

Advanced Technology for Interior Vibration Reduction for New CIVIC

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ABSTRACT

Steering vibration while idling and floor and accelerator pedal vibration while accelerating were reduced for the new CIVIC. Steering vibration while idling was reduced by positioning the engine mounts, which are the main transfer path, in locations with a small engine vibration amplitude. This reduced the engine vibration transferred to the body without lowering the spring constants of the engine mounts, and provided power train support stiffness while at the same time reducing the vibration transfer amount. Floor vibration while accelerating was reduced by positioning the exhaust mounts in locations with a small exhaust vibration amplitude to reduce exhaust vibration transfer, and by increasing the floor panel thickness and adding cross members to increase the floor stiffness and reduce the floor vibration sensitivity. Accelerator pedal vibration while accelerating was reduced by offsetting the position of the fuel pipe bracket connected to the dashboard lower where the accelerator pedal module mounting point is located.

1. Introduction

Customer interest in NVH performance is increasing. In addition to interior quietness, there are also high expectations for reduction of steering, floor, and accelerator pedal vibration, which are locations that passengers contact.

Vibration while idling and accelerating is a phenomenon that occurs when engine vibration due to engine torque fluctuation and inertia force is transferred to the body. Effective countermeasures include reducing the spring constants of bushings to reduce the vibration transfer amount, and body countermeasures involving weight increase to reduce vibration sensitivity. However, these countermeasures present issues for also achieving good handling, ride comfort, and fuel economy performance.

Therefore, interior vibration while idling and accelerating was reduced using methods that make it possible to also achieve good handling, ride comfort, and fuel economy performance.

2. Interior Vibration Reduction Goals

- (1) Reduction of steering vibration while idling.
- (2) Reduction of floor vibration and accelerator pedal vibration while accelerating.

This paper describes the technology applied to achieve the above goals.

3. Technology for Reduction of Steering Vibration while Idling

3.1. Mechanism

Steering vibration while idling occurs when engine vibration produced by engine torque fluctuation is transferred to the body via the main transfer path of the engine mounts that elastically support the power train.

This vibration transfer amount can be quantified using the engine vibration at the engine mount points, the spring constants of the engine mounts, and the vibration sensitivity from the engine mount connection points to the steering (hereafter, steering vibration sensitivity), which is a body side vibration characteristic.

Figure 1 shows the engine mount system configuration for the 1.5 L VTEC TURBO engine. The power train support load is shared by the two mounts (hereafter, main mounts) of the engine side mount located on the upper right side of the cylinder block and the transmission mount located on the upper left side of the transmission. The drive reaction force is supported by a torque rod that connects the lower part of the oil pan and the subframe. This torque-rod-type engine mount system employs a structure based on technology applied to the 2006 model year CIVIC⁽¹⁾.

3.2. Issues and Countermeasures

The idling engine speed for an inline 4-cylinder engine

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is approximately 600 to 900 rpm, and the frequency band of the 2nd-order component that is the main issue is approximately 20 to 30 Hz.

The vibration transfer amount can be reduced by reducing the spring constants of the engine mounts. However, this reduces the power train support stiffness and increases the vibration amount, so also achieving good handling and reducing the jerking feeling while accelerating is an issue.

In addition, a method of using the Supplemental Restraint System (SRS) module of the steering system as a dynamic damper⁽²⁾ has been developed as a method of directly reducing steering vibration. However, the resonance frequency of the steering system is approximately 40 Hz, which is higher than the idling frequency band, so reduction of the 2nd-order component of the steering vibration while idling has little effect. Furthermore, enhancement of vibration sensitivity by changes to the body and steering structure that do not involve weight increase are quite challenging from a technical perspective.

Investigation therefore focused on the power train vibration mode while idling, and investigated a method of reducing engine vibration at the main mount points without reducing the spring constants of the main mounts, by positioning the main mounts in locations with a small vibration amplitude.

3.3. Investigation of Optimal Main Mount Layout

The power train is forcibly excited by torque fluctuation while idling, and vibrates in the rotation direction with the torque roll axis⁽³⁾ (the axis determined by the inertia main axis and the crankshaft angle) shown in Fig. 2 as the rotation axis (hereafter, power train rolling vibration). The power train rolling vibration amplitude decreases as the power train rolling vibration approaches the torque roll axis. The engine vibration amplitude at the main mount points while idling can be reduced by positioning the main mounts in locations with a small power train rolling vibration amplitude.

Figure 3 shows the steering vibration sensitivity at the engine side-mount point with respect to vehicle longitudinal direction and vertical direction input. This shows that the vibration sensitivity in the vehicle longitudinal direction is approximately 10 dB lower than that in the vehicle vertical direction. Therefore, positioning the main mounts

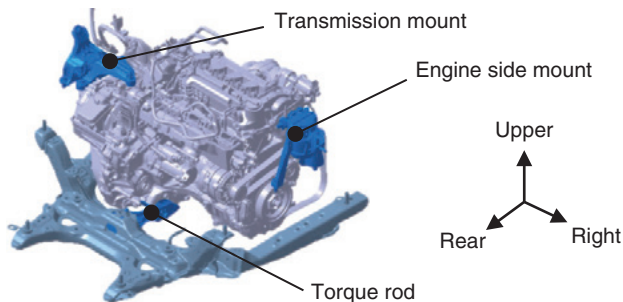


Fig. 1 Torque rod type engine mount system

in locations that minimize engine vibration in the vehicle vertical direction, even if vibration in the body longitudinal direction increases, was investigated.

3.4. Investigation Results of Optimal Main Mount Layout

The structure provides the two main mounts on the side frame at both ends in the crankshaft direction of the power train, leaving little freedom of movement in the vehicle lateral direction. In addition, the main mounts need sufficient support stiffness with respect to the drive reaction force, so lowering the position in the vehicle vertical direction reduces the support stiffness, which makes simultaneously reducing the jerking feeling while accelerating an issue. CAE was therefore used to investigate the optimal position in the vehicle longitudinal direction that minimizes the engine vibration in the vehicle vertical direction at the main mount points while idling.

Figure 4 shows the engine side-mount position and corresponding change in engine side-mount vibration in the vehicle vertical direction for the three cases when the engine side-mount position is located on the torque roll axis (zero longitudinal offset) (Case-1), moved 40 mm toward the front of the vehicle (Case-2), and moved 40 mm toward the rear of the vehicle (Case-3). This shows that the engine vibration in the vehicle vertical direction at the mount

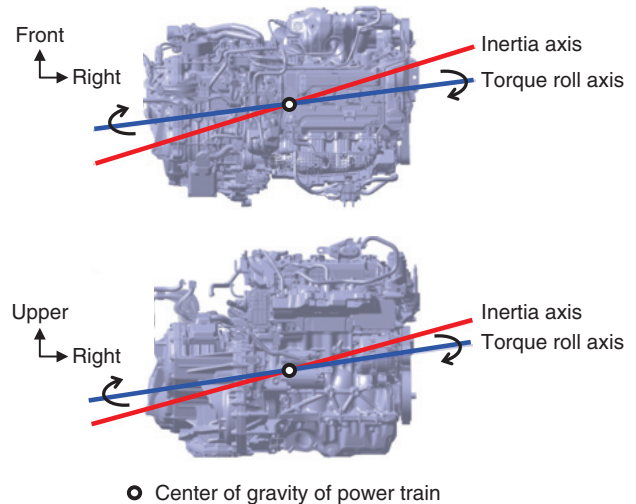


Fig. 2 Vibration mode while idling

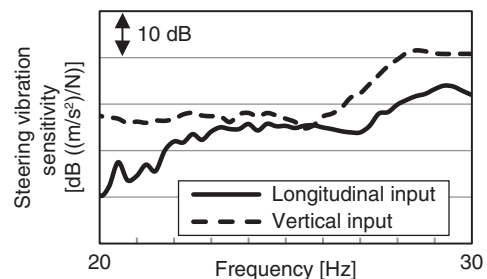


Fig. 3 Comparison of vibration sensitivity

position is smallest when the engine side-mount position in the vehicle longitudinal direction is positioned directly on the torque roll axis. These results were used to determine the positions of both main mounts.

Figure 5 shows the engine 2nd-order vibration in the vehicle vertical direction at the engine side-mount point of a vehicle equipped with the 1.5 L VTEC TURBO engine at the idling engine speed. Enhancement of the mount layout based on the above analysis results reduced the input vibration by approximately 3 dB compared to the previous model.

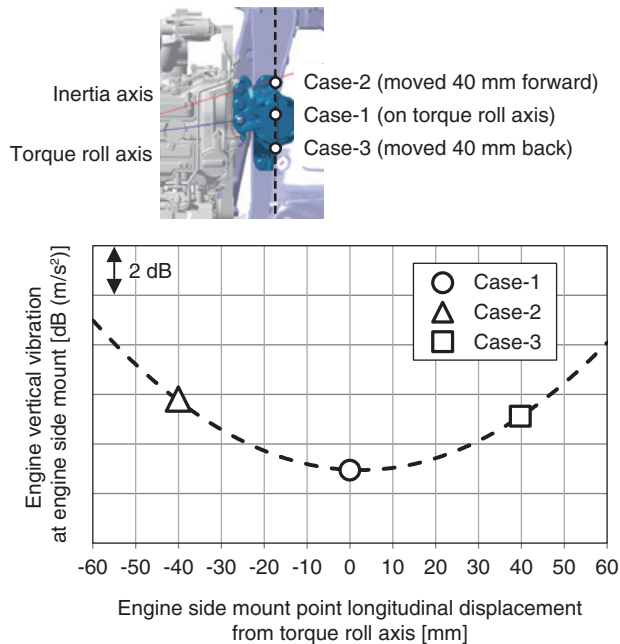


Fig. 4 Engine side mount point investigation result

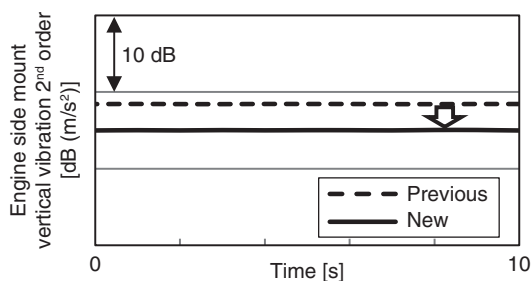


Fig. 5 2nd order engine vibration while idling

4. Technology for Reducing Floor and Accelerator Pedal Vibration

4.1. Mechanism

Floor and accelerator pedal vibration while accelerating occurs when vibration originating in the engine is transferred to the body via the engine mounts, the exhaust system, and hoses and pipes such as for the climate control and fuel

systems. For an inline 4-cylinder engine with a maximum engine speed of approximately 7,000 rpm, the frequency range of this vibration is mainly the frequency band of the 2nd-order component, or approximately 30 to 230 Hz.

Floor vibration is greatly influenced by the vibration of the exhaust system, which has hanger points on the underside of the body. Figure 6(b) shows the exhaust system configuration of the 1.5 L VTEC TURBO engine.

The exhaust system is supported elastically by a total of six mounts on the front subframe, the floor tunnel, and at the front and rear of the two main silencers. The number of main silencers was increased from one for the 1.8 L naturally aspirated engine of the previous model to two main silencers to support high power output.

In addition, the exhaust vibration at the floor tunnel exhaust hanger point shown by point B in Fig. 6 has a large influence. This means that floor vibration can be reduced by reducing the exhaust vibration amplitude at point B, and by reducing the vibration sensitivity from point B to the floor (hereafter, floor vibration sensitivity).

The accelerator pedal module (APM) is the accelerator pedal link part and is connected to the dashboard lower, so dashboard lower vibration in the vehicle longitudinal direction has a major influence on accelerator pedal vibration.

Figures 7 and 8 show the APM, heater hose, and fuel pipe bracket connection structures to the dashboard lower. The APM is connected to the interior side, and the fuel pipe bracket is connected to the engine compartment side. The heater hose passes through the dashboard lower and is connected to the climate control unit, but the fuel pipe

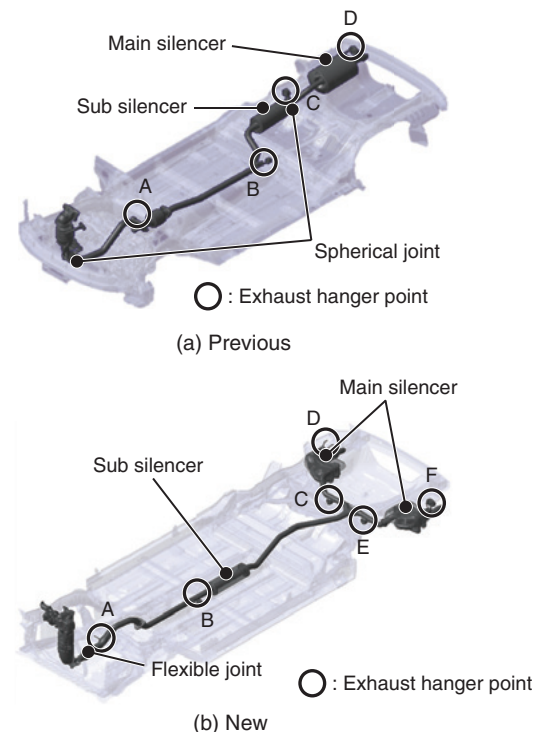


Fig. 6 Exhaust system

bracket has a clamp point to regulate heater hose movement. Engine vibration is transferred to the fuel pipe bracket via these pipes and hoses, and vibrates the dashboard lower. Therefore, one method for enhancement is to reduce the vibration sensitivity from the fuel pipe bracket to the APM (hereafter, APM vibration sensitivity) in order to reduce the accelerator pedal vibration.

4.2. Issues and Countermeasures

Engine vibration is transferred to the exhaust system via the joint with the catalyst, and amplified by the natural elastic resonance mode of the exhaust system (hereafter, exhaust elastic mode). Reducing the spring constants of the exhaust mounts is an effective means of reducing vibration transfer from the exhaust system. However, this reduces the exhaust system support stiffness and increases the vibration amount, so also achieving good handling becomes an issue in the same manner as when reducing the spring constants of the engine mounts.

In addition, while enhancement of body stiffness to reduce the vibration amplitude is an effective body-side countermeasure for floor and accelerator pedal vibration, this leads to an increase in vehicle weight, so also achieving fuel economy performance is an issue.

An effort was therefore made to reduce vibration transfer from the exhaust system to the floor by changing the exhaust joint structure to reduce the vibration transferred from the engine to the exhaust system, and by focusing on the exhaust elastic mode and positioning the exhaust hanger points in locations with a small vibration amplitude.

In addition, the floor stiffness was increased to enhance the body-side vibration sensitivity. Meanwhile, the floor system specifications, including sound isolation parts such as the floor panel and floor carpet, were also investigated to avoid increasing the vehicle weight. Regarding accelerator pedal vibration, the positions where the heater hose and fuel pipe bracket are connected to the dashboard lower were

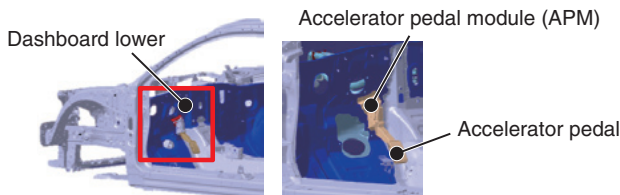


Fig. 7 Accelerator pedal module (APM)

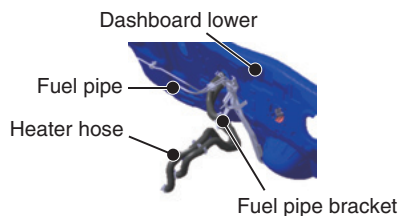


Fig. 8 Heater hose and fuel pipe bracket connection

changed to reduce the APM vibration sensitivity from the dashboard lower piping connections.

4.3. Reduction of Exhaust Vibration

4.3.1. Application of flexible joint

The spherical joints used in the previous model were changed to a flexible joint to reduce the amplitude of the engine vibration transferred to the exhaust system. This flexible joint has a bellows structure that provides elasticity and flexibility, effectively reducing vibration transfer. In order to maximize the vibration transfer reduction effect of the flexible joint, the layout positions the axial direction of the flexible joint on the engine rotation roll axis tangent to reduce vibration transfer in the axial direction (Fig. 9).

4.3.2. Exhaust elastic mode and exhaust mount layout

As a result of analyzing the exhaust elastic mode, investigation focused on the vertical bending elastic mode around 100 Hz as an elastic mode that has a major influence on floor vibration. It was found that in the exhaust system of the 1.5 L VTEC TURBO engine, the position around the floor tunnel part that has a small exhaust vibration amplitude is approximately 600 mm toward the front of the vehicle compared to the exhaust mount point B position set for the previous model (Fig. 10). So the position of exhaust mount point B was determined from these results.

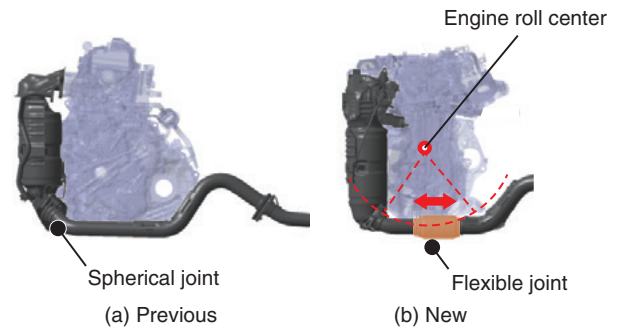


Fig. 9 Flexible joint layout

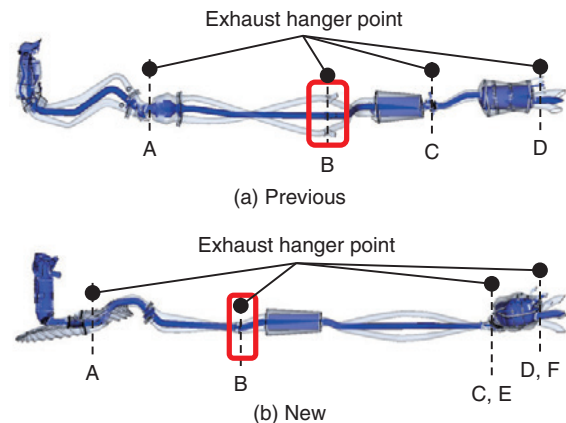


Fig. 10 Exhaust vertical bending mode around 100 Hz

Figure 11 shows the exhaust vibration in the vehicle vertical direction at exhaust mount point B. Application of the flexible joint reduced vibration by approximately 10 dB, and optimization of the exhaust mount point B position also reduced vibration by approximately 10 dB, for a combined exhaust vibration reduction effect at exhaust mount point B of approximately 20 dB compared to the previous model.

4.4. Reduction of Floor Vibration Sensitivity

Figure 12 shows the changes to the floor panel structure. The floor panel thickness was increased compared to the previous model and cross members were added to reduce the floor vibration sensitivity.

Excitation point inductance in the vehicle vertical direction is an index used to evaluate floor stiffness, and was reduced by approximately 20 dB compared to the previous model (Fig. 13) at the evaluation position shown in Fig. 12. As a result, the floor vibration sensitivity from exhaust mount point B was reduced by approximately 17 dB compared to the previous model (Fig. 14). Increasing the floor system weight was suppressed by reducing the weight of the floor carpet, which is a sound proof part.

4.5. Reduction of Accelerator Pedal Vibration Sensitivity

Investigation focused on the relative positions of the fuel pipe bracket and the APM on the dashboard lower as a means of reducing the APM vibration sensitivity from the fuel pipe bracket connected to the engine compartment side

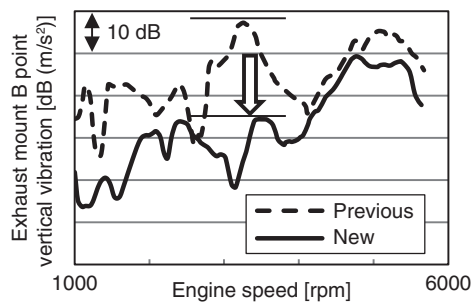


Fig. 11 Exhaust vibration reduction

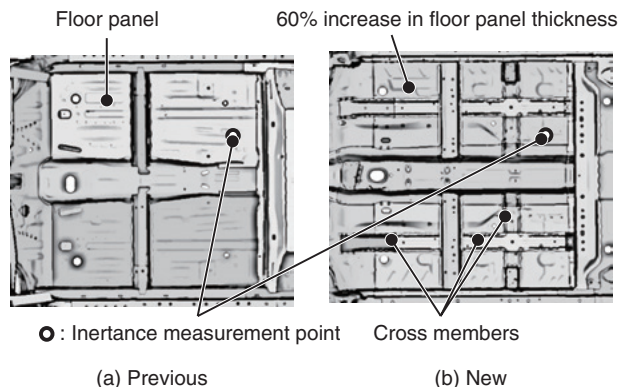


Fig. 12 Comparison of floor structure

of the dashboard lower. The new layout offsets the piping connection parts by 120 mm as shown in Fig. 15 compared to the previous model. As a result, the piping vibration transfer sensitivity to the accelerator pedal was reduced by approximately 10 dB (Fig. 16).

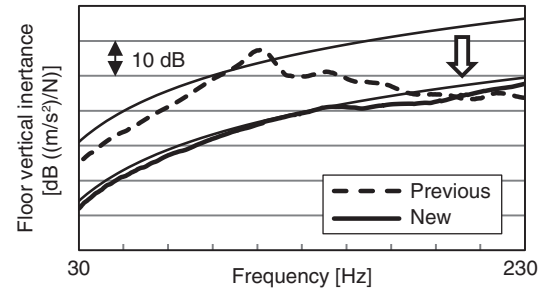


Fig. 13 Floor panel vertical stiffness

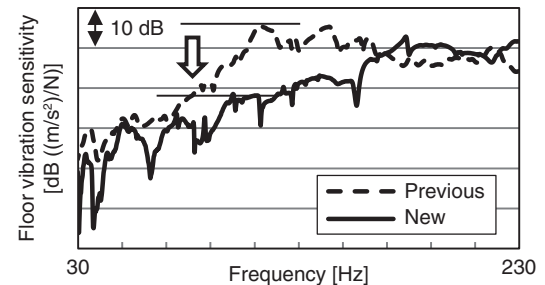


Fig. 14 Floor vibration sensitivity

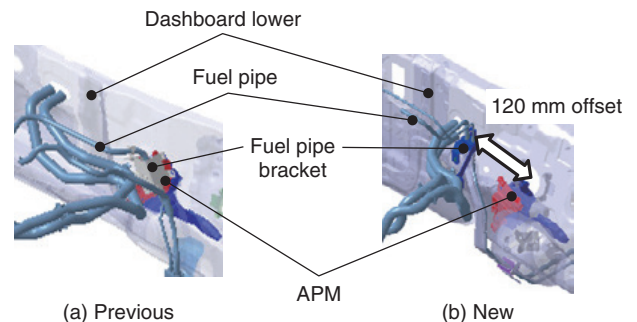


Fig. 15 Heater hose and fuel pipe bracket connection

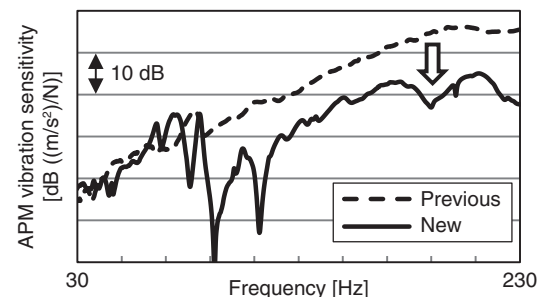


Fig. 16 Vibration sensitivity from fuel pipe bracket on dashboard lower to APM

5. Verification of Results in an Actual Vehicle

Application of the above technology achieved the target interior vibration reduction.

Figure 17 shows the steering 2nd-order vibration in the vehicle vertical direction while idling in the D range engine speed. Vibration was reduced by 8 dB compared to the previous model. Figure 18 shows the 2nd-order vibration of the floor in the vehicle vertical direction at the driver's foot position while accelerating, and Fig. 19 shows the 2nd-order vibration in the plane direction of the accelerator pedal head while accelerating. Vibration was respectively reduced by 10 and 7 dB, compared to the previous model.

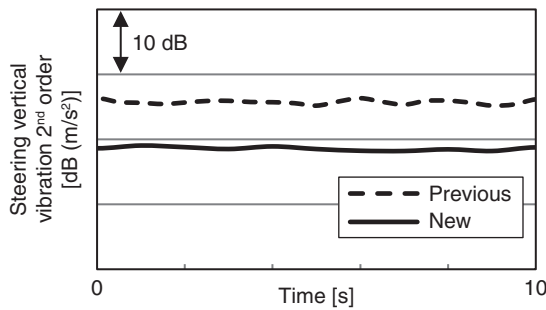


Fig. 17 Steering vibration while idling

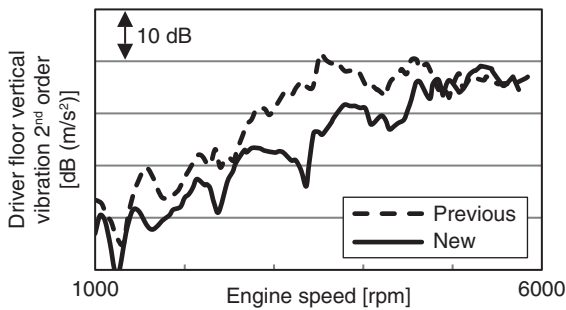


Fig. 18 Floor vibration while accelerating

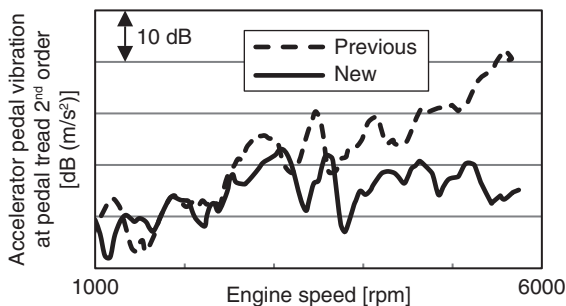


Fig. 19 Accelerator pedal vibration while accelerating

6. Conclusion

- (1) Steering wheel vibration while idling was reduced by analyzing power train rolling vibration while idling and positioning the main mounts in locations with the minimum engine vibration to reduce the vehicle vertical direction component of the engine vibration input from the main mounts.
- (2) Exhaust vibration transferred to the body was reduced by applying a flexible joint to the exhaust system and by positioning the floor part exhaust mounts in locations with a small vibration amplitude based on the exhaust elastic mode analysis results. In addition, vibration sensitivity was reduced by increasing the floor stiffness and by offsetting the APM mounting point and fuel pipe bracket position. These changes succeeded in reducing floor and accelerator pedal vibration while accelerating.

References

- (1) Yanagase, H., Tamura, T., Takabayashi, H., Ikebata, S.: Reduction of Noise and Vibration in Compact Car Engine Mount System, Honda R&D Technical Review, Vol. 17, No. 2, p. 90-95
- (2) Kondo, T., Terada, M., Kunitake, Y., Miyahara, K.: Development of SRS Module Damping Structure for Vibration Enhancement and Weight Reduction, Honda R&D Technical Review, Vol. 23, No. 2, p. 129-135
- (3) Boushingomu kenkyukai: Chapter 8 Boushin shiji sekkeihou, Boushingomu kaitei shinban, Gendaikougakusya, p. 90-92, (1975) (in japanese)

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