

Selection Technique of Sound Absorption Type Acoustic Insulation Material by Applying SEA Modeling Method

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ABSTRACT

This paper describes an effective method of developing a soundproof package, which balances both light weight and high noise insulation performance. Since it is necessary to propose the design of sound insulation in the early stages of development, the hybrid statistical energy analysis (SEA) modeling method is applied, which is practical for high frequency analysis. Also an acoustic characteristic estimation technique for multi layer structures is used.

As a result of applying these effective methods, the new 2006 CIVIC has enhanced road noise quietness and decreased weight when compared with the previous model.

1. Introduction

Enhancing quietness of automotive interiors is an important factor in increasing commercial appeal of vehicles. Meanwhile, reducing vehicle weight is an essential factor for achieving fuel efficiency targets. In general, achieving the quietness target by enhancing soundproof performance is incompatible with achieving the weight target. Until now, the investigation of noise treatments had been performed in the middle phase of the vehicle development, when the layout of these components is restricted. Therefore, the investigation for reducing noise in that stage inevitably led to an increase in weight and the difficulty of making effective and efficient countermeasures. In this paper, it is described how the soundproof package is developed using a hybrid SEA modeling method^{(1),(2)} and an acoustic characteristic prediction method of multi-layered porous materials^{(3),(4)} for the purpose of achieving the new CIVIC's goals for quietness and weight. The hybrid SEA modeling method is an analytical simulation technique which is an efficient and quantitatively verifiable method used to evaluate interior noise reduction in the early stage of a vehicle development. In this investigation, we used these technologies to develop a proposal to satisfy total acoustic performance through sound absorption and noise insulation. This paper will discuss details of this investigation. In addition to the noise absorption and insulation

performance, the road noise confirmation results for the actual vehicle are presented.

2. Methodology

2.1. Development Process

The new 2006 CIVIC represented a full model change. The targets were to reduce the weight of the soundproof package and enhance road noise quietness versus the previous model. To achieve these, the following steps for developing light weight soundproof package were applied;

- (1) Carried out a contribution analysis of the previous model using the hybrid SEA modeling method.
- (2) Selected the SEA subsystems which have very high contribution to the interior cavity.
- (3) Set damping loss factors (DLFs) that enabled achievement of the road noise target, but kept coupling loss factors (CLFs) between the interior cavity and the SEA subsystems selected in step (2) the same as the previous model.
- (4) Investigated a soundproof package which is 30% lighter than that of the previous model using the prediction method for acoustic characteristics of multi-layered porous materials, while keeping the DLF & CLF SEA parameters defined in step (3).

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2.2. Method of Analysis

This section discusses the hybrid SEA modeling method and the acoustic characteristic prediction method of multi-layered porous materials.

2.2.1. Hybrid SEA modeling method

The hybrid SEA modeling method combines analytical and experimental SEA models for representing the energy flow among the SEA subsystems as accurately as that of an actual vehicle. The model is constructed by the following six steps:

- (1) Create the analytical SEA model
- (2) Define power input subsystems
- (3) Predict dominant power paths between the power input subsystems and the interior cavity subsystem and formulate network diagram of the each dominant power path
- (4) Measure the SEA parameters
- (5) Replace the measured SEA parameters with the analytical ones which are in the model created in step (1)
- (6) Carry out hybrid SEA process

2.2.2. Acoustic characteristic prediction method of multi-layered porous materials

In this development, three-layered noise insulating structure is applied, which contains base steel panel and two layers of felt (see Fig. 1). Applying this structure, it is possible to reduce in total noise insulating material weight since the mass layer is removed. Generally, that would cause acoustic insulation performance to decline. However, by employing high-porosity materials with excellent acoustic absorption characteristics, an overall enhancement in acoustic characteristics can be realized.

A relationship between an acoustic pressure p_i at interface 1 and 2 of the felt 1 and a particle velocity u_i can be expressed as follows:

$$\begin{Bmatrix} p_1 \\ u_1 \end{Bmatrix} = \begin{bmatrix} \cosh(\gamma_1 l_1) & (Z_1) \sinh(\gamma_1 l_1) \\ (1/Z_1) \sinh(\gamma_1 l_1) & \cosh(\gamma_1 l_1) \end{bmatrix} \begin{Bmatrix} p_2 \\ u_2 \end{Bmatrix} \quad (1)$$

In the same way, a relationship between an acoustic pressure p_i at interface 2 and 3 of the felt 2 and a particle velocity u_i can be expressed as follows:

$$\begin{Bmatrix} p_2 \\ u_2 \end{Bmatrix} = \begin{bmatrix} \cosh(\gamma_2 l_2) & (Z_2) \sinh(\gamma_2 l_2) \\ (1/Z_2) \sinh(\gamma_2 l_2) & \cosh(\gamma_2 l_2) \end{bmatrix} \begin{Bmatrix} p_3 \\ u_3 \end{Bmatrix} \quad (2)$$

A relationship between an acoustic pressure p_i at interface 3 and 4 of the base plate and a particle velocity u_i is:

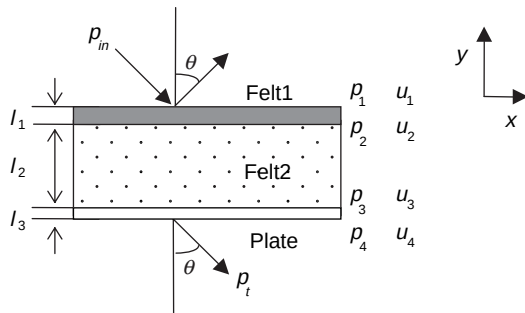


Fig. 1 Detail of three layers of a multilayered material

$$\begin{Bmatrix} p_3 \\ u_3 \end{Bmatrix} = \begin{bmatrix} 1 & Z(3) \\ 0 & 1 \end{bmatrix} \begin{Bmatrix} p_4 \\ u_4 \end{Bmatrix} \quad (3)$$

Equation (4) expresses a relationship between input acoustic pressure p_{in} and interface acoustic pressure p_i , and Eq. (5) shows a relationship between transmitted acoustic pressure p_t and interface acoustic pressure p_i :

$$p_{in} = p_i (Z(1) + \rho C_x) / 2 Z(1) \quad (4)$$

(ρ : Air density; C_x : Velocity of sound in air)

$$p_t = p_i \quad (5)$$

Where Z_i is an impedance of each layer, $Z_{(i)}$ is an acoustic impedance at the surface of each layer, γ_i is a transmission constant of the i th felt layer, and l_i is a thickness of the i th felt layer. Because the felt is fibrous material, the impedance is determined using an equivalent fluid model. An input sound pressure p_{in} and a transmitted sound pressure p_t from Eqs. (1)-(5) can be substituted in Eq. (6). Moreover, with solving Eqs. (7) and (8) a transmission loss is determined.

$$\tau_\theta = \frac{(p_t^2)}{(p_{in}^2)} = |T_r|^2 \quad (6)$$

$$\tau = 2 \int_0^{\theta_{lim}} d\theta |T_r|^2 \sin \theta \cos \theta \quad (7)$$

(θ_{lim} : limit value of angle)

$$TL = 10 \log_{10}(1/\tau) \quad (8)$$

Acoustic absorption is calculated using Eqs. (9)-(11).

$$R = \frac{Z(1) - Z_0}{Z(1) + Z_0} \quad (9)$$

$$\alpha_\theta = 1 - |R|^2 \quad (10)$$

$$\alpha = 2 \int_0^{\theta_{lim}} d\theta \sin \theta \cos \theta \alpha_\theta \quad (11)$$

3. Results of Analysis

3.1. Result of Contribution Analysis with the Hybrid SEA Model

For verifying the accuracy of the hybrid SEA model shown in Section 2.2., predicted and measured values of the interior noise are compared using the previous model CIVIC driving over a road noise evaluation course at 80 km/h. Figure 2 shows the results of this comparison. The difference between predicted and measured road noise is less than ± 3 dB. Therefore, it is safe to say that the hybrid SEA model is accurate enough.

Figure 3 shows the power contribution to the interior cavity from the contiguous subsystems, which is obtained from the hybrid SEA model. According to this graph, sound transmission from the floor including the tunnel and from the trunk have very high contribution to the interior cavity in the frequency range between 800 Hz and 2 kHz. Moreover, the sound leakage around the doors over 2 kHz is significant.

3.2. Selection of Important Parts for CLF

The result of the contribution analysis of Section 3.1. indicates the importance of the CLF of the floor carpet and tunnel, and the DLF of the trunk. Moreover, a countermeasure for sound leakage from the doors is necessary. In terms of the interior cavity soundproof package, the CLF of the floor carpet should be maintained at the same level as that of the previous model, while noise insulating materials are developed to reach the required interior cavity DLF for achieving the road noise target. This paper describes only the development of the interior cavity soundproof package. However, for achieving the overall target, other countermeasures are applied, which involve increasing the DLF of the trunk and enhancing the door seals.

3.3. Determination of Target Interior Cavity DLF to Enable Achievement of Road Noise Targets

Figure 4 shows the target DLF of the interior cavity and the DLF of the previous model. The target DLF of the interior cavity is set assuming that the road noise input power and the CLFs between the interior cavity and contiguous SEA subsystems remain at the same level as those of the previous model. Moreover, the effect from the other countermeasures to interior cavity is considered simultaneously.

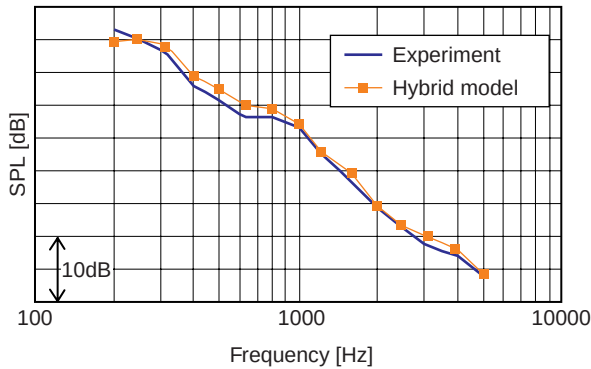


Fig. 2 Interior cavity sound pressure level (Road noise analysis)

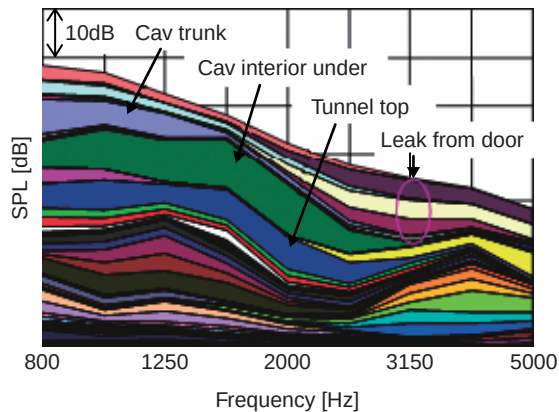


Fig. 3 Power contribution to interior cavity sound pressure level

3.4. Study of Lightweight Soundproof Package

This section will focus on the characteristics of the floor carpet, developed based on the three-layered noise insulating structure shown in Fig. 1 as part of the target to achieve the interior cavity DLF.

3.4.1. Floor carpet DLF and CLF

For achieving the DLF target of the interior cavity, the target absorption coefficients of each sound absorber (α) are reverse-calculated from the sound absorber surface area ratio to the whole interior cavity surface area. According to this result, the target absorption coefficient of the floor carpet is aimed at approximately three times more than that of the previous model over 1 kHz frequency range. However, the target transmission loss of the floor carpet is set at the same level as that of the previous model, since the CLF of the floor carpet had to be maintained. The prediction method for the acoustic characteristics of the multi-layered porous materials (Section 2.2.2.) is applied for determining the following design parameters: Thickness of the porous material, characteristics of the material and most importantly the air flow resistance. This analysis is also done with consideration of the soundproof insulator layout, which is fixed mostly at the early stages of the vehicle development. As a result, the absorption coefficient satisfied the target (see Figs. 5 and 6). Meanwhile, the mass layer elimination causes a 1-2 dB decline in the transmission loss compared to the previous model.

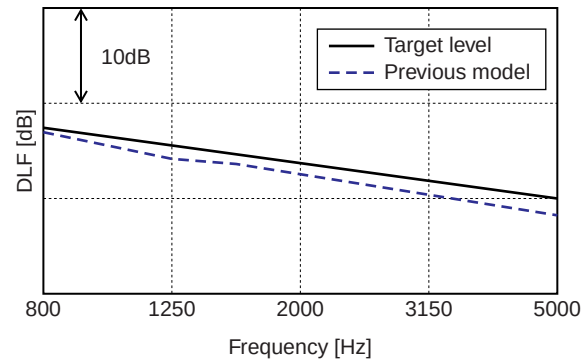


Fig. 4 Target for interior cavity DLF

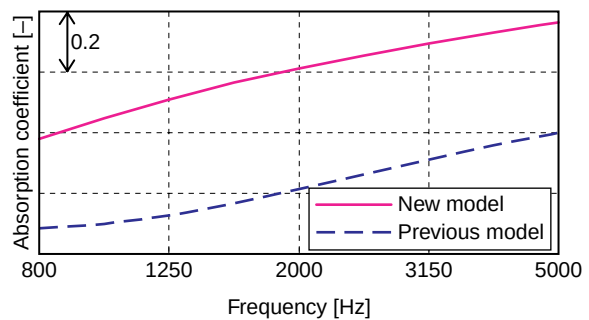


Fig. 5 Comparison of floor carpet absorption between previous and new models

3.4.2. Total acoustic characteristics of floor carpet

For determining how to recover the CLF decline by enhancing the interior cavity DLF, a simple SEA model with three subsystems (interior cavity, floor carpet and under-car cavity) was created (see Fig. 7). Figure 8 shows the difference of the interior cavity sound pressure level between the previous and new models' floor carpet designs. All other parameters are kept the same.

It is clear that the newly developed floor carpet is superior in the overall acoustic characteristic to the previous one.

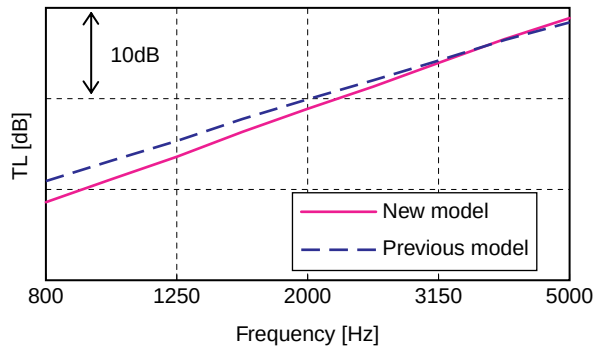


Fig. 6 Comparison of floor carpet transmission loss between previous and new models

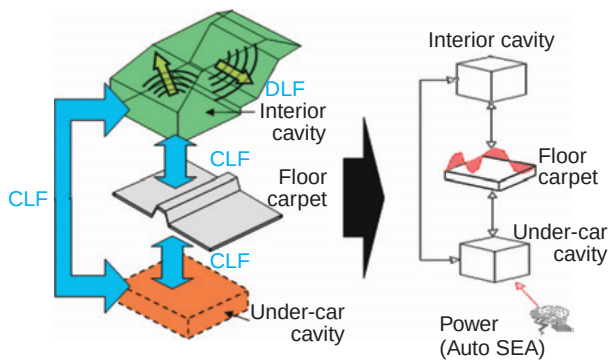


Fig. 7 SEA model (Three subsystems)

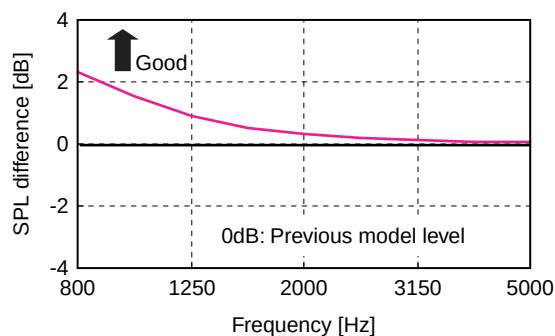


Fig. 8 Effect of new model floor carpet compared to previous model

4. Performance in a Vehicle

In this section, the performance of the vehicle with the newly developed soundproof package is discussed.

4.1. SEA Parameters (CLF and DLF)

The measurements verify that the new interior soundproof package is able to make the SEA parameters achieve the targets. Figure 9 compares the target DLF, which is shown in Fig. 5, with the measured DLF, and it is clear that the measured DLF has achieved the target. Figure 10 shows the floor to interior cavity CLF in the previous model versus the new model. This also indicates the achievement of the CLF target, which means the same level as the previous model was maintained.

4.2. Road Noise Level

Figure 11 shows the comparison for the interior road noise levels between the previous model, the new model with only the new interior soundproof package, and the new model with all noise countermeasures-enhanced door seals and an absorptive trunk package. The test condition is 80 km/h driving on a road noise evaluation course.

The newly developed interior cavity soundproof package reduces the sound pressure level in the high frequency range by approximately 2 dB as compared to the previous model. By applying all noise countermeasures, the reduction of approximately 2-4 dB is accomplished, and the primary target of this project is satisfied. In addition, the total weight of soundproof package has been reduced by more than 30% as compared to the previous model (Fig. 12).

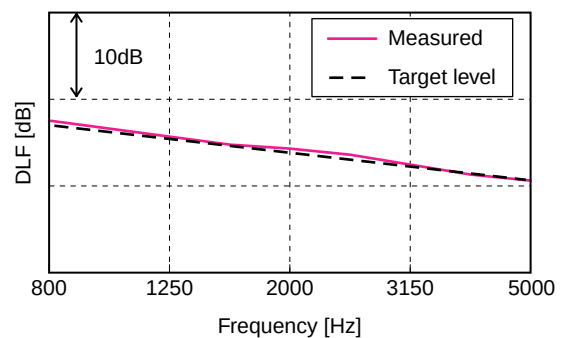


Fig. 9 Comparison of target and measured interior cavity DLF

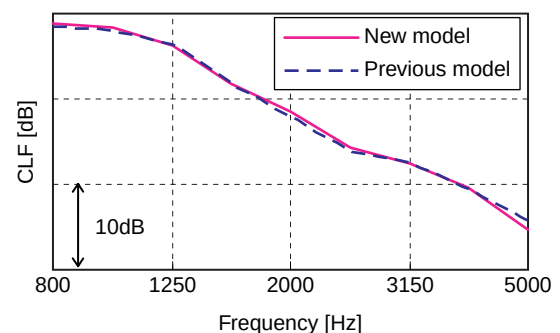


Fig. 10 Comparison of floor to cabin CLF between previous and new models

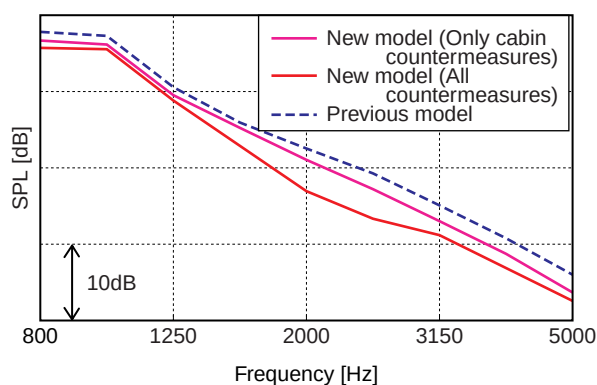


Fig. 11 Interior cavity sound pressure level at 80km/h on rough road

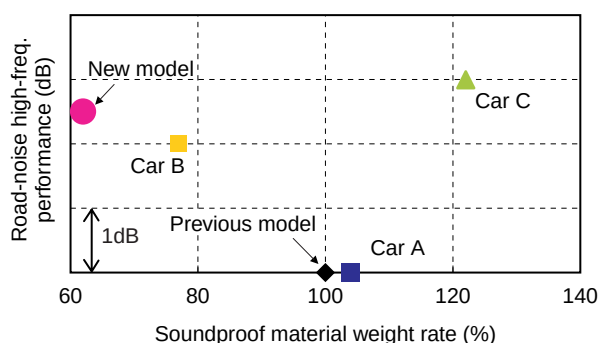


Fig. 12 Hierarchy map (weight rate / road-noise performance)

5. Conclusion

A predominantly sound-absorbing lightweight soundproof package has been developed using the hybrid SEA modeling method and the method of predicting the acoustic characteristics of multi-layered porous materials for the early stages of the development.

- (1) The validity of the hybrid SEA modeling method and the acoustic characteristic prediction technology of the multi-layered porous materials was confirmed.
- (2) A vehicle cabin noise prevention package, including specifications for a floor carpet that achieved total noise characteristics through noise absorption and noise insulation was developed.
- (3) As a result, the target of a 2 dB reduction in the road noise level in the high-frequency range was achieved, and the weight of the soundproof package was reduced by more than 30%.
- (4) These accomplishments enable the new 2006 CIVIC to achieve high performance in weight management and high frequency quietness.

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