Cooling Mechanism and Experimental Study of Oil-free Scroll Compressor

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Abstract

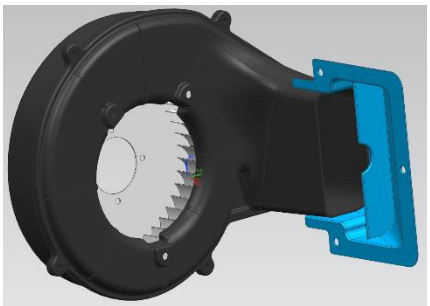
Two cooling methods of oil-free Scroll compressor are studied and analyzed, with emphasis on the common air cooling methods, and the influence of the basic geometric parameters of scroll case and multi-wing Centrifugal Fan on the aerodynamic characteristics of the fan is discussed. In order to find out the most suitable cooling method for the test prototype, the optimum combination of cooling structure was obtained by designing different cooling structures, which provides some theoretical and guiding significance for the cooling structure of the oil-free scroll compressor.

Keywords

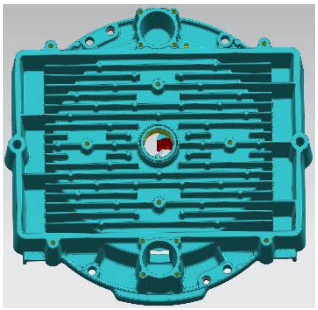
Scroll Compressor; Oil-free Type; Volute; Centrifugal Fan; Cooling System.

1. Introduction

The compressor is divided into oil-containing type and oil-free type according to lubrication. The oil-containing type compressor runs with oil when it works, so the compressed air has low grade and is difficult to be used directly, because the oil-free compressor does not contain oil in the working chamber, the compressed air can be used directly, so it is widely used in the fields of medical treatment, new energy electric vehicle and air brake pump. Scroll compressor is a new type of positive displacement compressor, which has simple structure, few working parts and produces much less noise when working than other types of compressors, therefore has the quite widespread application prospect. The oil-free Scroll compressor is a new type of scroll machine, although it has the advantages that other types of compressors can't match, however, because the oil-free scroll compressor works by the direct contact of the dynamic and static scroll disks, because of its small size, the machine has poor heat dissipation. The heat generated during the working process can't be transferred to the outside world automatically. Therefore, the temperature of the whole machine is extremely high during the compressed air process, it not only reduces the service life of the oil-free scroll compressor, but also greatly hinders the popularization and use of the oil-free scroll compressor.[1]-[2]



a) Air Cooled Structure



b) Water-Cooled Structure

Figure 1. Cooling structure

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At present, the two cooling methods of air-cooling and water-cooling are often used in oil-free scroll compressors in practical application, the air-cooled main cooling structure is shown in Fig. 1a), and the water-cooled main cooling structure is shown in Fig. 1b). The air-cooled structure is mainly composed of multi-wing centrifugal fan and volute, and the water-cooled cooling structure is mainly composed of liquid cooling and water-cooled conveying pipe.

At present, the air-cooling method is often used in the oil-free scroll compressor. Due to the limitation of the whole structure of the machine, it is necessary to limit the structure size of the centrifugal fan as much as possible, so that the spiral case profile is optimized, after the improvement, the structure size of the fan is reduced and the performance is improved [3]; It is proved that the optimized circular-arc vortex tongue can restrain the noise at the vortex tongue and reduce the aerodynamic noise of the centrifugal fan [4]; The axial position between the impeller and the volute has a great influence on the aerodynamic performance of the centrifugal fan, there is a relative value between the outlet width of the impeller and the total width of the volute [5]; Under the condition of constant rotating speed, the basic geometric characteristics of multi-wing centrifugal fan blades, the number of blades and the size of the impeller have great influence on the cooling effect, the rotational speed has a decisive influence on the cooling effect [6]-[7]; Under the condition of fixed structure size, the inlet installation angle of multi-blade blade and the distance between blade and volute have great influence on the performance of centrifugal fan [8]; Taking the total pressure of the centrifugal fan as the optimization objective, four key parameters of the fan are selected, the fan is optimized and the numerical simulation is carried out, the variation law between pressure and flow rate is obtained, and the overall structure of the fan is improved [9]; In order to optimize the blade of centrifugal fan, a parametric method of quadratic non-uniform b-spline curve is adopted, by limiting the exit angle of blade, chord length and maximum curvature of blade shape, the optimized blade profile improves the aerodynamic performance of the fan [10].

2. Exhaust Temperature of Scroll Compressor

At present, it can be found that the exhaust temperature of the oil-free scroll compressor is higher than that of the oil-free double-scroll compressor, and the exhaust temperature of the oil-free double-scroll compressor can reach above 200 °C, it is difficult to directly apply such high temperature in the actual situation, so it is necessary to take certain measures to reduce the temperature of scroll compressor and exhaust temperature. Table 1 shows the exhaust temperature of different scroll compressors.

Table 1. Oil-free Scroll Compressor Temperature

Reference	Lubrication Mode	Type \Use	Exhaust Temperature (℃)
Xiao Genfu. et al [11]	Oil-free type	Air compressor	180-200
Hu Ronghua. et al [12]	Oil-free type	Air compressor	165
Peng Bin. et al [13]	Oil-free type	Air compressor	104
Liu Tao.et al [14]	Oil-free type	Natural gas compressor	160
Cardone M .et al [15]	Oil-free type	Air compressor	150

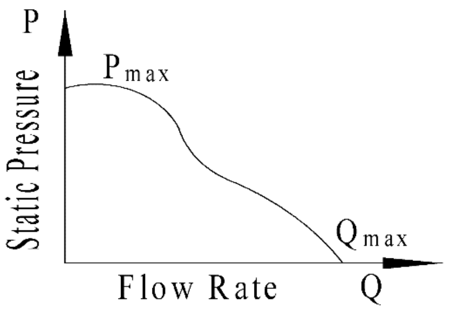

Figure 2. $P-Q$ Schematic Diagram of Curve

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3. Cooling Mechanism

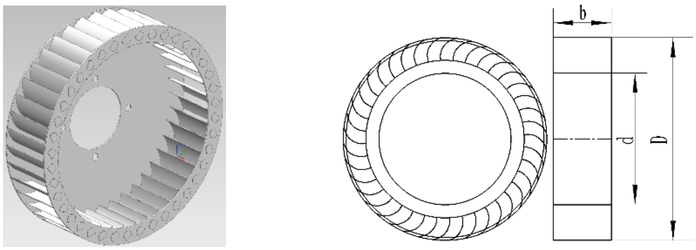
3.1 Cooling Methods

At present, the cooling methods of oil-free Scroll compressor include air-cooling and water-cooling. Air-cooled units with small displacement are often used, and water-cooled units with large displacement are often used.

3.2 Air Cooled

Fig. 2 shows the standard static pressure and flow rate of the Centrifugal Fan. Q_{max} The larger the flow rate is, the smaller the standard static pressure is.

3.2.1 Multi-blade Centrifugal Fan



a) 3D modeling b) Two-dimensional sketch

Figure 3. Multi-blade Centrifugal Fan

Fig. 3 shows the schematic diagram of the multi-blade centrifugal fan. Its simple structure is mainly composed of the blade and fixed support frame, impeller inside and outside diameter, impeller width, as well as the number of impeller, and other basic geometric parameters have a certain impact on the air volume, multi-wing centrifugal fan parameters are as follows:

$$\text{Outer Diameter of Impeller } D\text{: } D = \frac{60u}{\pi n} \tag{1}$$

Where, u - cycle time, n - Rotational speed;

$$\text{Leaf width } b\text{: } b = \frac{2}{5}D \tag{2}$$

$$\text{Number of blades } Z\text{: } Z = \frac{\pi D}{0.5(0.7{\sim}1)R_k} \tag{3}$$

$$\text{Discharge coefficient } \varphi\text{: } \varphi = 4D_m b_m c_m \tag{4}$$

Where, c_m- For the flow coefficient; D_m-Ratio of blade inlet to wheel diameter, $D_m = \frac{d}{D}$; b_m-Relative width of Blade, $b_m = \frac{b}{d}$;

$$\text{Fan Flow } Q\text{: } Q = \left(\frac{n_s p^{\frac{3}{4}}}{n}\right)^2 \tag{5}$$

Where, p -Total air pressure; n_s-Specific speed of Fan, it reflects the characteristics of the fan, the expression is as follows: $n_s = 5.54n\frac{\sqrt{0.5Q}}{PF^{\frac{3}{4}}}$

a) 3D Modeling b) Two-Dimensional Sketch

Figure 4. Schematic View of Spiral Case

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3.2.2 Spiral Case

The basic geometric parameters of the volute are calculated as follows:

$$\text{Expanded equivalent area } F_k:\ F_k = A \times B \tag{6}$$

$$\text{Volute Opening } A:\ A = Q/B \times C'_{2u} \tag{7}$$

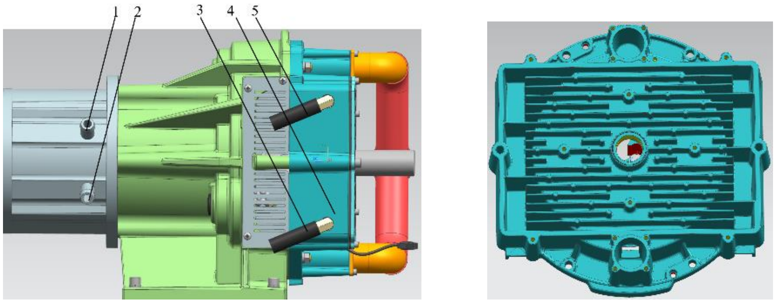
$$\text{Volute Width } B:\ B = (1.05 \sim 1.2)b \tag{8}$$

$$\text{Exit Length } C:\ C = (0.05 \sim 0.1) \times A \tag{9}$$

$$\text{Vortex Tongue Gap } t:\ t = (0.05 \sim 0.1) \times D \tag{10}$$

$$\text{Radius of Arc } r:\ r = (0.03 \sim 0.06) \times D \tag{11}$$

3.3 Water Cooling

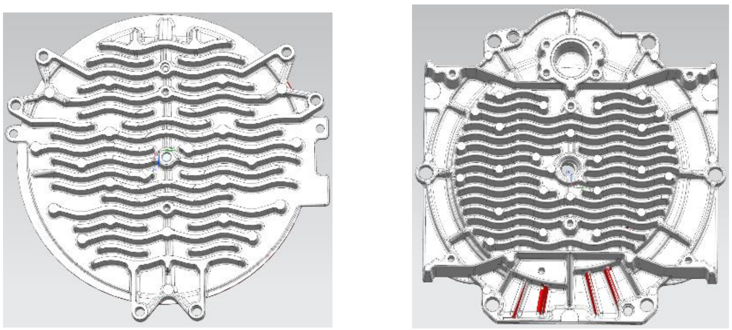


a) Cooling Position b) Static Volute Tank

Figure 5. Cooling System

Fig. 5 shows a certain type of water-cooled oil-free scroll compressor. The whole cooling system includes: drive motor water inlet 1, drive motor water outlet 2, stationary scroll plate water outlet 3, stationary scroll plate water inlet 5 and stationary scroll plate cooling sStructure 4. In order to limit the size of the whole machine, there is no cooling structure on the moving vortex plate, because the exhaust gas of the machine is large, which leads to high operating power and requires cooling both the machine and the drive motor The adoption of water-cooling type can effectively reduce the temperature of the whole machine and the exhaust gas, because the water circulation cooling system is added, the structure size of the whole machine set is increased.

3.4 Fins for Heat Dissipation



a) Fixed Scroll b) Orbiting Scroll

Figure 6. Active and Stationary Scroll Disks

The cooling air from the volute passage passes through the passage pipe to the back of the dynamic and static scroll disk, and both are cooled and cooled at the same time. In order to increase the cooling effect, in the oil-free scroll compressor structure design, but also often in the dynamic and static scroll plate to add heat sink, as shown in fig. 6. In order to improve the cooling effect, the wind direction at the back of the stationary scroll plate should be parallel to the fin arrangement direction, and the fin should be closed, as much as possible to increase the heat dissipation area and wind efficiency.

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4. Test Comparison

4.1 Air Cooling

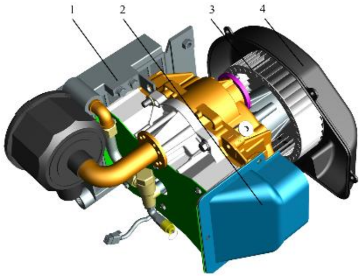
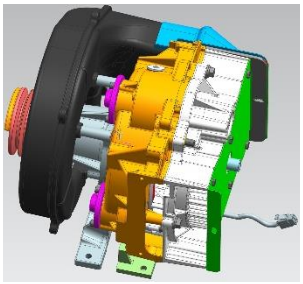
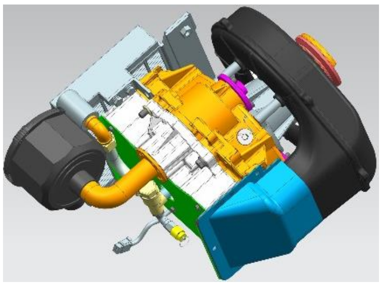


Figure 7. Air-Cooled Structure

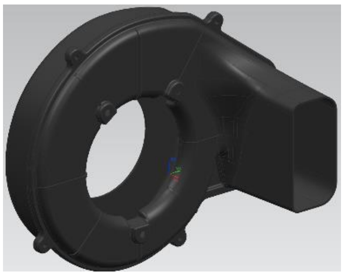
Fig. 7 shows the different heat dissipation structure of the scroll compressor. The whole test components include: compressor, Volute 4, Radiator 1, Guide Plate 2, Multi-wing Centrifugal Fan 3. The following 10 different combinations of machine tests were carried out. Each component is shown in Fig. 8. Working Condition 1: Scroll Compressor B; Working Condition 2: Scroll Compressor A; Working Condition 3:Scroll Compressor B, Wind Wheel A; Working condition 4: Scroll Compressor B, Wind wheel B; Working condition 5: Scroll Compressor A, Radiator B; Working Condition 6: Scroll Compressor A, Radiator B, wind wheel B; Working Condition 7: Scroll Compressor B, Air Guide Plate B; Working Condition 8: Scroll Compressor B, Air Guide Plate A, Wind Wheel B; Working Condition 9: Compressor A, Radiator B, Air Guide B; Working Condition 10: Compressor A, Radiator B, Air Guide Plate B, Wind Wheel B.



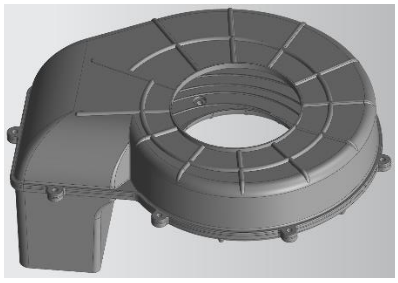
a) Scroll Compressor A



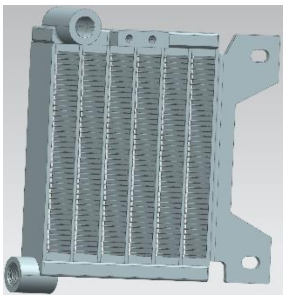
b) Scroll Compressor B



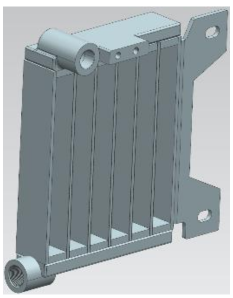
c) Spiral Case A



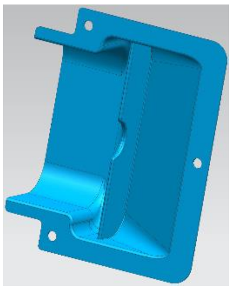
d) Spiral Case B



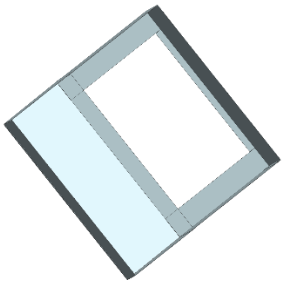
e) Radiator A



f) Radiator B



g) Air Guide A



h) Air GuideB

Figure 8. Different Heat Dissipation Structure of Scroll Compressor

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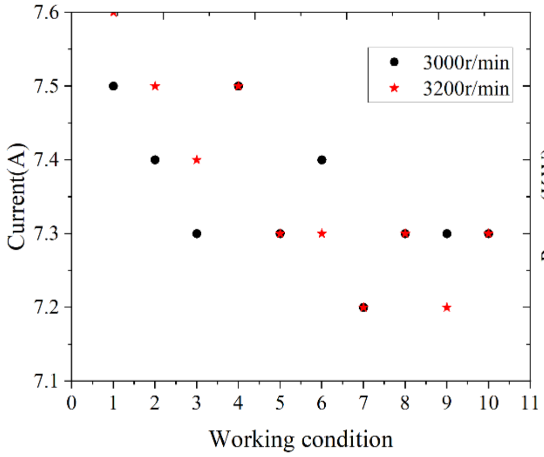
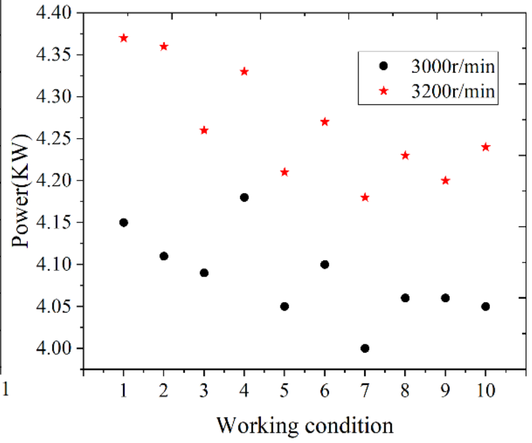
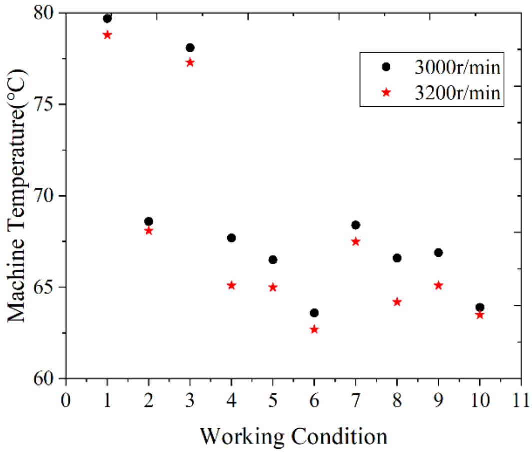
4.1.1 Structural Tests of Different Air Ducts



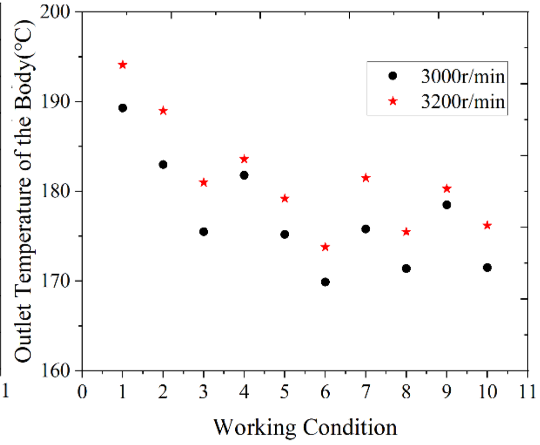
a) Current



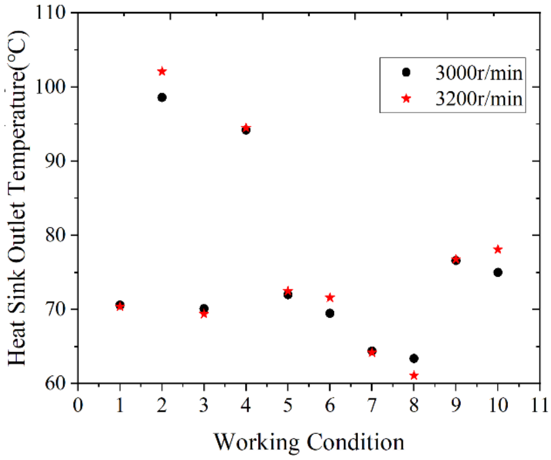
b) Power



c) Body Temperature



d) Out Temperature of the Body



e) Heat Sink Outlet Temperature

Figure 9. Performance Parameters

Fig. 9 shows the variation of drive motor current and power and exhaust temperature of scroll compressor under different operating conditions. It can be seen from the diagram that the exhaust temperature varies under different working conditions, the temperature difference of the engine body is the biggest under the same Working Condition 4, the biggest under the Working Condition 7, and the biggest under the Working Condition 2 and Working Condition 1 has the highest body temperature and exhaust temperature, Working Condition 2 has the highest exhaust temperature, and Working Condition 8 has lower temperature than other working conditions.

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4.1.2 Wind Measurement

In order to measure the wind speed and temperature of the air outlet of the scroll compressor, the following four models are assembled: Working Condition 1: Compressor A; Working Condition 2: Compressor A, Wind Wheel B; Working Condition 3: Compressor A, Wind Guide Plate A; Working Condition 4: Compressor A, Wind Guide Plate A, Wind Wheel B. Fig. 10 shows the positions of wind speed and temperature on the moving and stationary scroll disk of the scroll compressor.

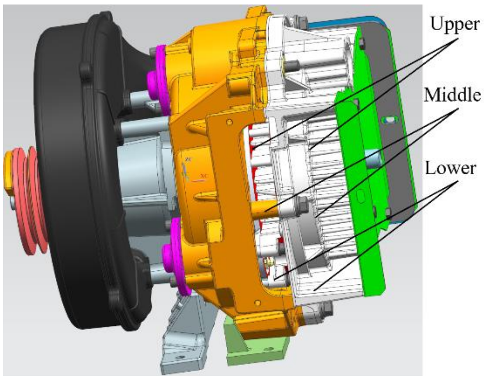
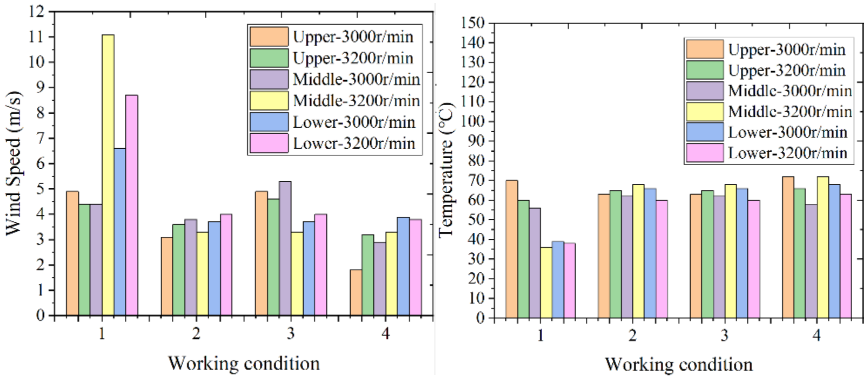
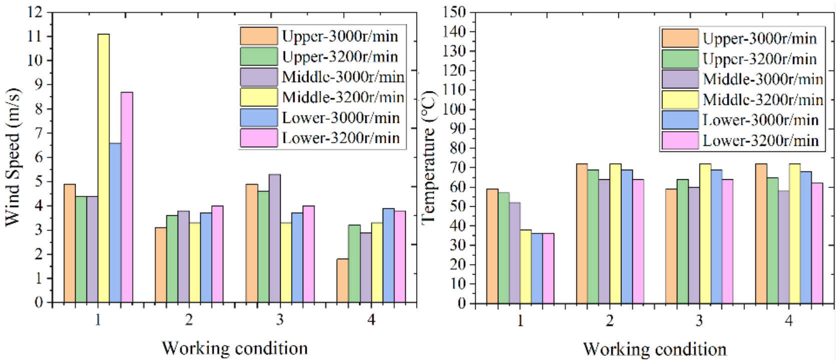


Figure 10. Location of Air Outlet



a. Wind Speed b. Temperature

1) Fixed Scroll



a. Wind Speed b. Temperature

2) Orbiting Scroll

Figure 11. Air Velocity and Temperature at the Air Outlet

Fig. 11 shows the variation of wind speed and temperature at the three positions of the air outlet of the oil-free scroll compressor under different operating conditions. It can be seen from the diagram that the wind speed at the moving scroll is higher than that at the stationary scroll, and the temperature is the opposite, the higher the speed of the compressor, the higher the wind speed at the exit, and the Lower the temperature.

4.2 Water Cooling

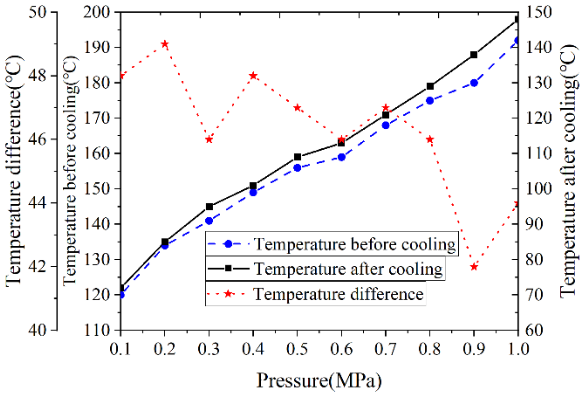


Figure 12. Water Cooling Test

Fig. 12 shows the variation of exhaust temperature with pressure in an oil-free scroll compressor. In the diagram, the exhaust temperature increases linearly with the increase of pressure, and at a pressure of 1 MPa, the exhaust temperature is 192 ℃, the cooling temperature is 148 ℃ and the temperature difference is 44 ℃, more and more heat will accumulate in the cooling liquid tank, which will weaken the liquid cooling effect.

5. Conclusion

(1) Two kinds of cooling methods for oil-free scroll compressor are expounded. The air-cooled type is usually used for the occasion of small exhaust volume, and the water-cooled type is usually used for the occasion of large exhaust volume.

(2) The output performance of the air-cooled cooling structure is mainly determined by the performance of the multi-wing centrifugal fan and the volute. The main performance of the water-cooled structure is determined by the flow rate of the circulating pump and the capacity of the liquid cooling box, however, due to the overall size of the compressor, liquid cooling system is not easy to do too large.

(3) The actual effect of the two cooling methods is verified by experiments. For the same type of machine, the cooling effect of air cooling mode 6 is the best.

Acknowledgments

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