

Countermeasures against Noise and Vibration in Direct Injection Diesel Engine

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ABSTRACT

The newly developed 2.2L 4-cylinder diesel engine for the new ACCORD marketed in Europe employs numerous noise and vibration reduction technologies. 2nd-order vibration balancers and other technologies have been used to reduce engine noise and vibration, and optimization of pilot injection has reduced combustion noise. In addition, a principal axis of inertia type engine mounting system with torque rods has been employed, and soundproof performance of the complete vehicle has been improved.

The new ACCORD using this new engine is powerful yet achieves the high quality cabin sound and low vibration levels, and has been extremely well received in the European market.

1. Introduction

Concerns for environmental issues are growing world wide, but Europe has been especially concerned about global warming. Currently Europe is striving to reduce CO₂ emissions and has developed a large market focused on diesel engines, as they provide high performance.

Now Honda has developed a new turbo charged diesel engine (intelligent- Common Rail Turbocharged Direct injection: hereafter i-CTDi). Figure 1 shows an external view of the engine.

The i-CTDi engine incorporates a variable geometry turbocharger and a DOHC four-valve direct injection system. In order to increase the fuel injection pressure, the latest 1 600-bar common rail control system is applied. Through these applications, both high output power and high fuel economy are achieved, and this engine has conformed to the Euro-IV regulations at an early stage⁽¹⁾.

However, the increases in power output and the fuel injection pressure cause more engine vibration and combustion noise which affect the quietness of a vehicle⁽²⁾⁻⁽⁴⁾.

In order to solve these issues, the focus was given to the following items to develop countermeasures against noise and vibration.

- (1) Reduction of engine noise and vibration
- (2) Reduction of combustion noise
- (3) Improvement of the engine mount system
- (4) Improvement in soundproof performance of the vehicle



Fig. 1 External view of i-CTDi engine

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This report discusses the reduction of engine noise and vibration through the application of a 2nd order vibration balancer, the reduction in combustion noise through the optimization of pilot injection, the application of a principal axis of inertia type mounting system with torque rods and improvements in soundproof performance of the vehicle.

2. Reduction of Engine Noise and Vibration

Compared to a gasoline engine, the diesel engine produces increased inertial forces and the combustion-induced vibrations which typically result in high NVH levels of the complete vehicle. The following actions are taken to resolve this issue for the i-CTDi engine.

2.1. 2nd Order Vibration Balancer

Increased inertial forces cause 2nd order vibration to increase, therefore a 2nd order vibration balancer system is employed to reduce 2nd order vibration. The system is driven by the crankshaft using a single strand roller chain which, as shown in Fig. 2, is placed inside of the oil pan. By employing this device, the power plant vibration is reduced, leading to significant reduction of the booming noise level in a cabin.

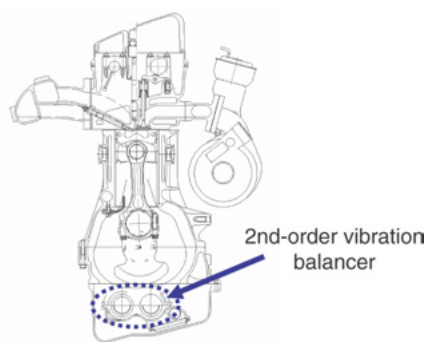


Fig. 2 Cross-section of engine

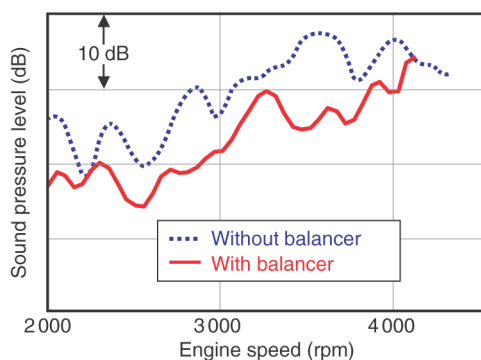


Fig. 3 Cabin booming noise

2.2. Top Acoustic Cover

Since high frequency noise such as high-pressure injector and combustion noise from the common rail system deteriorate a vehicle's marketability considerably, an acoustic cover is employed. As shown in Fig. 4, by optimizing the rib shape of the cover, the placement of the acoustic material, and the attachment points and characteristics of the isolating rubber, the noise level measured above the engine is reduced by 5 dB, as shown in Fig. 5.

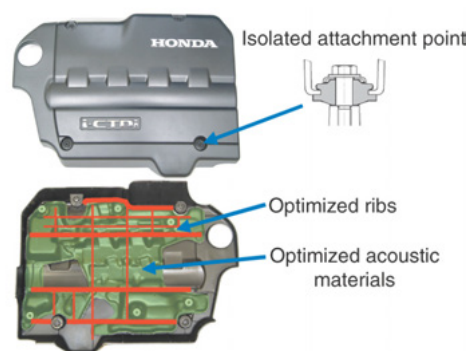


Fig. 4 Engine top acoustic cover

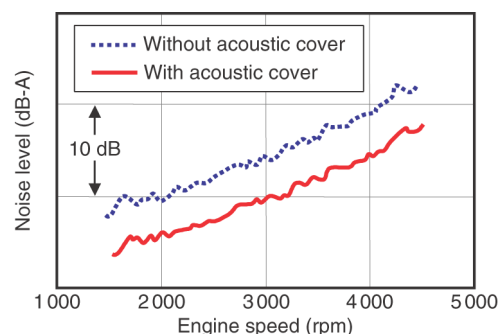


Fig. 5 Engine noise

2.3. Cylinder Block

A closed deck type aluminum block cast with cast iron sleeves is used for the cylinder block to realize a compact and lightweight structure that is able to withstand high combustion pressures⁽⁵⁾. As shown in Fig. 6, the dimensions of all sections (shape of cylinder block surface and journal thickness etc.) are optimized through a CAE study using the lower block of a gasoline engine as a reference.

In addition, the aluminum holder for the 2nd order balancer system is attached to the main bearing support in such a way to increase the total stiffness. High rigidity is achieved, as shown in Fig. 7.

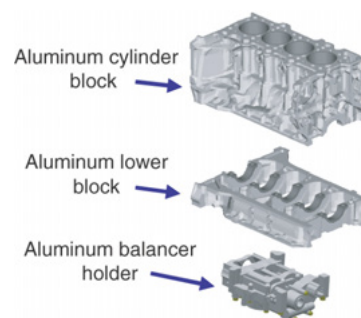


Fig. 6 Cylinder block and balancer holder

By CAE study on the surface of the cylinder block ribs, a reduction in noise emission is shown. Figure 8 shows the structural finite element model used for study as well as the rib placement employed. The structural attenuation of the cylinder block is shown in Fig. 9. Compared with competitors' blocks, including those made out of cast iron for

similar engine displacement, this engine block has superior attenuation.

Another characteristic of the cylinder block is that it is positioned offset from the center line of the crankshaft. As shown in Fig. 10, the crank center is offset to the thrust side of the bore center. The results of a CAE study on piston impact energy (Fig. 11) show that the impact force is mitigated in the direction of thrust.

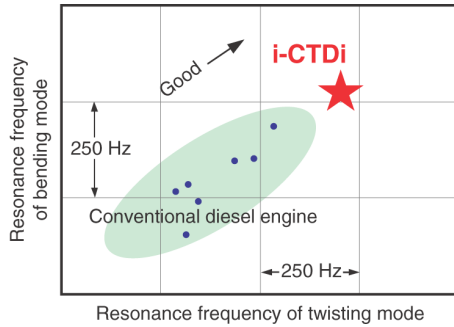


Fig. 7 Cylinder block dynamic characteristics

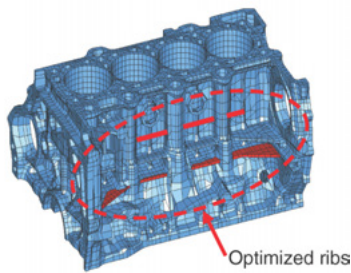


Fig. 8 FEM Model for optimizing ribs

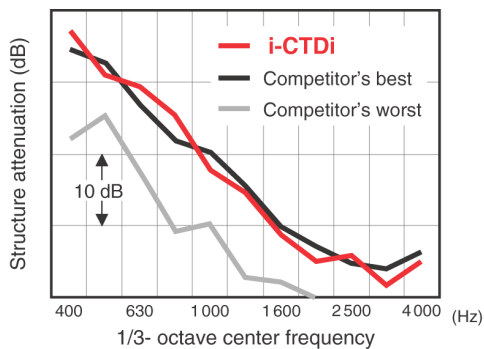


Fig. 9 Structural attenuation

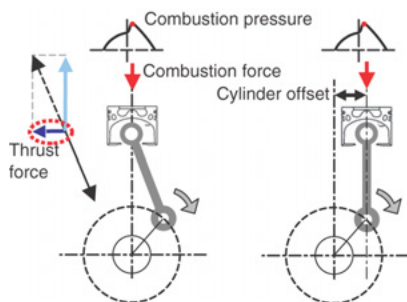


Fig. 10 Cylinder offset structure

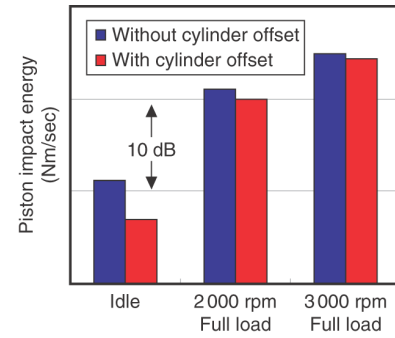


Fig. 11 Calculated piston impact energy

3. Reduction of Combustion Noise

By using the benefit of fuel injection control of the common rail system^{(2) - (4)}, pilot injection is employed in a large area. Figure 12 shows a conceptual diagram of the pilot injection.

Adjusting the process between pilot injection and main injection smooths out the ignition of the main injection and reduces the characteristic diesel combustion by preventing rapid combustion. Figure 13 shows the effects of the pilot injection on the combustion pressure and combustion speed.

In addition, the settings of the amount of fuel released and timing of the pilot injection were adjusted for all types of environmental conditions. As a result, as shown in Fig. 14, lower combustion noise compared to existing diesel engines is realized.

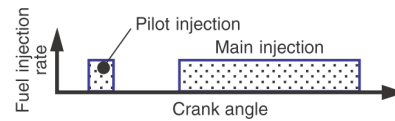


Fig. 12 Conceptual diagram of pilot injection

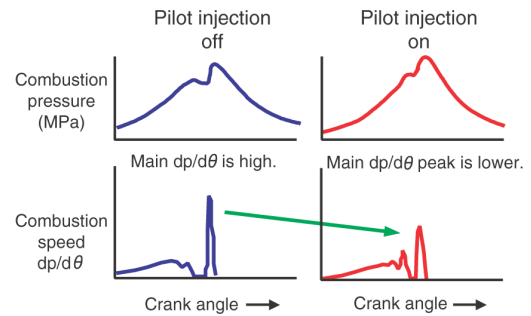


Fig. 13 Effect of pilot injection

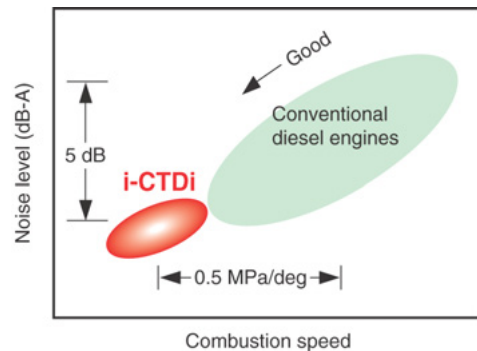


Fig. 14 Combustion noise

4. Improvement of Engine Mount System

In case of the diesel engine, the effect of combustion is large while idling and at engine speeds lower than 3 000 rpm during acceleration. 2nd order vibration is much worse, resulting in increased booming noise and steering vibration, compared to a gasoline engine⁽⁴⁾.

In order to efficiently control 2nd order vibration components, the i-CTDi includes the main mount placed on the principal axis of inertia and a mount system that has a torque rods placed in the upper and lower parts of the engine to react to the drive torque as shown in Fig. 15.

Due to the torque rods placed on the upper and lower parts of the engine, the torque fluctuation input is changed to the horizontal direction from the vertical direction, as in the stopper mount type, used in conventional Honda gasoline engine types (hereafter: conventional types), as shown in Fig. 16. As shown in Fig. 17, the body noise transfer function is reduced by 3 to 5 dB.

Figure 18 shows the benefit of this system for cabin noise compared to conventional types. A booming noise reduction of 3 to 5 dB in the 3 000 rpm region is achieved.

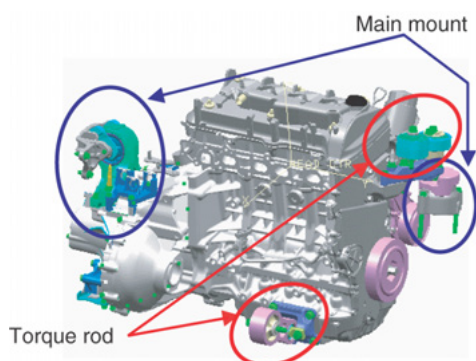


Fig. 15 Principal axis of inertia type mounting system with torque rods

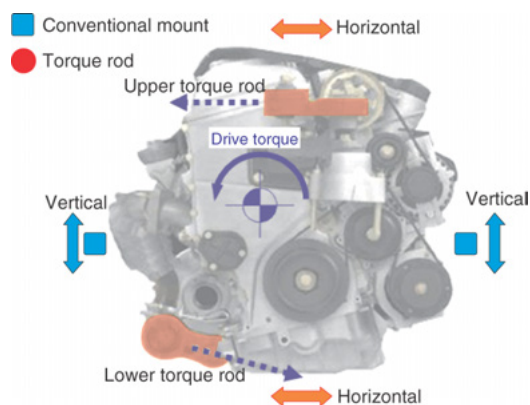


Fig. 16 Direction of principal input force

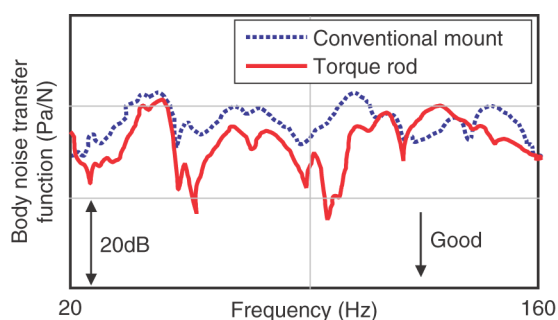


Fig. 17 Body noise transfer function

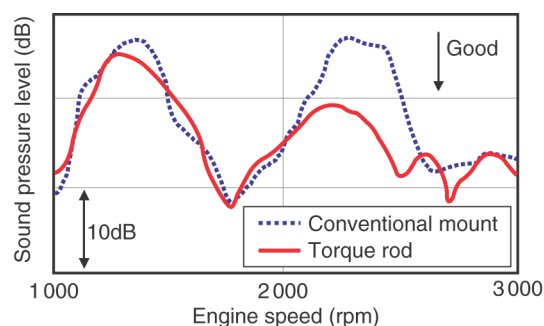


Fig. 18 Booming noise level

In general, the two important characteristics of the torque rod mount system are: 1) the installation angle of the torque rod under its operation, and 2) maintaining the engine mount rigidity in the vertical direction which has a large effect on riding comfort.

For this system, the installation angle of the torque rod, as shown in Fig. 16, is set in the normal direction to the operating drive torque. In addition, as shown in Fig. 19, the transmission lower mount on the lower end of the transmission is newly added.

Through improving the installation angle of the torque rod and adding the transmission lower mount, rotational rigidity under driving torque is assured, as shown in Fig. 20. Also, through employing a transmission lower mount, adequate rigidity in the vertical direction has been provided. Through these countermeasures, a level of riding comfort comparable to the European competitors' vehicles is achieved.

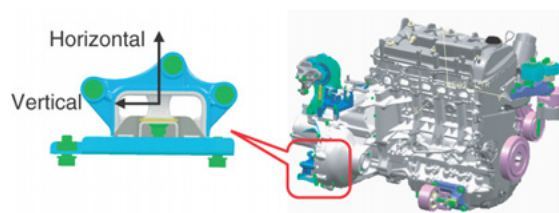


Fig. 19 Transmission lower mount

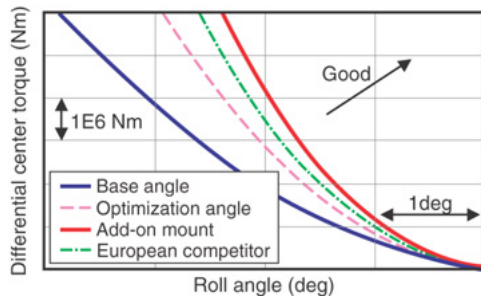


Fig. 20 Comparison of rotational stiffness

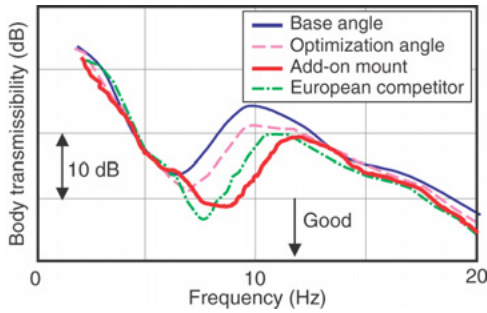


Fig. 21 Body transmissibility

Figure 21 shows the results of the vibration bench test for evaluating the riding comfort performance. Note, as the transmission lower mount is mounted on the sub frame, which has double vibration prevention measures, the deterioration due to noise and vibration is kept to a minimum.

5. Improvement in Soundproof Performance of Vehicle

In addition to the countermeasures for the power plant described above, improvements in vehicle soundproof performance were also investigated.

For optimizing soundproof materials, investigation was performed utilizing the panel contribution analysis method. As a result, it was found that the dashboard and floor are areas where soundproof materials should be effectively applied, as shown in Fig. 22.

The main countermeasures for the dashboard and surrounds are the following

- (1) Through changing the harness grommet structure, between the engine room and the cabin, from the current single layer construction to a hollow double-layer construction, this soundproof performance was improved.

A structural diagram for the grommet is shown in Fig. 23.

- (2) A cover was added to the lower part of the instrument panel so the instrument panel was given as an overall box

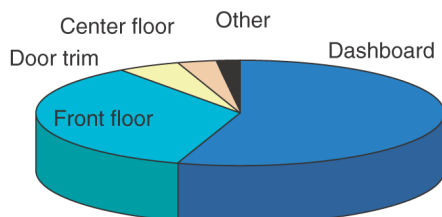


Fig. 22 Contribution analysis of panel

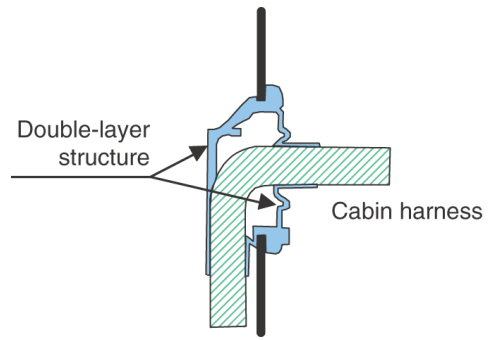


Fig. 23 Structure of cabin harness grommet

type structure. Moreover, on surface of inside instrument panel, acoustic material with improving performance (+25% compared to current materials) is applied to improve soundproof performance. As a result, acoustic material weight was reduced 60% compared to current material.

In addition, materials with high acoustic performance were also used for a floor carpet. Therefore, the soundproof performance of a vehicle was greatly improved compared to before applying the countermeasures as shown in Fig. 24.

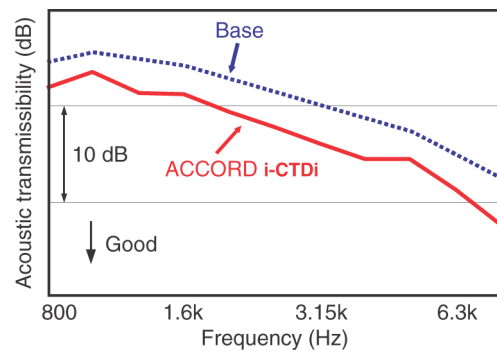


Fig. 24 Soundproof performance of completed vehicle

6. Cabin Noise of Complete Vehicle

As a result of the employment of noise and vibration reduction technologies discussed above, the new EU Accord, equipped with the i-CTDi engine, achieves quiet cabin noise levels as shown in Fig. 25.

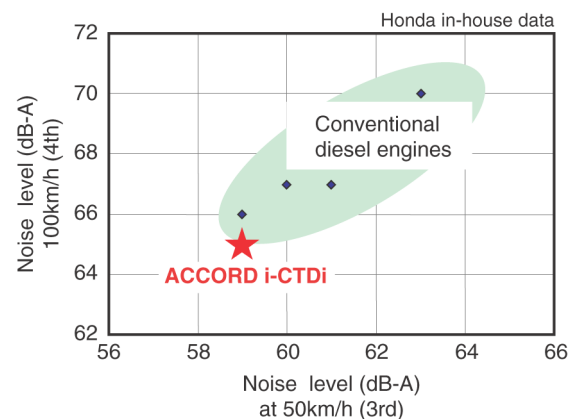


Fig. 25 Interior noise

7. Conclusion

The newly developed 2.2L 4-cylinder diesel engine for the new ACCORD marketed in Europe employed the following noise and vibration reduction technologies. This enabled the new ACCORD to be powerful yet achieves the high quality cabin sound and low vibration levels, associated with a luxury vehicle.

(1) Reduction of engine noise and vibration

The engine noise and vibration was reduced by increasing the rigidity of the cylinder block, employing a lower block structure, offsetting the cylinders, application of a top acoustic cover, and a 2nd order vibration balancer.

(2) Reduction of combustion noise

The use of a pilot injection reduces combustion noise by smoothing out the ignition of the main injection and by preventing rapid combustion.

(3) Improvement of engine mount system

In order to efficiently control 2nd order vibration components, a principal axis of inertia type mounting system with torque rods is employed, and the mount characteristics and installation angle of the torque rod are optimized. This leads us to the realization of a vehicle where noise and vibration is reduced and where the riding comfort is comparable to that of European competitors' vehicles.

(4) Improvement in soundproof performance of vehicle

The soundproof performance of a vehicle was greatly improved by changing the structure of the harness grommet and utilizing acoustic materials with excellent performance of noise absorption.

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