STUDY ON ACOUSTIC ATTENUATION PERFORMANCE OF PERFORATED BRANCH TUBE SILENCER ATTACHED WITH THIN FIBER LAYER

Zhongxu Kang

Beijing Municipal Institute of Labour Protection, Beijing, CHINA
email: zhongxukang@163.com.cn

Ruixiang Song, Lijuan Zhang, Rui Wu, Qiang Liu

Beijing Municipal Institute of Labour Protection, Beijing, CHINA,

The side-branched tube is widely used in noise control engineering, and increasing the number of tubes can improve the performance of sound absorption. In this paper, the transmission loss calculation model is built for multi-side-branched tube by using transfer matrix method. The calculation results show that, with the increasing of the number of side-branched tube the sound absorption performance is getting better, but the pass-by frequency on which the transmission loss is 0dB appears. For solving the problem of pass-by frequency, the perforated panel is added between the side and main tubes. In order to enhance the resistance effect, the thin fiber layer is attached on the perforated panel. Using the theoretical model, the transmission loss of side-branch tube with perforated panel and thin fiber layer is calculated. The results show that the peak value of transmission loss curve decreases, but the value on the pass-by frequency increases and the curve is getting smooth. The study shows that the problem of pass-by frequency is solved by perforated panel attached with thin fiber layer.

Keywords: branched tube, perforated panel, thin fiber layer, pass-by frequency

1. Introduction

Side-branch tube is the simplest reactive silencing structure widely used in practice[1, 2]. Generally, side-branched tube is only suit for narrow frequency band. Most of studies before are focus on the optimization of side-branch tube structure [3-6], which can wide the frequency band of sound absorption and enhance the transmission loss. Theoretical, analytical and numerical methods are all used to predict the resonance frequency and transmission loss of kinds of side branch structures more and more accuracy.

Complex structures designed in some studies could improve the sound attenuation performance, but it is difficult to be applied in practice [4, 6]. More important, the prediction and test results show that, when multiple reactive structures are used together, the transmission loss of some frequency would be getting lower, though results for some other frequency increases significantly. Even the lowest value could be close to 0 on frequency which is called pass-by frequency, meaning no sound attenuation performance exiting. Because of the existence of pass-by frequency, the application of resonance absorption structures is limited in practice.

According to the problem, the theoretical model is established using the plane wave propagation theory and transfer matrix method to calculate the transmission loss of multiple side-branch tubes. The model is used to analyse the pass-by frequency of multiple side-branch tubes with perforated panel installed between the branch and main tubes. The thin fiber layer is attached on the perforated panel to increase the resistance and improve the sound absorption capability. And the perforated acoustic impendence is applied in the model for the prediction of transmission loss.

2. Model

The structures of simple and multiple side-branched tubes are shown in Fig. 1.

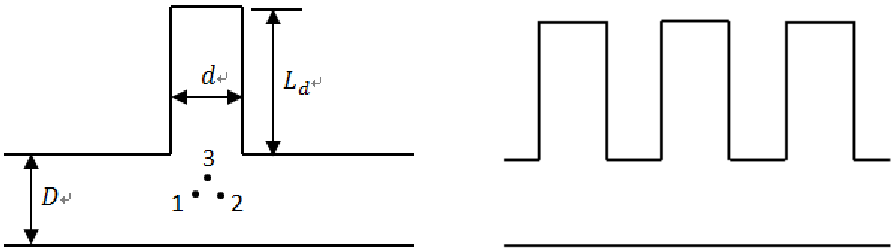

Figure 1: Structure of Side-branch tubes

For side-branched tube, whose first resonant frequency is far lower than the cut-off frequency in the pipeline, the analysis can be limited in the frequency range of one-dimensional plane wave theory. Based on the transfer matrix theory [1], the relationship between the inlet and outlet of the pipeline is shown as

$$\begin{Bmatrix} p_i \\ \rho_0 c_0 u_i \end{Bmatrix} = \begin{bmatrix} \cos(k_0 L) & j\sin(k_0 L) \\ j\sin(k_0 L) & \cos(k_0 L) \end{bmatrix} \begin{Bmatrix} p_o \\ \rho_0 c_0 u_o \end{Bmatrix}. \tag{1}$$

in which, ρ_0 is the air density, c_0 is the sound speed propagating in air, $k_0 = 2\pi f / c_0$ is the wave number, L is the length of pipeline.

For structure shown in Fig. 1, one end of the branch tube is closed and the other end is connected to the main pipe, so the acoustic impedance ratio of point 3 is

$$\frac{p_3}{\rho_0 c_0 u_3} = -j\cot(k_0 L_b). \tag{2}$$

Thus, the transfer matrix between the point 1and 2 is

$$\begin{Bmatrix} p_1 \\ \rho_0 c_0 u_1 \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ j\dfrac{S_3}{S_1}\tan(k_0 L_b) & 1 \end{bmatrix} \begin{Bmatrix} p_2 \\ \rho_0 c_0 u_2 \end{Bmatrix}. \tag{3}$$

And the relation expression between inlet and outlet of side-branched tube is

$$\begin{Bmatrix} p_i \\ \rho_0 c_0 u_i \end{Bmatrix} = [T_1] \begin{bmatrix} 1 & 0 \\ j\dfrac{S_3}{S_1}\tan(k_0 L_b) & 1 \end{bmatrix} [T_2] \begin{Bmatrix} p_o \\ \rho_0 c_0 u_o \end{Bmatrix} = [T] \begin{Bmatrix} p_o \\ \rho_0 c_0 u_o \end{Bmatrix}. \tag{4}$$

in which, $[T_1]$ and $[T_2]$ are transfer matrixes of uniform pipe before and behind the side-branched tube, respectively.

For multiple side-branched tubes, the whole transfer matrix is obtained by multiplying several straight pipe and side-branched tube transfer matrixes by order. And the final transmission loss of the structure is calculated by

$$TL = 20\log\left|\frac{T_{11} + T_{12} + T_{21} + T_{22}}{2}\right|. \tag{5}$$

The derivation of the formula above is based on the one-dimensional plane wave theory. Generally, the diameter of the main pipe and side branches is small, so the cut-off frequency is very high. Most of the internal acoustic waves are transmitted in the form of plane wave, but in the zone of the interface of side-branched tube and main pipe, the plane wave theory will be error due to the abrupt change of structure. In order to reduce the deviation, the influence of the three-dimensional wave is taken into account with the method of modifying the length of branch tube, and the correction formula is shown as [7]

$$L_b' = L_b + \delta. \tag{6}$$

$$\delta / r = \begin{cases} 0.8216 - 0.0644\varphi - 0.694\varphi^2, \varphi \le 0.4 \\ 0.9326 - 0.6196\varphi, \varphi > 0.4 \end{cases}. \tag{7}$$

in which, $r = d / 2$, $\varphi = d / D$.

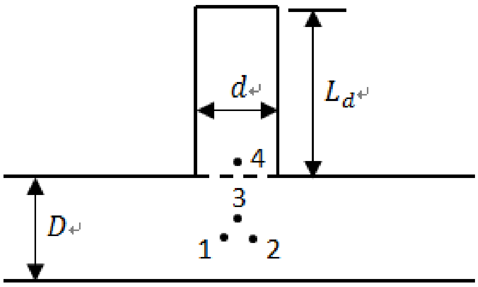

Figure 2: Structure of Side-branch tube with perforated panel

When the perforated panel is installed at the interface between the branch tube and main pipe the acoustic impedance ratio of point 3 is replaced by the impedance ratio sum of the perforated panel and point 4 which is shown as Eq.2.

$$\frac{p_3}{\rho_0 c_0 u_3} = \zeta_p - j\cot(k_0 L_b). \tag{8}$$

where, ζ_p is the acoustic impedance ratio of perforated panel, which consists of resistant and reactive components.

$$\zeta_p = \frac{(R_h + r) + jk_0(t_w + \alpha d_h + \gamma)}{\phi}. \tag{9}$$

in which, R_h is the acoustic resistance of perforated panel, t_w is the perforation thickness, d_h is the perforation diameter, α is the acoustic correction parameter of perforation thickness, ϕ is the perforation porosity, r is the resistance correction parameter and γ the reactive correction parameter t caused by thin fiber layer attached on the perforated panel.

From the experimental results in reference [8], when the perforated panel is attached with thin fiber layer commonly used in practice, the resistant and reactive correction parameters are 0.02 and 0, respectively.

3. Calculation results

3.1 Effect of branch tube number

The transmission loss of side-branched tube structure is calculated with the theoretical model above. The geometry parameters are: D =0.1m, d =0.1m, L =0.15m. For multiple side-branched tubes, the distance between branch tubes is 0.05m and the branch tube diameters and lengths are the same.

The transmission loss calculated with the above model of silencing structures with one, two and three side branched tubes are shown in Fig. 3. The results are only focus on frequency range near the first resonant frequency. The results show that the silencing structure with one side branch has a good attenuation performance in the range of 350-650 Hz. The transmission loss curve on both sides of resonance frequency 514Hz is basically symmetrical, and the peak appears on the resonance frequency. When the frequency is being far from the resonance frequency, the transmission loss is decreasing.

The resonant frequency of the structure with two side branched tube is not changed, but the transmission loss on the resonant frequency and the frequency after that increase significantly. But, for frequency before the resonance, 400-470Hz, the transmission loss decreases, and even close to 0dB near 440Hz. The effective frequency range becomes 470-750Hz. That is, the effective frequency range before the resonance is reduced while the range after the resonance is expanded.

Similar to the case with two side branches, the resonant frequency of the structure with three side branches remains unchanged. The transmission loss is further improved for frequency range 470-800Hz. The transmission loss is getting lower for range 350-470Hz and close to 0dB for frequencies near 380Hz and 460Hz.

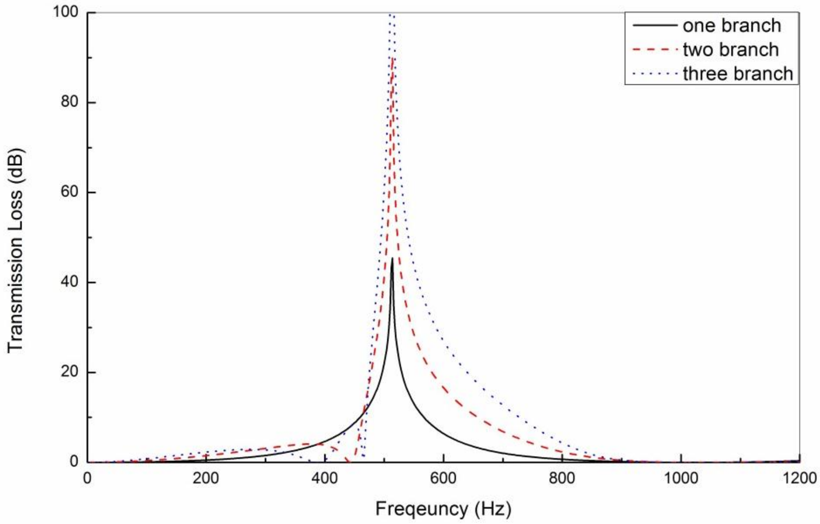

Figure 3: Transmission loss results of side-branch tube structure

Based on the analysis above, the resonant frequency of the structures are keeping unchanged, the transmission loss on resonance frequency is significantly improved with the increase of branch tube number, and the sound attenuation frequency range after resonance frequency is significantly increased. But, the attenuation frequency range before resonance frequency is reduced, and the transmission loss for some frequencies are significantly getting down, even close to 0.

3.2 Effect of perforated panel and thin fiber layer

The common side-branched tube structure is improved by installing perforated panel at the interface between the side branch and main pipe, and the thin fiber layer is attached on the perforated panel, as shown in Fig. 2. The perforation porosity of perforated plate is 25 %, the perforation thickness is 0.65 mm, the perforation diameter is 1.5 mm, and the thickness of thin fiber layer is 0.2 mm.

The calculated transmission loss of side-branched tube with perforated panel and thin fiber layer is shown in Fig. 4. The results show that the whole transmission loss curve shifts to the low frequency direction because of the perforated panel and thin fiber layer. And the transmission loss peak value is reduced. The change above is due to the resistant and reactive effect of the perforated panel and thin fiber layer. But, the attenuation frequency width is not changed obviously.

For the results of the structures with two and three side branches, as shown in Fig. 5 and Fig. 6, the transmission loss curves have valleys for frequency range before resonance, and pass-by frequencys appear. After setting the perforated panel and attached thin fiber layer, the transmission loss curves also move to low frequency, and the peak values are reduced. The transmission loss for frequency range before resonance is obviously improved, and the transmission loss on pass-by frequency is obviously improved. By using the perforated panel with attached thin fiber layer, the problem of pass-by frequency is basically solved, the valleys of transmission loss curve is brought up. The curves are getting smoother and the effective attenuation frequency band is getting wider.

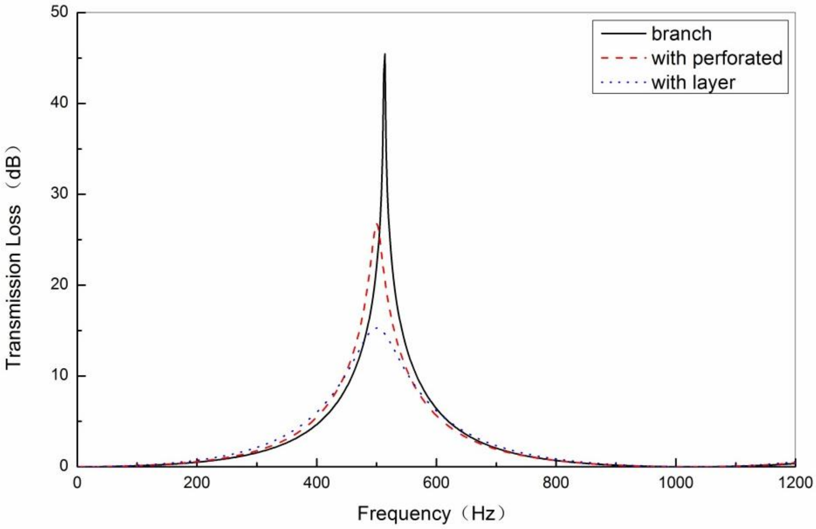

Figure 4: Transmission loss of structure with one side branch

Therefore, the resistive effect of the perforated panel and attached thin fiber layer can effectively improve the transmission loss of frequency range before resonance, and solve the problem of pass-by frequency caused by the combination of multiple side branches.

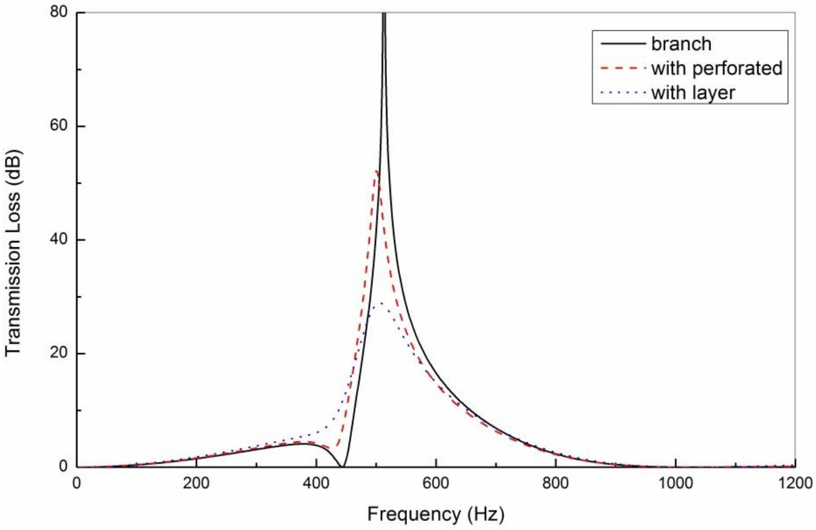

Figure 5: Transmission loss of structure with two side branches

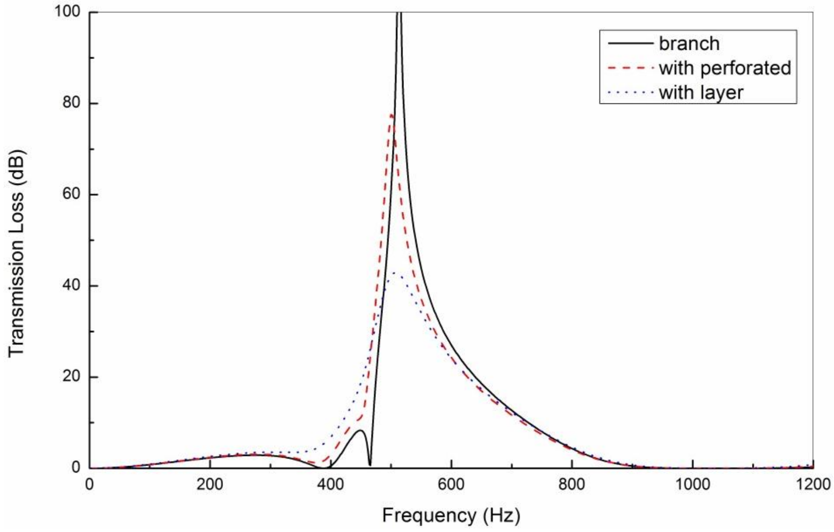

Figure 6: Transmission loss of structure with three side branches

4. Conclusion

The transmission loss calculation model for silencing structure with multiple side-branched tube is established using theoretical method. Transmission loss of structures with one, two, three side branches is calculated. The cases with perforated panel and thin fiber layer are also considered. It is found from the calculation results that, while combining multiple same side branches, the resonant frequencies keep the same, and the transmission loss on and after the resonance frequency increases significantly. The noise elimination frequency range is enlarged, but the transmission loss of frequency range before the resonance is reduced, even close to 0dB. After installing the perforated panel and attached the thin fiber layer at the intersection of the side branch and main pipe, the transmission loss for frequency range before resonance increases significantly. The problem of pass-by frequency caused by the combination of multiple side branches is solved and the sound attenuation frequency bandwidth is widened.

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