

Enhancement of Effective Mass and Transmission Loss by Low-Stiffness Region Control in Double-Felt Structures

Kanta Kasama¹⁾ **Ryoji Morisaki**¹⁾ **Shinichiro Iwai**¹⁾

¹⁾ HIROTANI Co., Ltd.

1153-10 Shiwahori, Shiwa-cho, Higashihiroshima, Japan

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A double-felt structure, consisting of two felt layers separated by a film, is widely used in dash silencers to provide both sound absorption and sound insulation. In general, the sound absorption coefficient (α) is strongly influenced by the thickness of the cabin-side felt and by the resonance characteristics of the film, whereas transmission loss (TL) is primarily governed by the mass of the constituent materials. Therefore, increasing the mass of the cabin-side felt, the film, or both is generally considered effective for improving TL. However, in conventional double-felt structures, the measured TL is only approximately 30% of the value expected from the combined mass of the cabin-side felt and the film. This finding suggests that some mechanism inhibits the effective mass contribution of the constituent materials. To clarify this mechanism and identify potential countermeasures, a spring-mass model was used in the present study.

To investigate the mass efficiency of the double-felt structure, it was considered that a single-degree-of-freedom spring-mass model, where the cabin-side felt and the film are represented as a single lumped mass, is insufficient to adequately describe the observed physical phenomena. In this study, we focused on the fine fiber fuzz present at the interface between the cabin-side felt and the film. Because this fuzz has an extremely low spring constant, it was hypothesized that it prevents the cabin-side felt mass from sufficiently following the sound-pressure-induced vibration of the film, thereby degrading mass efficiency. This fuzz layer was defined as a “low-stiffness region” and to investigate the aforementioned mechanism, the double-felt structure was modeled as a two-degree-of-freedom spring-mass model (Fig. 1). The inertance of the film, defined as its acceleration response to an applied excitation force, can be expressed as follows:

$$\frac{\ddot{x}_2}{F} = -\omega^2 \frac{(k_2 - m_1\omega^2)}{(k_2 - m_1\omega^2)(k_1 + k_2 - m_2\omega^2) - k_2^2}$$

When $k_2 = 0$, only the film contributes to the acceleration response. In contrast, when $k_2 = \infty$, the mass of the cabin-side felt, together with that of the film, contributes to the response. These results indicate that removing the low-stiffness region can effectively improve the mass contribution of the cabin-side felt.

To verify this hypothesis, a flat sample was fabricated by applying a smoothing treatment to the film-side interface of the cabin-side felt to remove the fiber fuzz. Load-displacement measurements confirmed that removing the low-stiffness region improved the load response.

TL measurements confirmed that removing the low-stiffness region improved mass efficiency from 30% to 70% (Fig. 2). Because the smoothing treatment was applied only to the felt surface, the felt thickness was maintained. As a result, improving TL without degrading α was made possible. The effectiveness of the proposed approach was also confirmed by vehicle testing.

This study identified the low-stiffness region formed by fine fiber fuzz at the interface between the cabin-side felt and the film as a key factor reducing TL in double-felt structures. Removing this region increased mass efficiency from 30% to 70%, thereby improving TL while maintaining α .

These results demonstrate that controlling the low-stiffness region is an effective strategy for improving TL in double-felt structures.

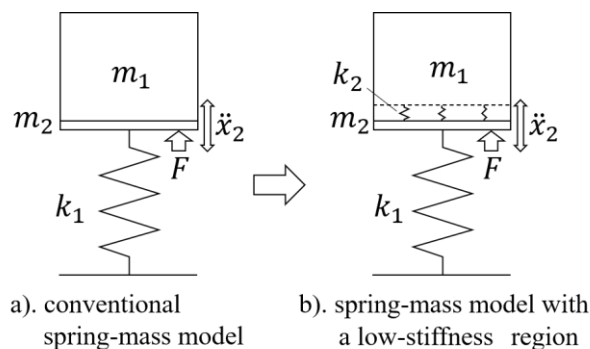


Fig. 1 Conceptual spring-mass models

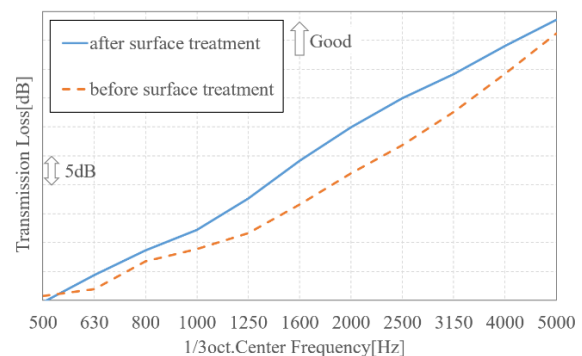


Fig. 2 Effect of low-stiffness region removal on transmission loss