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EXPERIMENTAL STUDY ON THE EFFECT OF VOLUTE TONGUE PARAMETERS ON THE FLOW-INDUCED VIBRATION OF CENTRIFUGAL FAN

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ABSTRACT

Volute tongue is an important part of centrifugal fan flow components, the structure change of which can cause the change of the unsteady flow field in the fan which will affect the flow excitation characteristic and vibration characteristics of the fan. Set up a decoupling test platform for separating vibration of different parts of a marine centrifugal fan. The influence degrees and effect laws of the inclining types, the parameter coupling of inclining angle of the volute tongue and blade-tongue clearance on the vibration of different positions of the fan were studied experimentally. In this paper, 11 volute tongues of different inclining angles and clearance were designed for testing and these two parameters were orthogonally distributed. The results show that the inclining type of keeping the radius of volute tongue constant is better to reduce vibration. The blade frequency amplitude of the volute vibration decreases firstly and then increases when the inclining angle and clearance increases independently. There is an optimum inclining angle for a particular blade-tongue clearance. The influence of inclining angle is more obvious under large clearance conditions. The vibration influence degree of the tongue clearance is greater than that of the inclining angle, and the vibration influence degree of the volute pathway is greater than that of the impeller-motor pathway. The blade frequency vibration amplitude of the optimal volute tongue in the volute tongue region is reduced by 12.8dB.

INTRODUCTION

Reducing the vibration and noise of marine centrifugal fans is helpful to reduce the vibration transmitted through the hull, reduce the underwater radiated noise of the hull. The vibration and noise of centrifugal fans generally include two parts, the rotary noise and the vortex noise, which are closely related to the aerodynamic characteristics of the gas between the impeller outlet and the volute tongue. The air flow at the outlet of the impeller is most intense in the tongue of the worm, so the worm tongue area is the most important source of vibration and noise of the centrifugal fan [1]. The blade frequency and harmonic frequency vibration which produced by periodically striking the air is the main components of the fan vibration.

The inclined volute tongue and the change of volute tongue clearance have little effect on the aerodynamic performance of the centrifugal fan, but the effect on the noise is very obvious, especially in the blade frequency [2]. Zhao Ting made an experimental study of 7 kinds of volute tongue with different inclining angles and blade-tongue clearances. It was found that the noise of fans decreased with the increase of inclining angle and volute tongue clearance [3]. Shuangcheng Fu simulated the flow field and noise of a centrifugal fan with inclined volute tongue. It was found that the effect of inclined tongue on reducing energy consumption and noise was significant [4].

So far, the research of low noise centrifugal fan is mainly focused on flow field and noise [5-7], and the research on vibration is very few. Now the research on the vibration damping of the fan urgently needs to solve the problem of limited application range of the existing single vibration damping technology and the mutual restriction and low integration of them. The single method of increasing the clearance or inclining angle has good or bad effects on size,

performance and vibration and noise. If the two methods can be combined, the vibration and noise of fans can be reduced without significantly affecting the size of volute and the performance of fans.

In this paper, 11 volute tongues of different inclining angles and clearance were designed and these two parameters were orthogonally distributed. And the effect laws of the inclining types, the parameter coupling of inclining angle and blade-tongue clearance on the blade frequency vibration of different positions of the fan were studied by using the decoupling test platform for separating vibration of different parts of a fan.

DESIGN OF THE VOLUTE TONGUE

Two different inclining methods of are shown in Figure 1. The inclining angle is the angle between the midpoint line of the circular arc of the two ends of the volute tongue and its projection line on the outlet plane. And the volute tongue clearance refers to the minimum distance between the volute tongue and the impeller projected to the rear panel of volute.

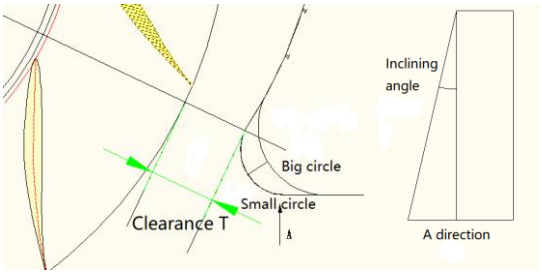
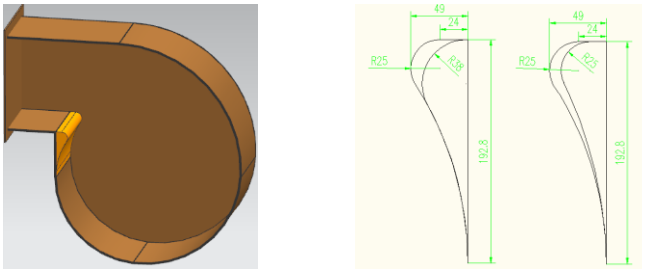


FIGURE 1: Volute tongue clearance and inclining angle

The volute used in this experiment is designed in the form of rectangle volute tongue, which has reserved the installation position of the volute tongue and the bolt connection hole, so it can conveniently replace different parameters and different forms of volute tongue. As shown in Figure 2(a), the volute tongue is connected to the position of rectangular volute tongue through four bolts, so the replacement of different parameters of the volute tongue can change the tongue clearance and inclining angle.



(a) The installation method (b)Type1 (c) Type2

FIGURE 2: Two Kinds of inclined volute tongue and the method of volute tongue installation

Two kinds of tongues with different inclining ways are designed in this paper. The first kind of inclining volute tongue increases the radius of the tongue from one end to the other along the axial direction. This method combines the effect of the radius of the tongue on the vibration and noise, and is the commonly used way of inclining the tongue. The second design does not change the size of the tongue radius. Instead, it inclines all the windward surfaces of the volute tongue by changing the height at both ends of the tongue, which combines the effect of clearance. As shown in Figure 2(b) (c).

This paper couples the two parameters that effect the vibration to one structure, and analysis the superposition effect from single parameter to double. A total of 11 different inclining angles and clearances of volute tongue were designed, as shown in Table 1. The original design of the inclining angle is 0 degrees, the radius of the tongue is 25mm, and the blade-tongue clearance is T2 (36.7mm). This paper first designed and processed two different inclined ways of the volute tongue with a inclining angle of 2 degrees and a clearance of T2. And change the angle and clearance of the tongue by changing the height of the two ends of the tongue at the same distance in the second kind of inclined way. With the angle of 0°, 2°, 4°, 5°, and the clearance of T1, T2, T2.5, T3 and T4, 10 different parameters of the volute tongue were designed.

TABLE 1: The parameter distribution of the volute tongue

	T1 (27.6 mm)	T2 (36.7mm)	T2.5 (41.2 mm)	T3 (45.7 mm)	T4 (54.9 mm)	Rectangular tongue
0°	T1-0°	T2-0°	/	T3-0°	T4-0°	T5-0°
1°	/	/	/	T3-1°	/	/
2°	/	T2-2° (**type1/2**)	T2.5-2°	T3-2°	/	/
4°	/	T2-4°	/	/	/	/
5°	/	T2-5°	/	/	/	/

TEST EQUIPMENT AND TEST METHOD

Test equipment

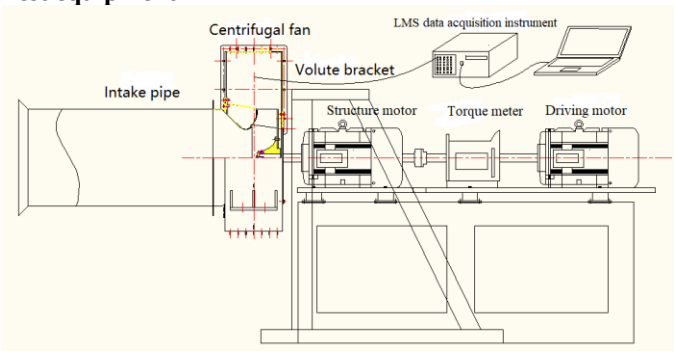


FIGURE 3: The centrifugal fan vibration decoupling test platform

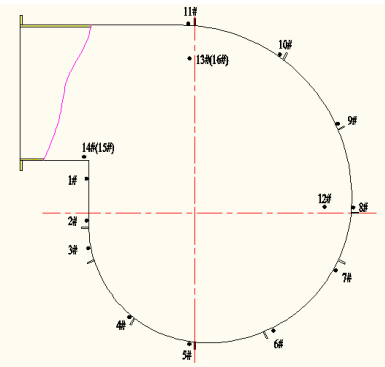
The centrifugal fan vibration decoupling test platform set up is shown in Figure 3. This test platform is mainly composed of the separation type volute module, the impeller driving module and the import and export test device. The separation type volute module consists of a volute, a collector and a volute bracket.

The fan volute is supported by the bracket, and the bracket is connected with rigid connection. In the impeller drive module, the impeller is connected with the structure motor, the torque meter and the driving motor through the rotating shaft. This module is supported by rubber isolators.

When the centrifugal fan is installed, the motor is generally connected with the volute and the impeller. The measured vibration of the motor's foot is the result of a mixture of several exciting sources, such as fluid, shafting and electromagnetic. It is also a result that the same excitation source is transferred through two paths which are the volute- motor and the impeller - shaft - motor. The volute of the experimental system is supported by the bracket separately, so that the volute module and impeller drive module can be physically separated, so as to separate the vibration generated by the fluid and the shaft, and separate the vibration transmitted by the volute path and the impeller-shaft-motor foot path. The structure motor is not energized, does not generate electromagnetic excitation, and is connected with the driving motor through the elastic coupling to separate the electromagnetic excitation of the drive motor, so as to achieve the effect of vibration decoupling. Therefore, the test platform can easily measure and analyze the influence of the change of the fluid excitation on the vibration acceleration of the different position of the centrifugal fan.

Test method

This paper takes a marine centrifugal fan as the research object. The impeller diameter is 510mm, the airfoil blade is backward, the number of blades is 12, the rated flow is 10000m3/h, and the rated speed is 2920r/min. Conduct fan flow test according to GB/T 1236 “performance test of standard air duct of industrial ventilator” and vibration and noise test of centrifugal fan according to GJB4058-2000 "measurement method of noise and vibration of ship equipment". The vibration testing system includes the B&K vibration acceleration sensors and the LMS data acquisition instrument. The vibration acceleration test range is 10Hz – 8kHz, and the layout of the vibration acceleration point of the fan is shown in Figure 4. The 1# - 11# measurement point is located at the 1/2 width of the fan volute and the direction is radial. 12#, 13# and 14# are located in the front panel of the volute, 15# and 16# are located in the rear panel and the direction is axial. Point 17# is located on the bracket of the volute, and point 18# - 21# is located on the feet of the structural motor, and the direction is vertical.



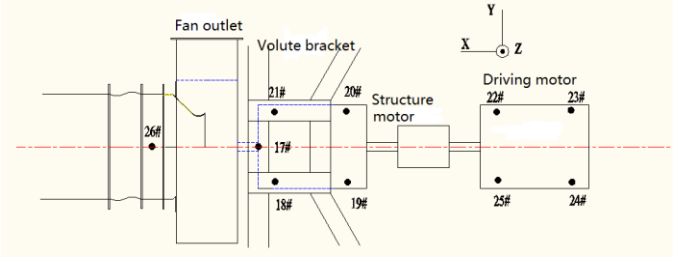


FIGURE 4: Layout of measuring points

The test is carried out at the rated flow rate and speed. Firstly, the original volute tongue was installed to measure the vibration acceleration of the blade frequency and the total frequency of each measuring point. On this basis, other volute tongue with different clearances, inclined angles and inclining ways should be replaced to repeat the test under the test conditions unchanged. Finally, another group of data was measured under the condition of a rectangular tongue which means without a volute tongue.

The blade frequency and harmonic frequency of the centrifugal fan are calculated by the following formula:

$$f_z = \frac{nz}{60} i \text{ (Hz)} \qquad (1)$$

In this formula: n is the speed, unit r/min; z is the blade number of the impeller; i—1, 2, 3... is the harmonic number. The blade frequency vibration of the fan is the strongest, and the vibration of the high order harmonic is gradually weakened. This paper mainly studies the change law of the blade frequency vibration. The blade frequency at rated condition is 584Hz by formula calculation.

ANALYSIS OF TEST RESULTS

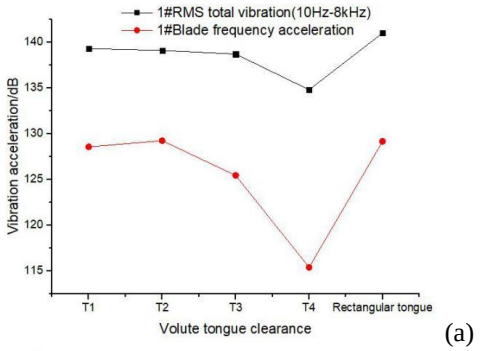
The influence of volute tongue clearance on the vibration

Analysis the five groups of test data when the inclined angle is 0 degree. Figure 5(a) is the variation curve of the RMS total vibration (10Hz-8kHz) and the blade frequency amplitude (584Hz) of point 1# in the tongue region of the volute under different volute tongue clearances. It can be seen that when the clearance is gradually increased from T1 to T4, the total vibration acceleration and the blade frequency vibration amplitude of the tongue area reach the minimum at T4. The blade frequency amplitude of point 1# was decreased by 13.2dB at most, and the total vibration decreased by 4.5db. When using the rectangle tongue which means without the volute tongue, the total vibration and blade frequency amplitude of point 1# are significantly increased.

Based on the energy average method, the spectrum of the 11 measuring points at the 1/2width of the volute are processed on average, and read the blade frequency amplitude and the total vibration after getting the radial average vibration acceleration spectrum of the volute, as shown in Figure 5(b). It can be seen that the point of the lowest blade frequency still appears in T4, which is reduced by 6dB compared with T2.

When the clearance is the largest under the rectangle worm tongue, only point 1# and 2# increase the amplitude of the

blade frequency. The other measurement points are all the minimum point of vibration. However, due to the vibration magnitudes of point 1# and 2# are the highest and the energy is the largest, it is still the result of vibration amplification after averaging the energy.



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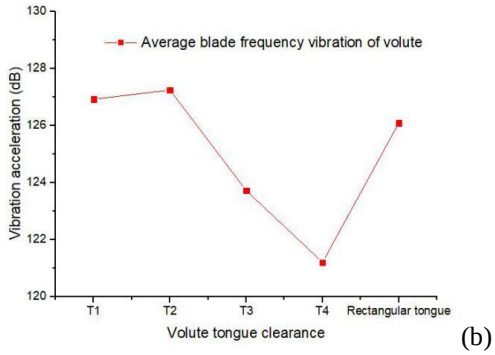
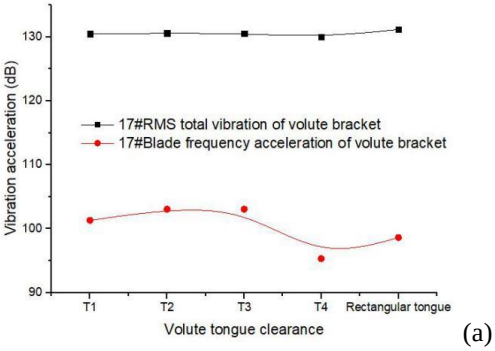


(b)

FIGURE 5: The vibration variation curve of tongue area and the volute in different clearances



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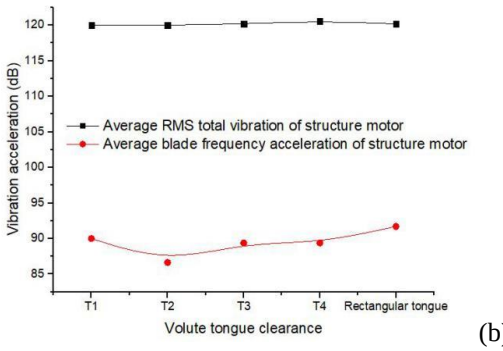


(b)

FIGURE 6: The vibration variation curve of volute bracket and structure motor in different clearances

As shown in Figure 6(a) is the variation curve of the blade frequency vibration amplitude in the direction of Z of point 17# which is in the installation position on the volute bracket. When the clearance increases from T1 to T4, the acceleration of the blade frequency is reduced by 6.0dB, which is similar to the volute tongue that the minimum value is reached at the distance of T4.

Figure 6(b) is the vibration change curve of the structure motor's feet after energy averaging. As the vibration decoupling test system is adopted in this experiment, the impeller-motor module is physically separated from the volute, so the blade frequency vibration of the motor foot is transmitted through the impeller-shaft-motor path. It can be seen that the change of the volute tongue clearance has little influence on the total vibration of the structure motor foot, and the variation of the blade frequency amplitude is smaller than that of the volute, which reduces 3.4dB at most. It is indicated that the vibration influence degree of the volute pathway is greater than that of the impeller-motor pathway for the change of volute clearance.

The influence of inclining way on the vibration of fan

TABLE 2: Comparison of the vibration of the two kinds of inclined volute tongue

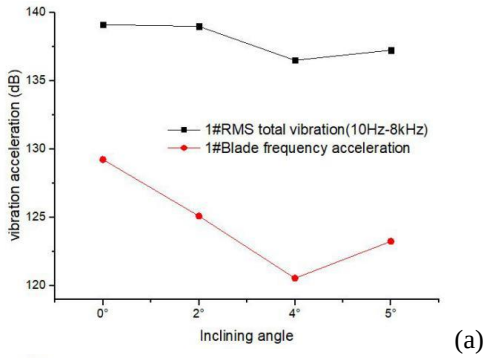
	Blade frequency（dB）		Total vibration（dB）	
Inclining way	Type1	Type2	Type1	Type2
1#	124.7	125.1	138.4	139.0
2#	131.4	131.9	140.5	140.9
3#	121.9	116.8	132.2	131.9
4#	122.5	119.7	136.2	136.0
5#	121.6	116.9	136.1	136.1
6#	127.7	115.8	138.3	137.8
7#	131.0	120.5	137.2	135.9
8#	124.9	115.3	136.5	136.5
9#	123.7	122.3	137.3	137.3
10#	128.0	120.4	136.6	136.1
11#	119.0	122.0	137.0	137.1
Radial average of the volute	126.8	123.9	137.3	137.3
17#	102.1	98.5	130.1	130.2
Average of structure motor feet	88.7	83.9	120.3	120.0

There is little difference between the total vibrations of each point in the two inclining ways. Table 2 is the contrast of the blade frequency vibration acceleration amplitude at the 1/2 width of the volute, the volute support and the motor's foot. It can be seen that except for point 1# and 2#, the amplitudes of blade frequency vibration of inclination Type2 is obviously less than that of Type1, as well as the radial average vibration of the volute. So the effect of inclination Type2 on the vibration damping of centrifugal fan is better.

The influence of inclining angle on the vibration of fan

Analysis the four groups of test data when the volute tongue clearance is T2. Figure 7(a) is the variation curve of the total vibration and the blade frequency amplitude of point 1# under different inclining angles. It can be seen that when the angle

gradually increases from 0 degree to 5 degree, the total vibration and the blade frequency vibration amplitude of point 1# first decreases and then increases, and the optimum angle is 4 degree. The blade frequency amplitude is reduced by 8.7dB at most, and the total vibration decreased by 2.6dB.



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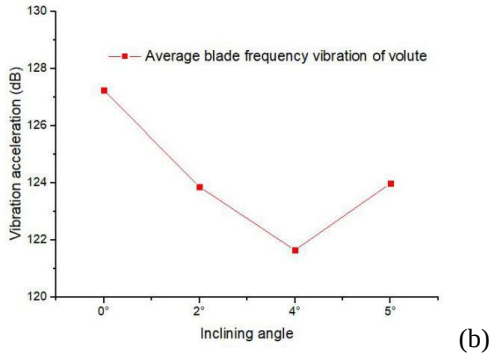
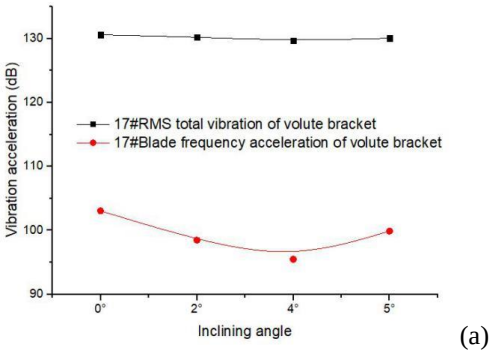


(b)

FIGURE 7: The vibration variation curve of tongue area and the volute in different angles



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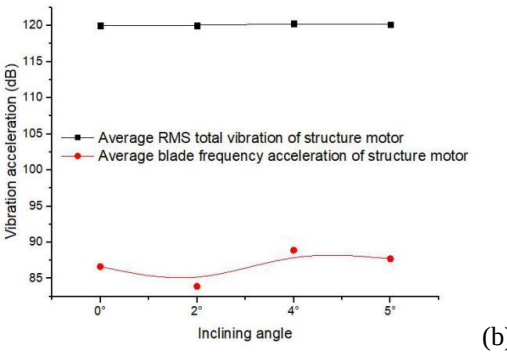


(b)

FIGURE 8: The vibration variation curve of volute bracket and structure motor in different angles

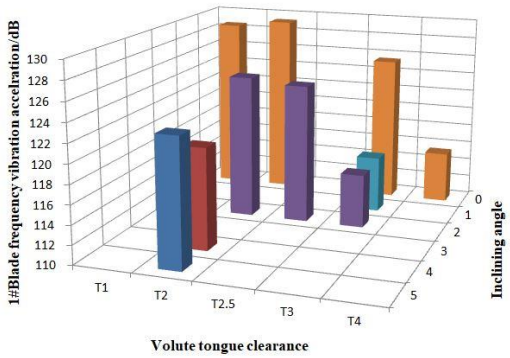
Figure 7(b) is the change curve of the blade frequency amplitude after averaging the spectrum of the measuring points of the volute. It can be seen that the blade frequency vibration acceleration first decreases and then increases with the increase of the inclining angle. The optimum angle is 4 degree and 5.6dB is reduced.

Figure 8(a) is the variation curve of the blade frequency amplitude of the installation position on the volute bracket. It can be seen that the variation trend of the blade frequency amplitude is the same as that of the volute tongue. It reaches the minimum at about 4 degree reduced by 7.5dB at most. From Figure 8(b), we can see that the result is similar to that of the tongue clearance that the change of the inclining angle has little effect on the blade frequency amplitude of the structural motor foot and there is no obvious change rule. It is indicated that the vibration influence degree of the volute pathway is greater than that of the impeller-shaft-motor pathway for the change of inclining angle.

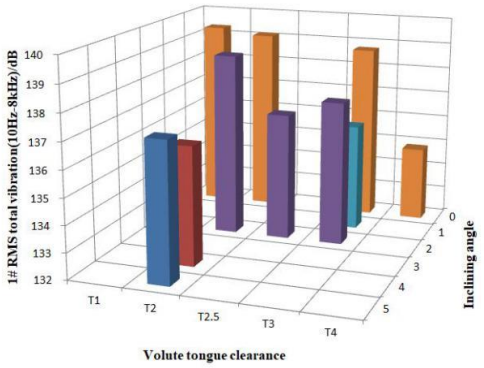
Through comprehensive comparison, it is known that there is a best inclining angle, and the best inclining angle for reducing fan vibration in this paper is about 4 degree. And compared with the volute tongue clearance, the effect of vibration reduction on the clearance is stronger than that of the inclining angle.

The parameter coupling of inclining angle and blade-tongue clearance

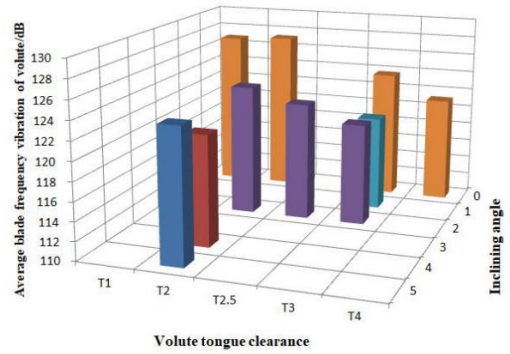
From figure 9(a) we can see that the blade frequency acceleration of point 1# is decreasing with the increase of the clearance. The amplitude of the blade frequency of the clearance of T4, the angle of 0 degree and the clearance of T3, the angle of 1 or 2degree are basically the same. The amplitude of the blade frequency of the clearance of T3, the angle of 0 degree and the clearance of T2 or T2.5, the angle of 2degree are basically the same. It shows that although the damping effect of inclined volute tongue is weaker than increasing blade-tongue clearance, the damping effect of large clearance can be achieved by applying inclining measures under the condition of small clearance. It can be used to solve the problem of large size and reducing the aerodynamic performance caused by increasing the blade-tongue clearance, and can be applied to the design of miniaturized low noise centrifugal fan.



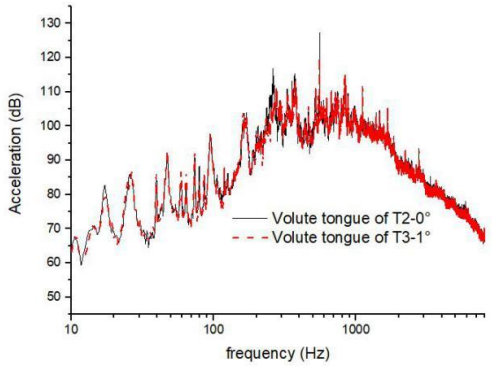
(a) Blade frequency acceleration of point 1#



(b) RMS total vibration(10Hz-8kHz) of point 1#



(c) Average blade frequency acceleration of volute



(d) Spectrum of T2-0 °and T3-1 °volute tongue

FIGURE 9: Vibration acceleration contrast of the volute tongue of different parameters

Contrast the vibration damping effect of the three groups of inclined volute tongue in clearance T3 with that of the four groups of inclined volute tongue in clearance T2, it can be found that the blade frequency amplitude decreased by 9.6dB when the inclining angle changes 1 degree at the clearance of T3, which indicate that the influence of the inclining angle on vibration is more obvious under large clearance.

From Figure9(a) to Figure9(d), we can see that the volute tongue with the clearance of T3 and the inclining angle of 1 degree is the best considering all aspects, whose blade frequency vibration amplitude is reduced by 12.8dB, and the total vibration is reduced by 3.2dB in the volute tongue area. The radial average blade frequency acceleration of the volute is reduced by 7.2dB.

CONCLUSION

The vibration of the volute of fan can be significantly reduced by changing the blade-tongue clearance and inclining angle, especially the blade frequency vibration. The inclining type of keeping the radius of volute tongue constant is better. The blade frequency amplitude of the volute vibration decreases firstly and then increases when the inclining angle and clearance increases independently. There is an optimum inclining angle for a particular blade-tongue clearance, which is 4 degree when the clearance is original design clearance.

The volute tongue is the area with the greatest change in the blade frequency vibration, followed by the installation position of the volute. Because of the vibration decoupling of the test device, the change of two kinds of volute tongue parameters has the least influence on the blade frequency vibration of the impeller route to the motor's foot.

The vibration influence degree of the tongue clearance is greater than that of the inclining angle, but the damping effect of large clearance can be achieved by applying inclining measures under the condition of small clearance. The influence of the change of inclining angle on blade frequency vibration of centrifugal fan is more obvious under large clearance.

In the volute tongue area, the blade frequency acceleration is reduced by 12.8dB and the total vibration is reduced by 3.2dB when using the best volute tongue designed by two parameters coupling.

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