Effect of Volute Structure Modification on Centrifugal Fan Performance and Noise (Postprint)

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Abstract

Numerical simulations were conducted using Ansys Fluent software to investigate in detail the effects of volute structural modifications on the aerodynamic performance and sound power level of centrifugal fans by varying the volute width and tongue inclination angle separately. The results demonstrate that within the recommended design range for centrifugal fans, there exists an optimal volute width that yields the minimum sound power level; increasing the volute width leads to a slight decrease in total pressure and efficiency, while the static pressure increases; fixing the tongue radius R1 at the back plate of the centrifugal fan volute and increasing the tongue radius R2 at the front plate can effectively reduce the sound power level of the centrifugal fan; in terms of noise reduction effectiveness, modifying the tongue gap is superior to altering the tongue inclination angle.

Full Text

Effect of Volute Configuration on Aerodynamic Performance and Noise Level of Centrifugal Fans

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Abstract

This study employs Ansys Fluent software for numerical simulation to investigate the influence of volute structural modifications on the aerodynamic performance and sound power level of a centrifugal fan, specifically by varying volute width and volute tongue inclination angle. The results reveal that within the recommended design range, an optimal volute width exists that yields the minimum sound power level. Increasing volute width leads to a slight decrease in

total pressure and efficiency while causing static pressure to rise. Fixing the volute tongue radius R1 at the rear plate and increasing the radius R2 at the front plate effectively reduces the fan' s sound power level. Furthermore, modifying the volute tongue clearance demonstrates superior noise reduction compared to altering the tongue inclination angle.

Keywords: centrifugal fan; sound power level; inclined volute tongue; volute width

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Centrifugal fans are widely utilized across various sectors of the national economy. Statistics indicate that centrifugal fans account for approximately 5% of the nation' s total annual electricity generation. However, many operational fans suffer from low efficiency and high noise levels. Existing research [?, ?] has shown that due to strong unsteady interaction between the wake flow at the impeller outlet and the volute, the volute—particularly the tongue region—constitutes the primary noise source in centrifugal fans. Consequently, modifying volute structure represents a highly targeted noise reduction approach.

Numerous scholars have investigated this phenomenon and proposed various volute modification methods to reduce centrifugal fan noise, including increasing volute width [?], employing acoustic-absorbing volutes [?], utilizing stepped tongues [?], optimizing volute outlets [?], implementing inclined tongues [?], and enlarging the impeller-tongue gap [?]. Among these, increasing volute width and employing inclined tongues are the most commonly adopted methods.

This paper examines a centrifugal fan model used in train unit applications to investigate the effects of increased volute width and inclined tongue designs on aerodynamic performance and sound power level.

1. Numerical Simulation of Aerodynamic Performance and Sound Power Level

This study utilizes Ansys Fluent to simulate the aerodynamic performance and noise characteristics of the centrifugal fan. The process involves modeling and meshing the fan, conducting steady-state calculations to obtain aerodynamic performance data, and then using these results as initial conditions for unsteady calculations to acquire noise source information. After the unsteady calculations converge, the FW-H equation is employed to predict fan noise.

1.1 Model Establishment and Mesh Generation

The centrifugal fan comprises three components: an inlet collector, impeller, and volute. ICEM CFD software is used to generate high-quality hexahedral structured meshes. The mesh counts for the impeller, collector, and volute are approximately 960,000, 160,000, and 870,000 cells, respectively, yielding a total mesh count of about 1.99 million cells.

1.2 Numerical Calculation Methods

1.2.1 Aerodynamic Performance Prediction Following mesh generation, numerical calculations are performed using Ansys Fluent. The maximum Mach number of the internal airflow is below 0.3, classifying it as incompressible flow; therefore, density remains constant during calculations. The steady-state calculations employ the Multiple Reference Frame (MRF) approach. Boundary conditions include a mass-flow-inlet at the fan inlet with uniform mass flow at the design operating point, and a pressure-outlet at the outlet. The Realizable k- turbulence model is selected, and to avoid excessive wall mesh refinement, scalable wall functions are applied.

1.2.2 Aerodynamic Noise Prediction The steady-state calculation results serve as initial conditions for unsteady calculations. The Sliding Mesh technique is used to simulate rotor-stator interaction. The time step for the unsteady process is calculated according to formula (1):

$$\Delta t = \frac{60}{n \cdot K \cdot Z}$$

where n represents rotational speed (rpm), K denotes the number of calculation steps per flow passage (K=30 in this study), and Z is the number of blades.

The FW-H equation is used for noise prediction, with quadrupole sources neglected. After calculation completion, FFT transformation is applied to the time-dependent discrete sound pressure data to obtain the linear sound pressure level at monitoring points.

1.2.3 Sound Power Level Synthesis from Sound Pressure Level Following international standard ISO 3745, this study employs the enveloping surface method. Twenty monitoring points are arranged on a surface enclosing the centrifugal fan. The sound power level is synthesized from measured sound pressure levels using the following formula:

$$L_w = 10 \log_{10} \left(\sum_{i=1}^{20} 10^{L_{pi}/10} \right) + 10 \log_{10} \left(\frac{S_1}{S_0} \right)$$

where L_{pi} represents the sound pressure level at each monitoring point (dB), L_w denotes the sound power level (dB), S_1 is the area of the enveloping surface (m^2), and S_0 is the reference area.

2. Effect of Volute Width on Aerodynamic Performance and Sound Power Level

Existing experience indicates that increasing volute width can effectively reduce the fundamental frequency noise of centrifugal fans while increasing broadband noise [?]. Numerical simulation is employed to determine the optimal volute width that minimizes the fan' s sound power level. In this study, volute width is increased from the rear plate side. The original volute width is $B = 108$ mm, progressively increased to 114 mm, 120 mm, 126 mm, and 132 mm.

[Figure 1: see original paper] illustrates the variation in static pressure, total pressure, and efficiency under design flow conditions for different volute widths. Analysis shows that as volute width increases, static pressure gradually rises while total pressure slowly decreases. At a volute width of 108 mm, the total pressure is 3835.04 Pa; when increased to 132 mm, the total pressure becomes 3798.27 Pa, representing minimal change. The total pressure efficiency also declines slowly with increasing volute width, though the rate of decrease accelerates after the width reaches 126 mm. At 108 mm width, efficiency is 0.819; at 126 mm, efficiency is 0.816, showing virtually no change. Further increasing the width to 132 mm reduces efficiency by only 0.009 compared to the original model. Overall, when volute width increases from 108 mm to 126 mm, total pressure and efficiency change insignificantly.

[Figure 2: see original paper] shows the variation in sound power level for different volute widths. The sound power level initially decreases then increases with volute width, reaching a minimum value of 107.64 dB at a width of 120 mm—1.86 dB lower than the initial level. This behavior occurs because the fundamental frequency noise decreases with increasing width while broadband noise increases. With modest width increases, the reduction in fundamental frequency noise dominates, causing overall sound power level to decrease. However, with further width increases, the opposite effect occurs.

3. Effect of Inclined Volute Tongue on Aerodynamic Performance and Sound Power Level

Employing an inclined volute tongue can reduce the peak values of fundamental frequency and higher-order harmonics in centrifugal fans, thereby decreasing noise [?]. In this study, the inclined tongue design features a larger radius R_2 at the front plate than radius R_1 at the rear plate.

Fixing the volute tongue radius at the rear plate at $R_1 = 28$ mm, the radius at the front plate R_2 is increased to the maximum structurally permissible value of 60 mm, corresponding to a tongue inclination angle θ of 15°. Aerodynamic performance and sound power level are calculated for both a straight tongue ($\theta = 0°$) and an inclined tongue ($\theta = 15°$), with results presented in .

Analysis of reveals that at $\theta = 0°$, the calculated total pressure is 3827.29 Pa, efficiency is 0.817, and sound power level is 107.64 dB. When the inclination angle increases to 15°, total pressure decreases by 76.14 Pa to 3751.15 Pa, efficiency drops by 0.013, and sound power level decreases by 2.08 dB to 105.56 dB. Fixing R_1 and increasing R_2 effectively reduces the fan' s sound power level by 2.08 dB. However, this approach is limited by volute outlet length, restricting the inclination angle to 15°. To further increase θ, R_1 must be reduced while keeping R_2 constant at 60 mm. shows the corresponding R_1 values for different inclination angles θ when $R_2 = 60$ mm.

[Figure 3: see original paper] illustrates the variation in static pressure, total pressure, and efficiency with different tongue inclination angles. When increasing θ by fixing R_2 and reducing R_1, both static and total pressure increase with inclination angle. At $\theta = 15°$, static pressure is 3396.9 Pa and total pressure is 3751.2 Pa; when θ increases to 25°, static pressure rises by approximately 1.4% (about 50 Pa) and total pressure increases by about 0.7% (28 Pa). Efficiency increases slightly with inclination angle: at 15°, efficiency is 0.804, and at 25°, it increases by only 0.007.

[Figure 4: see original paper] shows the variation in sound power level with different tongue inclination angles. When increasing θ by fixing R_2 and reducing R_1, the sound power level increases with inclination angle. At $\theta = 15°$, the sound power level is 105.56 dB; when θ increases to 25°, it rises to 106.7 dB. This approach reduces the distance between the impeller outlet and the tongue, which may explain the increase in overall sound power level. This suggests that increasing tongue clearance is more effective for noise reduction than increasing tongue inclination angle.

Conclusions

This study employs numerical simulation to investigate the effects of increasing volute width and modifying inclined tongue angle on the aerodynamic performance and sound power level of a centrifugal fan. The results demonstrate that:

1. Within the recommended volute width range for centrifugal fans, an optimal width exists that minimizes the fan' s sound power level.
2. Increasing volute width causes a slight decrease in total pressure and efficiency while increasing static pressure.
3. Fixing the volute tongue radius R_1 at the rear plate and increasing the radius R_2 at the front plate effectively reduces the fan' s sound power level. Conversely, fixing R_2 and increasing the inclination angle by reducing R_1 at the rear plate increases fan noise.
4. For noise reduction effectiveness, tongue clearance modification is superior to tongue inclination angle variation.

References

[1] Liu Q, Qi D, Tang H. Computation of Aerodynamic Noise of Centrifugal Fan Using Large Eddy Simulation Approach, Acoustic Analogy, and Vortex Sound Theory[J]. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2007, 221(11): 1321-1332.

[2] Mao Yijun, Qi Datong, Xu Changleng, et al. Effect of Interaction between Centrifugal Impeller and Volute Tongue on the Performance and BPF Noise[J].

Chinese Journal of Applied Mechanics. 2006, 23(3): 368-372.

[3] Liu Xiaoliang, Qi Datong, Ma Jianfeng, et al. Numerical and Experimental Study of the Impact on the Aerodynamic noise of the Centrifugal Fan by Changing the Volute Width[J]. Journal of Xi' an Jiaotong University, 2008, 42(11): 1429-1434.

[4] Gu Y, Qi D, Mao Y, et al. Theoretical and Experimental Studies on the Noise Control of Centrifugal Fans Combining Absorbing Liner and Inclined Tongue[J]. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. 2011, 225(6): 789-801.

[5] Li Dong, Gu Jianming. Practice and Analysis to Reduce the Fan Noise with Step-tongue Volute[J]. Fluid Machinery. 2004, 32(2).

[6] Liu Xiaoliang, Yuan Minjian, Mao Yijun, et al. Numerical Optimization of Volute Outlet Structure for Forward-Curved Blades Centrifugal Fan[J]. Journal of Xi' an Jiaotong University. 2009, 43(5): 61-65.

[7] Zhao Ting, Zhao Cun, Ren Gang, et al. Experimental Study on the Effect of Inclined Volute Tongue on the Noise Reduction of Centrifugal Fan[J]. Fluid Machinery. 2012, 40(3): 1-7.

[8] Datong Q, Yijun M, Xiaoliang L, et al. Experimental Study on the Noise Reduction of an Industrial Forward-curved Blades Centrifugal Fan[J]. Applied Acoustics. 2009, 70(8).

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Note: Figure translations are in progress. See original paper for figures.