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Structural parameter effect of porous material on sound absorption performance of double-resonance material

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Abstract. In view of the noise feature and service environment of urban power substations, this paper explores the idea of compound impedance, fills some porous sound-absorption material in the first resonance cavity of the double-resonance sound-absorption material, and designs a new-type of composite acoustic board. We conduct some acoustic characterizations according to the standard test of impedance tube, and research on the influence of assembly order, the thickness and area density of the filling material, and back cavity on material sound-absorption performance. The results show that the new-type of acoustic board consisting of aluminum fibrous material as inner structure, micro-porous board as outer structure, and polyester-filled space between them, has good sound-absorption performance for low frequency and full frequency noise. When the thickness, area density of filling material and thickness of back cavity increase, the sound absorption coefficient curve peak will move toward low frequency.

1. Introduction

Recently, with the rapid development of economy and the increase of urban scale, many power transmission projects are under way[1]. Due to shortage of land source, many substations are located in urban densely-populated areas and disturb the lives and work of the nearby residents, being the urban substations noise a special cause of considerable public concern. Urban substations noise is featured by medium and low frequency, long wavelength, slow attenuation, and strong penetration to the building, with its frequency spectrum mainly concentrated on 50Hz and its octave[2-5]. Common noise reduction materials, for example mineral wool, cannot meet the requirements of absorbing low frequency and full frequency noise.

In view of the noise feature and service environment of urban power substations, our research team used the idea of compound impedance[6-7], using the advantages of resonance sound-absorption materials for low-frequency noise[8-11]and porous sound-absorption materials for high-frequency noise[12-16]. We finally developed a new-type of composite acoustic board with double-resonance structure, being the first resonance cavity filled with porous sound-absorption materials. Compared with commonly used materials, the absorbing band of our acoustic board is broadened and its low-frequency absorption ability is enhanced. The double-resonance structure consists of micro-porous fiber composite acoustic board, which is made with aluminum fibrous sound-absorption materials with an area density of 500 g/m^2 and thickness of 1mm[17-19], and a micro-porous acoustic board with the hole spacing of 6mm and thickness of 1mm[20-21]. The filling material is a kind of weather-resistant, economic and environmental friendly polyester[22-24]. The sound-absorption properties of these materials are shown in Figure 1. Through the combination of polyester and double-resonance materials with different structural parameters, the authors analyze the influence of structural parameters of the new-type of composite acoustic board on its sound-absorption performance, which is significant to the structure optimization and sound-absorption material development.

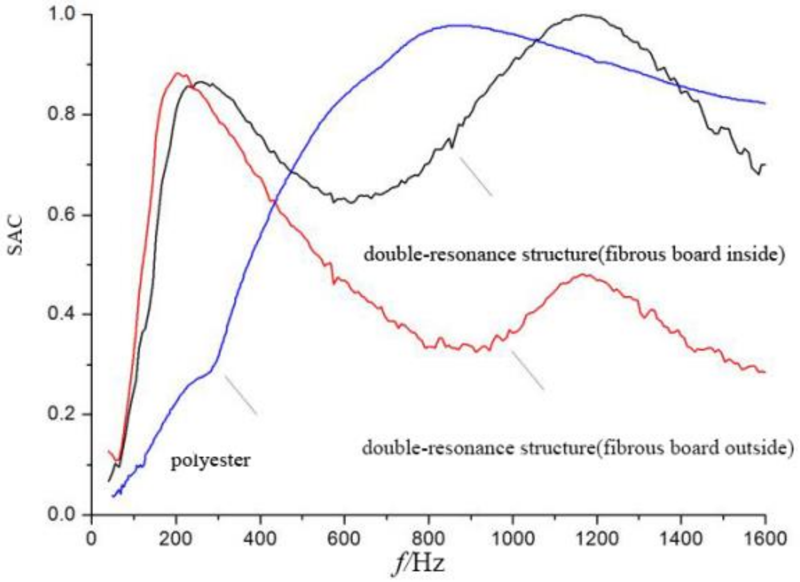

Figure 1. Sound absorption coefficient curves of different materials.

2. Experiment

The sound-absorption performance of the new-type of composite acoustic board mainly depends on the property of compound impedance, which is related to the assembly order, the area density and thickness of the filling material, and the thickness of the back cavity. Thus, in order to acquire good acoustic property, this research conducted several acoustic tests and evaluations according to GB/T18696.2-2002 Acoustics-Determination of Sound absorption coefficient and impedance in impedance tubes-Part 2: Transfer function method[25]. The test equipment is B&K impedance tube, as shown in Figure 2. The samples include aluminum fibrous acoustic board, micro-porous board and polyester, as shown in Figure 3. The experimental plan is shown in Table 1.While testing, the test samples were composited according to the compound mode of experimental plan. The composite was put into test equipment for testing, and the test results were evaluated.

Figure 2. B&K impedance testing system.

(a) aluminum fibrous acoustic board (b) polyester (c) micro-porous board

Figure 3. Test samples.

Table 1. Experimental plan of the new-type composite acoustic board.

No.	Outer structure	Inner structure	Filling materials	Thickness of filling materials	Area density of filling materials	Thickness of back cavity
1#	micro-porous board	aluminum fibrous acoustic board	polyester	20cm	1500g/m^2	0cm
2#	aluminum fibrous acoustic board	micro-porous board	polyester	20cm	1500g/m^2	0cm
3#	aluminum fibrous acoustic board	micro-porous board	polyester	20cm	1500g/m^2	10cm
4#	aluminum fibrous acoustic board	micro-porous board	polyester	20cm	1500g/m^2	20cm
5#	aluminum fibrous acoustic board	micro-porous board	polyester	10cm	1500g/m^2	0cm
6#	aluminum fibrous acoustic board	micro-porous board	polyester	25cm	1500g/m^2	0cm
7#	aluminum fibrous acoustic board	micro-porous board	polyester	20cm	1000g/m^2	0cm
8#	aluminum fibrous acoustic board	micro-porous board	polyester	20cm	2000g/m^2	0cm

3. Result and discussion

3.1. Influence of assembly order

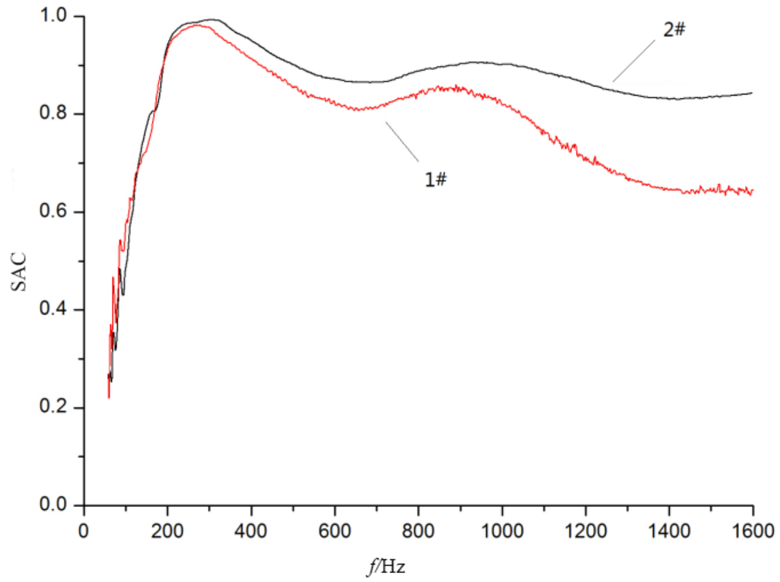

Figure 4. Comparison of sound absorption coefficient (SAC) curves for the new-type of composite acoustic boards with different assembly orders.

Figure 4 shows the comparison of sound absorption coefficient (SAC) curves for the new-type of composite acoustic boards, with the micro-porous board and the aluminum fibrous acoustic board in different positions, and filled by polyester with a thickness of 20cm and area density of 1500g/m2, being the thickness of back cavity of0cm. The results show that, when the other parameters are the same, the acoustic board containing aluminum fibrous acoustic board outside and micro-porous board inside exhibits the following behavior: the SAC remains near 0.8 after it reaches the peak, and it does not decrease much at higher frequencies. In comparison, the new-type of acoustic board with aluminum fibrous acoustic board inside and micro-porous board outside exhibits the following behavior: the SAC is nearly the same as the one with different assembly order up to300 Hz, while after 300Hz, a difference shows up. Especially after 1000Hz, SAC decreases rapidly, and reaches the value of 0.6 at1600Hz. The reason of this behavior is that the micro-porous board mainly absorbs noise through the effect of Helmholtz resonance, which means that it needs the resonance of the back cavity to dissipate sound energy. When the cavity is filled with porous sound-absorption material, the thickness of the cavity is reduced and the resonance effect is suppressed. While the aluminum fibrous acoustic board has the property of acoustic resistance due to its inclusion of aluminum fiber felt, the filling of porous sound-absorption materials can optimize the impedance matching and acquire perfect sound absorption. Thus, the structure with aluminum fibrous acoustic board outside and micro-porous board inside is more beneficial to the absorption of urban substation noise.

3.2. Influence of the back cavity thickness

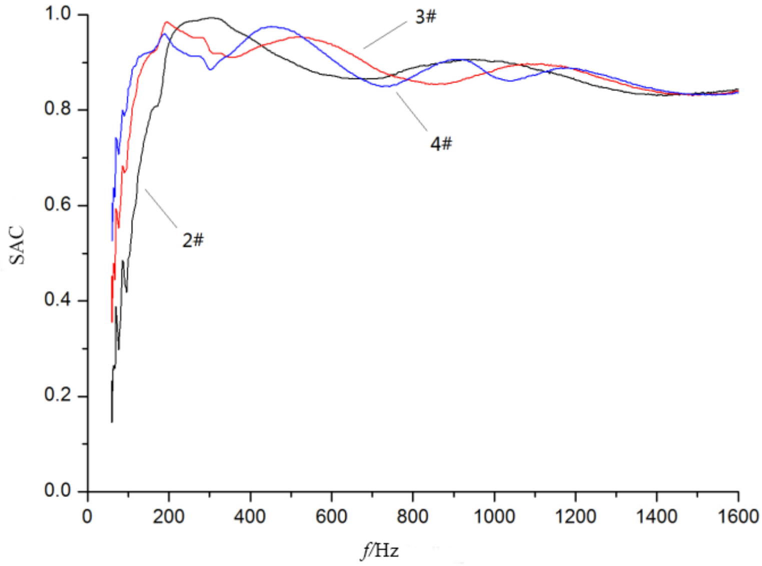

Figure 5. Comparison of sound absorption coefficient (SAC) curves for the new-type of composite acoustic boards with different thicknesses of back cavity.

Figure 5 shows the comparison of SAC curves for the new-type of composite acoustic boards with different thicknesses of back cavity, being filled by polyester with a thickness of 20cm and area density of 1500g/m^2, where the outer structure is aluminum fibrous acoustic board and the inner structure is micro-porous acoustic board. The test results show that when the thickness of the back cavity increases, the peak of SAC curve moves toward low frequency. The reason for this behavior is that the low-frequency wavelength is long, and the back cavity can resonate easily and dissipate the noise energy when the thickness is large. It's shown in Figure 5 that, when the thickness of back cavity is 20cm, its SAC reaches 0.85 at100Hz, and it's not lower than 0.84 in the range of 100~1600Hz, which guarantees that the SAC curve for the new-type of composite acoustic board covers the low, medium and high frequency of substation noise.

3.3. Influence of the filling material thickness

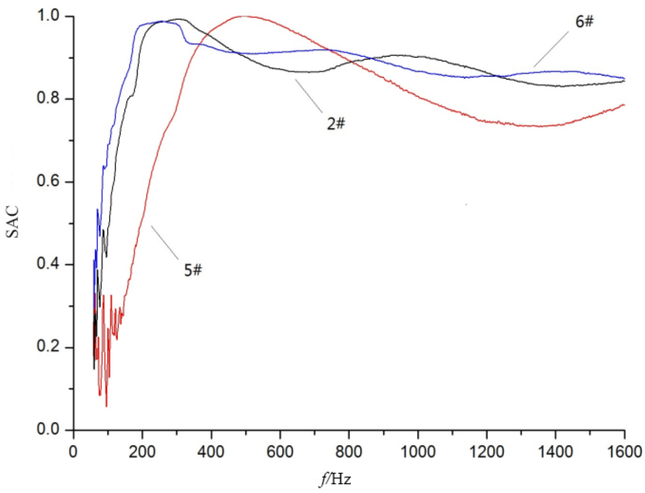

Figure 6. Comparison of sound absorption coefficient (SAC) curves for new-type of composite acoustic boards with different thicknesses of filling material.

Figure 6 shows the comparison of SAC curves for the new-type of composite acoustic boards filled by polyester with the area density of 1500g/m^2 and different thicknesses, where the outer structure is aluminum fibrous acoustic board and the inner structure is micro-porous acoustic board. The test results show that, when the other parameters are the same, the increase of thickness of the filling material moves the peak of SAC curve towards low frequency, and the full-frequency absorption ability is enhanced, while the enhancing effect is weakened when the thickness increases. The reason is that the filling material will increase the thickness of the first resonance cavity, and enhance the sound-absorption performance for medium and low frequency noise. Meanwhile, the increase of thickness can increase the material acoustic resistance, which is helpful to the absorption of medium and high frequency noise. Thus, the full-range sound-absorption performance is strengthened. Furthermore, the dissipation of sound energy increases with the thickness of filling material, while the increase rate becomes lower. It is also reflected in the SAC curves that the moving trend of curve peak and the enhancing effect of sound-absorption performance become weakened. Figure 6 also shows that, when the thickness increases from 20cm to 25cm, the SAC curve does not change significantly.

3.4. Influence of the filling material area density

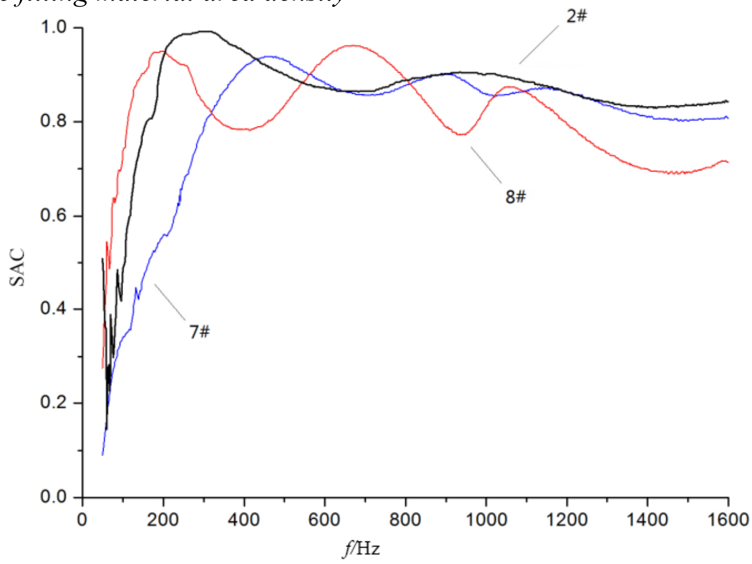

Figure 7. Comparison of sound absorption coefficient (SAC) curves for the new-type of composite acoustic boards with different area densities of filling material.

Figure 7 shows the comparison of SAC curves for the new-type of composite acoustic boards filled by polyester with a thickness of 20cm and different area densities, where the outer structure is aluminum fibrous acoustic board and the inner structure is micro-porous acoustic board. The test results show that, when the other parameters are the same and the area density increases, the SAC curve peak of the new-type of composite acoustic board moves toward low frequency, and the full-frequency acoustic performance is enhanced to some degree, while the moving trend and the overall sound absorption performance become weakened as the area density continuously increases. The reason is that the amount of fiber increases with the area density and, as a result, the polyester becomes much denser and the pore channels inside becomes tiny and twisted, which consumes more sound energy. It is shown in the SAC curves that the full-frequency sound absorption performance is enhanced at the beginning stage of the area density increase, while after the threshold, the increasing area density means that most of the space is occupied being harder to the sound wave to enter the sound-absorption material, and the overall sound absorption performance is weakened. As shown in Figure 7, when the area density increases from 1500 g/m^2 to 2000 g/m^2, the enhancing effect is not obvious and the fluctuation of sound absorption performance appears in medium and high frequency.

4. Conclusions

Adopting the test method of impedance tube, this paper researched on the influence of structural parameters, including assembly order, thickness and area density of filling material, and back cavity thickness and on the sound-absorption performance of the double-resonance material. The results provide a guide for the development of noise reduction material for urban substation noise:

1) Influence of assembly order: To make full use of the acoustic impedance property of aluminum fibrous board, this research designs a new-type of acoustic board with aluminum fiber as outer structure, micro-porous board as inner structure, and polyester filling inside the cavity. This assembly order can optimize the impedance matching and broaden the sound-absorption frequency.

2) Influence of the back cavity thickness: As the low frequency wavelength is long, when the thickness of back cavity is large, it is easy for the new-type of composite acoustic board to resonate, and the sound absorption curve peak will move toward low frequency.

3) Influence of the filling material thickness: The thickness increase of the filling material has the same effect as the thickness increase of first resonance cavity on sound-absorption performance. Besides, due to the increase of flow resistance caused by the filling material, the full frequency sound-absorption performance of the composite acoustic board is enhanced. After the threshold, the increase rate becomes lower and lower, and the enhancing effect is weakened.

4) Influence of the filling material area density: When the area density of the filling material increases, the pore channels inside the material will become tiny and twisted, this is helpful to the sound energy consumption. After the threshold, the increasing area density means that most of the space is occupied, being harder to the sound wave to enter the sound-absorption material, and the overall sound absorption performance is weakened.

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