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New concept single screw compressors and their manufacture technology

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Abstract. Single screw compressors were generally acknowledged as one of the nearly perfect machines by compressor researchers and manufacturers. However the rapid wear of the star-wheel in a single screw compressor during operation is a key reason why it hasn't previously joined the main current compressors' market. After more than ten years of effective work, the authors of this paper have proposed a new concept single screw compressor whose mesh-couple profile is enveloped with multi-column. Also a new design method and manufacture equipment for this kind of compressor have been developed and are described in this paper. A lot of prototype tests and a long period of industrial operations under full loading conditions have shown that the mesh-couple profiles of the new concept single compressors have excellent anti-wearness.

1. Introduction

A single screw compressor (SSC) is consist of a screw rotor, two star-wheels and a housing. SSC belongs to a kind of rotary compressors. Considering its structure and working property, it is mainly used in compression, transport of air, petrol gas and refrigeration media. Its application is the same as or overlaps that of reciprocating compressors, screw compressors, scroll compressors etc. shown in figure 1.

Especially, in some new and high-tech engineering fields SSC can't be substituted. For example, gas transportation engineering with large flow-rate and high compression ratio, air compression engineering with high compression ratio and oil free, some lower noise facilities in naval ships.

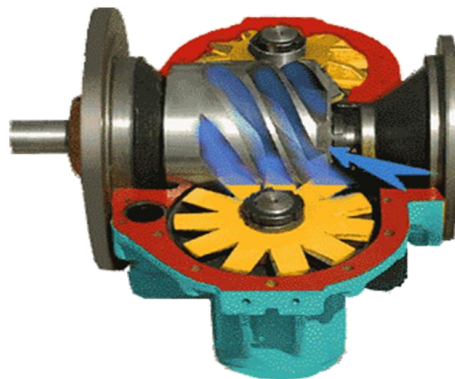


Figure 1. The structure of a single screw compressor.



In 1960, Zimmern opened his patent to public of SSC, and in 1962 the first SSC prototype was produced in Europe [1, 2]. In past over 50 years, a lot of this traditional SSC, in which single straight line and single column are used to envelope engaging profiles of rotors and star-wheels, were produced in many companies from England, Germany, America, Austria, Japan and so on. This made SSC played a role in the world compressor market.

China began to develop SSC in 1970s. Beijing First General Machinery Factory, Xi'an Jiaotong University and Shanghai 704 Institute then developed prototypes of this traditional SSC [3]. But star-wheel's rapid wear increased leakage seriously within a short time, which of course, hindered SSC's coming into a wilder market.

Since 1990's, along with the improvements of Chinese machinery manufacture level and the broad applications of PEEK material, star-wheel wear-resistant has been improved obviously. This made traditional SSC met the needs of common engineering in the whole. In this way, many kinds of SSC products from Guangdong GANEY, Shanghai FHOG, Shanghai GANRS etc. came into the market. In 2012, a report from Chinese Compressor Association says that SSC's output is over 8000~10000 every year in China. But in the same time screw compressor's output is up to about 100~130 thousand.

Outstanding advantages of a single screw compressor are as follows:

- 1) Axial and radial compound forces acted on a screw rotor by gas in compression chamber is balanced with zero. There is only a gravity force of a rotor acting on the bearing.
- 2) The forces acting on a star-wheel is very small, as it is only about one fourth of that acting on the screw rotor while operating in same conditions.
- 3) There is no leakage triangle area in an engaging pair of SSC, which always exists in a screw compressor.
- 4) Engaging forces between a rotor tooth and a star-wheel tooth is very small.
- 5) Noise level of SSC is lower as 3~5dB (A) than that in screw compressor.

All these advantages encourage a lot of researchers and customers to study and develop SSC.

2. Research of new conception engage profile

Authors of this paper examined several SSC's star-wheels which are produced by a famous international compressor company. Its star-wheel is only put into operation for 3~5 hours. The star-wheel's back and front surfaces are shown respectively in figure 2a and figure 2b. It is obviously that there is a straight edge in each surface. Figure 3 shows engaging situation of a star-wheel tooth with a rotor groove in different rotation positions. At any position on the star-wheel' engaging profile, there is only one edge point which is always contacting with the rotor tooth groove flank. In other words, the edge can be easily wear out and increase the leakage.

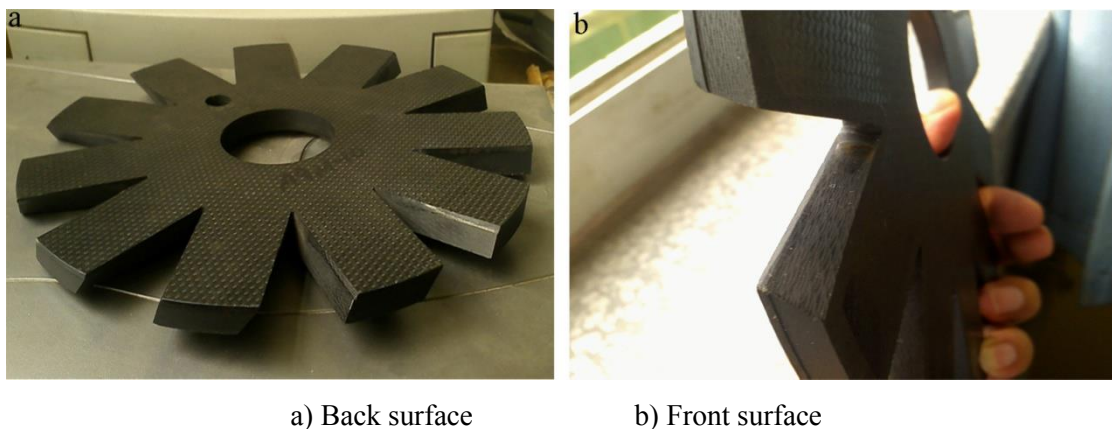


Figure 2. Star-wheel enveloped with single straight line (3~5 hours operation).

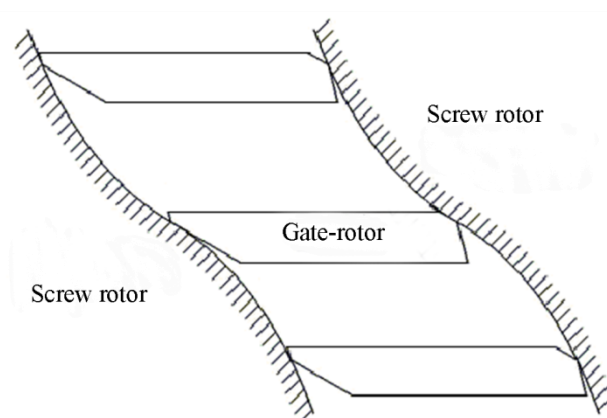


Figure 3. Engaging profile enveloped with single straight line.

Figure 4 expresses the enveloping principle of single column profile (bar milling) for a rotor groove. After processing of the rotor groove with a bar milling machine, the surface on a bar milling cutter contacting with the rotor groove flank is then characterized as the star-wheel tooth's engaging profile. Because engaging profile of a star-wheel tooth for single column is very small compared to the whole flank surface, friction and wear will still take place seriously. This result can't satisfy the requirements of most engineering situations.

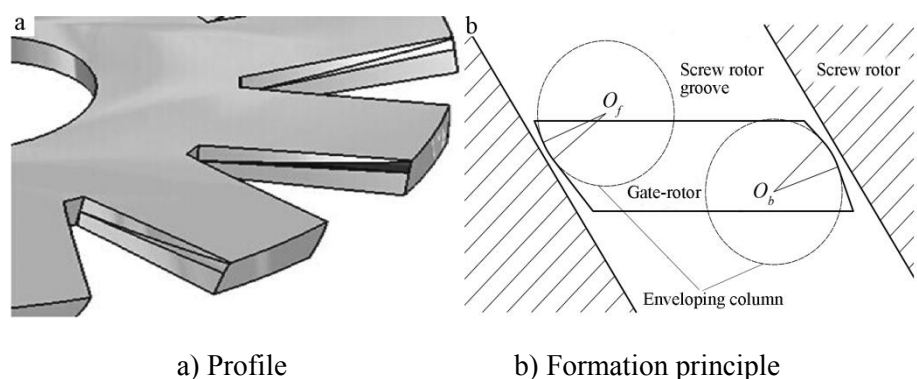


Figure 4. Profile enveloped with single column and its formation principle.

Engagement pair enveloped with single straight line or single column both belongs to traditional profile. Its main disadvantages are: star-wheel tooth is easy to wear out and cause more leakage. It takes a long time to machine rotor groove with a cutter. The material of star-wheel is quite expensive, furthermore, it is easy to lose its shape and sometimes to be scraped and broken. In past 50 years many researchers made every effort to find a machinable enveloping profile for the engagement pair, with which different areas of a star-wheel tooth surface can touch the rotor groove flank in turn[4,5].

The authors had proposed the conception and theory of multi-straight line and multi-column compound enveloping engagement pair of SSC 10 years ago [6, 7]. Compound envelopment means the cutter or milling cutter is used repeatedly to process the tooth of a star-wheel in different directions and positions (figure 5). At the same time, according to the space arrangement of these milling cutters above, the part surface of a bar milling in every space arrangement, which contacts screw rotor groove flank, can be taken in their original positions and be connected with each other by several tangent planes. Thus, an engaging profile on star-wheel tooth is constructed. Figure 6 shows a star-wheel tooth flank profile enveloped by multi-column. Figure 6a shows the flank profile at the back side and figure 6b is the front flank profile. It should be pointed out that the multi-columns used for the enveloping engagement pair

does not have to be the same in length. Figure 7 describes screw rotor groove flank profile which is enveloped with non-equal length's multi-columns. Figure 7a shows screw rotor groove profile which is enveloped by the star-wheel tooth profile in figure 6a. Figure 7b shows screw rotor groove profile which is enveloped by the profile in figure 6b. It is obvious that compound-enveloped profile with multi-columns is not a regular shape as the common traditional one [8].

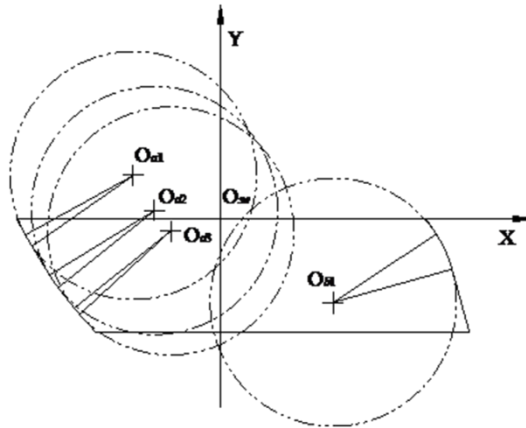


Figure 5. Locations of multi-column milling cutters.

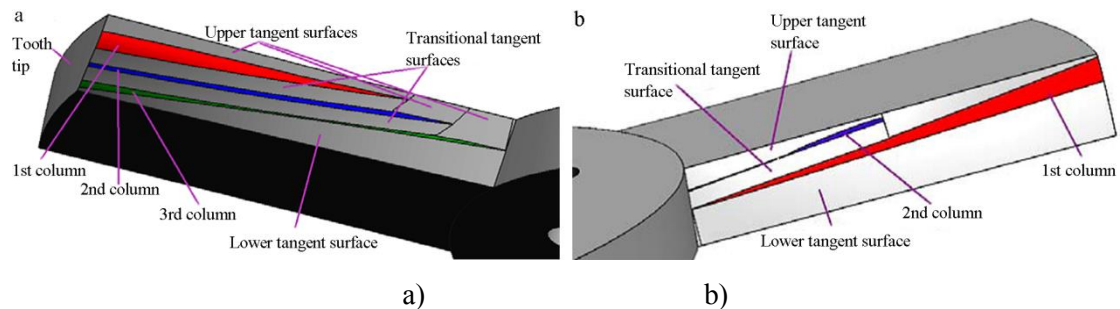


Figure 6. Numerical simulated envelopment profile constructed by multi-column on star-wheel tooth surface.

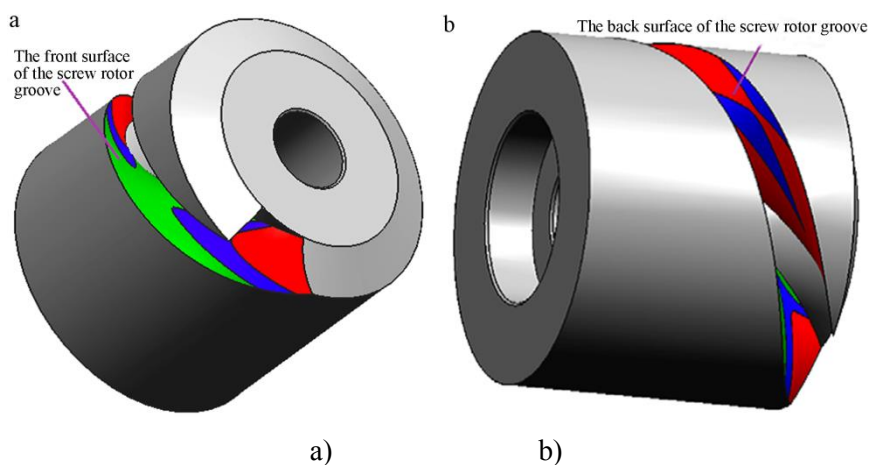


Figure 7. Numerical simulated profile enveloped by multi-column on the screw rotor groove surface.

3. Research of new conception engage profile

In order to precisely and efficiently process the screw rotor and star-wheel of new concept SSC, the authors make numerical simulation of their processing repeatedly. Finally a scheme of screw rotor processing was achieved and a special milling machine was developed as shown in figure 8, in which milling cutter can move in the X and Y coordinates direction. Milling cutter axis can also rotate in this plane. Actually this milling machine is built with six coordinates. This machine can process screw rotor with diameter around 100~400mm. According to the profile, the NC programs for this milling machine was also studied and developed. After 3 years' processing tests and improvements, the range of processing error for this machine is brought down to 0.015mm. Simultaneously, the authors researched and developed a special grinding machine, as well as the NC programs related to the profile, for processing star-wheel tooth profile. In this machine, shown in figure 9, large diameter grinding wheel composed of diamonds are used to eliminate the error of grinding wheel wear. Processing error is reduced within 0.01mm.



Figure 8. Screw-rotor processing machine.

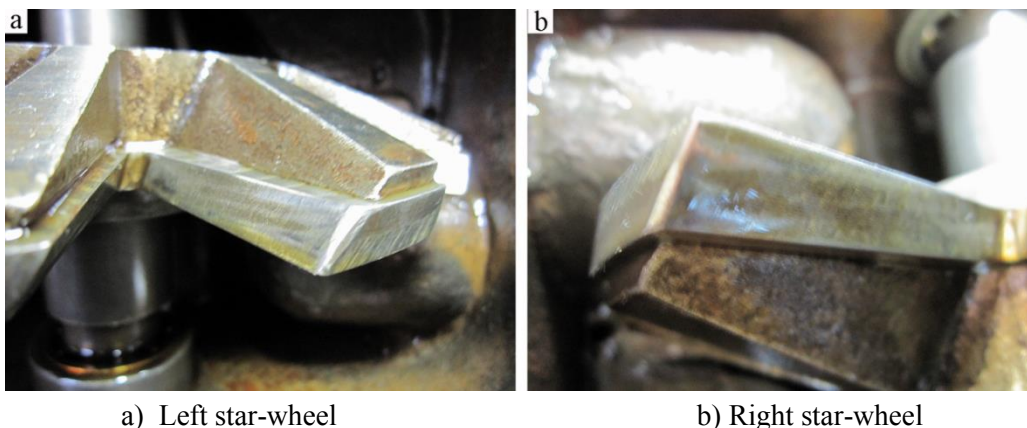


Figure 9. Star-wheel processing machine.

4. Development of new concept SSC prototypes and their performance tests

Since 2013, there are 6 companies have been cooperated with the author's group, and many kinds of new concept SSCs have been developed, such as two injection types with oil lubricated and water lubricated, several power models as 22kW, 37kW, 75kW, 110kW, 132kW, 250kW and etc.. In order to show the advantages of new concept SSC, nodular cast iron is used as material for star-wheel with oil lubricated, see figure 10.

There were many researchers took nodular cast iron as the material of star-wheels in past. However, just after several hours' operation those star-wheels in traditional SSC were worn out, and the compressor's flow-rate went down over 10%. In development of water-lubricated compressors recent years, PEEK is generally used as the material of star-wheels. These kinds of star-wheels can be put into operation for thousands hours at most. Still, flow-rates of the compressors' decrease down apparently after that.



a) Left star-wheel

b) Right star-wheel

Figure 10. Nodular cast iron star-wheel after 2000h's operation.

Authors separately designed and manufactured 3 kinds of the new concept SSCs (two with oil lubricated, one with water lubricated), as well as their testing systems. 2000 hours' performance tests were then conducted. Discharge pressure of those were all kept at 0.8 MPa (G) in the testing operation. The flow-rates of them were measured every 24 hours. Table 1 shows the flow-rate results measured at some time nodes for the two oil lubricated prototypes.

Table 1. Tested flow-rate results of oil lubricated compressors.

operation time (h)	5	400	800	1200	1600	2000
	flow-rate (m ³ /min)					
Oil lub1#	2.85	2.88	2.87	2.86	2.87	2.86
Oil lub2#	7.98	7.99	8.00	8.00	7.98	7.98

For the water lubricated one, copper is used as material for the screw rotor and PEEK for the star-wheel, see figure 11. The designed flow-rate is 6 m³/min, with pure water used as the lubricating fluid.

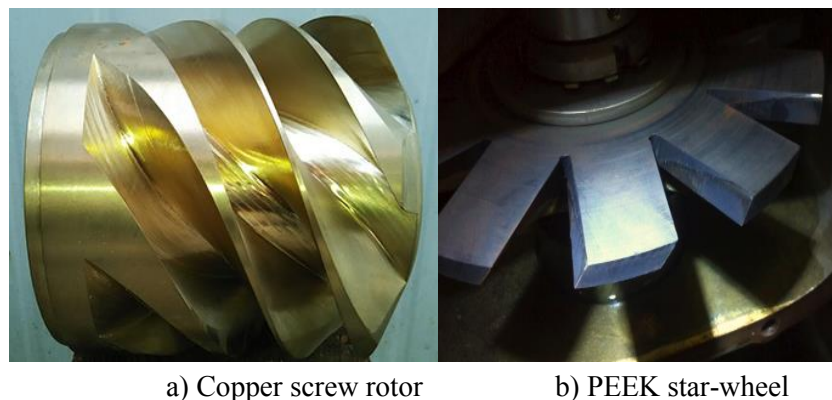


Figure 11. Water lubricated screw rotor and star-wheel.

The testing set-up is shown in figure 12. The air was first purified by the air inlet filter and then transported to suction chamber for compressing. The compressed air together with the lubricated water were discharged to the separator. The compressed air was then available through the air discharge valve. The water converging at the separator bottom was transported to the cooler as the lubrication fluid by the pressure difference between the suction chamber (inlet pressure) and the separator (separator pressure). The injection water was cooled down by the cooling water and went through two water filters to the injection end.

The testing results is shown in figure 13. Obviously, there are some changes at the beginning of the operation, which is because the whole system needs some time to run-in. A big drop of flow rate happened around 150 hours, the machine was stopped and checked. There were some changes on the position of both the star-wheels and the screw rotor through their axial direction. Besides, the environment temperature change can directly influence the suction temperature, which will lead to undulations of the flow-rate. Both the star-wheels' and screw rotor' positions were reset. After about 500 hours' operation, the flow-rate keeps steady around 5.37 m³/min till the end of the testing (2350hours). The average volume efficiency is 89.5%. The new concept profile avoids the problem of wearing out and reaches a really high sealing property.

All results show that there are no big changes on the flow-rates for these 3 kinds of new concept compressors in 2000 hours' testing operation, which proves the new concept profiles all work well with a long time operation.

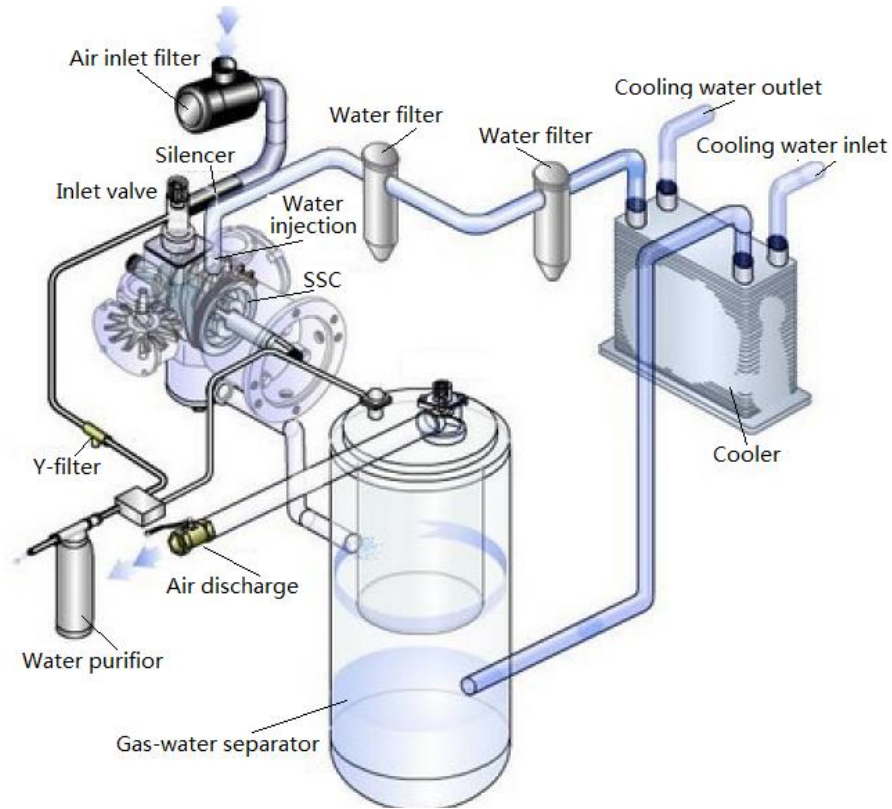


Figure 12. Water lubricated prototype compressor testing set-up.

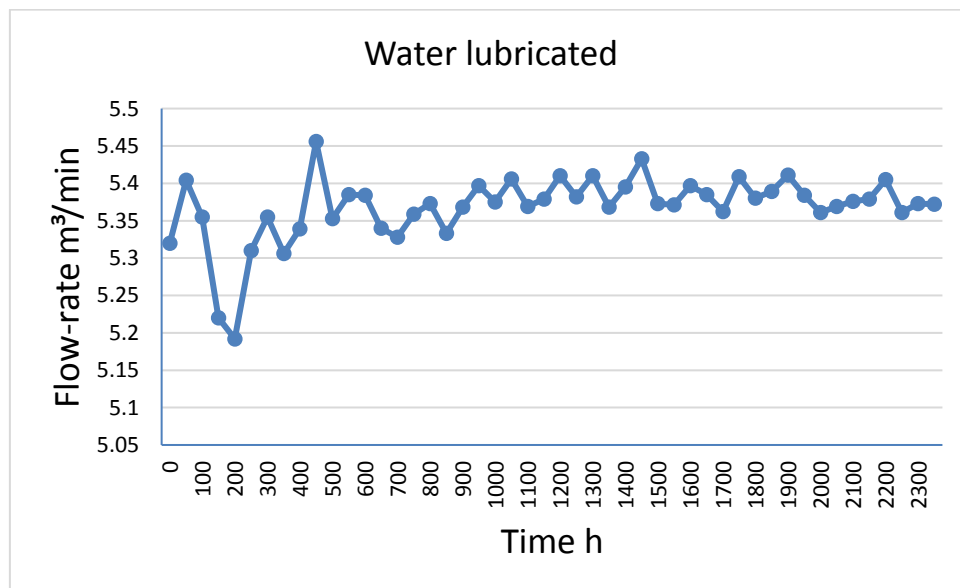


Figure 13. Testing results for the water lubricated prototype compressor.

5. Conclusions

- 1) The paper reveals wear mechanism of a star-wheel in a traditional SSC that star-wheel tooth flank profile enveloped with single straight line can't offer an essential lubricated condition for compressor operation.
- 2) Multi-columns enveloping profiles for engaging pairs of SSCs are proposed, which is designed to achieve a liquid floated engagement in screw rotor and star-wheel system.
- 3) Precise and effective milling machines are developed for processing screw rotor and star-wheel engaging pairs with multi-columns enveloping profiles respectively.
- 4) Many kinds of new concept SSC and their prototypes are developed and tested. Especially the water-lubricated SSC, which use water instead of oil working as the injection fluid. It is more pro-environmental and can also meets the requirements of oil-free working conditions. Experiments proved these new concept SSCs can work for a long time period without any obvious decrease of the flow-rates. The wear out problems of the star-wheels are solved.

References

- [1] Zimmern B 1965 Worm rotary compressors with liquid joints (USA) 3180565
- [2] Zimmern B 1984 From water to refrigerant: twenty years to develop the oil injection-free single screw compressor *The 1984 Purdue Compressor Technology Conference: Purdue University, West Lafayette, IN, USA* pp 513-18
- [3] Jin G X and Tang Y 1986 *A study of the single screw compressor profile* (Purdue, West Lafayette, IN, USA, 1986)
- [4] Zhao B 2010 Fault diagnosis for the gate rotor of the single screw compressor based on wavelet finite element method *Journal of Computational Information Systems* **6**(11) pp 3849–58
- [5] Guohui L and Xiaonan P 2004 *Research on three performances of a single screw compressor engaging pair machinery* **05** pp 29–31
- [6] Quanke F, Bei G and Cun Z 2005 Profile design method of multi-straight line enveloped engage pair in a single screw compressor *Compressor technology* **03** pp 1–5
- [7] Wu W F and Feng Q K 2009 A multicolumn envelope meshing pair for single screw compressors *Journal of Mechanical Design, Transactions of the ASME* **131**(7) 0745051-0745053
- [8] Cun Z, Weifeng W and Quanke F 2010 *Constructing method of engage pair profile enveloped with non equal length multi-column in a single screw compressor* (China, ZL) 201010293319.1. 2010
- [9] Li J, Feng Q, Liu F *et al* 2013 Experimental studies of the tooth wear resistance with different profiles in single screw compressor *Tribology International* **57** pp 210–15