

Advanced Technology for Road Noise Reduction for New CIVIC

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ABSTRACT

Road noise performance was enhanced when developing the new CIVIC. To reduce low-frequency road noise when driving on rough road surfaces, the suspension main vibration mode and sub-frame vibration mode frequencies were controlled so that they do not overlap with the acoustic mode frequencies that are determined by the cabin shape and volume. In addition, to reduce high-frequency road noise when driving on flat road surfaces, soundproof specifications were applied to locations with a high contribution to cabin noise, and the sealing performance of the doors was enhanced. These measures achieved road noise performance that is competitive as a global model.

1. Introduction

Customer interest in NVH performance continues to increase. In particular, the quietness of competing vehicles centering on the European premium class has evolved to a high level of quality that surpasses mere quietness and makes an impression on customers. Efforts are being made to reduce road noise over a wide frequency band from low-frequency road noise when driving on a rough road surface to high-frequency road noise when driving at high speeds. This paper describes the technology applied to reduce both low- and high-frequency road noise, which have different mechanisms.

2. Road Noise Reduction Goal

Figure 1 shows the cabin noise spectrum when driving on a rough road surface. As a result of comparison with the previous model, competing vehicle A, and competing vehicle B, enhancement of low-frequency road noise from approximately 100 to 200 Hz and high-frequency road noise in the frequency band above 800 Hz were set as enhancement goals for the new CIVIC.

The following two technologies were applied to achieve the above goals.

- (1) To reduce low-frequency road noise, the suspension and subframe vibration modes were analyzed, modes with a

high contribution were identified, and these frequencies were separated from the cabin acoustic mode frequency to reduce the sound pressure.

- (2) To reduce high-frequency road noise, the soundproof package layout was optimized based on panel contribution analysis, and the size of the holes and gaps (hereafter, body leakage area) was reduced.

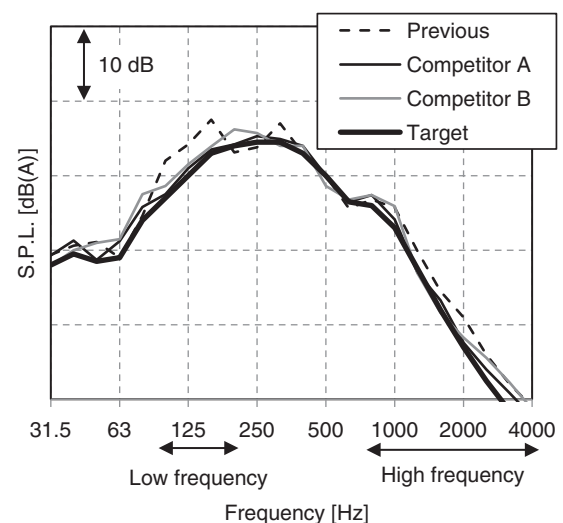


Fig. 1 Road noise comparison to competitors

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3. Low-frequency Road Noise

Low-frequency road noise produced when driving on a rough road surface is a phenomenon wherein tire and suspension vibration excited by the road surface roughness is transmitted to the body via the suspension bushings, and the body panels vibrate the air, producing noise. Therefore, an effective method for reducing low-frequency road noise is to reduce the spring constants of the suspension bushings to isolate vibration. In addition, adjusting the main vibration mode frequencies of the suspension in consideration of the combination with the cabin acoustic modes is also a known method for reducing low-frequency road noise⁽¹⁾.

However, reducing the spring constants of the suspension bushings reduces the suspension support stiffness, which has a significant influence on handling. Therefore, to realize the target chassis dynamic performance of the new CIVIC, it is necessary to select a method that can simultaneously achieve both handling and road noise performance.

3.1. Low-frequency Road Noise Reduction Goals

The new CIVIC uses a strut-type front suspension and a multi-link-type rear suspension. The rigid camber mode and elastic camber mode of each suspension are known to be the main vibration modes that have a major influence on low-frequency road noise⁽¹⁾. The suspension vibration at these vibration mode frequencies has a resonance peak, so it is necessary to adjust the suspension vibration mode frequencies so that there is no overlap with the body response-side characteristic peak.

The body characteristics are evaluated by the cabin noise produced when the suspension connecting point is excited (hereafter, body acoustic sensitivity). The cabin acoustic modes are one factor that determines the body acoustic sensitivity. Figure 2 shows the cabin acoustic modes that strongly influence the body acoustic sensitivity. Low-frequency road noise was reduced by separating these frequencies and the front and rear suspension mode frequencies.

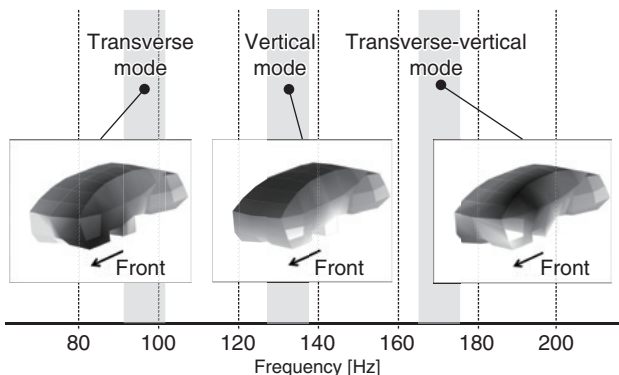


Fig. 2 Cabin acoustic mode

3.2. Front Suspension

The new CIVIC uses a strut-type front suspension. This suspension has an elastic camber mode at approximately 180 Hz where the wheel rotates in the camber direction while the wheel disk surface, hub bearing, knuckle, and other parts undergo elastic deformation (Fig. 3).

It is known that cabin noise can be reduced the more the cabin acoustic mode frequency (approximately 170 Hz) and the elastic camber mode frequency are separated⁽¹⁾. The cabin acoustic mode frequency is determined by the cabin shape and volume, so it is not easily changed. Therefore, increasing the elastic camber mode frequency was investigated, and the elastic camber mode target frequency range was set from 195 to 205 Hz based on the cabin noise reduction target.

The strain energy density of the suspension parts in elastic camber mode was analyzed using CAE, and the results showed that the area from the hub to the damper connection part of the front knuckle has a high strain energy density and a high contribution to the elastic camber mode frequency (Fig. 4).

The elastic camber mode frequency could be increased to the target range by increasing the thickness by approximately 9 mm at the position indicated by the arrows in Fig. 5(a) (original) and (b) (modified). Figure 6 shows the damper vibration and Fig. 7 shows the cabin noise during wheel excitation. These figures show that the elastic camber mode frequency was separated from the acoustic

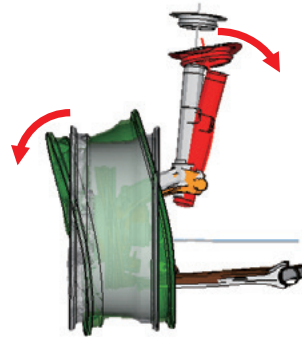


Fig. 3 Front strut suspension in elastic camber mode

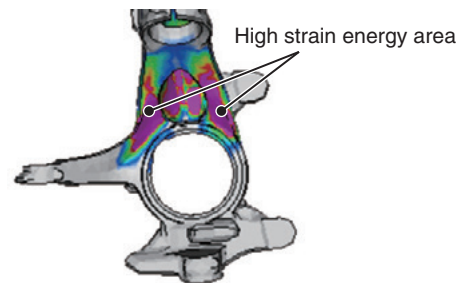


Fig. 4 Strain energy density of front knuckle in elastic camber mode

mode frequency, which enabled reduction of the sound pressure in the 170 to 180 Hz range by 3 dB (approximately 30% reduction).

3.3. Rear Suspension

The multi-link-type rear suspension has a rigid camber mode at approximately 125 Hz where the knuckle and wheel rotate together in the camber direction (Fig. 8).

In addition, the suspension has a rear subframe part

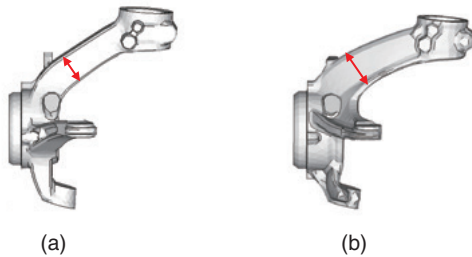


Fig. 5 Front knuckle modification

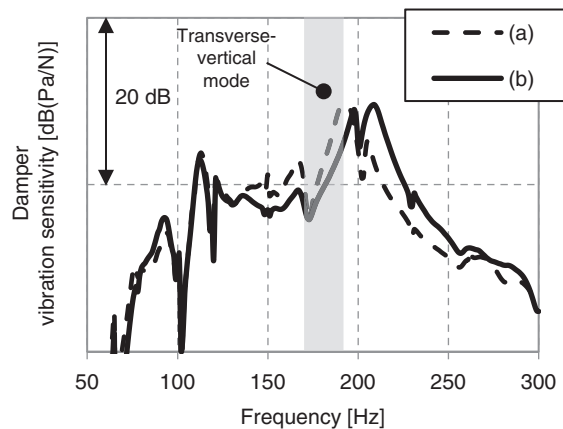


Fig. 6 Front suspension vibration sensitivity

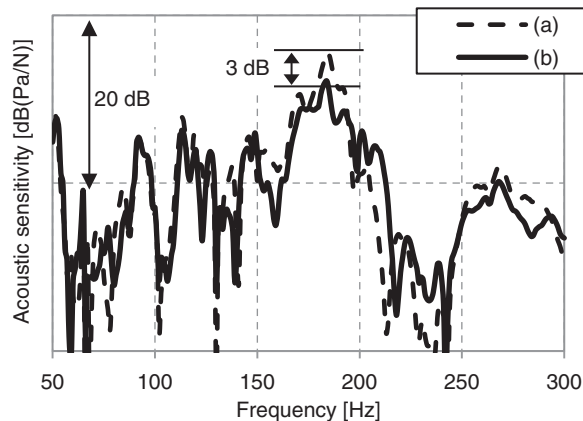


Fig. 7 Reduction of road noise by increasing stiffness of front knuckle

that connects the rear suspension and the body. This rear member has a longitudinal resonance mode at approximately 130 Hz, which is close to the rigid camber mode of the suspension (Fig. 9).

There is also a cabin acoustic mode at approximately 130 Hz, so to reduce road noise at this frequency, it is necessary to control the rear member resonance of the rear subframe in addition to the rigid camber mode of the rear suspension.

Unlike the elastic camber mode, the rigid camber mode does not involve elastic deformation, so it is not easy to change the vibration mode frequency by changing the stiffness of the arm, knuckle, or other parts. It was therefore decided to separate the rear subframe vibration mode frequency from the cabin acoustic mode frequency. The target frequency was set to the range from 185 to 195 Hz from the viewpoint of also achieving handling stiffness performance. Figure 10 shows this frequency arrangement.

The vibration mode of the rear member of the rear subframe produces deformation in the longitudinal direction as shown in Fig. 9. In order to increase the vibration mode frequency, it is necessary to increase the stiffness of the connection between the rear and side members. Figure 11 shows the rear subframe shape. Stiffness was increased by modifying the shape of the rear member to increase the size and widen the connection with the side member as shown in Fig. 11(a) (original) and (b) (modified). This made it

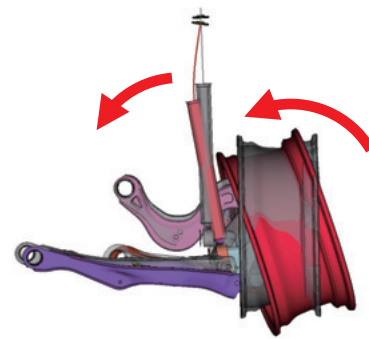


Fig. 8 Rear multi-link suspension in rigid camber mode

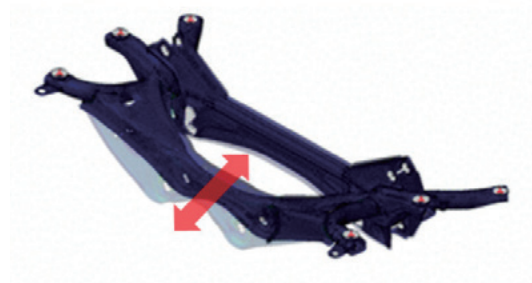


Fig. 9 Longitudinal resonance mode of rear member of rear subframe

possible to achieve the target frequency.

Figure 12 shows the rear subframe longitudinal vibration and Fig. 13 shows the cabin noise during rear wheel excitation. Subframe vibration at the cabin acoustic mode frequency in the vehicle longitudinal direction was reduced by 7 dB, and cabin noise was reduced by 5 dB.

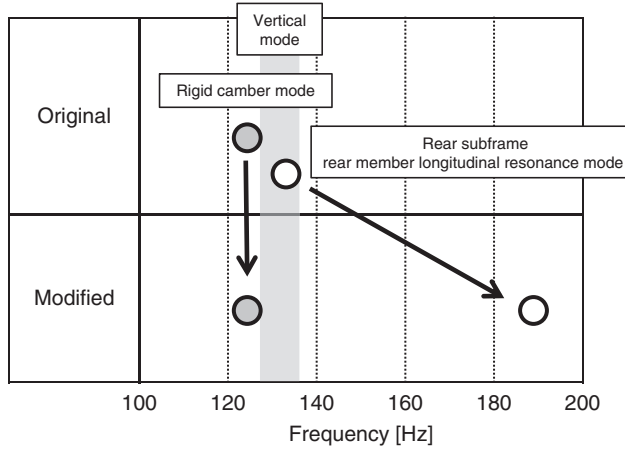


Fig. 10 Rear suspension resonance map

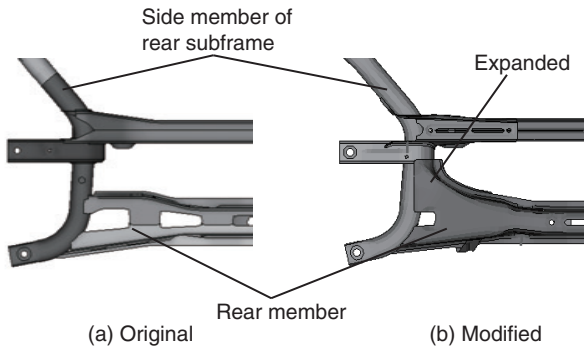


Fig. 11 Rear subframe design change

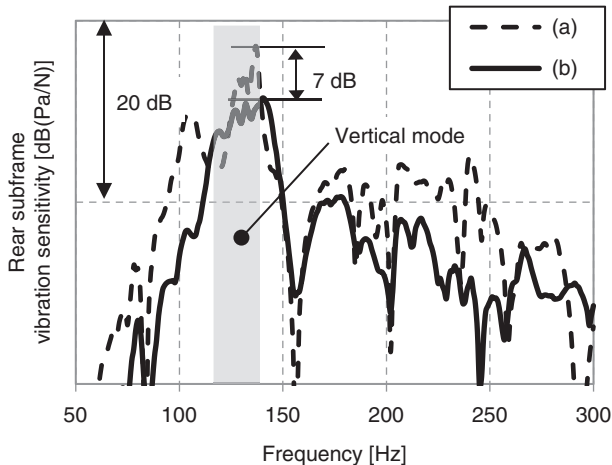


Fig. 12 Rear subframe vibration reduction

4. High-frequency Road Noise

High-frequency road noise includes phenomena such as tire radiation noise produced when road surface roughness vibrates the tires and the resulting tire surface vibration vibrates the air, and pumping noise produced when the air in the tire grooves is trapped by tire contact with the ground and then released. These noises enter the cabin by penetrating the panels and through gaps in the body, so the application of soundproof materials is one effective measure. However, the addition of soundproof materials increases the weight, so simultaneously achieving vehicle weight reduction to enhance fuel economy performance is an issue. For this reason it is necessary to investigate countermeasures, including the body side structure to which the soundproof materials are applied, to minimize the increase in soundproof system weight accompanying the enhanced performance.

4.1. High-frequency Road Noise Goals

First, body locations with a high contribution to road noise were identified, and the soundproof package layout was optimized. Next, countermeasures were taken to block sound entry paths by reducing the body leakage area.

4.2. Optimal Soundproof Package Layout Based on Contribution Analysis

Contribution analysis was performed and the soundproof specifications were investigated as an index for evaluating the energy transmission loss of each acoustic input path to the cabin⁽²⁾. Figure 14 shows the contribution analysis results at 1 kHz.

These results showed that the highest contribution rate was from the wheel house and floor around the driver and the rear-seat foot areas, and accounted for approximately 60% of the total.

Enhancement of the acoustic absorption performance of the under-floor space, the noise insulating performance of the floor surface, and the acoustic absorption performance

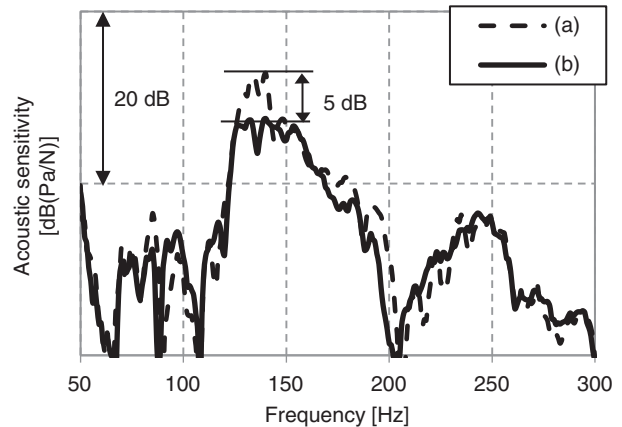


Fig. 13 Reduction of road noise by increasing stiffness of rear member of rear subframe

inside the cabin are effective means of enhancing the energy transmission loss at the floor. Acoustic absorbent materials were applied to the floor undercover and the tunnel heat baffle to enhance the acoustic absorption performance of the under-floor space. In addition, a structure that arranges carpet formed with an integrated insulator and carpet skin was used to increase the noise insulating performance of the floor (Fig. 15).

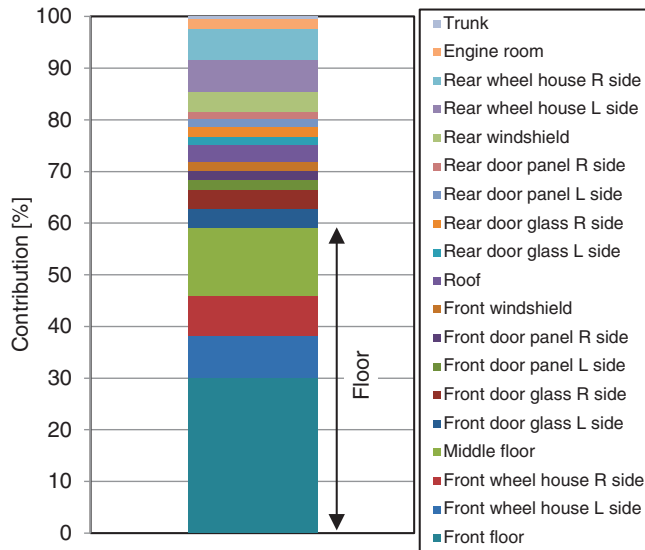


Fig. 14 Area contribution to 1 kHz road noise

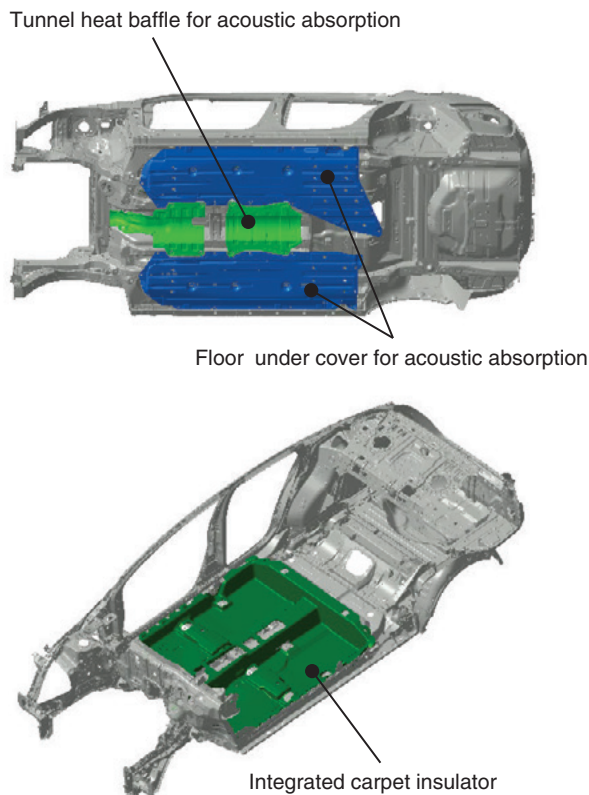


Fig. 15 Sound proof system

These countermeasures enhanced reduced the energy transmission loss of the floor by 3.5 dB compared to the previous model (Fig. 16).

4.3. Reduction of Body Leakage Area to Help Prevent Noise Entry

Noise entry paths can be blocked by reducing the body leakage area, representing an effective means of reducing high-frequency road noise.

Contribution analysis was performed for the body leakage area in the previous model, and the results showed that the doors make a large contribution, accounting for approximately 40% of the overall leakage area. The results of more detailed analysis showed that the main factors were the drain holes located at the bottom of the doors, the gaps at the ends of the inner weather strips, and the gaps in the hole seal that covers the door work holes (Fig. 17).

A lip-shaped door lower seal that covers the drain holes was applied to prevent noise entry from the drain holes (Fig. 18). Molded rubber was applied to both ends of the inner weather strip to reduce the gaps with the door inner panel (Fig. 19). A structure that covers the door harness clip with the hole seal was used to reduce the gap between the hole seal that covers the door work holes and the door harness (Fig. 20).

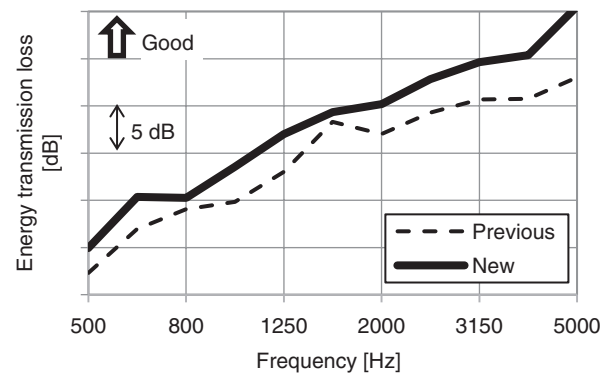


Fig. 16 Energy transmission loss at floor

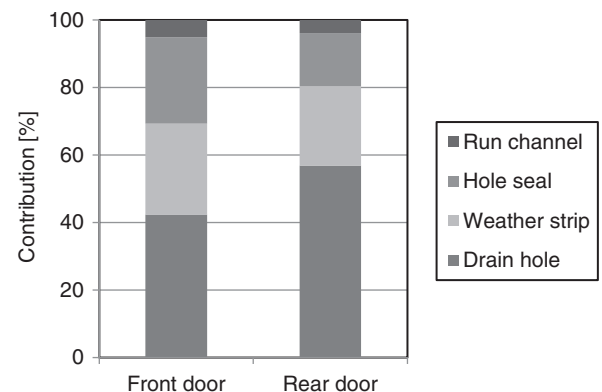


Fig. 17 Body leak area contribution of door

As a result of these measures, the body leakage area was reduced by approximately 30% compared to the previous model.

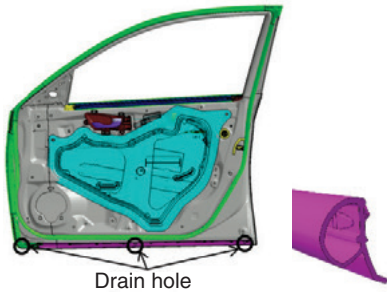


Fig. 18 Door lower seal

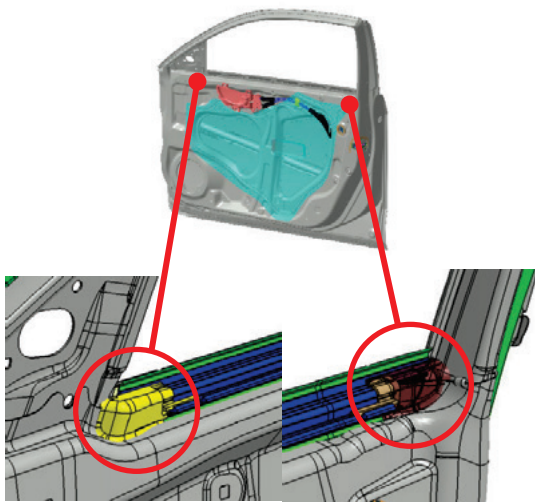


Fig. 19 Door inner weather strip with mold rubber

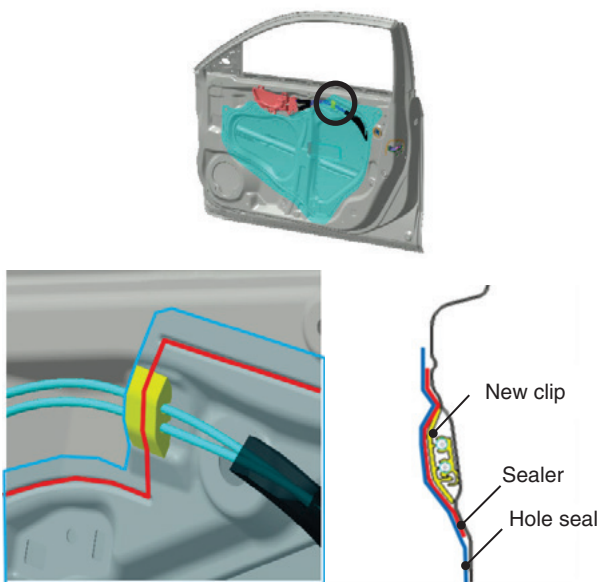


Fig. 20 Door harness clip

5. Results of Verification in an Actual Vehicle

Incorporation of the above technology made it possible to achieve the target quietness while cruising.

Figure 21 shows the cabin noise spectrum at the front seat when driving on a rough road surface. The developed technology achieved road noise reduction of 5 dB at the low frequency of 125 Hz and 3 dB at high frequencies of 1000 Hz and above compared to the previous model.

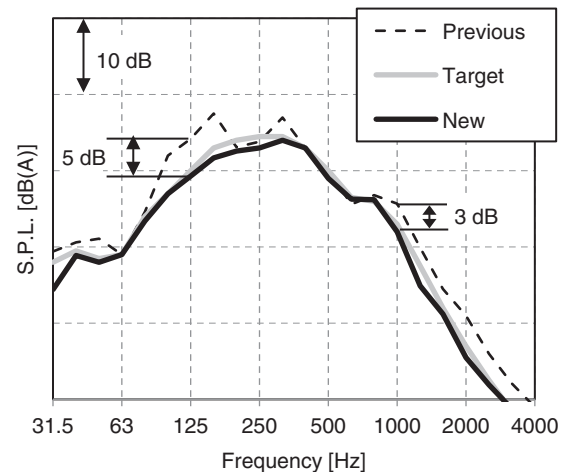


Fig. 21 Road noise on rough surface

6. Conclusion

- (1) The suspension and subframe were analyzed with regards to low-frequency road noise, and modes with a high contribution to cabin noise were identified. Low-frequency road noise was reduced by 5 dB by separating these frequencies from the cabin acoustic mode frequencies.
- (2) Panel contribution analysis was performed with regards to high-frequency road noise, the floor was identified as making a large contribution, and the soundproof package layout was optimized. In addition, the doors were identified as making a major contribution to body leakage, and countermeasures were taken to enhance the sealing performance. These measures reduced high-frequency road noise by 3 dB.

The above technology achieved road noise performance that is competitive as a global model.

References

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