enhancement of ACM Characteristics

There are concerns that the NV performance in a completed vehicle may drop during 3-cylinder drive as a result of increased vibration amplitude due to halving of the base vibration order with the reduction in firing cylinders, and a rise in the combustion pressure due to the increased amount of work per cylinder. However, the 2014 model year ACURA RLX equipped with this engine is the ACURA flagship sedan and is categorized as a mid-size luxury sedan, so higher NV performance is required. The authors set the high target value of 3 dB lower than that of existing models, and aimed for NV levels that make 3-cylinder drive unnoticeable to not only the driver but also the passengers.

For these reasons, the active control engine mount (ACM) capacity was expanded and the characteristics were enhanced.

ACM realizes high anti-vibration performance that makes 3-cylinder drive unnoticeable by absorbing vibration. This is done by building actuators into the bottoms of the liquid-sealed mounts that support the front and back of the engine, and extending and retracting these actuators in-phase and in-sync with the engine vibration⁽³⁾. This system achieved the required ACM setoff displacement performance, which is determined from the maximum torque that can be used during cylinder deactivation, by raising the ACM drive voltage output. Figure 20 shows a comparison with the previous model.

In addition, the NV characteristics of the transmission torque converter, exhaust system and steering system were also enhanced. Figure 21 shows the steering vibration level and engine torque during 3-cylinder drive. This shows that the conflicting elements of NV performance enhancement and expansion of the 3-cylinder drive torque could be simultaneously achieved.

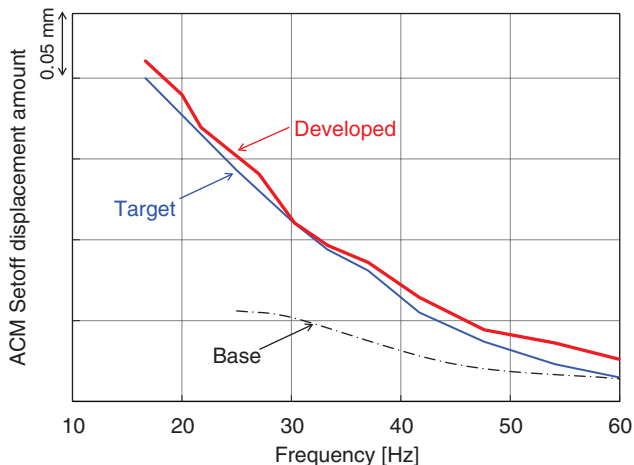


Fig. 20 Characteristics of ACM

7.2. Investigation of Gear Ratio

High-power performance is required of the RLX. However, there is the issue that when using a high-torque engine with comparatively large displacement, the load required for city driving is low, and the increased pumping loss results in a noticeable drop in fuel efficiency. The VCM system addresses this issue by enabling shifting from a low-load operating point to a more efficient high-load operating point, making it possible to simultaneously achieve both high-power performance and high fuel efficiency. The transmission gear ratio was optimized to more effectively increase the frequency of 3-cylinder drive. Figure 22 shows the relationship between the gear ratio and the 3-cylinder

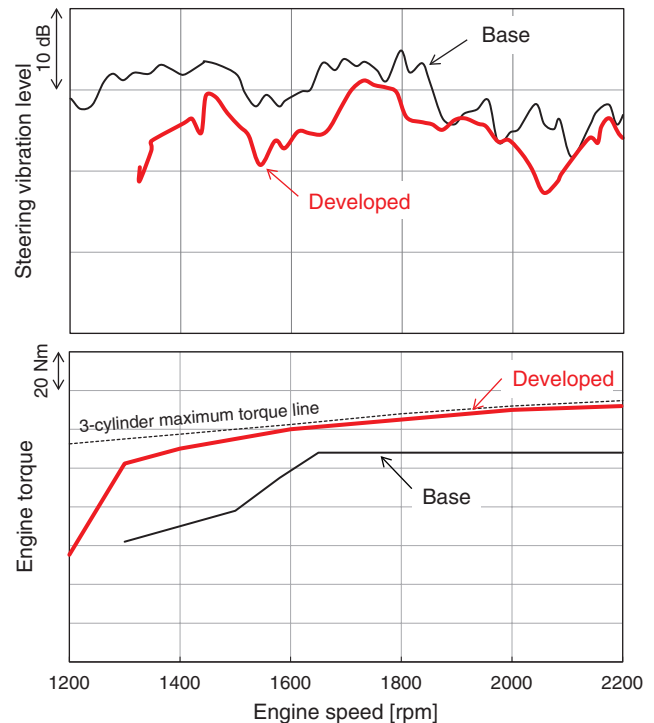


Fig. 21 Steering vibration of enhanced engine torque

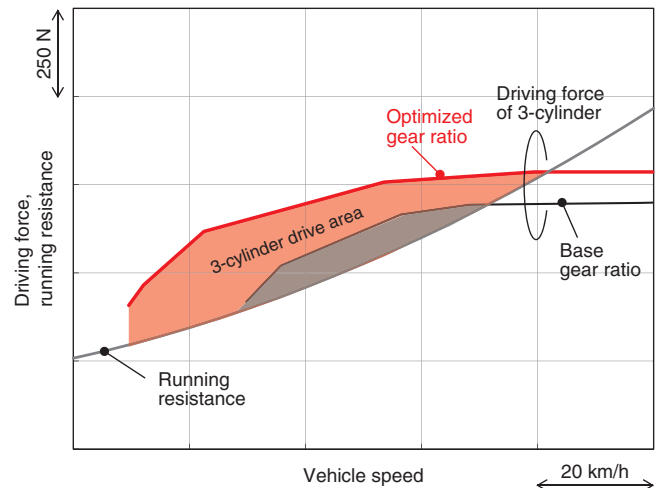


Fig. 22 Optimization of transmission gear ratios

Table 2 EPA mode fuel economy

	Highway (mpg)	City (mpg)	Combined (mpg)
2012 model year RL	24	17	20
RLX	31	20	24
Improvement	+29%	+18%	+20%

drive area. The vehicle speed range in which 3-cylinder drive can be performed was expanded by establishing a lower gear ratio than the base gear ratio.

Figure 23 shows VCM operation in EPA highway mode. The new engine features higher 3-cylinder torque, enhanced NV performance due to ACM enhancement, and an optimized transmission gear ratio, enabling 3-cylinder drive during most of highway mode.

7.3. Fuel Economy of a Vehicle

In addition to introduction of the technology described above, thorough body measures were taken to reduce the energy required to propel the RLX equipped with this engine. These measures include reducing the weight of each part to reduce the vehicle body weight, enhancement of bearings, brakes and tires to reduce rolling resistance, and aerodynamic enhancement. As a result, fuel economy was enhanced by 29% in EPA highway mode and 18% in city mode compared to the 2012 model year RL (Table 2).

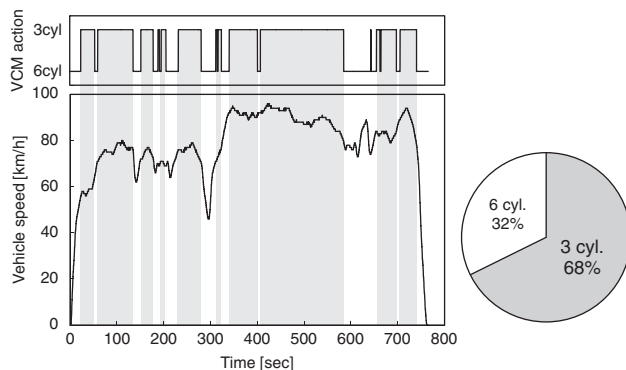


Fig. 23 VCM action of EPA highway mode

8. Conclusion

The new V6 3.5 L engine enhances combustion and pumping loss with the DI VTEC VCM system, adopts friction reduction technology and VCM applied technology, and has a downsized displacement. This produced the following results.

- (1) The maximum output was increased by 3.3% and torque characteristics equal to those of the previous model were also obtained, while downsizing the displacement.
- (2) Fuel consumption was enhanced by 5% during 6-cylinder drive and 20% during 3-cylinder drive compared to the conventional engine. In addition, the

fuel economy of an actual vehicle was enhanced by 29% in EPA highway mode and 18% in city mode.

- (3) Expansion of the ACM capacity enhanced NV performance during 3-cylinder drive while at the same time expanding the 3-cylinder drive torque range.

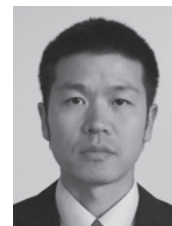
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■ Author ■



Nobuo SUZUKI



Yasutaka HAYASHI



Kazuya ISHIKI



Atsushi SATO



Tatsuhito ESAKI



Satoshi WATANABE