

Development of a 1.5L Lean-burn Engine for the 2001 Civic

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ABSTRACT

A 1.5L SOHC-VTEC lean burn engine designed for the 2001 model Civic achieves higher fuel economy (20km/liter based on the 10-15 mode) and an emissions reduction of 50% over the Japan 2000 emission standards. Engine friction is reduced and a newly designed intake-port and combustion chamber are utilized for improved combustion characteristics. In addition, a NOx adsorption reduction type three way catalyst is used with the new exhaust system to achieve low-emissions.

1. Introduction

Protecting the global environment and conserving natural resources have increased the demand for higher fuel economy automobiles with reduced exhaust emissions. There are a variety of gasoline engines, in addition to the lean-burn engine, such as the direct injection and Miller cycle types, that have been researched and commercialized. Honda is continuing the development of lean-burn engines that apply the VTEC mechanism (VTEC: variable valve timing and lift electronic control) such as the 1.5 L VTEC-E lean-burn engine⁽¹⁾ in 1992 for the Civic, the 1.5 L 3- stage (VTEC) lean-burn engine⁽²⁾ that was combined with continuously variable transmission (CVT) in 1996, and the 1.8 L VTEC lean-burn engine⁽³⁾ for the Accord in 1998. This technical review introduces the development of a new power train incorporating a further modified 1.5L SOHC – VTEC lean-burn engine with a CVT for the new Civic model.

2. Aims of the Development

The basic configuration of the power train was reviewed in order to realize the developmental concepts of the new Civic model, namely “creating new values through innovative packaging,” “designing for safety and environmental compatibility” and “suitability for use almost anywhere in the world”. Based on a compact design to match the packaging of the chassis, this research aimed at improved fuel economy by better engine combustion, reduced engine friction and improved CVT efficiency, and at lower emissions by adopting a lean NOx catalyst and improved exhaust system.

The detailed objectives for the development were as

follows:

- (1) The best fuel economy in the domestic popular car class.
- (2) Low-emission performance that conforms to global standards (potential compatibility with the U.S. Ultra-low Emission Vehicle (ULEV) standard).
- (3) Engine Vibration and Noise Reduction.
- (4) 10% smaller engine compared to the current engine.
- (5) Better response under normal driving conditions.

3. Outline and Main Specification of the New Engine Design

Fig. 1 shows an external view of the engine and Table 1 describes the main engine specification.

The more compact design, involving position changes to several external components, involves a re-designed cylinder block and a substantial change in the layout of the induction system, including the use of a resin intake manifold. As can be seen in the overhead view of the engine (Fig. 2), the air cleaner and intake resonator chambers are both located above the engine and transmission, giving a more compact design for the entire power train and achieving a modular concept.

Almost all of the engine parts had to be re-designed to achieve the optimum combustion chamber shape, including the crown shape of the piston to reduce the friction of each component, and to further reduce emissions.

Fig. 3 shows the engine performance curves. Importance was placed on better low-speed torque to match the CVT characteristics. Compatibility has been achieved between high fuel economy and the feeling of linear drive in normal use.

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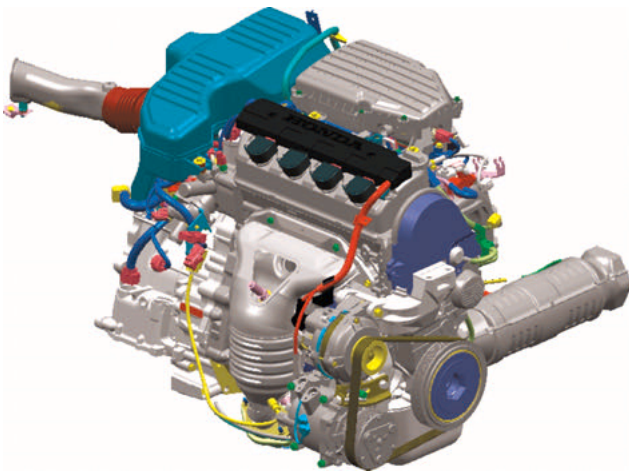


Fig.1 View of 2001 model lean-burn engine

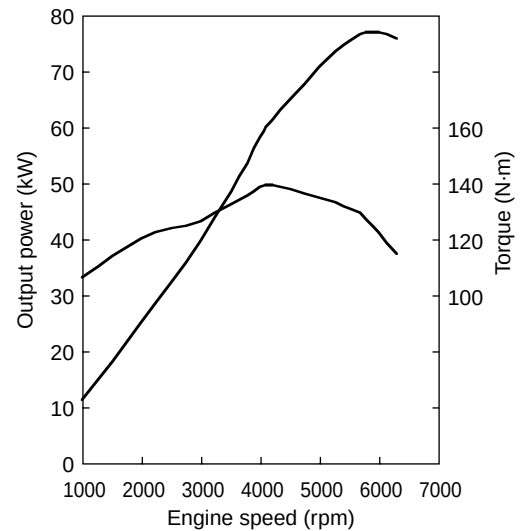


Fig.3 Engine performance

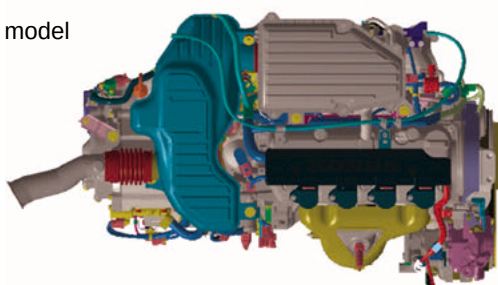
Table 1 Engine specification

Engine code	D15B	
Cylinder configuration	In-line 4-cylinder	
Bore × stroke (mm)	75 × 84.5	
Displacement (cm ³)	1493	
Compression ratio	10.2 : 1	
Valve train	SOHC VTEC	
Number of valves	4 per cylinder	
Valve diameter (mm)	In.	30
	Ex.	26
Fuel supply system	Programed fuel injection	
Ignition system	Programed ignition	
Max. power (kW/rpm)	77 / 5800	
Max. torque (N·m/rpm)	139 / 4200	

4. Low Fuel Consumption Technology

Higher targets were set for the engine, CVT and chassis in order to develop the technology required for high fuel economy (Fig. 4). As a result, we have achieved a fuel economy performance of 20 km/L in the 10-15 mode.

2001 model



1999 model

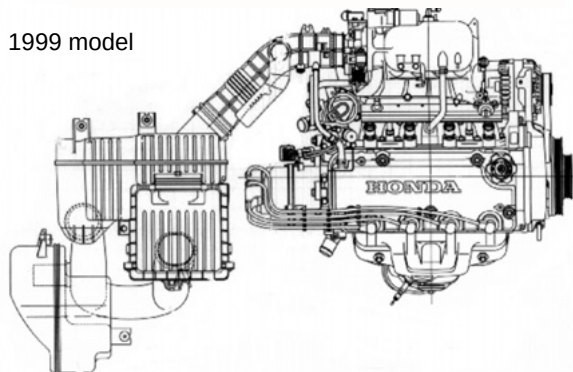


Fig.2 Overhead view of engine

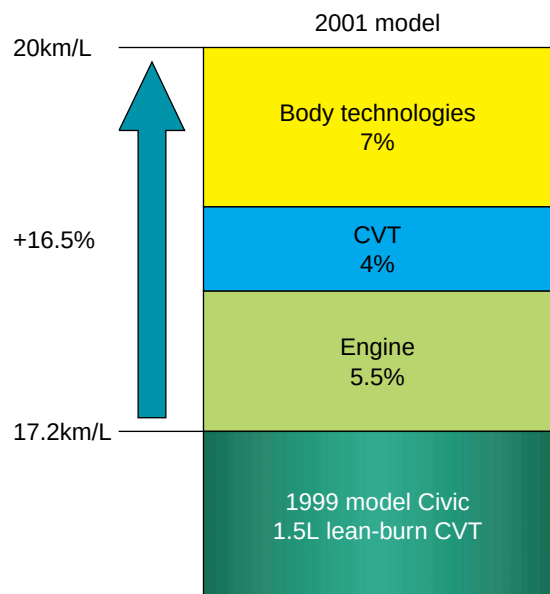


Fig.4 Ratio of contributions for improved 10- 15 mode fuel economy (4door)

4.1. Fuel Economy Mode Positioning

Fig. 5 shows the relationship between the vehicle weight and domestic 10 - 15 mode fuel economy. In comparison to the current vehicles with a stoichiometric air-fuel ratio engine, vehicles with a lean-burn engine have approximately 10% better fuel economy. Direct injection (DI) provides a further 8% improvement in fuel economy for lean-burn engine vehicles, indicating the advantage of direct injection.

The newly developed lean-burn engine for the Civic offers approximately 8 - 12% better fuel economy than that of a DI engine vehicle.

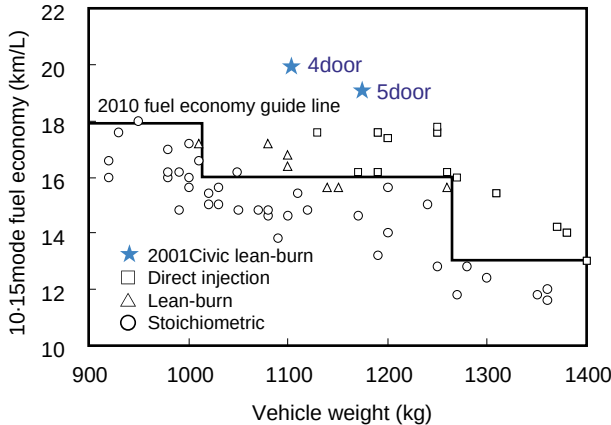


Fig.5 Relationship between vehicle weight and 10- 15 mode fuel economy in production gasoline vehicles

4.2. Methods for Improving the Engine Fuel Economy

Fig. 6 shows the relationship between the total displacement and brake specific fuel consumption (BSFC). A BSFC reduction of 8%, with regard to current engine types, with stoichiometric combustion was attained with this engine. With lean burn combustion, another 10% BSFC reduction was attained for a total BSFC reduction of 18%. This value is comparable to the Insight engine when differences in displacement are taken into consideration⁽⁴⁾⁽⁵⁾.

The improved fuel economy of this engine involved modification of the lean-burn characteristics and significant reductions in engine friction. The lean burn characteristics have been modified by a new swirl port, which further enhances the turbulence of the air-fuel mixture inside the cylinder, and the use of a more compact combustion chamber, which improves the thermal efficiency. Engine friction has been reduced by a comprehensive review of the

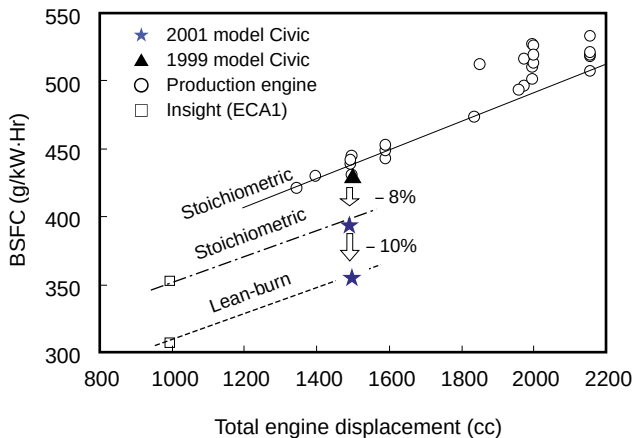


Fig.6 Improvement of engine thermal efficiency

shape of all components in the engine, changes in materials, and modification of the forming processes.

The next section discusses the technological elements applied to achieve the improved fuel economy.

4.2.1. Shapes of the Intake Port and Combustion Chamber

To stabilize the burn of a lean mixture flowing into the cylinder, it is necessary to form an easily ignitable air-fuel mixture around the spark plug with a flame front that quickly propagates throughout the combustion chambers. It is important to have a good balance between the swirl (horizontal vortex) and tumble (vertical vortex) inside the combustion chambers to achieve this combustion. The newly developed intake port enhances the tumble components of turbulence to achieve a swirl ratio of 2.6, tumble ratio of 2.0 and swirl inclination angle⁽⁵⁾ of 37 degrees (Fig.7). This swirl inclination angle shows good correlation with the lean-burn limit in the test results of the 1.0L to 1.8L lean-burn engines and has provided the authors with an effective index for designing the shape of the intake port.

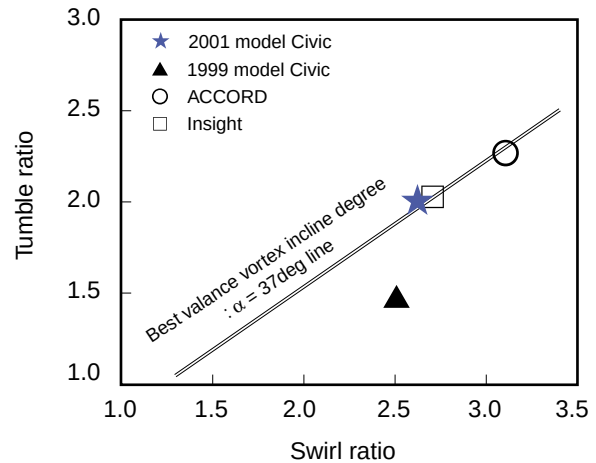


Fig.7 Relation between swirl and tumble intensity

Another important factor in lean-mixture combustion is the distribution of the air-fuel mixture inside the combustion chamber. This distribution was studied by simulating the shape of the intake port under the following conditions:

Average air-fuel ratio A/F = 22 (excess air ratio: 1.5)

Fuel injection timing: 40 degrees after TDC of the intake stroke.

The simulation showed the horizontal sectional view and vertical sectional view at the position of the electrode in the center of the spark plug. Fig. 8 shows the distribution of the air-fuel mixture in the combustion chamber 40 degrees before the top dead center of the compression stroke equivalent to the ignition timing of an actual engine. The new port produces a richer air-fuel mixture near the electrode in the center of the plug, than the current port. A good correlation was confirmed with the test results (Fig. 9) for the improved lean-burn limit.

The same simulations and tests were performed to identify the optimum combustion chamber shape. The results were used to select the bowl-in-crown shape of the piston and the squish area.

Ne = 1500rpm
 P intake = 48kPa
 A/F (averaged) = 22
 Crank angle = 40deg BTDC.

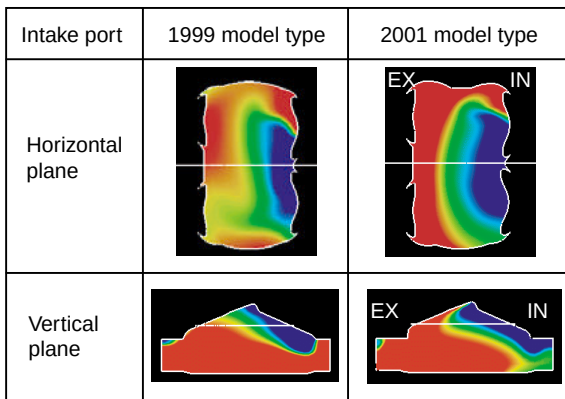


Fig.8 Effect of intake port shape on in-cylinder A/F distribution

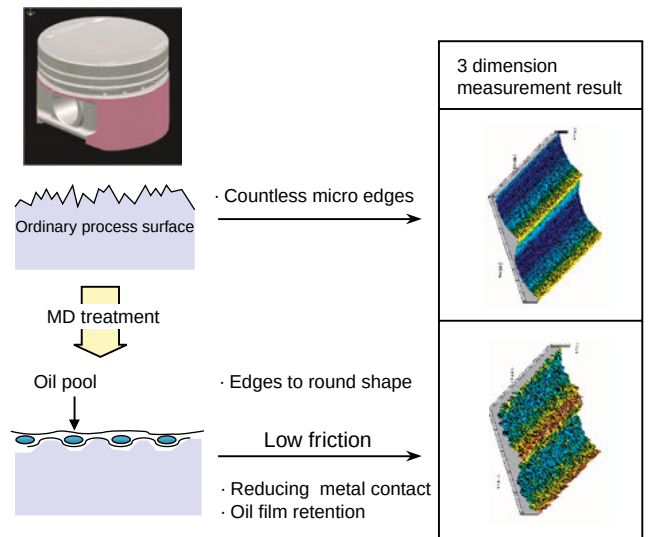


Fig.10 Face treatment of piston skirt portion

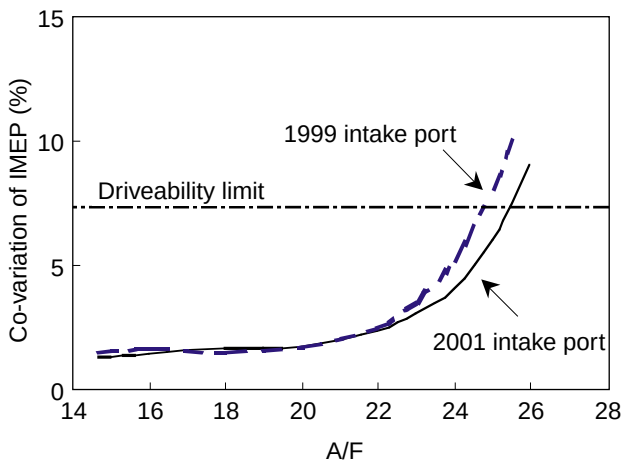


Fig.9 Comparison of lean-limit characteristics based on intake port shape

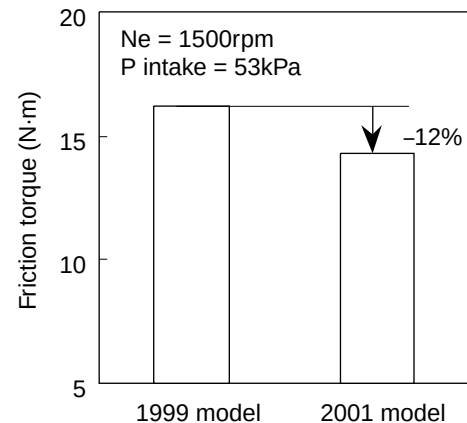


Fig.11 Friction loss comparison

4.2.2. Reduction of Friction

Together with the improved combustion characteristics, it was also important to reduce engine friction to achieve improved fuel economy.

The following modifications were taken to reduce engine friction:

- Micro dimple (MD) processing⁽⁶⁾ of the pistons
- Low-tension piston rings
- Reduced crank pin width
- Low-viscosity engine oil (0W-20)
- Roller cam followers

Fig.10 describes the MD processing of the piston skirt. This processing uses basically round ceramic beads with an average granule diameter of 40 μ m to impact the surface of the piston skirt at a speed of 100 m/s or more to create microscopic indentations, or dimples. These enhance the performance of the oil film retention between the piston and

the cylinder to reduce piston wear, decrease piston friction loss and increase the load for seizure.

In addition to this low-friction treatment of the pistons, technologies for valve spring load reductions, piston ring tension reduction, crankshaft pin width reduction, and low-viscosity engine oil⁽⁷⁾ (0W-20/SJ/GF2) were adopted.

The friction loss of the engine is shown in Fig. 11, indicating a reduction of 12% compared with the current engine.

4.3. CVT

CVT enables the engine to be operated within the range of low fuel consumption (BSFC) to improve the fuel economy. Honda has been mass-producing CVT for the Civic since 1996. Enhanced hydraulic control of the CVT and modified belt side pressure resulted in improved transmission efficiency of the power train.

Fig. 12 shows the running characteristics of the improved CVT in comparison with those of the 4AT. The engine speed was controlled to maintain the operating envelope in the low-speed zone and achieve a low BSFC.

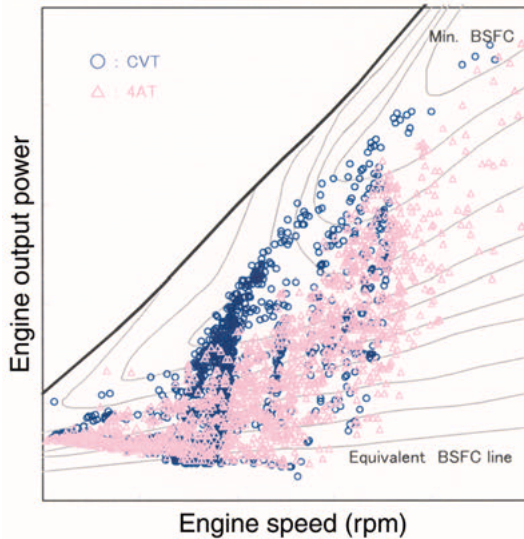


Fig.12 Comparison of the CVT and 4AT in 10- 15 mode driving range

5. Low Emission Technology

The three-way catalyst (TWC) unit could not be expected to reduce NO_x in the lean-burn condition involving excess-air combustion, but we nevertheless had to achieve low emissions.

A target figure of 50% of the 2000 emission standard (certified as a superior low-emission exhaust) was selected for the domestic sales model. At the same time, studies were conducted for each specification based on the premise that the component would have the potential to clear the US ULEV standard, which is considered the global standard.

5.1. Exhaust System

The exhaust system of this engine is shown in Fig.13. A three-way catalyst is used for exhaust conversion in cold and stoichiometric air-fuel ratio ranges. This TWC unit is close coupled to the exhaust manifold, and a NO_x absorption reduction type three-way catalyst⁽⁸⁾ is situated under the floor for NO_x reduction in the lean-burn range.

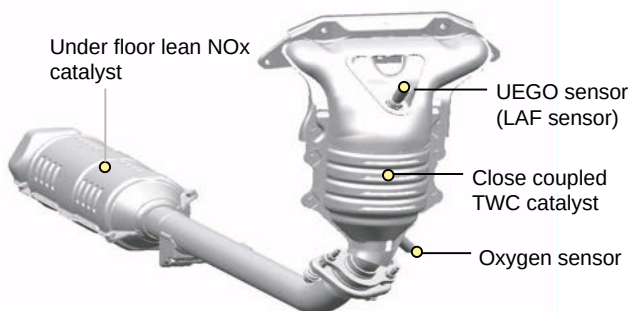


Fig.13 Layout of NO_x adsorption reduction type three way catalyst system

5.2. Multi-hole Injector

The 4-hole injector used in this engine is shown in Fig. 14. The use of this injector has helped to achieve a lighter and more compact injector with 33% of the length and 65% of the weight of the current injector. Also, 4-hole type injection pores were used instead of the pintle types on current engines. Better atomization of the spray and reduced gasoline coating on the air intake port were achieved so that hydrocarbon emission could be reduced by 14% at cold starts (LA-4 cold transient mode) as shown in Fig.15.

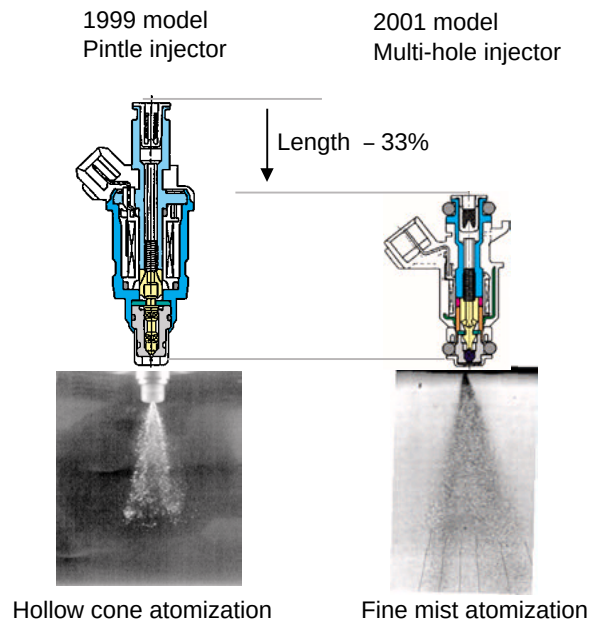


Fig.14 Small fuel injector delivering efficient atomization

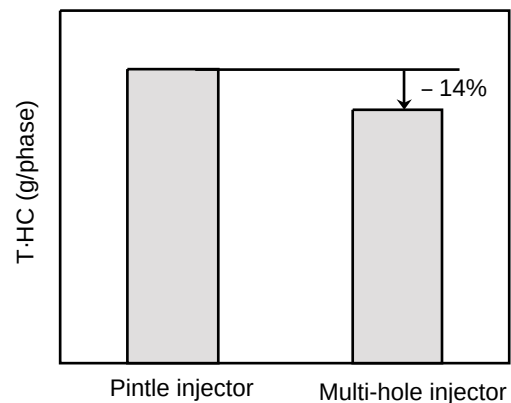


Fig.15 LA-4 cold transient mode emission

5.3. Achieved Emissions

In addition to the reduction of emissions just described, engine control was optimized when shifting between lean-burn combustion and stoichiometric air-fuel ratio ranges, and in the EGR range. A fuel consumption of 20 km/L in the 10-15 mode and an emission level of 50% of the 2000 emission standard have been achieved. (Fig. 16)

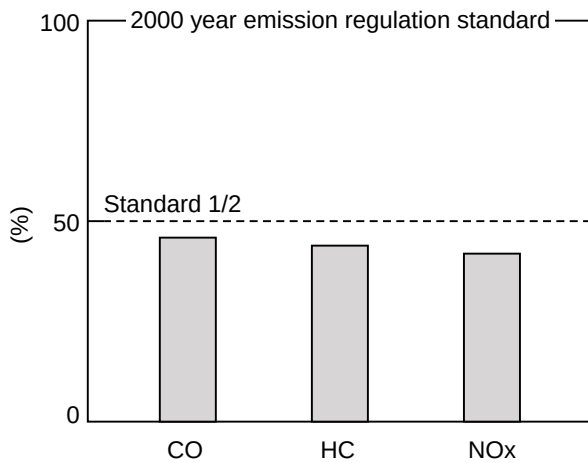


Fig.16 11 mode emission

6. Engine Vibration and Noise Reduction

Improving the quietness of the engine was one of the main development objectives, in addition to improved fuel economy and reduced emissions. The main aims were to reduce the engine noise when accelerating and at high engine speeds. A highly-rigid engine side mount bracket is used, the crankshaft rigidity is improved, and intake rumble noise is reduced by employing equal length intake manifold pipes.

A comparison of the radiated engine noise is shown in Fig. 17. A reduction in noise of 2 to 3 dB in the high speed operation range was attained.

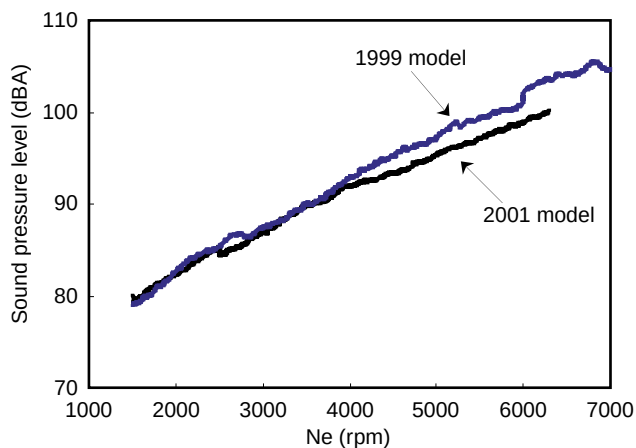


Fig.17 Reduction of engine radiation noise

6.1. Engine Side Mount Bracket

Fig. 18 shows a comparison between the new and old engine side-mounting brackets. Material for this bracket is changed from cast iron to aluminum, and it is integrated with the ACG stay to attain both high rigidity and weight reduction. This reduces vibration transmission from the engine to the chassis.

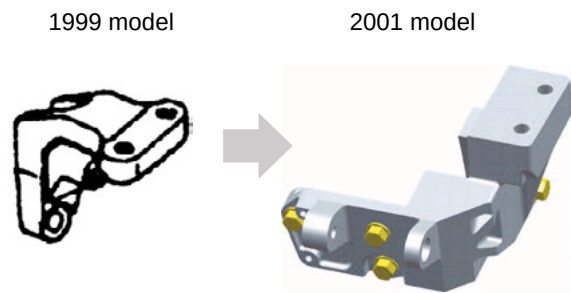


Fig.18 Improving the rigidity of the engine side mount bracket

6.2. Crankshaft

As shown in Fig. 19, the width of the crankshaft pin has been reduced from 23 mm to 20 mm to enable the crankshaft web to be increased by 1.5 mm. This increased the overall rigidity of the crankshaft to reduce the rumble noise. Furthermore, the narrower width of the crankshaft pin has reduced the friction of the big-end bearings.

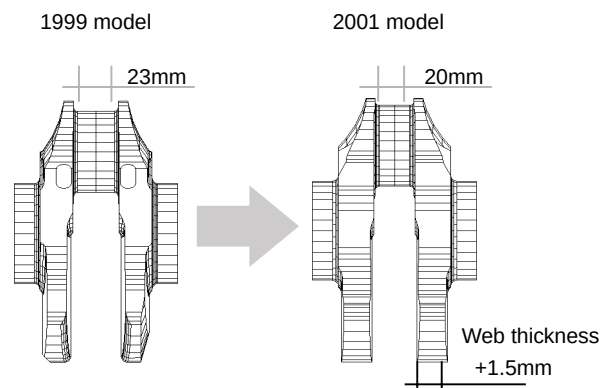


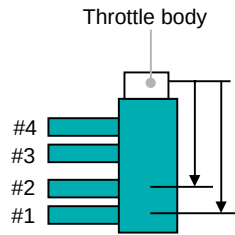
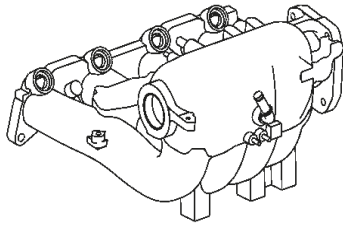
Fig.19 Improving the rigidity of the crank shaft

6.3. Intake Manifold

One of the sources of the rumble noise in the induction system is caused by a half-order harmonic from the intake port. This occurs because the lengths from the throttle body to the intake open ends of individual cylinders are not equal. The material used for the intake manifold on this engine is changed from aluminum to resin, and the greater forming freedom for this material has enabled each intake pipe to have equal length (Fig. 20).

Fig. 21 shows the sound spectrum of the induction noise from the engine's intake ports. It is clear from a comparison between the new and old models that the half-order harmonic has been substantially reduced resulting in reduction of the rumble noise.

1999 model



2001 model

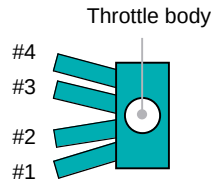
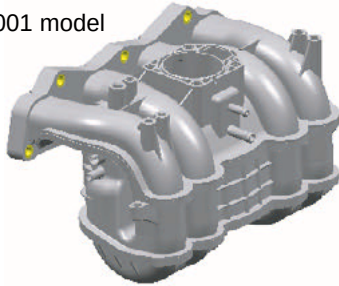
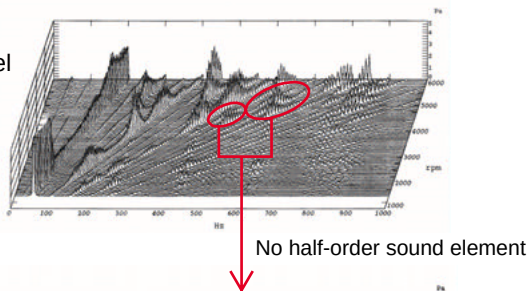


Fig.20 Adopting pipes of equal length

1999 model



2001 model

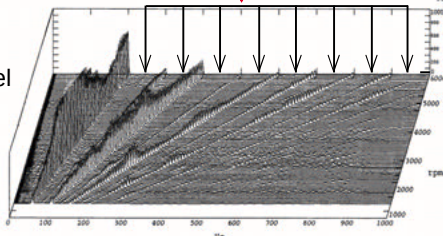


Fig.21 No air-sucking-induced rumbling noise

7. Conclusion

The enhanced thermal efficiency of the new D15B lean-burn engine achieved by using improved combustion and reduced friction, enhanced CVT transmission efficiency, and the improved aerodynamics and rolling resistance of the body have led to the achievement of a fuel consumption of 20 km/L in the 10-15 mode. The use of a combined NO_x adsorption reduction type three-way catalyst system that compliments the lean-burn exhaust has enabled the low emission level of 50% of the Japan 2000 emission standard (certified as a superior low-emission exhaust) to be achieved.

8. Postscript

The lean-burn system developed for this engine is used on the 1.7L model being sold in the United States. The high fuel economy from the lean-burn system conforms to the ULEV standard, so that the original aim of a “low-emission system conforming to global standards” has been achieved.

This new power train system is one answer to the serious issue of compatibility between low emissions and fuel economy which will become ever more important in the 21st century. More modifications will be made in the future to develop a highly efficient power train system that can meet the demands of the time.

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