2018

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ABSTRACT

During the operation of the air compressor unit, the suction and exhaust process of the air compressor and the operation of other equipment will cause air flow pulsation, which is often accompanied by the generation of air compressor noise. Numerical simulation method, as an important means to study the flow field characteristics and noise characteristics of air compressors, has been widely used in recent years.

This article takes the noise enclosure of a certain air compressor unit as the research object, and use numerical simulation method to study the air intake part of the enclosure. The influence of inlet louver and suction deflector on the aerodynamic performance of air compressor noise enclosure was analyzed, and the influence of different inlet louver structures and different suction deflector structures on noise was compared. This paper uses the broadband noise model to predict the distribution of air flow pulsation noise. In order to quantitatively study the noise, the FW-H model based on Lighthill's acoustic analogy method was used for the aerodynamic noise simulation, and the frequency response of the aerodynamic noise of air compressor was obtained.

1. INTRODUCTION

Screw air compressor is an essential and widely used equipment in industrial production. The noise control of screw air compressor has already been a hot issue around the world. From the production mechanism, the aerodynamic noise, mechanical noise and electromagnetic noise are the main noise sources of the screw compressor. The aerodynamic noise is formed by the air vibration caused by the gas movement, which mainly contains noise caused by air suction, air exhaust, and rotor high speed rotation.

Wenlong Y. and Jisheng Y. (2008) designed a micro-perforated plate muffler for Fcs50 air compressor. After being equipped with the muffler, the noise of air compressor group is decreased by almost 30dB. Cheng S. *et al.* (2007) suggested that the installation position of exhaust check valve can affect the exhausting noise of air compressor. They also made improvement to noise enclosure and sound-absorbing material. Liu H. (2013) used sound enclosure for noise reduction in the noise control projects of two screw compressors in a mining enterprise. The material selection, layout, structural design of the sound enclosure, and ventilation and heat dissipation of the equipment after sound enclosure equipped are analyzed in detail. Sangfors B. (2000) proposed a computer numerical calculation method for simulating the noise caused by the pulsation of the air flow generated by the opening and closing of the intake and exhaust ports of the screw compressor. This method not only considers the influence of blade combination, wrap angle, diameter ratio, leakage of meshing clearance, exhaust port, but also considers the oil content in the gas and the resonance of the compressor discharge chamber and the downstream pipe.

The soundproof enclosure is a kind of integral soundproof measure, which has the characteristics of convenience and high efficiency, low cost and good effect. Adding sound-absorbing cotton is also an effective means to strengthen the sound insulation effect. However, there are few researches on the influence of the soundproof enclosure structure on the air flow pulsation noise. The related work still needs to be carried out.

This paper takes the noise enclosure of an air compressor unit as the research object. The assembly drawing of the air compressor unit is shown in Figure 1. By analyzing the equipment assembly and inside space, it can be found that air from the environment will be inhaled mainly through the grid plate, which is shown in the dotted line frame.

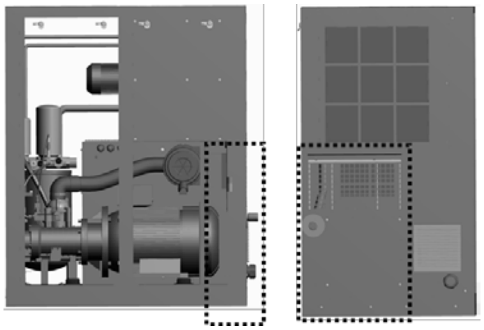


Figure 1: Assembly drawing of the air compressor unit

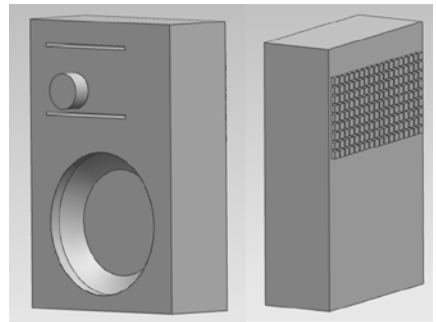


Figure 2: Finite element model

While the machine is running, both the air compressor and the centrifugal fan will inhale large amounts of air. The grids on the plate can play a role of initial air filter, but can also increase air flow resistance, which can cause disturbances in nearby fluids. Combined with the principle of air flow pulsation noise generation, it can be inferred that a large airflow pulsation noise will be generated around the grid plate. As demonstrated before, this paper will mainly focus on the grid plate (as shown in the dotted line frame) to analyze the air flow pulsation noise. Based on the analyzing results, the structure of grid plate will be modified. The noise of these different structures will be compared to analyze the influences of structure modification.

2. NUMERICAL SIMULATION MODEL

2.1 Finite Element Model

Hence the finite element model can directly decide the accuracy of simulation, it is necessary to simplify the original geometry model. Geometric features and details which affect little to the acoustic and fluid simulation will be cleaned. From Figure 1, it is obvious that the grid plate is the main structure that affected the aerodynamic performance of inside fluid. Besides, the deflector in front of the suction pipe connection and the cambered surface of the compressor motor may also influence the flow field. Under the permission of ensuring the main feature of fluid field, the finite model will be cleaned.

The simplified finite element model is showed in Figure 2.

The fluid domain model is divided into three parts: inlet surface, outlet surface and fluid area. The surface of grid plate is the inlet surface, and the outlet surface is on the suction pipe connection. In order to ensure the accuracy of the simulation and reduce the influence of the inlet and outlet turbulence on the flow field, the inlet area and outlet area are both lengthened in the calculation.

For the calculation, set the fluid inlet pressure to a standard atmosphere pressure. The suction process of the air compressor is a low Mach flow, and the working fluid is considered to be an incompressible and steady flow. It is known that the intake air volume of the air compressor is 390m3/h, the air density is 1.225kg/m^3, and the outlet surface mass flow is 0.1327 kg/s.

2.1 Simulation Model

2.1.1 Acoustic Analogy Modeling: For the simulation of the middle and far field noise, ANSYS Fluent use the “Acoustic Analogy Modeling " based on Lighthill equation. The Acoustic Analogy Modeling is used to decouple the wave equation and the flow equation, and to use appropriate control equations such as the unsteady Reynolds average, DES separation vortex or les large eddy simulation in the Near field flow. Then the solution result is used as the noise source, and the analytic solution is obtained by solving the wave equation. Thus, the flow solution process can be separated from the acoustic analysis.

Sub-sub-section headings: Sub-sub-sections should be avoided. If they are used, they should be justified left, in normal small letters, with the text beginning to the right.

2.1.1 Broadband Noise Model: The turbulent noise in many engineering applications does not have an obvious frequency band, and the acoustic energy is continuously distributed over a wide range of frequencies. These cases may involves the issue of broadband noise. In the broadband noise model of ANSYS Fluent, the turbulence parameters are obtained by RANS equations, and then some semi-empirical correction models (such as Proudman equation model, boundary layer noise source model, linear Euler equation source term model, Lilley equation source term model) are used to calculate the noise power of surface units or volume units.

3. PREDICTION OF AERODYNAMIC NOISE CONTRIBUTION

According to the working process of air compressor, the inlet pressure is considered as the local standard atmospheric pressure, and use ANSYS fluent to simulate the flow field.
Figure 3 shows the streamline of the fluid. It can be observed that, as flowing through the grid plate and deflector in front of the suction pipe, the fluid has a large disturbance and generate a number of eddies. Therefore, combined with the factors affecting the fluctuation noise, it can be predicted that these two parts may greatly contribute to the noise of the airflow fluctuation.
Figure 4 is the contour of surface acoustic power level. The brighter the color is, the larger the noise is. It is obvious that the noise near the inlet grille and the deflector are larger. Based on that, it is considered to modify the structure of inlet grid and deflector to reduce airflow fluctuation noise in target area, and the influence of different structure on airflow fluctuation noise will be discussed.

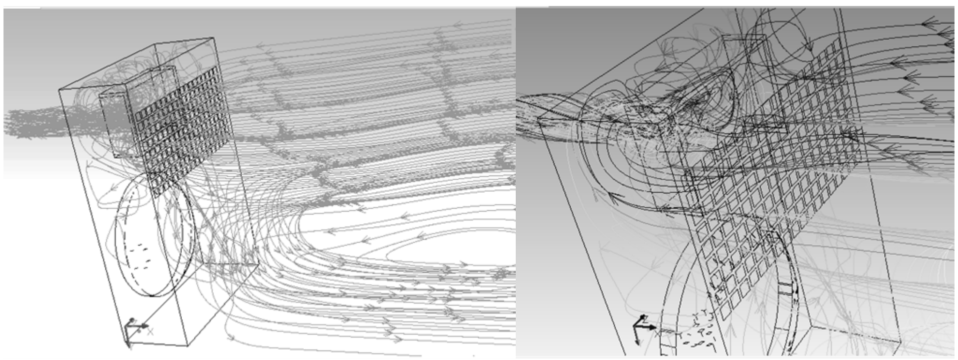


Figure 3: Streamline

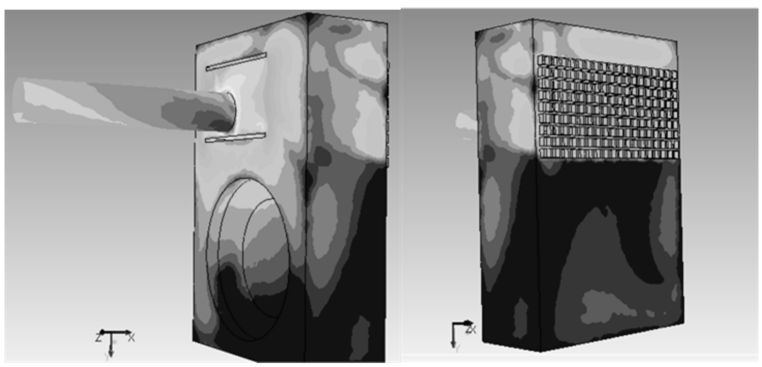


Figure 4: Contour of surface acoustic power level

4. THE INFLUENCE OF PARALLEL LOUVER

In this chapter, three kinds of modification are made to the inlet grille, which are parallel louver, A-shape louver and grille with different openings rate. The influence of louver angle, louver form and the opening rate of grille on pulsation noise are compared later.

4.1 Structure of Parallel Louver

In this section, the entrance grid is adjusted to the parallel blinds, and the angle with the horizontal line are respectively 0°,15°,30°,45°,60°. The percentage of opening is 78.6%. Figure 5 is the structure mode of 15° of horizontal angel. Figure 6 is flow field. Figure 7 show the side view of flow field model for 15° of horizontal angel.
As shown in Figure 8, 6 monitoring points are taken at the center axis of the suction pipe section. Point 1 is at the grille exit section. The intervals between point 1 and point 2, point 2 and point 3 are 500mm. Point 4 locates at the center of suction pipe suction. The intervals between point 4 and point 5, point 5 and point 6 are 500mm.
According to the sound power test standard ISO 3744, taking the point 3 as an example, sound pressure level curves of different structures are compared as followed. The results are showed in Figure 8 to Figure 12.

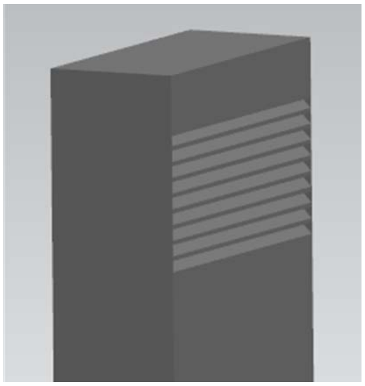


Figure 5: Structure mode

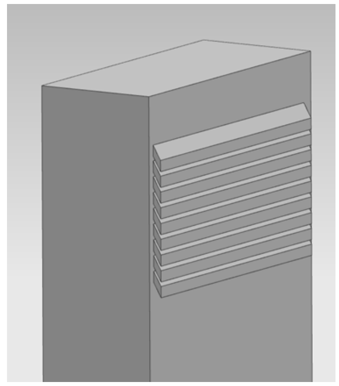


Figure 6: Flow field

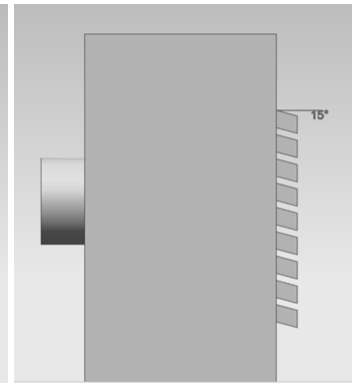


Figure 7: Side view of flow field

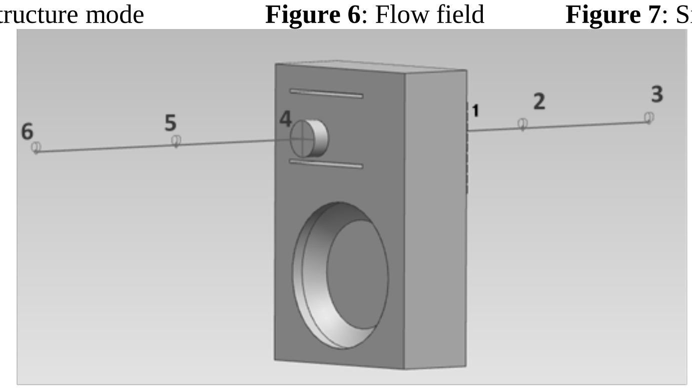


Figure 8: 6 monitoring points

4.2 Results Analysis

As seen from Fig.7, when the angle of the louver is 0° and 30°, the total sound pressure at each monitoring point is higher than other cases including the original structure. When the angle of the louver is 15°, 45°, 60°, the total sound pressure level is lower than the original structure. Combined with the line chart, it can be seen that noise generated by structure with parallel louver has great differences in band of 0Hz to 200Hz. At 80Hz and 200Hz, the sound pressure level of the original structure is lower. Fig.13 shows the differences between original structure and louver structures. It can be seen that when the louver angle is 0° and 30°, 80Hz and 200Hz noise are significantly higher than other angles. And when the angle of the louver is 15°, the sound pressure level is lower. It can also be observed from the line chart that after changing the structure into parallel blinds, the intermediate frequency and high frequency noise are obviously improved.

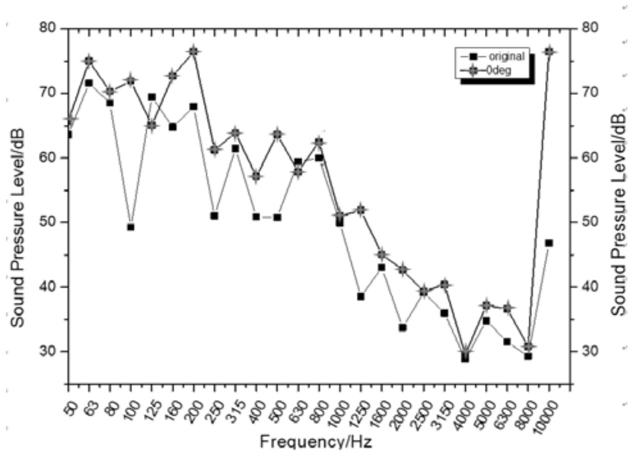


Figure 9: Sound pressure level for 0° louver angle

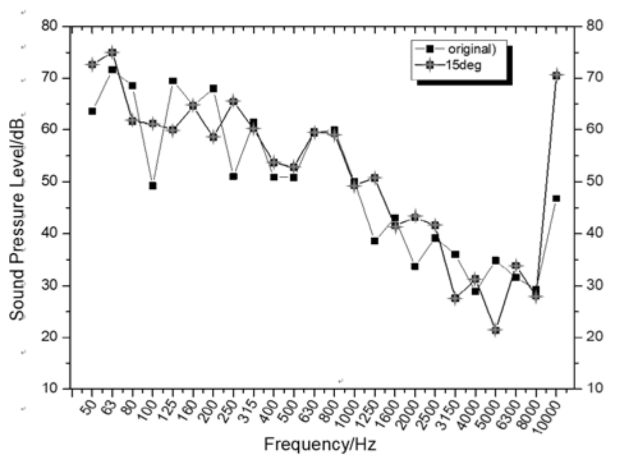


Figure 10: Sound pressure level for 15° louver angle

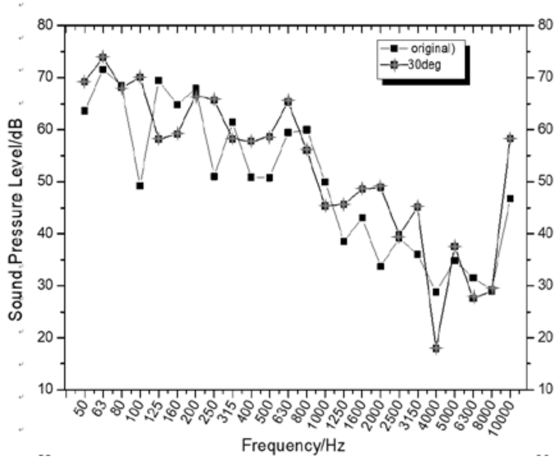


Figure 11: Sound pressure level for 30° louver angle

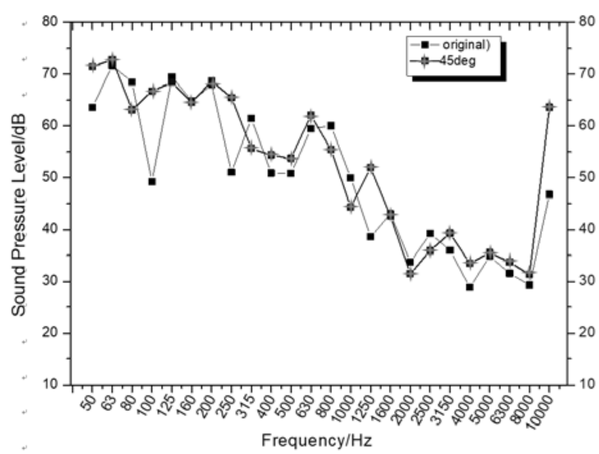


Figure 12: Sound pressure level for 45° louver angle

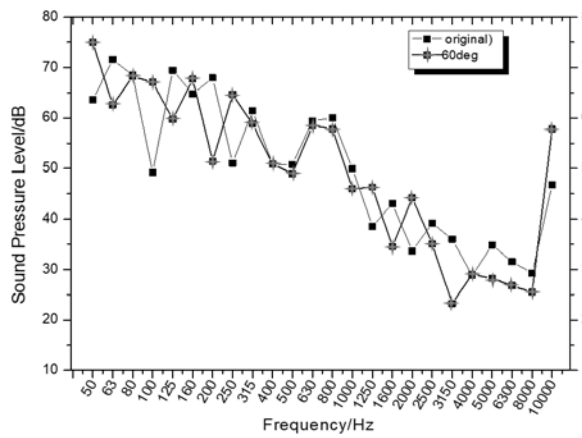


Figure 13: Sound pressure level for 60° louver angle

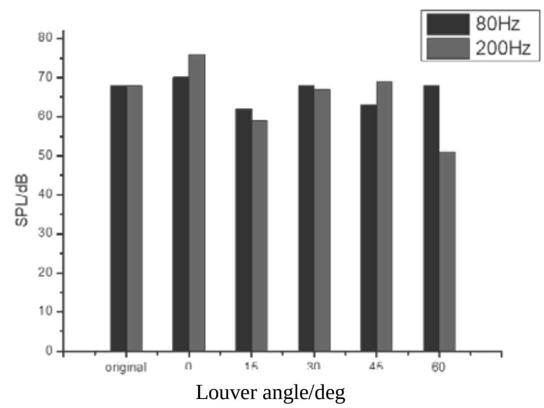


Figure 14: Sound pressure level at 80Hz and 200Hz

From Figure 15, it is obvious that when the inlet form is a grid, the area with larger sound pressure is the grid boundary, and the small and dense openings on the grille cause larger sound pressure. And with the entrance form of the parallel blinds, surface dipole noise is mainly generated by the edge of the louver, which is shown in the green highlighted part in the figure. Because the gas can pass the entrance with lower resistance, the gas disturbance is slighter, and the aerodynamic radiation noise becomes smaller.

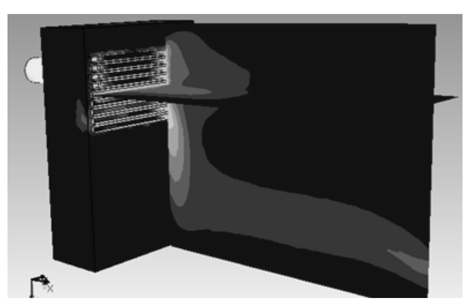


Figure 15: sound pressure contour of 15°louver angle

5. INFLUENCE OF A-SHAPE LOUVER

5.1 Structure of A-shape Louver

In this section, the entrance grid is adjusted to A-shape louver, and the horizontal angle of the louver is 15°, 30°, 45° and 60°. The structure model of A-shape louver is shown in Fig.15, the vent installation position is the same as the

grille of the original structure. Fig.16 is the fluid field model of structure. The section diagram of louver is shown in Figure.17. The width of the cross section of the louver is 30mm. A fluid field model with louver angles of 30°is shown in Figure 18.
According to the Sound Power Test standard ISO 3744, a monitoring point shall be taken on the surface which is one meter away from the reference body. As can be seen from Fig.19, the trend of point 6 is more typical. So taking point 6 as an example, compare the SPL curves of original structure with other structures. The results are shown in Figures 20 to 23.

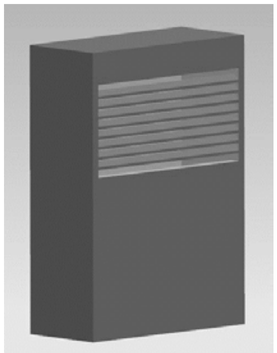


Figure 16: Structure model of A-shape louver

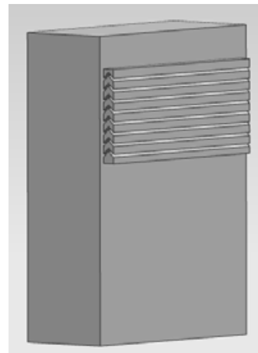


Figure 17: Fluid field model

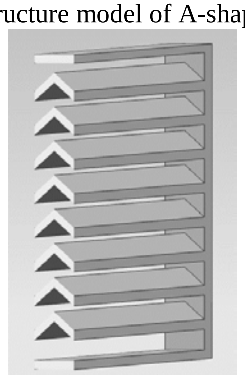


Figure 18: Section diagram of louver

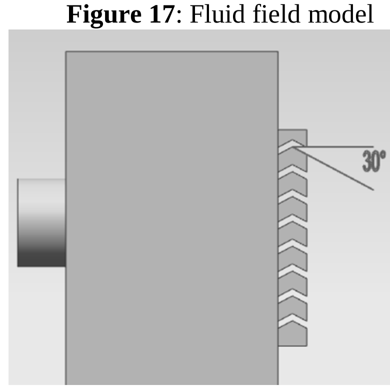
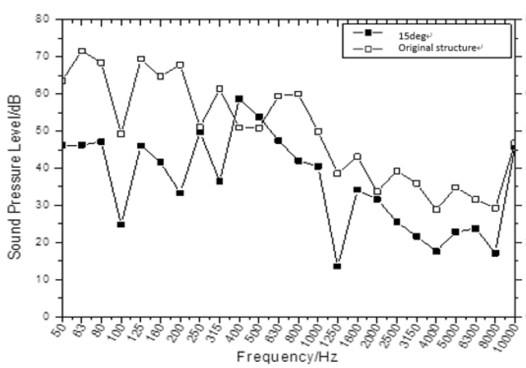
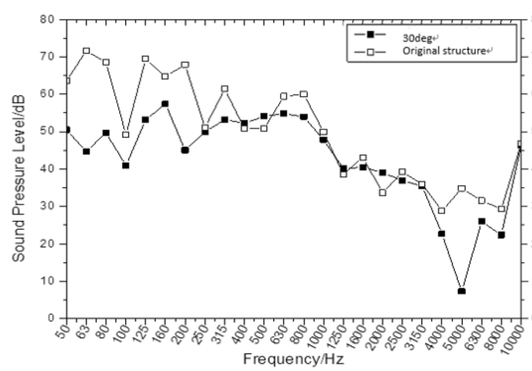


Figure 19: Side view of fluid field with 30° louver angle

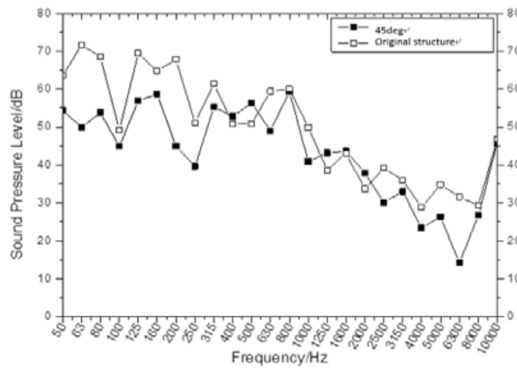
5.2 Comparison of A-shape Louver in Different Angles



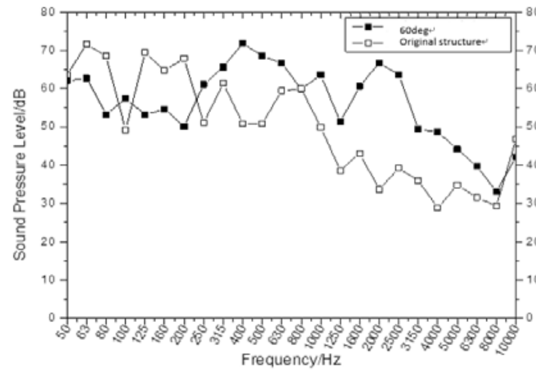
Figures 20: Sound pressure level of 15° louver angle



Figures 21: Sound pressure level of 30° louver angle



Figures 22: Sound pressure level of 45° louver angle



Figures 23: Sound pressure level of 60° louver angle

From the above line charts, it can be seen that when the angle of louver is 15°, the noise in the low-frequency area is significantly lower than the original structure. Even up to 400Hz, noise generated by the A-shape louver with 15°louver angle is lower than the original structure. Among the band of 400Hz-500Hz, the noise of the original structure is slightly lower, while in the higher frequency bands, the noise generated by the A-shape louver is lower, especially around 1250Hz and 4000Hz. While the angles of the louver are 30° and 45°, the situations are similar. In the low frequency band, the noise of A-shape louver is lower than that of the original structure, while among the 400 Hz-3150 Hz band, the noise characteristics of the A-shape louver and the original structure are similar. The noise generated by the original structure is higher than the A-shape louver between the 3150 Hz-10000 Hz band.

From Figure 23, it can be analyzed that, in the low-frequency region, where the noise level of another other three kinds is lower, the noise generated by 60°louvers is smaller than the original structure, though not obvious. Besides, from 250Hz to much higher frequency, the noise of A-shape louver is even larger than original structure.

From analysis above, it can be seen that louver angle of 15°, 30° and 45° have an improved effect on the aerodynamic noise, and the improvement is significant at low frequency band of 0-400Hz. In the middle frequency and high frequency band, the noise produced by the louver angle of 15°is lower than that of the original structure for the most part, while the structures with angle of 30° and 45° has obvious effect in the High-frequency region of 3150Hz-10000Hz. The aerodynamic noise generated by the 60°louver angle is larger than that of the original structure, which is mainly caused by the noise of medium frequency noise and high frequency noise.

And it can be seen from sound pressure contour that higher sound pressure is generated at the edge and corners of louver. When the angle of the louver is 15°, the fluid entrance path is unobstructed and the organization of flowing is orderly with a less series of eddy at upper right corner. By contrast, when the louver angle is 60°, fluid is more chaotic. When entering the vent, fluid pass through a large angle and get disturbed, resulting in less organized flowing with more turbulence. The analysis above is also the contribution of the maximum noise of 60° louver angle.

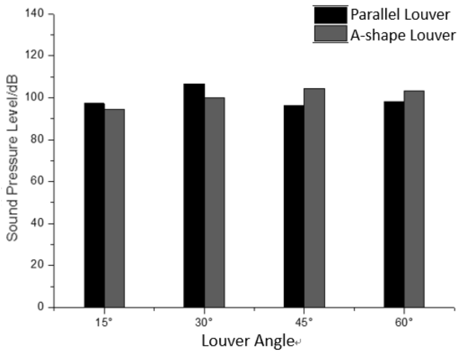
5.3 Comparison of A-shape Louver with Parallel Louver

This paper has discussed the different effect of the parallel louver vents with 15°, 30°, 45° and 60°louver angle on the aerodynamic radiated noise. In this section, the noise of parallel louver and A-shape louver vents with the same angle will be compared to explore the similarities and differences between the two forms.

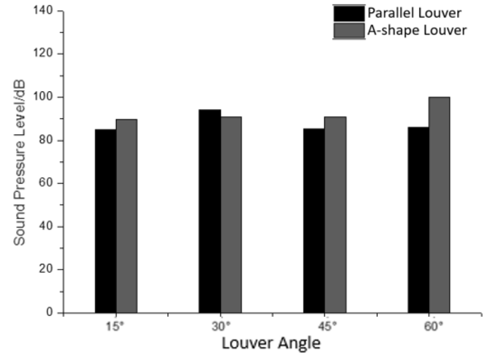
The following figures are the compare of total sound pressure level between the two structures.

It can be seen from the figures that when the angle is 15°, the aerodynamic noise generated by the A-shape louver is obviously lower, especially in the low-frequency band. Combined with the analysis in the previous section, it can be concluded that low-frequency noise generated by A-shape louver of 15°is lower than parallel louver and original structure. In the middle and high frequency region, it can be seen that when frequency is greater than 630Hz, the tendency of frequency curve of A-shape louver and parallel louver is similar, but the sound pressure of the A-shape louver is lower. Compared to Figure 31 and Figure 32, it can be seen that compared with the parallel louver, the sound pressure of A-shape louver is lower in the High-frequency region. Compared with the original structure and the A-shape louver can draw a similar conclusion.

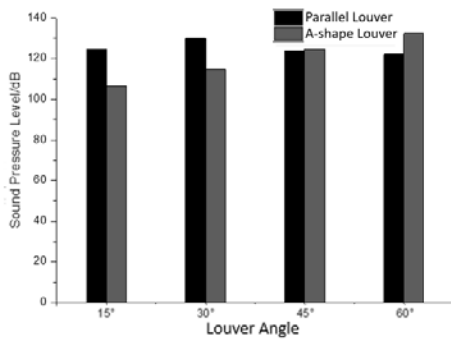
When the angle is 60°, it can be seen that the sound pressure level of the A-shape louver is significantly higher than the parallel louver in each frequency band. In combination with the discussion in the above section, it can be concluded that the noise of the aerodynamic radiation generated by the A-shape louver of 60° is larger than other structures. A-shape louver of 60°is not an improving measure.



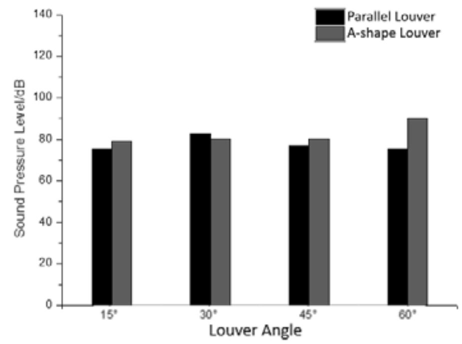
Figures 24: Sound pressure level at monitoring point 1



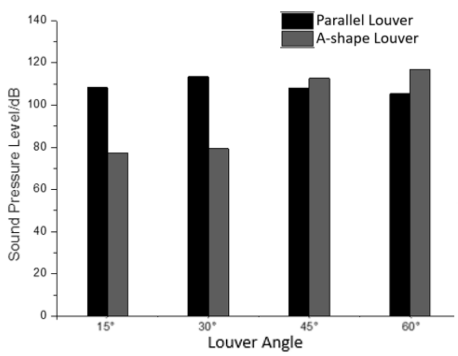
Figures 25: Sound pressure level at monitoring point 2



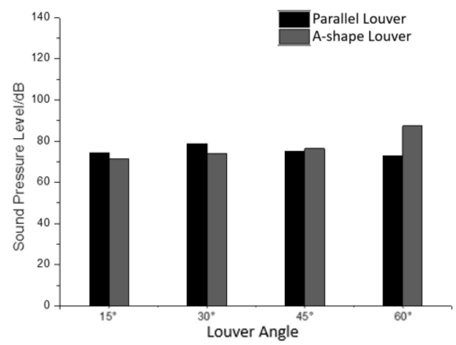
Figures 26: Sound pressure level at monitoring point 3



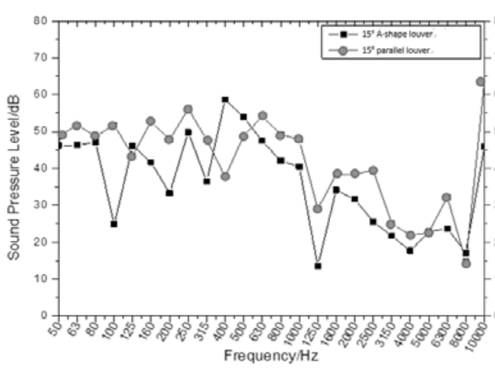
Figures 27: Sound pressure level at monitoring point 4



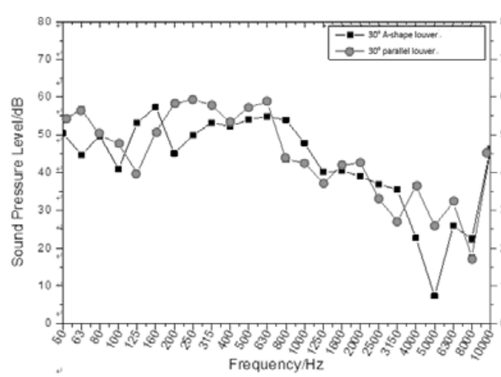
Figures 28: Sound pressure level at monitoring point 5



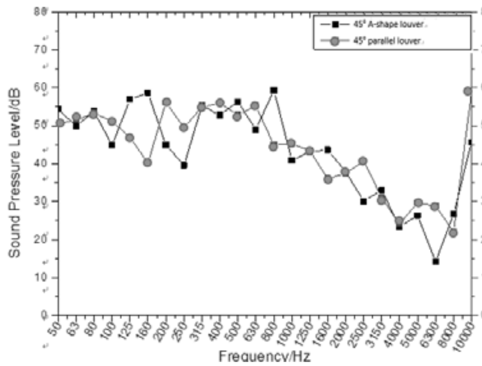
Figures 29: Sound pressure level at monitoring point 6



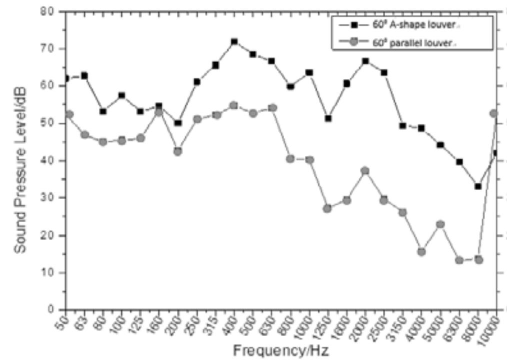
Figures 30: Sound pressure level of 15°louver angle



Figures 31: Sound pressure level of 30°louver angle



Figures 32: Sound pressure level of 45°louver angle



Figures 33: Sound pressure level of 60°louver angle

6. MODIFICATION OF DEFLECTOR

From the surface dipole acoustic pressure contour Figure 4, it can be seen that the deflector in front of suction pipe also part has a great influence on the noise generation. The surface of deflector is laid by sound absorbing cotton, which can reduce noise, but can also change the aerodynamic characteristics. The modification of this structure in this section shows a positive effect on noise reduction.

6.1 Structure Model

As shown in the figure, the deflector is changed to a cylindrical surface, and the installation position and overall size of the deflector are unchanged. Figure 34 is a vertical profile and structure. Figure 35 is a streamline of fluid flow.

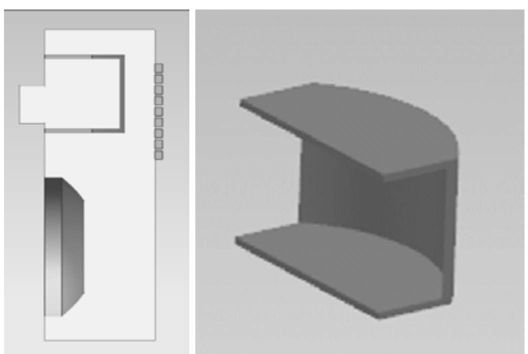


Figure 34: Vertical profile and structure

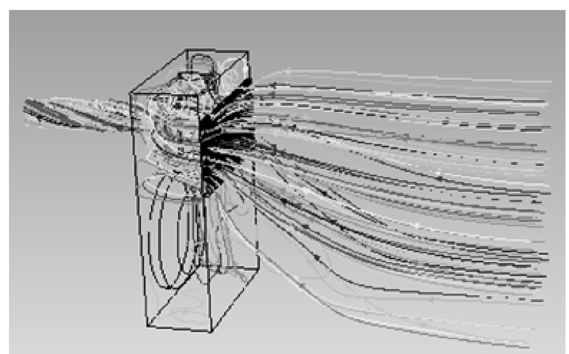


Figure 35: Streamline

6.2 Results Analysis

As is shown in Figure 35, changing deflector structure into cylindrical surface can mainly influence the fluid flow around the suction pipe connection.

According to sound power test standard, take the signal at monitoring point3 and point6 to analyze. Combining with the results of original structure, the comparison shows in Figure 36 and Figure 37.

From the line chart of monitoring point 3 and other line chart of entrance, it can be seen that the effect of deflector structure modification to the high frequency noise is obvious. In the low-frequency region, especially around 80Hz and 200Hz, the noise-reducing effect is also better than parallel louver. At the monitoring point 6, cylindrical deflector is effective in reducing noise around 100Hz and 5000Hz. Therefore, it contributes to the reduction of both low frequency and high frequency noise.

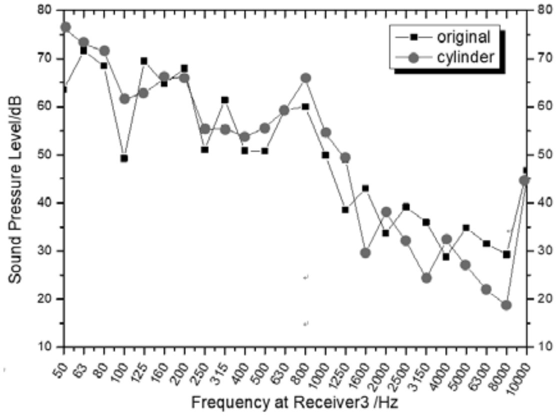


Figure 36: Sound pressure level at receiver 3

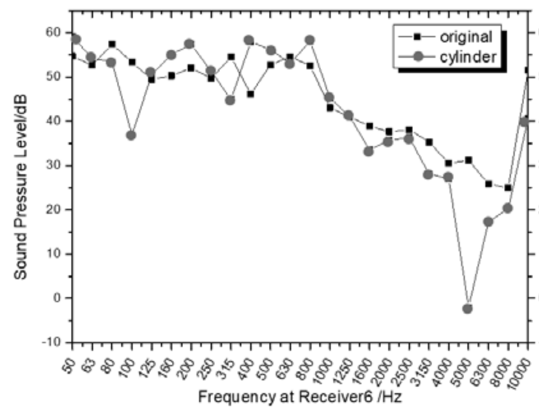


Figure 37: Sound pressure level at receiver 6

7. CONCLUSION AND DISCUSSION

It can be seen from the above analysis that the airflow fluctuation noise is reduced by changing the grid plate structure into parallel louver structure. When the angle of the louver is 15° and 60°, the improvement effect is obvious, and it mainly concentrates on the medium frequency noise and high frequency noise band. When the angle of the louver is 30°, it is counterproductive to reduce the airflow fluctuation noise, which is mainly because the contribution of low-frequency noise becomes larger.

When using A-shape louver, the airflow of 15°louver angle is more orderly, and aerodynamic noise is lower than other kinds of A-shape louver. The noise of 15°angle A-shape louver is also smaller than the parallel louver with the same angle, especially in Low-frequency band.

It is also effective to reduce the noise of airflow fluctuation noise by changing the deflector in front of the compressor suction pipe into a cylindrical surface. Compared with the effect of the parallel louver on noise reduction, the advantages of the cylindrical deflector are mainly on low frequency noise band. In addition, the cylindrical deflector also has a great improvement on the high frequency noise. And as shown in the streamline diagram, the flowing is more orderly and smoothly after changing to cylindrical surface.

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