

Optimization of an FCEV Air Exhaust System for Flow-Induced Noise Reduction and Cost Efficiency

-Resonator-Based Structural Improvement of the Air Exhaust Silencer-

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Fuel cell electric vehicles (FCEVs) show NVH characteristics different from those of conventional internal combustion engine vehicles because combustion noise is absent and flow-induced noise becomes relatively dominant. In the production air exhaust system of the NEXO FCEV, vehicle evaluation identified discharge noise in the 1-3 kHz band as the main NVH issue, while radiated noise was dominant in the 4-8 kHz range. In particular, the 1-3 kHz discharge noise was considered closely related to cabin-perceived noise under high flow-rate operating conditions.

To investigate the cause of this problem, the air exhaust system and the upstream APC (Air Pressure Control) valve were analyzed. The APC valve includes a flap-type geometry and abrupt flow-direction change, which can induce flow separation and turbulence. These flow characteristics were found to be strongly related to the generation of discharge noise. In addition, analysis of the production silencer revealed that the existing porous sound-absorbing tube provided only limited improvement in tailpipe-end discharge noise, despite its relatively high cost. Another structural limitation was that some discharge noise was transmitted through the drain-tube path without effectively passing through the sound-absorbing region. Therefore, the current structure was judged to be inefficient in terms of both acoustic performance and cost effectiveness.

Based on these findings, a structural optimization concept was developed by relocating the noise reduction zone to the front side of the silencer and moving the gas-liquid separation zone to the rear. This arrangement was intended to make a larger portion of the discharge noise pass through the effective acoustic treatment region, including the drain-path-related noise. To replace the costly absorptive parts, a Helmholtz resonator-based concept was introduced because the dominant target band was concentrated in the 1-3 kHz range. Two improved concepts were proposed. Improved Design 1 employed four resonator chambers tuned to approximately 990 Hz, 2249 Hz, 2513 Hz, and 3005 Hz, whereas Improved Design 2 employed two resonator chambers and one absorptive chamber.

The acoustic performance of the production specification and the two improved concepts was evaluated using transmission loss analysis. Both improved designs showed better transmission loss than the production specification in the 270-2700 Hz range. Among them, Improved Design 1 showed the best overall performance. In band-wise RMS comparison, it achieved improvements of 16.6 dB in the 30-1000 Hz band, 10.9 dB in the 1-2 kHz band, and 3.9 dB in the 2-3 kHz band, compared with the production specification. Improved Design 2 also showed improvement, but its performance was lower than that of Improved Design 1 due to its relatively simplified structure.

The functional performance of the optimized structure was also verified through gas-liquid separation evaluation. The water drainage ratio through the drain tube was about 87% for the production specification and about 90% for Improved Design 1, indicating that the optimized design maintained or slightly improved the required separation performance. As a result, Improved Design 1 was selected as the final optimized structure. This study confirms that a resonator-based air exhaust system can effectively reduce flow-induced discharge noise in FCEVs while improving cost competitiveness by reducing dependence on expensive sound-absorbing components.

In addition, the proposed structure reduces the use of expensive sound-absorbing components and simplifies the internal configuration. Although the quantitative cost data cannot be disclosed for confidentiality reasons, the optimized design was confirmed to provide a substantial cost reduction compared with the production specification.

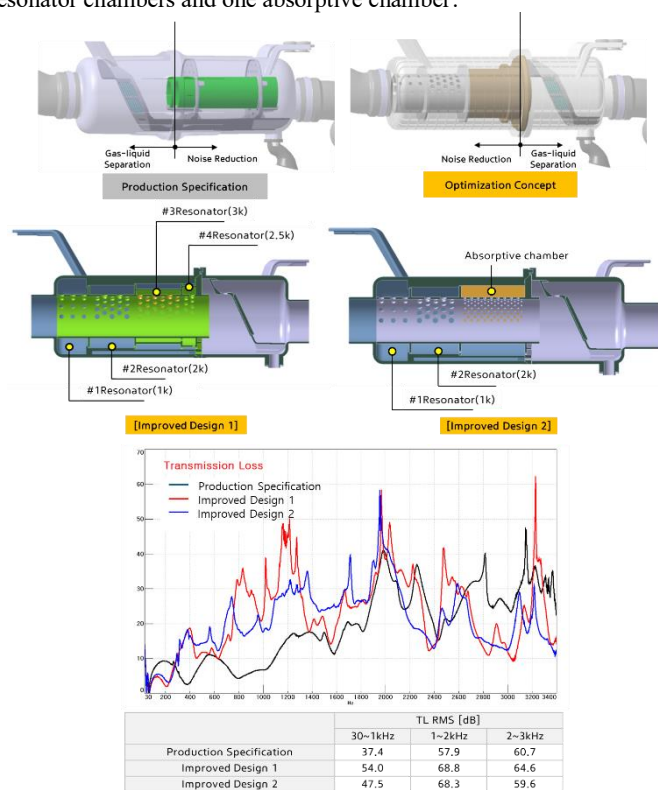


Fig.1 Comparison of transmission loss performance between the production specification and improved designs.