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Experimental Studies of the Multi-column Envelope Profile Meshing Pair in Single Screw Compressor

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ABSTRACT

In order to verify the reliability and utility of the multi-column compound profile theory, a couple of designed multi-column compound profile meshing pairs are applied in an oil-flooded single screw compressor as the experimental prototype, then the prototype runs 2000 hours continuously in the experimental platform, and the displacement is detected. Results show that the prototype has a steady displacement, and the energy efficiency grade is very close to the best grade. This proves that the new pair has a good sealing performance. A comparative observation on the star wheel tooth flanks are conducted at the end of test, and the results demonstrate that the nodular cast iron star wheel with multi-column compound profile has a high wear resistant property and a good hydrodynamic lubrication characteristic. This result also demonstrate that the nodular cast iron can be used to make star wheel to reduce the cost of single screw compressor instead of the expensive PEEK material.

1. INTRODUCTION

Since the first single screw compressor was invented in 1960s (Zimmern, 1965), it has been successfully used in various industrial fields (Wu and Tao, 2006). Compared with other screw compressors, a single screw compressor has excellent mechanical balance, lower noise, higher compression ratio and good maintenance performance. However, it does not occupy the main position in screw compressor market because of poor wear resistance performance of the star wheel (Wu and Feng, 2009).

In order to improve the wear resistance of the star wheel, a high wear-resistant material, PEEK, is used as the manufactured materials of the star wheel. However, the adoption of this material means high costs. Then, for reduce the costs, it is important to improve the meshing pair profile of the star wheel. The original profile is a fixed straight line, invited by Zimmern (1960), which is obviously easy to be worn. Thus, Zimmern (1976) developed a column envelope meshing pair, so that the contact line can move on the star wheel tooth flank. A straight line double envelope meshing pair and a column double envelope meshing were introduced by Jin GX (1982,1986). The double envelope meshing pair means using the straight line or columns enveloped surface of the screw rotor groove flank as a generating tool to envelop the star wheel tooth flank. However, because the machining difficulties, this kind of profile has not been applied. In 2005, our team developed multi-straight lines envelope profile with the purpose of dispersing friction area to prolong the operating life (Feng *et al.*, 2005).there are several straight lines on the tooth flank, and these lines mesh with the screw groove flank alternately. In 2009, our team developed multi-column envelope meshing pair (Wu and Feng, 2009), which was based on the column envelope and multi-straight lines envelope meshing pairs.

In order to verify the reliability and utility of the multi-cylinders compound profile theory, a designed multi-column compound profile meshing pair is applied in an oil-flooded single screw air compressor as the experimental prototype, then the prototype ran 2000 hours continuously in the experimental platform, and the displacement is detected.

2. MULTI-COLUMN ENVELOPE PROFILE

The designed multi-column envelope profile is indicated in Fig.1. Both the tooth flank and the screw flank are multi-segment surfaces. The tooth flank consisted of more than two parts cylindrical segments. The screw flank is consequently consisted of multi-enveloped surface, which is the envelope of the columns. During the meshing, the columns of the tooth mesh with the multi-enveloped surface of the groove flank alternatively. The contact line is moved on the tooth flank and the screw flank, so that the contact area is enlarged and the friction is dispersed. In order to reduce the gas leakage along the length of the tooth, the first column is designed as close to the high pressure side of the star wheel as possible.

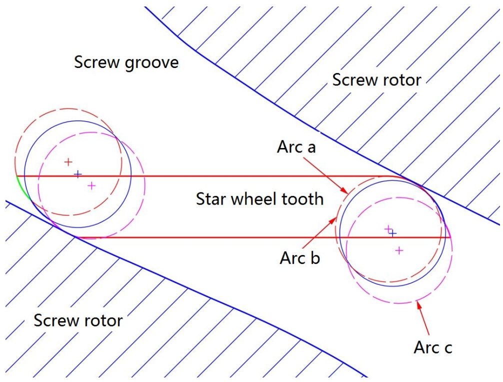


Figure 1: Multi-column envelop profile

3. TEST DESIGN

3.1 Compressor unit system

An oil flooded single screw compressor unit is used as the experiment platform. The system include gas path, oil path and electronic control. The major parameters of the compressor unite and the meshing pair are shown in table 1.

Table 1 The major parameters of the compressor unit and the meshing pair

Unite parameter	Value	Meshing pair parameter	Value
Ratio of teeth number to grooves number	6/11	Center distance of the compressor/mm	164
Discharge pressure /MPa	0.5~0.7	Diameter of screw rotor/mm	205
Moto power/KW	45	Diameter of star wheel/mm	221
Rotation rate/$r\cdot min^{-1}$	2970	Width of tooth/mm	28
Cooling mode	Air cooling	Material of star wheel	nodular cast iron

The gas path include air filter(do not shown in Fig.2), single screw compressor, oil and gas separator, minimum pressure valve, air cooler, moisture separator and so on. After been cleaned by air filter, air is sucked in the single screw compressor, and mixed with the oil injected. The mixed gases enter the oil and gas separator after been compressed, then, the oil is collected in the tank at the bottom of the oil and gas separator, and the compressed gases flow out and enter the cooler. Eventually, the cooling compressed gases exhaust after passing through the moisture separator.

The oil path include a tank(at the bottom of the oil and gas separator), oil cooler, oil filter, delivery valve, and oil injection pipe. At the beginning of the operating, the gases pressure is set up in the oil and gas separator at first. Because the pressure is bigger than the pressure in the compression chamber, the oil is driven pass through the oil cooler, oil filter, and the delivery valve. and finally injected into the chamber. The oil not only take the heat generated from compressing process, but also is helpful for sealing and lubricating which can reduce the gas leakage and the friction of the tooth.

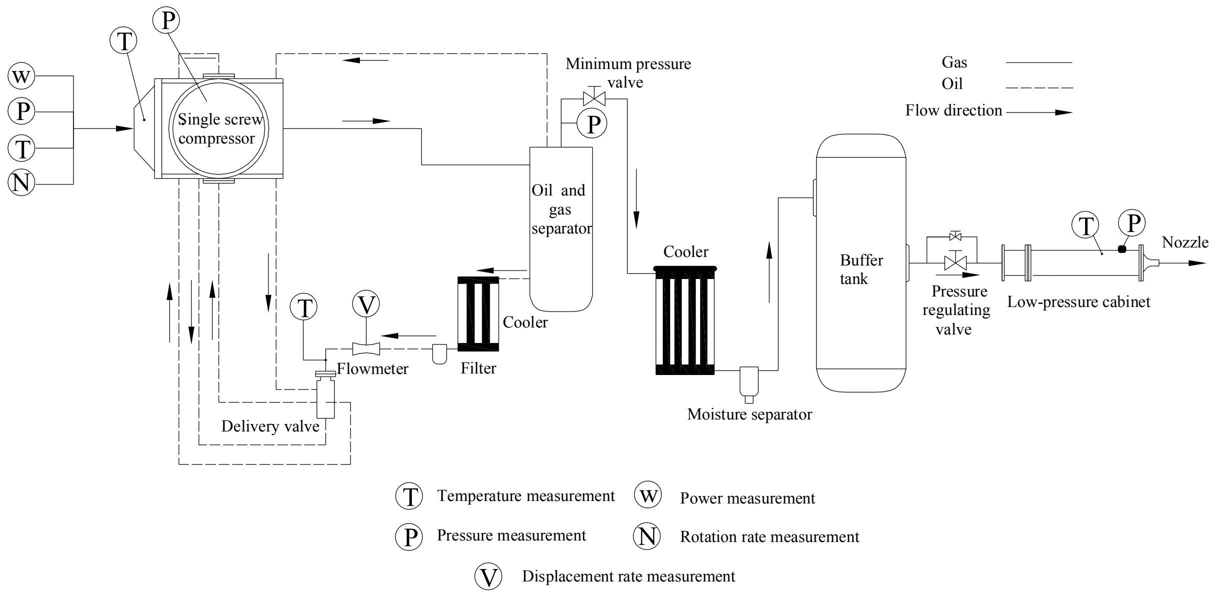


Figure 2: The experiment system of single screw compressor

3.2 Prototype

The multi-column envelope meshing pairs are applied in an oil flooded single screw compressor instead of the original straight-line envelope meshing pairs, as shown in Fig.3. The new star wheels are made by nodular cast iron.

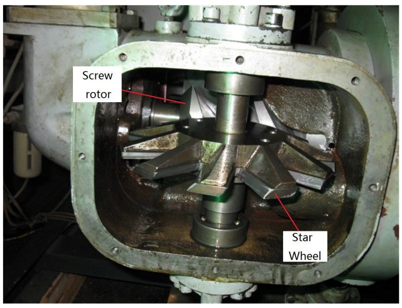


Figure 3: Prototype with multi-column envelope meshing pairs

In this paper, a single screw compressor performance experiment in accordance with GB/T3853-1998 " Methods of flow measurement for displacement compressor" requirements of China. The main test measurement data are suction temperature, suction pressure, discharge temperature, discharge pressure, displacement, motor speed, and motor power and so on.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The rated power of the motor is 45KW, but the motor input power will achieve 60KW when the prototype operates at 100% capacity at 0.7 MPa discharge pressure. For prevent motor faults, the discharge pressure is set to 0.5MPa. When measuring the performance parameters, the discharge pressure is adjusted to the desired pressure.

4.1 Analysis of the prototype displacement

The Variation of the displacement with time is indicated in Fig.4. When the discharge pressure is 0.5MPa, the displacement is approximately 8.17 $m^3 \cdot min^{-1}$ and presents a stable performance. When the discharge pressure is 0.7MPa, the average displacement is 8.15$m^3 \cdot min^{-1}$. The displacement has a slightly decrease when the discharge pressure changes from 0.5MPa to 0.7MPa (Fig.6). The stability of the displacement with time proves the multi-column envelope profile has a good wear resistance.

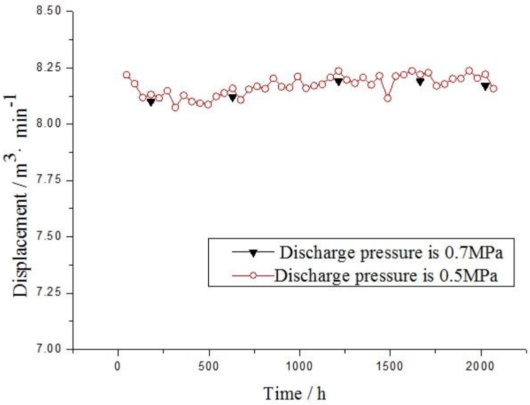


Figure 4: Variation of the displacement with time

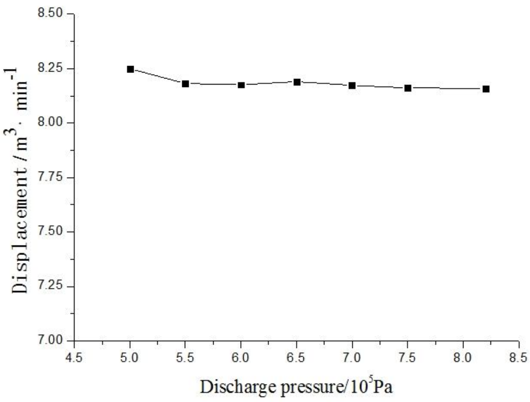


Figure 5: Variation of the displacement with discharge pressure

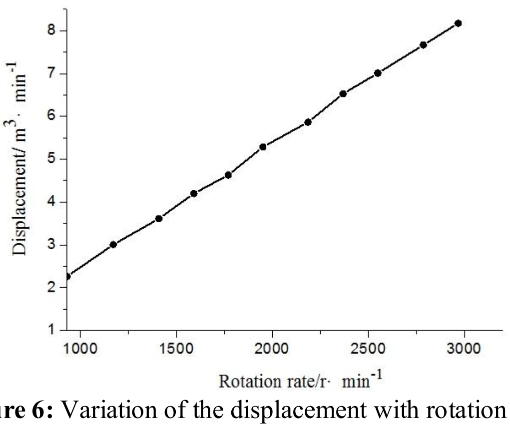


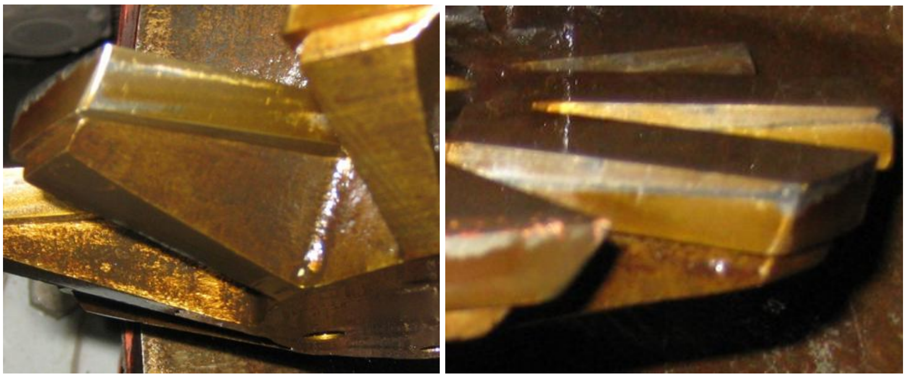
Figure 6: Variation of the displacement with rotation rate

When the discharge pressure is 0.5MPa, the rotation rate of the motor is regulated by frequency converter (Fig.6). The displacement increases linearly with the rotation rate increases, which is coincidence with the theoretical calculation. It is indicated that the volumetric efficiency and the adiabatic efficiency do not change significantly with the rotation rate, and the meshing pair with multi-column envelope profile has a good sealing performance at different rotation rate. These features will facilitate displacement regulation by using frequency converter.

4.2 Analysis of the wear of the tooth

After 2000 hours running, the side cover is opened and the tooth flanks are observed. As indicated in Fig.7, the white area is the column surfaces. It is observed that the top of the tooth and the bottom of the tooth has a slightly wear.

After analyzing, the slightly wear may caused by machining errors, assembling errors, and the reduction of the clearance width due to thermal deformation. Because the temperature in the compression chamber is very high(about 90℃), the thermal deformation of the screw and the tooth is significant, then, thermal deformation maybe the major reason of the wear. Therefore, the machining errors and assembling errors should be minimized in the next prototype, and the clearance width between the groove flank and the tooth flank should be properly increased.



（a）Front side of the tooth （b）Back side of the tooth

Figure 7: The tooth flank appearances after 2000 hours running

5. CONCLUSIONS

The multi-column envelope profile meshing pair has been applied in an oil-flooded single screw compressor as the experimental prototype. After 2000 hours running, three conclusions can be obtained as follows:

1.The displacement of the prototype is $8.15m^3 \cdot min^{-1}$, when the discharge pressure is 0.7MPa. The volumetric inefficiency is 91.3%, and the energy efficiency grade is very close to the best grade. If the unreasonable design of the casing and the system is modified, the energy efficiency grade will be improved further.

2. The fact that the prototype has a steady displacement proves the multi-column envelope profile has a good wear resistance, and the star wheel can be made by nodular cast iron.

3.There exist a slightly wear on the tooth flanks. After analysis, the thermal deformation of the tooth and the screw maybe the major reason of the wear, so ,the clearance width should be properly increased in future designs.

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