2004

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DESIGN OPTIMIZATION OF AN OIL-FLOODED REFRIGERATION SINGLE SCREW COMPRESSOR

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ABSTRACT

A single screw compressor is usually sealed by means of its tiny clearances. The theoretical research and the practice application shown that the leakage in the working process is always the key factor influencing the performance of this kind of compressor. Besides meeting the need of lubrication, the oil injection can greatly improve the sealing effect. It is obvious that the reduction of clearance, the increase of sealing line, low oil temperature and large oil rate can greatly reduce the leakage and improve the volumetric efficiency. But in the meantime, the flow resistance loss and the friction power are thus increased. This means an optimization problem.

Taking the volumetric specific power (ratio of compressor power and cooling capacity) as the target, some structure parameters and oil-injection parameters of single screw compressor are optimized in this paper. And the results of optimization are also analyzed. It provides scientific basis for rational design and improving performance of the compressor.

1. INTRODUCTION

The single screw compressor has been investigated and developed for more than 30 years in China, coming through complete machine imitation, design and profile curve development, special manufacturing machine equipment, and processing technology. Now, there are several companies in China who produce single screw compressors in small mass. At present, the main problem on single screw compressor field in China is that the product performance and quality desiderate further improving and stabilization. One of the main reasons is that this kind of compressor is still on the experiencing design phase and the systemic, thorough research to the thermodynamics and the dynamics mechanisms of its working process is relatively weak. Thus, all sorts of parameters are determined without theory basis.

Therefore, based on the computer simulation on the working process of single screw compressors, some key design parameters were optimized in this paper, the optimization results were thoroughly investigated and some suggestions to determine these parameters were also provided.

The volumetric efficiency of a single screw compressor is mainly dependent on its clearances. In order to improve the sealing effect, lubricating oil is usually injected to its working volumes. Theoretical researches and practical applications both showed that, leakage in the working process of this kind of compressor is always the main factor that affects the performance. Apparently, the leakage will be decreased effectively by minishing the clearance and increasing the length of seal line, or decreasing the temperature of injecting oil and increasing the quantity of injecting oil. The volumetric efficiency is thus high up. But at the same time, flow resistance loss, agitation loss and frication power consumption will increase correspondingly. So that, the integrated results would not always make the performance improve. It is obvious that the change of structure and oil-injecting parameters to decrease the leakage always goes with the increasing of power consumption. There must be some optimal values.

A single screw compressor with 35KW refrigerating capacity was investigated in this paper. Its structure and oil-injecting parameters were optimized to obtain the optimal performance. The mathematical model of working process of a compressor in optimization calculation has been proved (J. H. Wu, 1988). The final optimization results were also analyzed.

2. MATHEMATICAL MODEL OF OPTIMIZATION DESIGN

The optimization design means, with certain constrained conditions, to seek the optimal design variables. According to the characteristics of a single screw compressor, the variable-tolerance method is used.

2.1 Objective Function

Considering that the volumetric specific energy is an integrated target of the compressor performance, which reflects the influence of many factors such as the leakage, the power consumption etc.， it was taken as the objective function in this paper:

$$F(x) = \frac{w_i + w_f}{Q_0} \tag{1}$$

2.2 Design Variables

Single screw compressor has nine leaking channels (Figure 1). Among them, the primary channels is the leaking channel L9 and L6, the former one is the clearance between the seal column of screw discharge section and the cylinder hole, the latter one is the clearance between the surface of gaterotor and the cylinder wall. The corresponding structure parameters are clearance and length shown as l_9 and l_6. For the oil-injecting parameters, the quantity of oil-injection Q_{oil} and the temperature of oil-injection T_{oil} were taken into account. Thus there were six variables needing to be optimized. They can be expressed as:

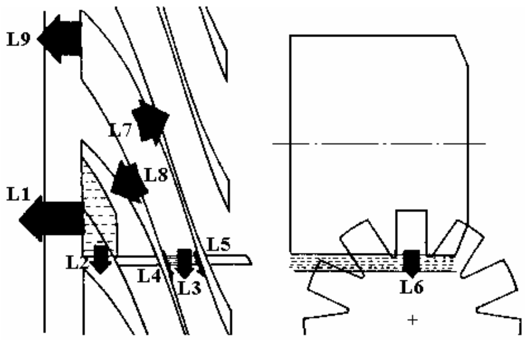


Figure 1 Leakage channels

$$X=[x_1,x_2,\ldots x_6]^T=[\delta_9, l_9, \delta_6, l_6, Q_{oil}, T_{oil}]^T \tag{2}$$

2.3 Constrained Condition

According to the structure, intensity, working temperature and ethnics requirement of the single screw compressor, the constrained conditions of each design variables were determined as:

$$1.0\times10^{-5} < \delta_9 < 20\times10^{-5} m \qquad 7mm < l_9 < 28mm$$

$$1.5\times10^{-5} < \delta_6 < 30\times10^{-5} m \qquad 4mm < l_6 < 20mm$$

$$4l/\min < Q_{oil} < 20l/\min \qquad 35^\circ C < T_{oil} < 55^\circ C$$

3. ANALYSIS OF THE OPTIMIZATION RESULTS

3.1 The Effects of Design Variables on the Object Function

The influences of structures and oil-injection parameters on the volumetric ratio energy is dependent on the effects of the leakage and frication power consumption, a pair of incompatible factors, on the performance of the compressor.

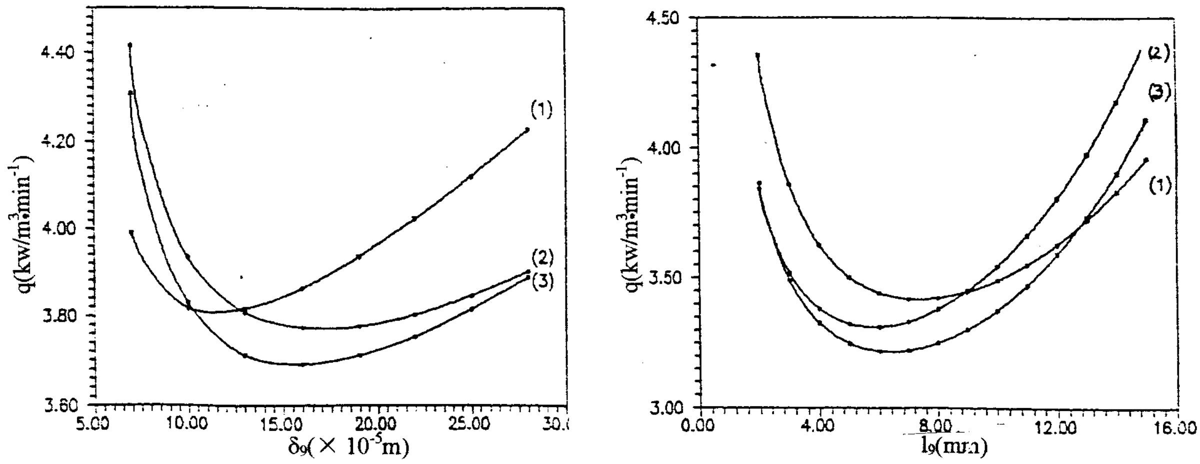
The effect of the structure parameters on the volumetric specific power is showed in Figure 2 and Figure 3, in which the curve 1, 2, 3 represent three working conditions respectively:

1：n=3000rpm, T_{oil}=40℃, Q_{oil}=12 *l*/min

2：n=3000rpm, T_{oil}=50℃, Q_{oil}=12 *l*/min

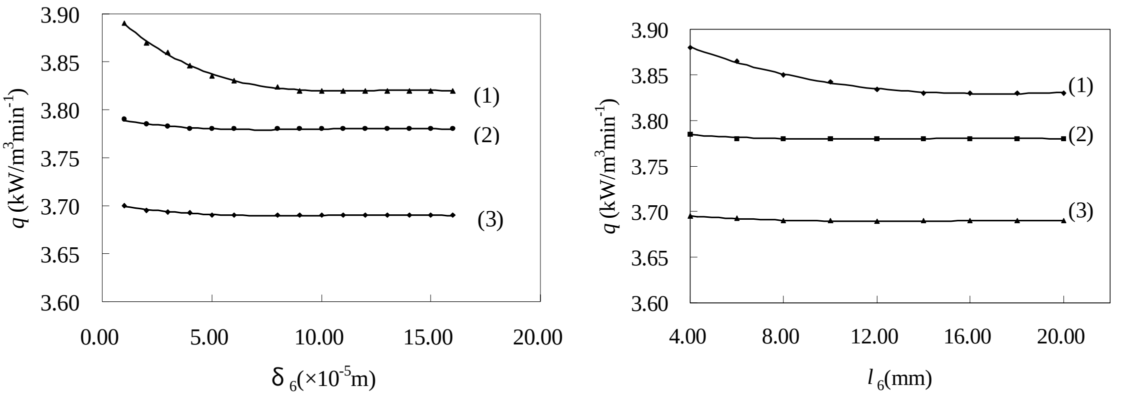
3：n=3000rpm, T_{oil}=40℃, Q_{oil}=8 *l*/min

Figure 2 a) shows the effect of the clearance δ_9 of the leaking channel L9 on the volumetric specific energy. As shown in the figure, the curves on three different working conditions have the same change trend, and there is an optimal clearance value. Comparing curve 1 with 2, volumetric specific energy is lower at the higher temperature of oil-injecting when the clearance is small. It is because that, at this time, the leaking ratio is less and the proportion of frication power consumption is larger. The viscosity of the oil will decline obviously with high oil temperature, the frication power consumption would decline accordingly too. When the clearance increases to a certain value, the influence of leakage becomes larger than that of oil viscosity, the seal performance becomes bad, and the volume efficiency declines correspondingly. Therefore the specific power in curve 2 is higher than that in curve 1.



a) b)

Figure 2 The effect of L9 on the volumetric specific power



a) b)

Figure 3 The effect of L6 on the volumetric specific power

Comparing curve 1 with 3 in Figure 2 a), the rotary speed and the oil temperature are the same, when the clearance is small, the effect of frication, agitation, and flow resistance loss are great. So that the less the oil-injection quantity is, the lower the specific power is; When the clearance gets large, the leakage becomes the main factor which effects the performance of the compressor, thus the volumetric specific energy of curve 3 may quickly rise up, even exceeds that of curve 1.

Fig.2b shows the relationship between the length of L9 and the volumetric specific energy. The seal effect is bad when l_9 is small, the leakage will be the main factor. While increasing l_9, at the beginning, the leakage quantity declines remarkably, and the volumetric specific energy declines too. When l_9 exceed to a certain value, the seal effect has no remarkable improvement, but the power consumption becomes the main factor. At this time, the volumetric specific energy would ascend if l9 increase continuously. The effects of the working conditions to the performance of the compressor are similar to Fig.2 a).

Fig.3 shows, on different working conditions, how the clearance and the length of the leaking channel L6 affect the volumetric specific energy. It is known from this figure that, on wording condition 1, the volumetric specific energy declines when δ_6 and l_6 increases. But as δ_6 and l_6 increase to a certain value the effect is not remarkable.

To working condition 2 and 3, the effects are much less. The reason is that the sealing condition between the gaterotor plane and the cylinder is much better, and there is only oil leaking. Therefore, the effects on the volumetric specific energy are mostly the frication loss and the lubricating oil out of the cylinder while the gaterotor rotating. The oil temperature is high on working condition 2 and the oil quantity is small, so that the influences of them on the volumetric specific energy are not remarkable.

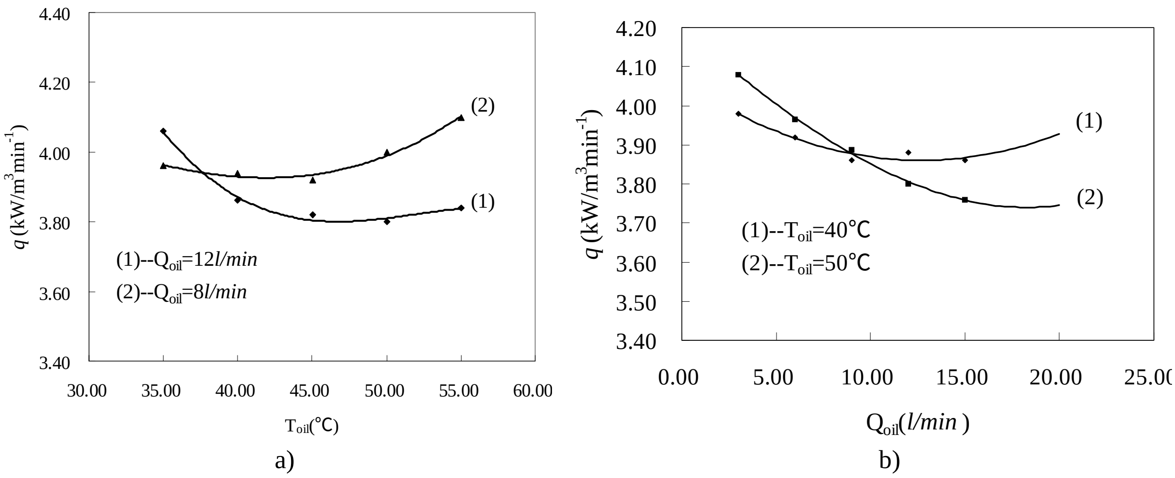


Figure 3 The effect of L6 on the volumetric specific power

Figure 4 shows the effect of oil-injecting parameters T_{oil} and Q_{oil} to the performance of the compressor. In the Figure 4 a), the discrete points are experiment values and the continuous curves are calculating results. Both of them have the same changing trend, this accounts for that the results of simulating calculation of the compressor is basically correct and accurate. It is obvious from this figure that, with the same clearances, the optimal temperature of oil-injection is about 47℃ for curve 1 and about 43℃ for curve 2. This is because that, for curve 2, the quantity of oil-injection is little and the leakage is serious. Then the decrease of oil temperature will improve the seal condition and the power loss declines, so the optimal point moves to the left.

Figure 4 b) shows the relationship between the quantity of oil-injection and the volumetric specific energy. In the figure, the temperature of oil-injection T_{oil}=40℃ for curve 1 and 50℃ for curve 2. As known from the figure, the quantity of oil-injection affects the specific power greatly and the volumetric specific power decreases with the increase of the oil quantity. But when it increases to a certain value, the trend becomes smooth, and even gets rise. So the quantity of oil injection also has an optimal value. The optimal quantity of oil injection is 9~10 *l/min* at low oil temperature, Curve 1. When the oil temperature is high, more oil is needed to strengthen the seal. So the optimal point moves to about 18*l/min*.

3.2 The Results of Optimization

According to the mathematical model of working process and the optimization model, the optimal value of each variable and its specific power q is obtained as Table 1.

Table 1: Optimization results

	Design Variables						Objective function
Parameter	δ_9(mm)	l_9(mm)	δ_6(mm)	l_6(mm)	T_{oil}(℃)	Q_{oil}(l/min)	q(kw/m^{3}min^{-1})

Original value	0.050	15.00	0.060	7.000	40.0	8.0	4.90
Optimal value	0.037	6.96	0.048	9.880	50.0	10.3	4.35
Round value	0.040	7.00	0.050	10.000	46.5	12.1	4.40

The operation parameters of prototype machine are shown as:

Rotating speed n=3000*rpm*
Discharge capacity Q_o=1.3m^3/min
Pressure ratio P_{sd}=5.53

Owing to the need of engineering practice, some optimized design variables (structure parameters) must be rounded. But other variables may not be in their optimal combinations after the round of these variables. Subspace seeking optimum method is recommended to deal with this issue. If there are k variables being rounded, the other (N-k) variables can be optimized in the subspace (N-k) of the original N-dimensional space. Thereby, optimal combination with k rounded design variables is achieved.

As shown in Table 1, after the optimization, the volumetric specific energy has declined 11.22% compared with the original one and 10.20% in case of variable rounded. Moreover, the original length of seal line L9 is: l_9 =15mm and the optimal value is 7mm. It accounts for that, from the seal point of view, l_9=7mm is enough. If it is too long, the power consumption will increase evidently; then the quantity and the temperature of oil injection thereby need properly increasing and rising respectively.

4. CONCLUSIONS

The oil-injected single screw compressor in certain working conditions, there exists optimal structure parameters and oil-injecting parameters, with which the minimum specific power can be achieved, and the optimization results can make the volumetric ratio energy decline about 10%.

The analysis of the influence of the design variables on the performance of the compressor shows that, the clearance δ_9 and length l_9, the oil injection temperature T_{oil} and the oil quantity Q_{oil} of the leaking channel L9 have the greatest influence on the performance of the compressor. Therefore, they should be chosen carefully in design.

The optimization results can be used as a reference for the design of oil-flooded single screw compressors.

NOMENCLATURE

l	length	(mm)
L	leakage channel	(–)
n	rotating speed conference fee	(rpm)
P	pressure	(MPa)
Q_o	discharge capacity	(m^3/min)
Q	oil quantity	(l/min)
q	volumetric specific power	(kW/$m^3$$min^{-1}$)
T	temperature	(℃)
W	power, loss	(kW)
δ	clearance	(mm)

Subscripts

oil	oil
s	suction
d	discharge

REFERENCES

J.H.Wu, G.X. Jin, 1988, The Computer Simulation of Oil-Flooded Single Screw Compressors, Proc. of ICECP, Purdue University: p362-p368