

Development of V6 i-VTEC Engine with Variable Cylinder Management

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ABSTRACT

A V6 i-VTEC engine equipped with a variable cylinder system has been developed to achieve high output, high fuel economy and low emissions. The variable cylinder system uses the VTEC mechanism to close the rear bank of three cylinders. To increase the accuracy of switching control, it is essential to increase the responsiveness of switching when oil pressure is low at low engine speeds. High responsiveness has been ensured in this engine by contriving the way of switching synchro pin and spool valves. The increased accuracy of control has enabled valve close timing to be synchronized with the stopping of the fuel supply to the deactivated cylinder bank. As a result, the system is able to switch instantaneously between three- and six-cylinder operation to enable engine output to respond to the different driving conditions with no loss of drivability. The new engine has been employed in the new model INSPIRE. It is a high-power (184 kW [250 ps]) and high-torque (296 Nm [30.2 kgm]) engine, and achieves a fuel consumption of 11.6 km/l in Japanese 10 - 15 mode and meets ultra-low emissions standards while maintaining regular gasoline specifications.

1. Introduction

As environmental protection and economical operation are becoming a higher priority, the development of the next generation i-series engine and power train with improved environmental characteristics, fuel economy, and driving performance is being pursued. The new V6 Variable Cylinder Management (VCM) system engine has been developed as the V6 i-VTEC engine by adding VCM system to a Honda VTEC engine.

A V6 engine can be thought of as two 3 cylinder engines put together. When the ECU deems the conditions to be suitable, it instantly stops the movement of the valves of 1 bank 3 cylinders of the V-style engine. The engine then runs on the 3 remaining cylinders only. This defines the VCM System.

When the accelerator is firmly pressed or if conditions are deemed correct, the engine is instantly returned to full 6 cylinder power. Thus the implementation of an engine with the high power of a large displacement engine and the fuel economy and low emissions of a small displacement engine has been successful.

This report discusses the increase in power output, low emissions, and better fuel economy technologies, used in the development of the V6 3.0L i-VTEC VCM engine (Fig. 1), which is being used in the new model INSPIRE.

2. Development Goals

The development goals of the new V6 i-VTEC VCM system engine were, as environmental protection and fuel

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Fig. 1 View of V6 3.0L i-VTEC engine

economy requirements become more strict, to decide what technologies would be needed for future large displacement superior engines as well as cost reduction, and to pursue technologies that were desired throughout the world. From these goals a superior vehicle engine was developed for the environmentally conscious.

Specific goals are listed below:

- (1) Fuel Economy of a typical 2.0L base engine.
- (2) Environmental protection; meet Japan's ultra low emission standard.
- (3) A power output appropriate for a superior V6 class engine.
- (4) Power output control at time of switchover through the electronic control of the throttle.

3. Engine

3.1. Engine Specifications

The main specifications of the J30A V6 3.0L i-VTEC VCM engine that is mounted in the new INSPIRE are shown in Table 1.

3.2. Structure of the Variable Cylinder Management System

Figure 2 (a) shows the rear bank 3 cylinder VCM system valve structure and the hydraulic passage while Fig. 2 (b) shows an overall structural view of the system. When in normal driving mode, with the synchro pin in place, the valve lift rocker arm and valve stop rocker arm move back and forth in tandem, as shown in Fig. 3 (a) for operation of the intake and exhaust valves. When the ECU recognizes that the vehicle has entered cruise mode, a synchro-piston is pushed into and stored in the stop rocker arm by hydraulic pressure. As can be seen in Fig. 3 (b) the interlock of the rocker arm is in inactive mode and though the cam continues to operate the valve lift rocker arm, it is just moving. In this condition, the stop rocker arm as well as the intake and exhaust valves cease operation, leading to a sealing in the cylinders and reducing engine pumping losses.

In an existing VTEC engine, hydraulic pressure pushes the synchro-pin, coupling the rocker arms. A spring is then used to return the synchro-pin, separating the rocker arms. In order for the decoupling to occur swiftly and reliably, a spring with a significant amount of reaction force was required. Therefore, in order for the hydraulic pressure to interlock the mechanism, it had to have enough pressure to overcome the spring force.

Table 1 Engine main specifications

Cylinder configuration		60° V-6 Variable Cylinder Management (VCM)
Bore × Stroke (mm)		86 × 86
Displacement (cm ³)		2997
Compression ratio		10.5 : 1
Valve train		SOHC i-VTEC
Number of valves		4 per cylinder
Valve diameter (mm)	Inlet	35
	Exhaust	30
Exhaust manifold		Includes cylinder head
Fuel		Regular
Max. power (kW[PS]/rpm)		184[250]/6000
Max. torque (N·m[kgm]/rpm)		296[30.2]/5000

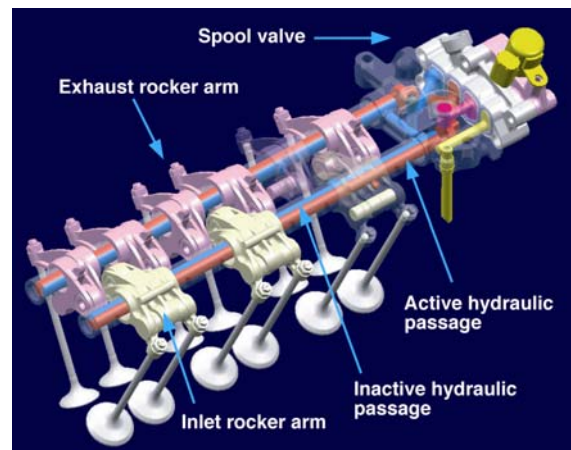


Fig. 2 (a)

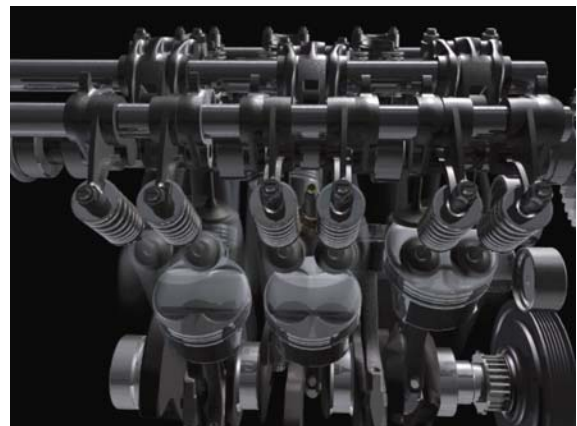


Fig. 2 (b) View of valve train

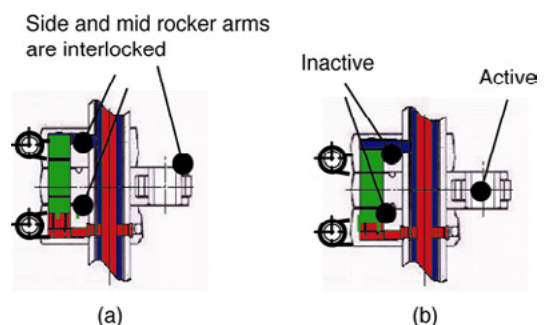


Fig. 3 Valve active and inactive condition

The VCM system is required to have a quick switchover response for valve operation and stop even at low hydraulic pressure generated at low engine speeds. To make the all hydraulic system feasible a new technology 2 way hydraulic circuit⁽¹⁾ was developed. This new technology is used for the new VTEC hydraulic switchover system. Figure 4 shows the previous VTEC and new VTEC systems.

As can be seen in Fig. 5, the hydraulic pressure required for switchover in this newly developed VTEC engine is 1/5 the pressure of the previous design. Therefore, a new oil pump or other additional equipment is not necessary and it is possible for the system to switchover at low rpm and low hydraulic pressures such as at idle. This makes it possible for the VCM system to provide maximum fuel economy improvement.

Another important technology for this VCM system is an improvement in switchover responsiveness. The VCM system is required to be able to change from 3 to 6 cylinders and accelerate the instant the driver steps on the accelerator, taking the vehicle out of a cruise condition. In order to ensure this response, a newly developed 3 way solenoid spool valve, as can be seen in Fig. 6, is used. Through the use of this 3 way solenoid valve, the system stop side of the hydraulic circuit is not connected to the drain. Thus it has become possible to quickly move the synchro-piston leading to fast decoupling of the rocker arm. When switching to normal operation mode, the hydraulic oil pressure that had been used for decoupling is lowered by allowing the oil to flow out the

drain while instantly raising the coupling pressure. It was possible to improve the switchover response time to 1/3 that of the previous system, as can be seen in Fig. 7.

3.3. Variable Cylinder Management System Control and Area of Operation

The VCM system mainly uses the throttle opening information along with vehicle speed, engine speed, and gear location to determine if the vehicle is in either cruise mode or deceleration. The system then turns off the cylinders switching over to 3-cylinder operation, as can be seen in Fig. 8. Also, in order to perform switchover precisely, it also judges whether or not the hydraulic oil temperature and the converter temperature are within an appropriate range.

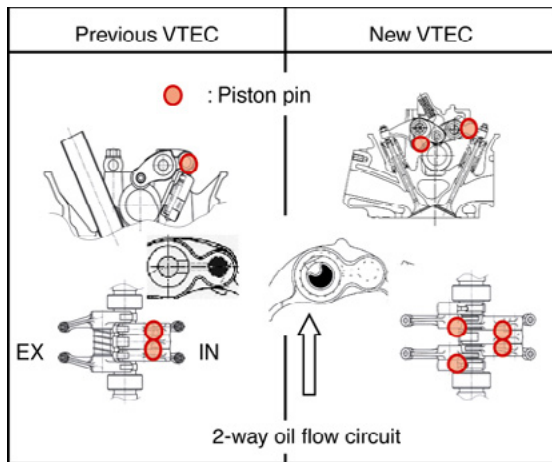


Fig. 4 Previous VTEC and new VTEC

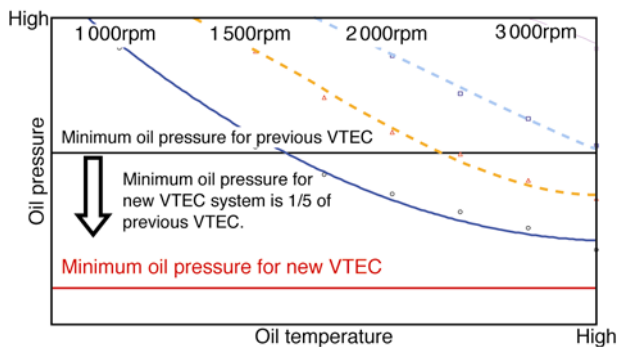


Fig. 5 Minimum oil pressure for VTEC

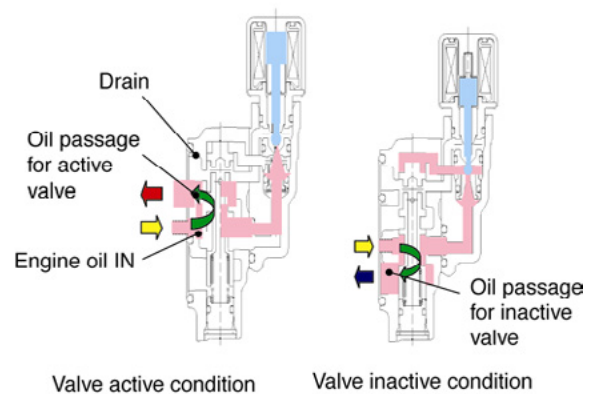


Fig. 6 Spool valve and hydraulic passage

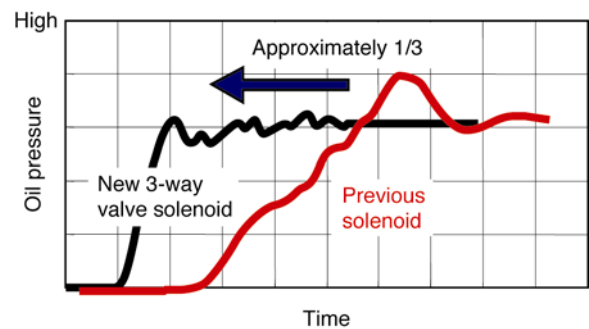


Fig. 7 Spool valve response

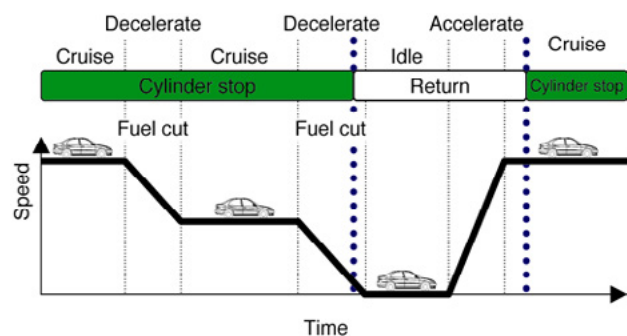


Fig. 8 Operation of cylinder stop system

An actual example is shown in Fig. 9. For instance, in the event the valves incorrectly return to operation before the fuel injection returns to operation, after the pumping cycle in which intake and exhaust valves work without fuel injection, the engine returns to the normal all-cylinder operation. On the other hand, in the event the valves incorrectly return to operation late, the intake valve stays shut while fuel is injected and on the next cycle there will be 2 cycles worth of

fuel pulled into the cylinder. These types of incorrect operation cause fluctuations in the air fuel ratio. This results in the torque change shown in Fig. 10 at the time of switchover and causes deterioration in drivability. In order to overcome these types of malfunctions the switchover response accuracy has been improved by adopting this new VTEC engine. It has been possible to develop smooth switchover without any torque changes, through being able to start and turn off fuel simultaneously with that of the operation of the intake and exhaust valves.

At the time of VCM switchover, the switchover synchronism using hydraulic oil pressure, the spark timing control, the throttle control using electronic throttle control and the AT lock-up control are simultaneously carried out. Through this type of cooperative control, it has been possible to develop a switchover that is smooth and that does not contain any torque changes as can be seen in Fig. 11.

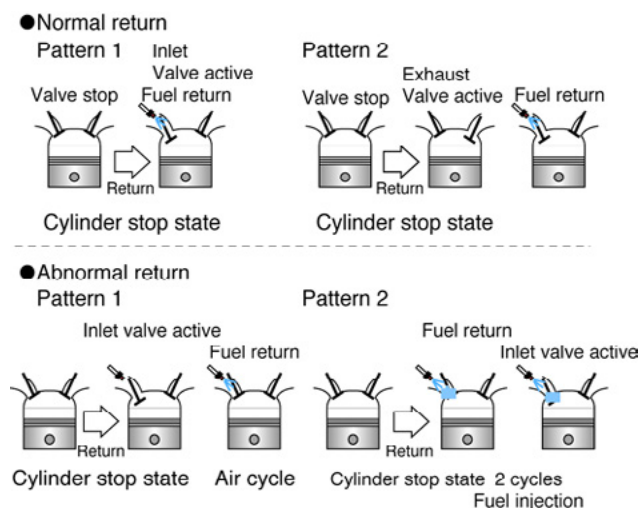


Fig. 9 Pattern at time of fuel return

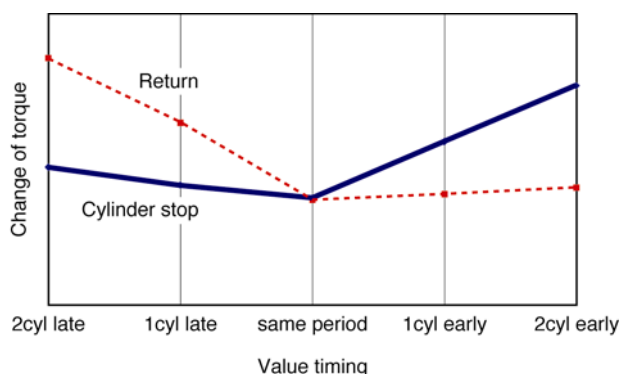


Fig. 10 Effect of change in timing on torque

3.4. Engine Performance

The output performance characteristics of the J30A V6 3.0L i-VTEC engine are shown in Fig. 12. Even when using regular gasoline, this engine's characteristics are: maximum power of 184 kW [250 ps] at 6 000 rpm and maximum torque of 296 Nm [30.2 kgm] at 5 000 rpm, achieving performance at the top of its class.

This power output has become possible through improvement in air intake efficiency through the use of a resonance type manifold with a switchover mechanism, and enlarging the valve diameter. Placing the catalytic converter directly under the cylinder head makes it unnecessary to keep the exhaust hot for the catalytic process. This allows for an exhaust pipe layout that improves exhaust flow efficiency and favors increase in power output.

3.5. Fuel Economy

In the V6 VCM system engine, the valves for 1 bank of 3 cylinders, are turned off instantaneously and the engine runs on the 3 remaining cylinders. This reduces the pumping losses of the bank that has been turned off, and engine friction associated with valve drive losses. Further opening of the throttle gives much less pumping losses of the operating bank. Through using a more favorable load area of the engine, the engine's thermal efficiency is improved. And the fuel economy is improved by expanding the amount of time for fuel-cut mode.

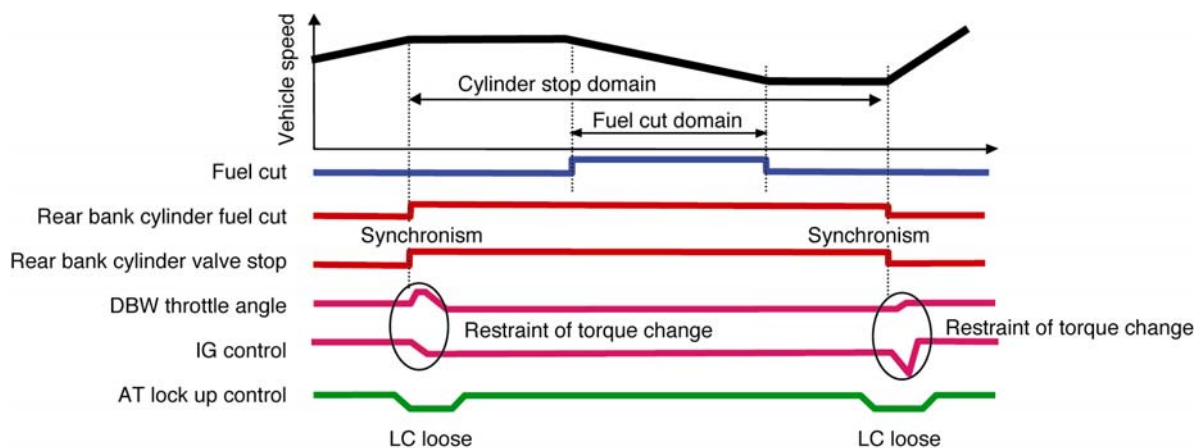


Fig. 11 Pattern of VCM operation

Figure 13 shows the base engines fuel economy improvement rate when it has switched over from 6 cylinders to 3 cylinders. Also, Fig. 14 shows the relationship between BSFC and the engines complete displacement while it is running at an engine speed of 1 500 rpm with a power output of 2.94 kW. The switchover from 6 to 3 cylinders provides the base engine a 30% improvement in fuel economy, and while it is a 3.0L displacement engine, it has achieved the same BSFC as a 1.7L displacement engine.

The new INSPIRE's main technology for fuel economy improvement is the VCM system. Other technologies employed are precise control of the lock-up mechanism of the Automatic Transmission, EPS (Electric Power Steering) and friction reduction. As can be seen in Fig. 15, while this has a displacement of 3.0L, it has a 14% improvement in fuel economy as compared to the previous INSPIRE's 25V 2.5L

displacement engine. This new engine achieved an 11.6 km/l fuel economy in Japanese 10 - 15 mode equivalent to that of the 2.5L direct injection engine.

3.6. Environmental Performance

As this system does not use lean burn to improve fuel economy, specific equipment such as a NO_x adsorption reduction type catalytic converter is not needed. This leads to both a lower cost and a reduction in CO₂. It is therefore a system that has realized high performance in both fuel economy and environmental areas.

The diagram of the system used for low emissions in this engine is shown in Fig. 16. There are separate exhaust clean up systems on both banks of this V6 VCM system engine. A high density 900 cell 3-way catalytic converter has been placed just under the cylinder head of each bank, eliminating the exhaust manifold. Through this arrangement, the heat capacity of the system has been reduced and the warm up characteristics in cold area have improved leading to excellent emissions clean up performance. Running the engine on only one bank leads to a temperature difference between the banks. In order to maintain very precise control of the air fuel ratio even in these conditions a LAF (Linear A/F) sensor and O₂ sensor have been placed on each of the banks. This gives excellent responsiveness while not being affected by the other bank and is perfect for the air fuel

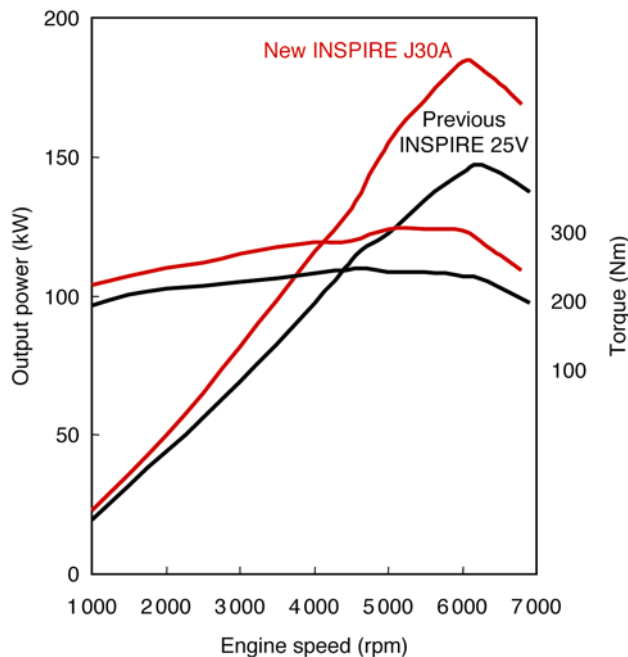


Fig. 12 Output performance

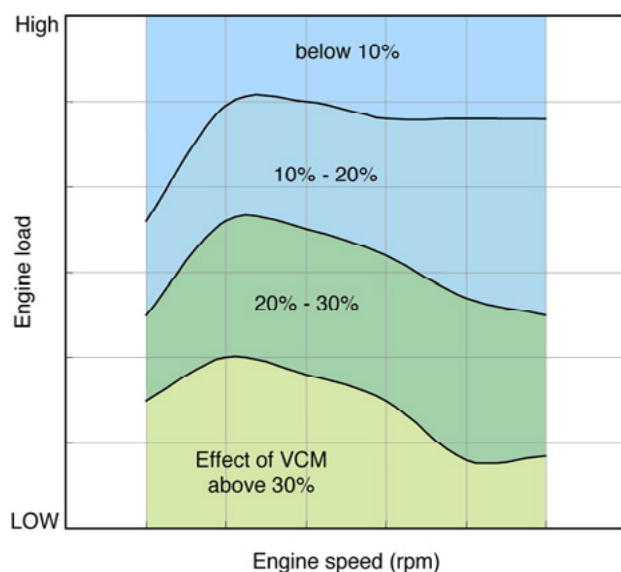


Fig. 13 Effect of VCM on fuel economy

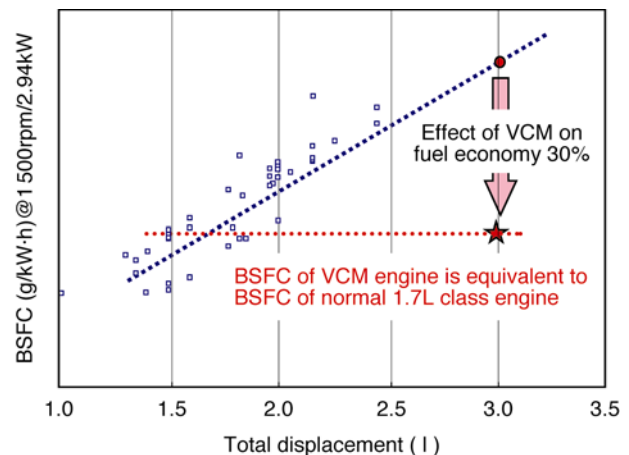


Fig. 14 VCM effect on BSFC

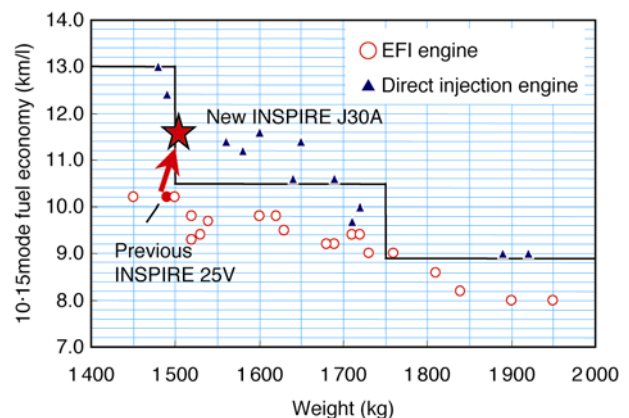


Fig. 15 10 - 15 mode fuel economy

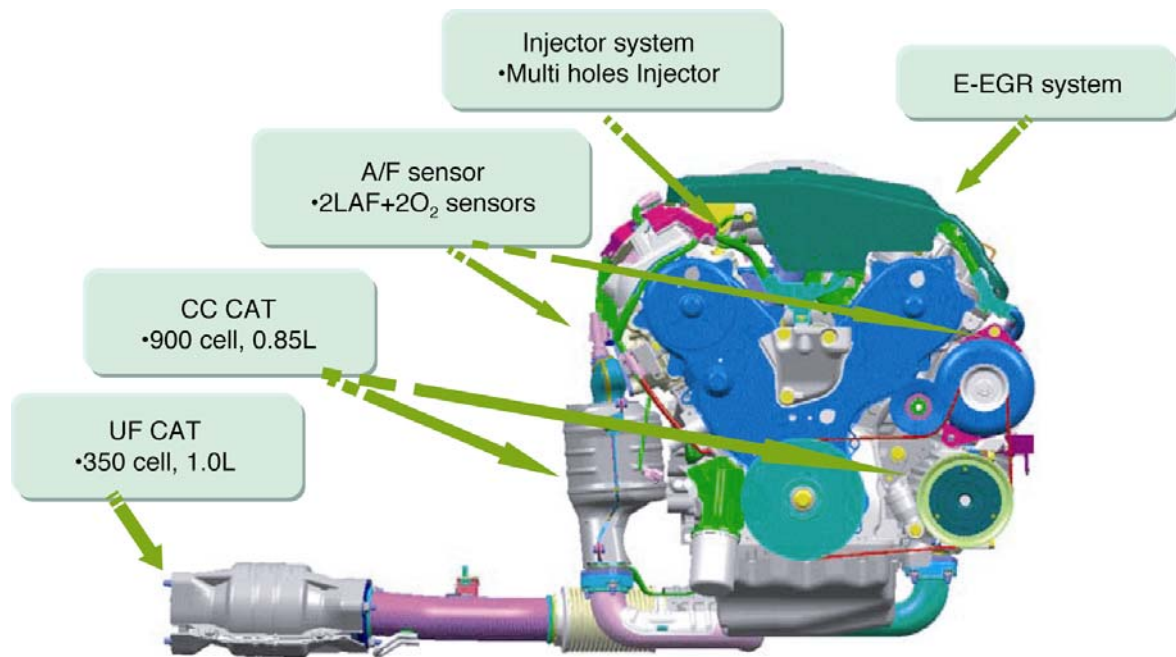


Fig. 16 Engine configuration and control system enable three-stars clean emission rating

control of this V6 VCM system engine. A 350 cell catalytic converter has been placed under the floor, after the O_2 sensor, in order to both ensure excellent emission clean up capability. It also reliably cleans the exhaust of the bank that stops because that bank's catalyst is not always warmed up.

In addition to the exhaust gas related technology listed above, a 12 hole injector with improved fuel atomization capability is used. Also, an electric EGR valve with high precision control has been applied. As can be seen in Fig. 17, the engine has a fuel economy of 11.6 km/l in Japanese 10 - 15 mode and meets the ultra low emissions standard, thus it has achieved both a high standard of emissions and of environmental protection.

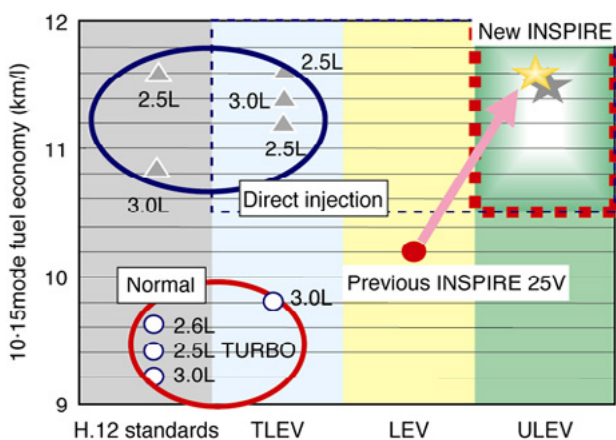


Fig. 17 Achievement of both ULEV emissions rating and conformity with 2010 fuel economy standard

4. Comfort

One of the important elements of being able to deliver a comfortable superior vehicle is its NV (Noise and Vibration) performance. The V6 i-VTEC engine has vibration patterns during 3 cylinder operation that do not exist on the previous V6 engine. Trying to find a way of suppressing this vibration became a subject of study. As a countermeasure, a long torsion spring is used on the lock-up damper of the transmission in order to reduce the drive train vibration during 3 cylinder operation. This countermeasure resulted in a 3 dB reduction of the noise level in the front seat and a 5 dB reduction in the vibration level of the drive train. A newly developed ACM (Active Control engine Mount) that predicts engine vibration and actively reduces the vibration is used⁽²⁾. Also, ANC (Active Noise Control) which reduces cabin noise and does not add very much weight has been adapted⁽³⁾. Thus both fuel economy and a product appropriate for the superior class have been achieved.

5. Conclusion

An engine with the VCM system as a core technology was developed with the reduction of friction and improvement in combustion. This has lead to a system that has high power output, high fuel economy, and high environmental performance. This system was developed in a lower weight and lower cost package. The following results have been obtained through the development of this V6 i-VTEC VCM system engine.

- (1) Through development of the new VTEC engine, the hydraulic pressure required for switchover is 1/5 that of the previous system and the response time has been reduced to 1/3 of what the previous system requires. At an engine speed of 1 500 rpm and output power of 2.94 kW, the VCM system provides roughly a 30%

improvement in fuel economy and has the same BSFC as a 1.7L displacement engine though this engine's displacement is 3.0L.

- (2) This engine has a 14% improvement in fuel economy as compared to the previous INSPIRE's 25V 2.5L engine, achieving 11.6 km/l in Japanese 10 - 15 mode.
- (3) Through the use of a LAF sensor and O₂ sensor for each bank of the VCM system engine, precise control of the air fuel ratio has been made possible and the above-mentioned fuel economy has been achieved. It also passes the ultra low emissions vehicle standard as certificated by the Ministry of Land, Infrastructure and Transport Government of Japan, meeting standards that have been set for the year 2010. In these ways, the engine meets the needs of the environment.
- (4) While achieving the fuel economy and meeting environmental standards described above, the engine has a maximum power of 184 kW [250 ps] at 6 000 rpm and a maximum torque of 296 Nm [30.2 kgm] at 5 000 rpm, while using regular gasoline, achieving a power output at the top of its class.

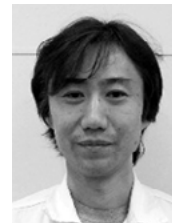
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