

Finite Element Simulation Analysis and Verification of Broadband Silencers

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Abstract—Silencers have widespread applications. In industrial settings they are used at large-scale combustion, gas turbine, blower and compressor system junction points to control noise. The most common methods of noise elimination via silencer are varying of the size and cross-sectional area of the transmission pipe such that during sound wave transmission, non-uniform impedance is produced. Partial sound wave reflection is an echo source or consumes the energy of transmitted sound waves to achieve noise elimination. In this study, COMSOL Multiphysics, commercial finite element analysis and simulation software, was the main analytical tool. The aim of this study was to investigate the effects of variations in silencer structure on acoustic attenuation. Based on finite element method simulation, the optimal silencer geometry for noise cancellation was determined.

Keywords—silencer; transmission loss; finite element simulation

I. INTRODUCTION

In 2002, Selamat et al.¹ applied 2D symmetry similar with method simulation of double expanded chamber silencer to study transmission loss. In addition, through structural changes, they observed the variations in transmission loss. In 2015, Fang et al.² studied multiple types of expanded chamber silencers with multiple openings, tapered pipes, extended pipe necks and sound-absorbing cotton to discuss acoustic attenuation. In addition, they applied 3D finite element methods, coupling methods and actual measurements and observations. In 2018, Xue et al.³ used silencer with U-shaped structure series connections to study the effects on noise elimination characteristics. They also used finite element methods to carry out simulations and establish a testing system for comparisons. In this study, COMSOL Multiphysics, commercial finite element analysis and simulation software, was the main analytical tool. First, based on the silencer structure proposed by Xue et al. in 2018, we used COMSOL to carry out finite element method simulation and verification. Second, we used a simplified model to analyze the effects of geometric structure on silencer acoustic attenuation properties.

II. THEORETICAL VERIFICATION BY FEM

Xue and Sun proposed a formula for calculating noise cancellation bandwidth for U-shaped wave silencers. With this formula, it is possible to approximate the noise cancellation bandwidth of a silencer. The variables used in this formula are geometric variables. Figure 1 is the geometric diagram and the formula is given below:

$$f_L = \frac{0.103C_0}{h_c^{0.71} d_m^{-0.13} l_c^{0.38} w_s^{0.04}} \quad (1)$$

$$f_U = \frac{0.331C_0}{h_c^{0.4} d_m^{0.46} l_c^{0.12} w_s^{0.02}} \quad (2)$$

$$\text{bandwidth} = f_U - f_L \quad (3)$$

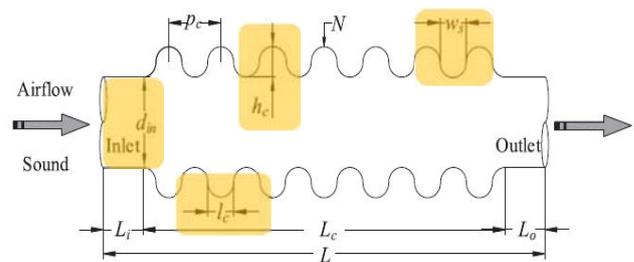


FIGURE I. GEOMETRIC DIAGRAM

In this study, transmission loss was used to assess the main silencer parameters, such that the outlet lacked reverberation and there was discrepancy between the inlet reverberation level and outlet transmitted reverberation. The formula is as follows:

$$TL = L_{W_{in}} - L_{W_{out}} = 10 \cdot \text{Log}_{10} \left(\frac{W_{in}}{W_{out}} \right) \quad (4)$$

While carrying out simulation using finite element analysis simulation software, the coarseness or fineness of mesh was used to determine the efficiency and accuracy of the simulation model. Therefore, before formal simulation, it was necessary to consider the results of mesh refinement analysis. Next, we used a simple U-shaped wave silencer to observe the maximum mesh Dmain/N (Dmain refers to inlet pipe diameter). Under single frequency convergence, the results are shown in Figure 2. Larger N values represented finer mesh. Results neared stability at N>10. Therefore, sound field maximum mesh size was set at Dmain/10.

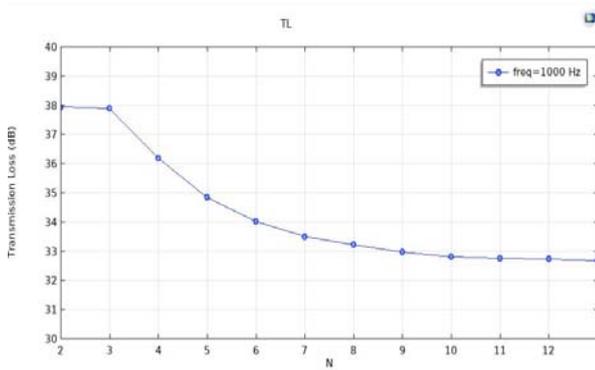


FIGURE II. MESH CONVERGENCE ANALYSIS

Before simulation, the geometry of the silencer was based on the target bandwidth of 1000Hz-2000Hz and the above formula to obtain the geometric parameters $h_c=25$ mm $l_c=16$ mm $d_{in}=90$ mm $w_s=8$ mm. Upper and lower bandwidth frequencies were $f_U=2177$ Hz and $f_L=904$ Hz, respectively.

During sound field simulation, settings within the pipe were air, temperature, and pressure 1 atm. Figure 3 is the geometric diagram and Figure 4 shows the results of acoustic attenuation.

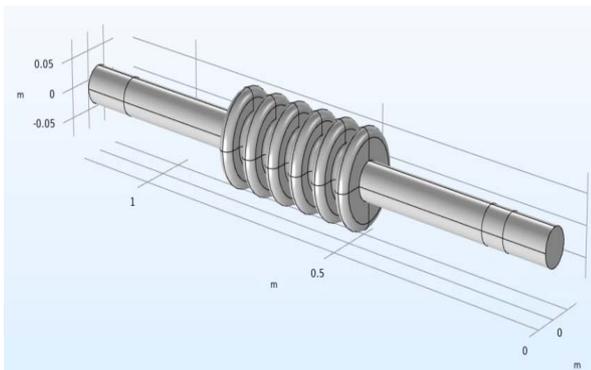


FIGURE III. GEOMETRIC DIAGRAM

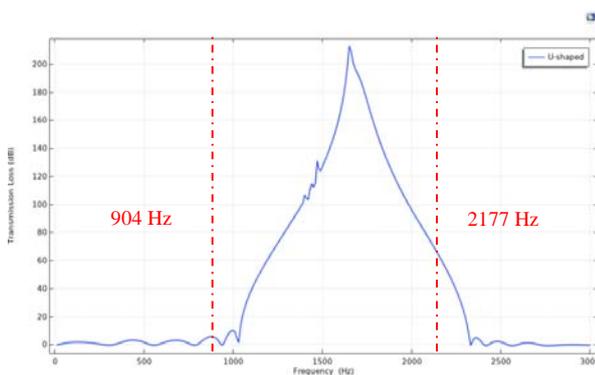


FIGURE IV. SILENCER TRANSMISSION LOSS SIMULATION RESULTS

There was a deviation of approximately 200Hz with shift toward lower frequency between the theoretically estimated silencer bandwidth and that obtained on simulation. Moreover, simulation results revealed outstanding noise elimination

properties of U-shaped wave silencer. At 1200Hz-2200Hz there was noise elimination at 60 dB and above.

A. Comparisons of Squared and U-shaped Wave Silencers

When the rounded edges of wave-shaped silencer were replaced with right angles (red curved lines in Figure 5), the overall noise elimination frequency showed a deviation of approximately 200 Hz toward lower frequency. Moreover, the peak value of noise elimination was elevated 15 dB. Simulation results are shown in Figure 6.

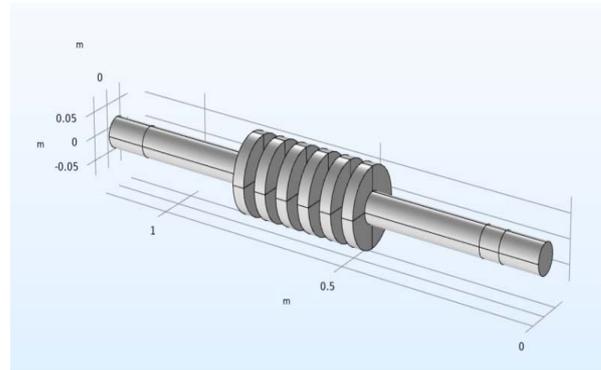


FIGURE V. GEOMETRIC DIAGRAM

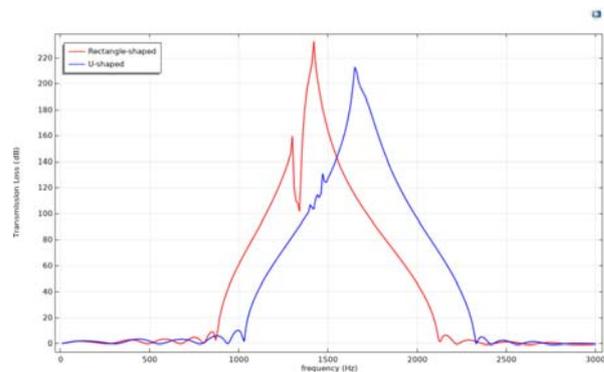


FIGURE VI. TRANSMISSION LOSS SIMULATION COMPARISONS

B. Effects of Wave Structure Number (N) on Sound Elimination

Simulation results also revealed that U-shaped wave silencer has excellent acoustic attenuation properties and that it is possible to calculate approximate noise elimination bandwidth. Next, we analyzed the results of increased or decreased U-shaped structure number (N) to understand noise elimination efficiency in a limited space. The results are shown in Figure 7. Larger N value represented elevated noise elimination properties for the overall noise elimination bandwidth. Moreover, the maximum and minimum frequencies did not follow the variations in N.

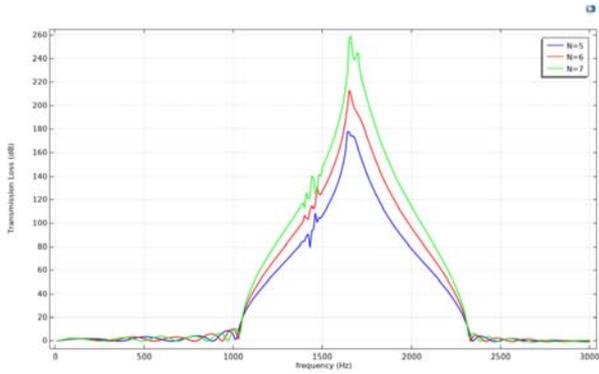


FIGURE VII. EFFECTS OF STRUCTURE NUMBER N ON TRANSMISSION LOSS

III. GEOMETRIC PARAMETER ANALYSIS

The structure of a single U-shaped silencer simplified from a U-shaped wave silencer is shown in Figure 8. Based on depth of H:U structure and angular diameter of W:U, we carried out geometric analysis.

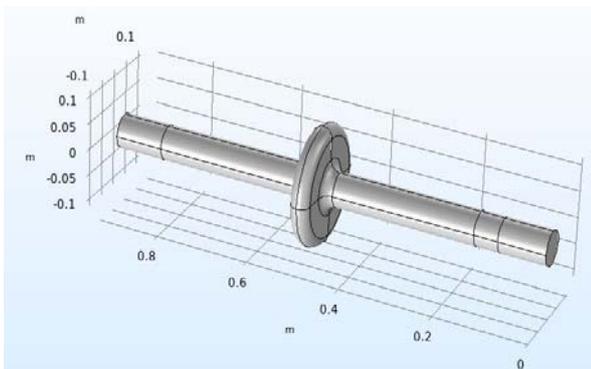
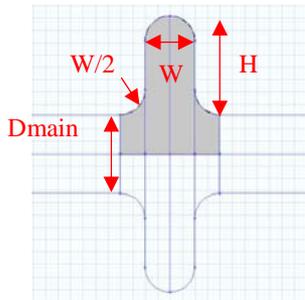


FIGURE VIII. GEOMETRIC DIAGRAM

We first explored the condition of fixed H (depth of U-shaped structure) to test the effects of W (angular diameter of U-shaped structure) =20mm, 40mm or 60mm on acoustic attenuation. The results are shown in Figure 9, Figure 10 and Figure 11.

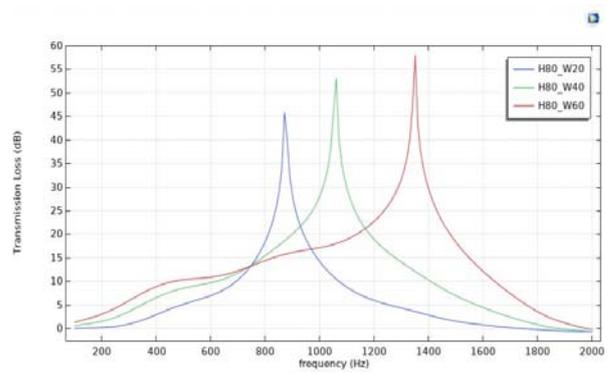


FIGURE IX. H=80, W=20, 40, 60(MM)

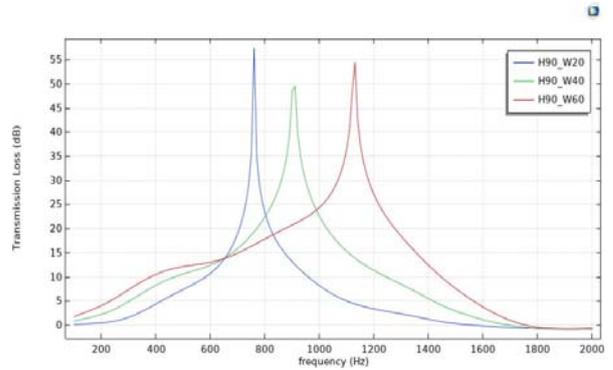


FIGURE X. H=90, W=20, 40, 60(MM)

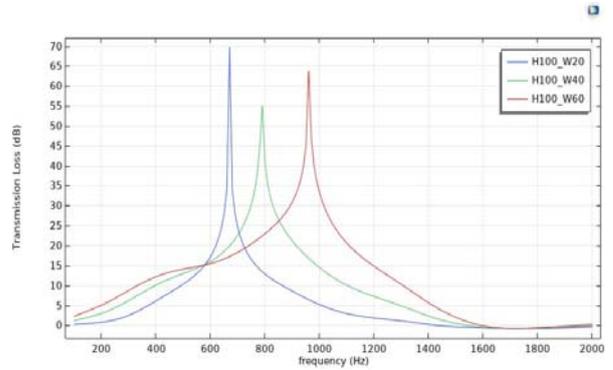


FIGURE XI. H=100, W=20, 40, 60(MM)

From the results, when H does not change and W increases, the noise elimination peak value shifts toward higher frequency and the noise elimination bandwidth increases. Moreover, the degree of shift toward higher frequency decreases with increasing H.

From the results of the second geometric analyses, when W was fixed, the effects of H=80mm, 90mm or 100mm on noise elimination properties were observed. The results are shown in Figure 12, Figure 13 and Figure 14.

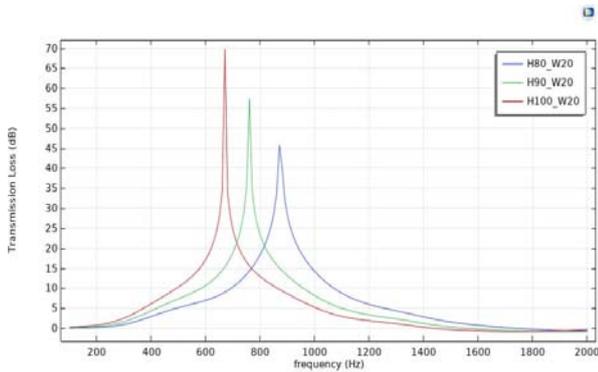


FIGURE XII. W=20, H=80, 90, 100(MM)

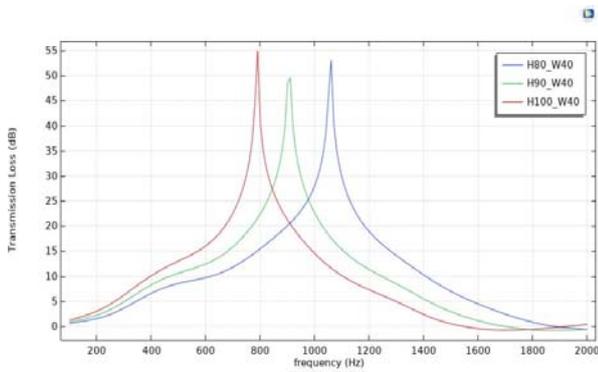


FIGURE XIII. W=40, H=80, 90, 100(MM)

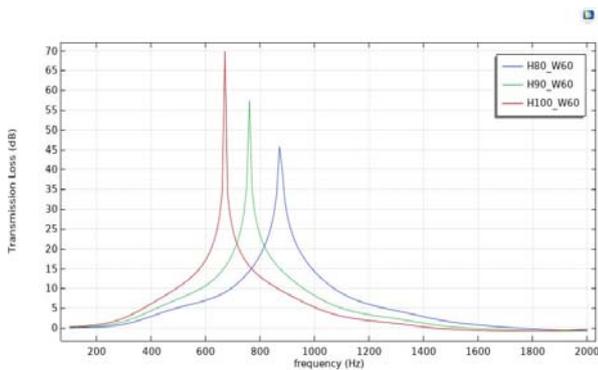


FIGURE XIV. W=60, H=80, 90, 100(MM)

From these results, when W was fixed and H increased, the noise elimination peak value shifted toward lower frequency. Noise elimination peak value increased with increasing H.

IV. CONCLUSION

Silencers possess widespread industrial applications. Previous studies have suggested using periodic structural connections to achieve better acoustic attenuation. In this paper, COMSOL Multiphysics, commercial finite element analysis and simulation software, was used to test U-shaped wave silencers and theoretical values. Moreover, through simple structural variations, noise elimination bandwidth shifts were observed with a focus on noise elimination frequency range for more efficient noise elimination. Finally, combinations of geometric parameters H and W were used with specified noise elimination

frequency ranges to achieve efficient noise elimination. U-shaped expanded silencer revealed narrow frequency range and high degree of noise elimination. Through COMSOL Multiphysics simulation, it is possible to reduce the time and cost required for research, development and testing. Finally, we would like to thank Fusheng Co., Ltd. for providing valuable guidance and technical assistance.

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