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Compressor Profile Optimization Based on Hybrid Intelligent Algorithm

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

In order to improve the working characteristics of the scroll compressor, according to the scroll profile of the compressor, the energy efficiency ratio (EER) of the scroll compressor is taken as the objective function, and the number of scroll turns N and knots are determined based on the genetic annealing algorithm. The distance p, the height of the scroll body h, and the thickness of the scroll profile t are optimized. In the optimized solution set, three sets of optimized profile and initial profile are selected for theoretical calculation of thermodynamic characteristics and volume characteristics, and the specific influence of scroll compressor profile parameters on compressor characteristics is explored in detail, and compared with the unoptimized scroll. The initial parameters of the rotary compressor are compared with the theoretical performance. The results show that the pitch p has a significant effect on the energy efficiency ratio and discharge volume of the scroll compressor, and the number of scroll turns N has a significant effect on the characteristic of suction volume. Three kinds of optimized scroll profile parameters S2, S3, S4 are selected in the optimal solution set. Compared with the initial value S1, the working characteristics are improved. The energy efficiency ratio was increased by 38.10%, 42.58%, and 50.26%; the suction volume was increased by 66.1%, 82.3%, and 73.9%; the exhaust volume was increased by 21.1%, 29.6%, and 50%; the internal volume ratio was increased by 36.4%. 40.9%, 27.3%. It is proved that the use of genetic annealing algorithm achieves the purpose of improving the compressor's operating characteristics.

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Keywords: Scroll compressor; scroll profile; energy efficiency ratio; suction volume; discharge volume; internal volume ratio; optimized design; genetic annealing algorithm.

1. INTRODUCTION

As the country continues to advance the new energy automobile industry, it has also led to the vigorous development of automobile air-conditioning systems. As the "heart" of the air-conditioning system, the compressor plays a vital role in providing circulating power for the entire air-conditioning system [1]. Because the scroll compressor has the characteristics of high efficiency, strong reliability, and small size, it has the advantages of both volumetric and rotary compressors. Therefore, the research on the performance of scroll compressors has become a hot spot in the current compressor industry [2]. The scroll of the scroll compressor is a key component of the compressor, and the quality of its basic parameters directly affects the performance of the compressor, so it is of great significance to optimize the relevant parameters of the compressor scroll [3].

Scroll compressor scroll optimization is mainly to study specific profile, especially to determine the base circle radius, number of vortex coils, pitch and other structural parameters to optimize. In recent years, due to the outstanding performance of intelligent algorithms in solving complex nonlinear optimization problems, more and more scholars at home and abroad apply them to the optimization design of scroll compressors. Liu Tao et al. used genetic algorithm to optimize the internal volume ratio of the scroll compressor [4]. Guo Renning et al. optimized the relevant parameters of the scroll compressor with specific power as the objective function [5]. Wang Zuohong and others used EER as the objective function to optimize the compressor's orbiting and static scrolls [6]. For the improvement of traditional algorithms, foreign researchers have also conducted a lot of research. Das et al. used a new restart strategy based on the elite principle to improve the performance of the genetic algorithm. The proposed restart scheme can detect the premature convergence of the genetic algorithm and trigger the restart of the algorithm to avoid this from happening [7]. Jiquan Wang et al. proposed an improved real-coded genetic algorithm (IRCGA) to solve the constrained optimization problem, adding a replacement operation after the crossover operation, so that there are no identical individuals in general, and the diversity of the population is rich, so Helps avoid premature convergence [8]. Song Guozhi et al. proposed a nested plan planning algorithm based on particle swarm optimization algorithm, which nested simulated annealing to optimize plan planning (PSO-SA-NoC), and verified the algorithm through simulation [9].

The basic parameters of the scroll compressor scroll have a huge impact on the performance of the compressor. Therefore, for the optimization of the basic parameters of the compressor scroll, how to make the optimized basic parameters of the scroll more reasonable has an important impact on improving the energy efficiency ratio of the compressor and reducing the energy consumption of the compressor. It can be seen from the above-mentioned documents that the algorithms currently used for scroll compressor optimization are relatively simple. Although traditional optimization algorithms have an effect on improving the design and performance of scroll compressors, the optimization of traditional single algorithms generally has slow convergence of optimization functions, easy to fall into local optimal solutions, and easy to get false optimizations for many constraints. In this paper, the genetic algorithm and the annealing algorithm are coupled, the improved genetic annealing algorithm is used to optimize the main performance parameters of the scroll compressor, and theoretical calculations are performed. The results show that the algorithm has good performance and meets the demand.

2. BASIC PRINCIPLES OF THE ALGORITHM

2.1 Genetic Algorithm

Genetic algorithm is a kind of simulation algorithm, which is designed based on the evolution theory of "natural selection by nature, survival of the fittest in nature. The genetic algorithm optimization process mainly includes parameter encoding, initial population initialization, fitness function evaluation, selection, crossover, mutation, etc [10]. It has global convergence under certain conditions, but in practical applications it will converge prematurely and fall into a local optimal solution.

2.2 Simulated Annealing Algorithm

The simulated annealing algorithm is the source solid annealing principle. It is a calculation optimization algorithm based on random sampling criteria. It mainly includes two parts, the Metropolis algorithm and the annealing process. The annealing algorithm has a sudden jump characteristic and can randomly find the optimal solution of the objective function in the solution space. But in the actual optimization process, when the optimization scale is too large, the search for the optimal solution calculation process will take a lot of time [11].

2.3 Improved Genetic Annealing Algorithm

The genetic algorithm and the annealing algorithm are comprehensively compared, take the advantages of these two algorithms and eliminate the disadvantages of these two algorithms, and the two algorithms are combined into a new and improved genetic annealing algorithm (MGASA). In addition to the ideological fusion of genetic algorithms and annealing algorithms, the MGASA algorithm also uses machine learning ideas. The population mutation operator in the genetic algorithm is replaced by the simulated annealing algorithm, and the Metropolis sampling process in the simulated annealing algorithm is integrated with the genetic algorithm. It not only makes full use of the annealing algorithm's ability to easily jump out of the local optimal solution, but also makes use of the genetic algorithm's strong parallel search ability, so that the optimization process can obtain the required optimal solution in a short time. The improved algorithm flow is shown in Fig. 1.

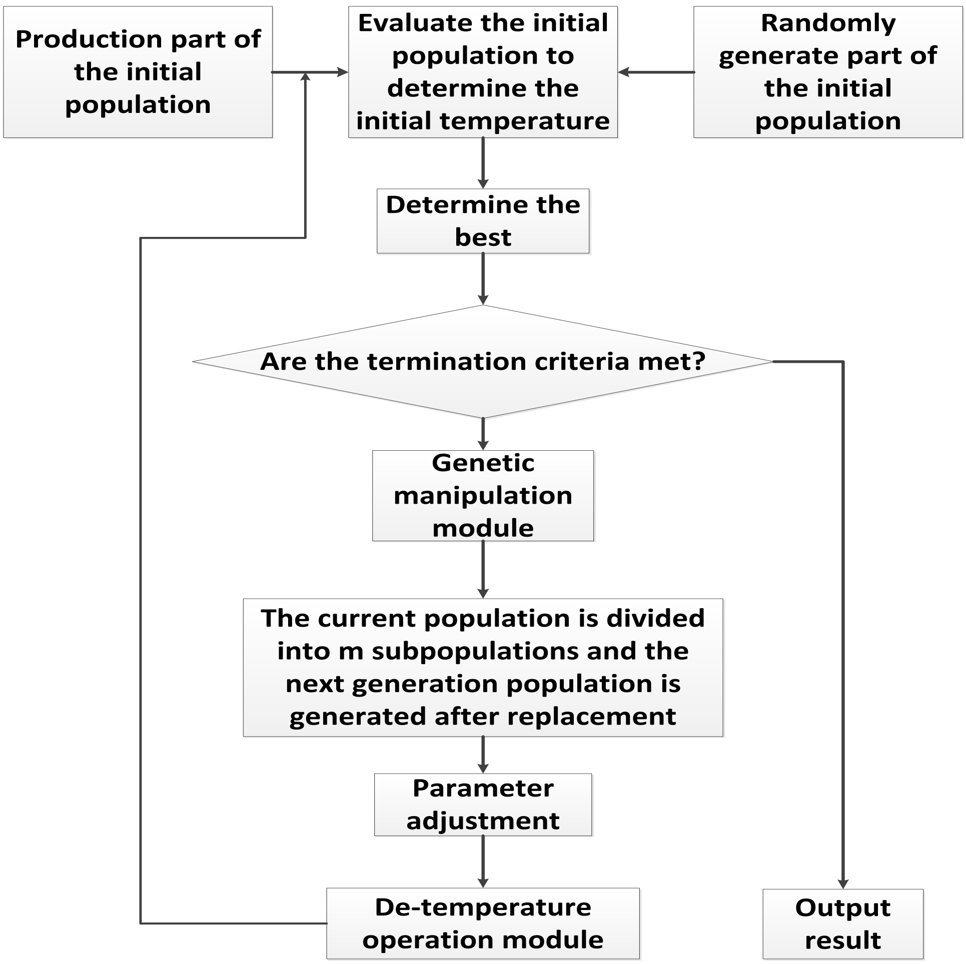

Fig. 1. Flow chart of improved algorithm

3. OPTIMIZATION MODEL

3.1 Compressor Scroll Profile Model

Through theoretical and performance studies, it is found that the base circle involute has the advantages of high effective volume ratio, high area utilization coefficient, stable spindle torque change, etc. It is a single profile that is widely used at present. Since the moving and static scrolls are installed relatively horizontally, this article establishes the XOY coordinate system for the static scrolls, and the equations of the fixed scrolls are shown in (1) and (2) [12].

Inside the scroll arm:

$$\begin{cases} x_1 = r\left[cos\left(\varphi_1+\alpha\right)+\varphi_1 sin\left(\varphi_1+\alpha\right)\right] \\ y_1 = r\left[sin\left(\varphi_1+\alpha\right)-\varphi_1 cos\left(\varphi_1+\alpha\right)\right] \end{cases} \qquad (1)$$

Outer side of scroll arm:

$$\begin{cases} x_2 = r\left[cos\left(\varphi_2-\alpha\right)+\varphi_2 sin\left(\varphi_2-\alpha\right)\right] \\ y_2 = r\left[sin\left(\varphi_2-\alpha\right)-\varphi_2 cos\left(\varphi_2-\alpha\right)\right] \end{cases} \qquad (2)$$

The main parameters of the scroll gear are as follows:

$$p = 2\pi r \qquad (3)$$

$$t = 2r\alpha \qquad (4)$$

$$M = N + 1/4 \qquad (5)$$

$$\varphi_e = 2\pi M \qquad (6)$$

$$R = p/2 - t \qquad (7)$$

In the above formula, φ is the involute expansion angle parameter variable; α is the starting angle; r is the base circle radius, m; subscript 1 is the inner wall parameter; subscript 2 is the outer wall parameter; p is the pitch, m; t is the wall Thickness, m; h is the foot height, m; N is the number of vortex turns; M is the number of involute coils; φ_e is the involute spread angle of the center plane of the vortex; R is the radius of gyration, m.

3.2 Determination of Objective Function and Fitness Function

Take Guangzhou Guihong SHS-33H4203 scroll compressor as the prototype, and take the test conditions: refrigerant R134a, evaporation temperature 10.4℃, condensation temperature 44.8℃, compressor motor power 3.088kW, motor efficiency 86%, spindle speed 4000r /min. The volumetric efficiency is 0.989, the isentropic efficiency is 0.718, the specific volume V1=0.063m3/kg, and the unit cooling capacity q0=164.05KJ/Kg.

For hybrid automobile refrigeration systems, scroll compressors consume more energy, so this paper takes scroll compressor energy efficiency ratio EER as the optimization goal.

$$EER = \frac{Q}{W} \qquad (8)$$

In the formula, Q is the refrigeration capacity of the scroll compressor, kW; W is the compressor input power, kW;

And because the optimization algorithm is generally a minimum problem, the inverse of the energy efficiency ratio is taken as the fitness function of the optimization algorithm.

$$Q = \frac{nV\eta_v q_0}{V_1^{'}} \qquad (9)$$

$$V = \pi p(p-2t)(2N-1)h \qquad (10)$$

In the formula, n is the spindle speed, r/s; V is the suction volume of one rotation of the spindle, m^3; η_v is the volumetric efficiency, %; q_0 is the unit refrigeration capacity, kJ/kg; $V_1^{'}$ is the specific volume, m^3/kg, and N is the vortex number of turns.

According to the above mathematical relationship analysis, the fitness function of the optimized design is:

$$min\ f(X) = f(p,t,N,\ h) = \frac{1}{EER} = \frac{5.7251\times 10^{-6}}{p(p-2t)(2N-1)h} \qquad (11)$$

3.3 Optimizing Variable Selection

This article mainly selects four parameters that can directly affect the size of the scroll compressor, the difficulty of manufacturing, and the axial leakage of the scroll compressor. They are the pitch p, the wall thickness of the scroll body t, and the number of scroll turns. N. The height of the vortex is h. So these four variables will be used as optimization variables,Namely $X=\left[p,t,N,h\right]^T=\left[X_1,X_2,X_3,X_4,\right]^T$.

3.4 Constraint Determination

(1) Scroll compressor profile pitch p
The profile used in the scroll is a circular involute. If the pitch p is too large, the volume of the scroll compressor will increase, and if the pitch p is too small, it will increase the difficulty of processing the scroll compressor. Therefore:

0.01m<p<0.02m

(2) Scroll profile thickness t
The thickness of the scroll profile has an impact on the performance of the scroll compressor. If its parameter is too large, it will cause the overall size of the scroll compressor to be too large, which is not conducive to assembly; if its parameter is too small, it will cause the scroll compressor to scroll. The strength and rigidity of the disc become lower, which makes it difficult to process and causes its gas leakage and thermal performance to decrease due to heat and force during operation, namely:

0.0025m<t<0.005m

(3) Number of vortex turns N
Too many vortex turns will cause difficulty in processing, and will also cause poor local heat dissipation performance and larger scroll body deformation; too small number of vortex turns will reduce the amount of compressed gas and reduce the compression efficiency of the compressor . Select:

2<N<3

(4) Scroll profile height h
When the compressor stroke volume is constant, the increase of the arm height h is beneficial to reduce leakage, but if it is too large, the stability of the compressor during operation will become poor and it is not easy to process. Therefore:

0.02m<h<0.05m

(5) Structural parameters

If the structure parameter $\lambda=\frac{h}{p}$ is too large, the overturning moment of the orbiting scroll will be too large, causing the local stress peak value of the orbiting scroll to increase, and the stress generated by the axial force becomes smaller. If the value is too small, the average stress generated by the axial force will become larger. Therefore, when the value is an appropriate value, the local total stress can be reduced and its dynamic performance can be improved. The value is:

2< λ <3.5

4. COMPARISON OF RESULTS

The mathematical model of optimal design is the mathematical abstract expression of the actual problem, which mainly includes three basic elements of design variables, objective function and constraint conditions. All mathematical expressions of objective function and constraint conditions are called mathematical models. According to the above analysis, it can be concluded that the optimized mathematical model of the scroll compressor is:

$$\begin{cases} \min f(X)=f(p,t,N,\ h)=\dfrac{1}{EER}=\dfrac{5.7251\times 10^{-6}}{p(p-2t)(2N-1)h} \\ g_1(X)=p-0.01>0 \\ g_2(X)=0.02-p>0 \\ g_3(X)=t-0.0025>0 \\ g_4(X)=0.005-t>0 \\ g_5(X)=N-2>0 \\ g_6(X)=3-N>0 \\ g_7(X)=3.5-\lambda>0 \\ g_8(X)=\lambda-1>0 \end{cases} \tag{12}$$

In order to explore the impact of the four parameters P, t, N, and h on the energy efficiency ratio, four sets of local optimal solutions were taken from the optimization process for comparison. Table 1 shows the optimized scroll compressors S2, S3, S4 (corresponding to Numbers 2-4 in the table) and the geometric parameters of the initial value S1.

Table 1. Initial value and optimization of local optimal solution parameters

Number	p（m）	t（m）	N	h（m）	Min f(x)
1	0.0170	0.0044	2.635	0.022	0.4372
2	0.0173	0.0047	2.785	0.029	0.3161
3	0.0174	0.0041	2.920	0.024	0.3079
4	0.0188	0.0043	2.722	0.023	0.2921

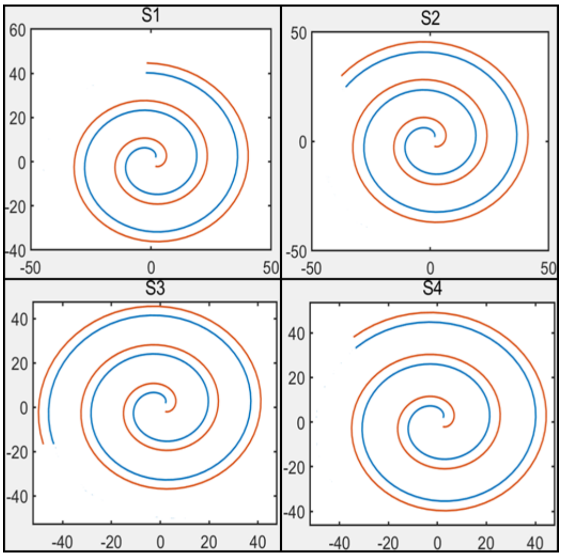

Fig. 2. Scroll compressor model line comparison

Fig. 2. shows the comparison of the scroll compressor profile before and after optimization using the Matlab drawing function

Figure 2 is the static plate diagram of the scroll compressor, which can be seen from the figure. The optimized and improved S2-S4 scroll compressor has a longer compression stroke than the unoptimized S1, longer compression time and smaller discharge volume, so it has a higher volume ratio.

3.1 The Influence of Optimized Parameters on EER

In this paper, a genetic annealing hybrid algorithm is proposed to optimize the design of multiple parameters of the scroll according to the geometric performance of the scroll compressor. Through the optimization calculation of the scroll compressor, it is verified that the genetic annealing hybrid intelligent algorithm has fast search speed, simple logic, and can effectively avoid falling into a local solution during the solution process, and has outstanding advantages in solving multi-parameter optimization. Figure 3 shows the effect of optimized parameters on EER. From Figure 3, it can be seen that the S4 scheme is the optimal scheme, and its energy efficiency ratio is 3.423, which is 49.68% higher than the energy efficiency ratio of scheme 1. Its optimal parameter p=0.0188m, t=0.0043m, N=2.722m, h=0.023m. By combining the analysis of Table 1 and Figure 3, it can be seen that when the difference between t, N, and h is not large, the influence of the parameter of pitch p on EER is significantly greater than the other three parameters, which is of significance for scroll design.

3.2 Influence of Optimized Parameters on Volume Characteristics

The theoretical volume characteristic calculation of scroll compressor [13] is as follows:

$$V_s = \pi P(P-2t)\left(2N-1-\frac{\phi_s}{\pi}\right)h \qquad (13)$$

$$\phi_s = 2\pi[1-(N-INT(N))] \qquad (14)$$

$$V_d = \pi P(P-2t)h\left(3-\frac{\phi_d}{\pi}\right) \qquad (15)$$

$$\phi_0^2 + 2\phi_0 \sin(\phi_0-\alpha) + 3\cos(\phi_0-\alpha) = (\pi-\alpha)^2 - 2 \qquad (16)$$

$$\phi_d = \frac{3}{2}\pi - \phi_0 + \alpha \qquad (17)$$

$$V_e = \frac{V_s}{V_d} \qquad (18)$$

Where; V_s is the theoretical suction volume of the scroll compressor, m^3; V_d is the theoretical discharge volume of the scroll compressor, m^3; n is the compressor speed, r/min; I takes 1; ϕ_s is the suction angle, °; which is the scroll when the compressor's moving and static scrolls are engaged, the driving crankshaft angle at the moment when the suction chamber is closed; ϕ_d is the discharge angle, which is the driving crankshaft angle when the compression chamber is closest to the discharge chamber and the discharge chamber is about to be the same; ϕ_0 is the interference point gradually opening angle; V_e is the ratio of internal volume.

Fig. 4 shows the effect of different compressor optimization parameters on volume characteristics. It can be seen from the figure that the suction volume is sorted as S1<S4<S2<S3, and in conjunction with Table 1, it can be seen that the parameter of the number of vortex turns N has a greater impact on the exhaust volume. It can be seen from formula (17) that the larger the number of vortex turns, the smaller the exhaust angle. Under the condition that the other parameters are not much different, for S1, when the number of vortex turns N=2.635, the inspiratory volume is 31cm^3. Compared with S3, the number of vortex turns is N=2.920, which corresponds to an inspiratory volume of 56.5cm^3, and S3 is 82.3% higher than S1.

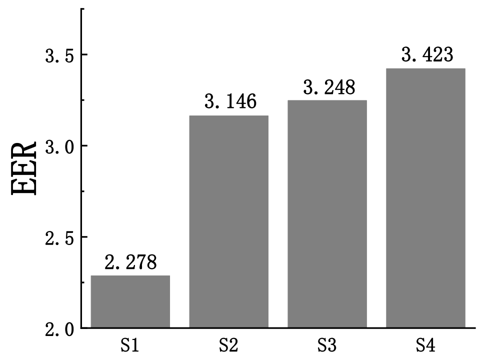

Fig. 3. Influence of optimization parameters on EER

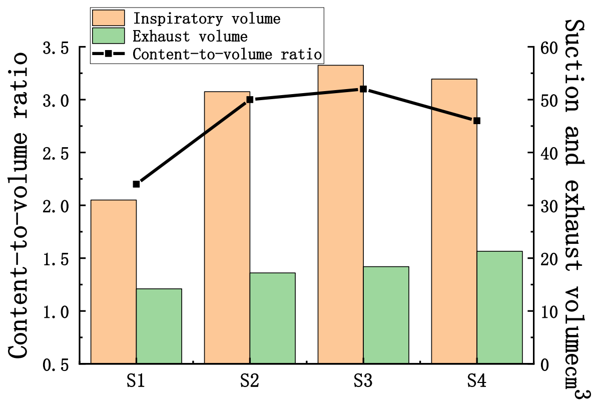

Fig. 4. Influence of optimization parameters on volumetric characteristics

When the orbiting scroll of the scroll compressor rotates and translates, and its rotation angle is ϕ_d, the compressor just enters the discharge stage. At this time, the angle ϕ_d corresponding to the discharge process is the starting discharge angle, V_d which is the discharge volume. From Fig. 4, it can be seen that the order of the discharge volume is S1<S3<S2<S4. It can be seen from formula (15) that when the other parameters are not much different, the characteristic parameter pitch p has an effect on the scroll compressor's the discharge volume has a greater influence, and the larger the pitch p value, the larger the discharge volume of the scroll compressor. For S4, when its pitch p=0.0188m, the exhaust volume is 21.3cm^3. For S1, when the pitch p=0.0170m, the exhaust volume is 14.2cm^3, and the exhaust volume of S4 is 50% higher than that of S1.

The internal volume ratio is an important indicator of scroll compressors, which is of great significance for evaluating the performance of scroll compressors. It can be seen from Figure 4 that the order of the internal volume ratio is S1＜S4＜S2＜S3. According to equations (14), (16), (18), it can be seen that the internal volume ratio of the scroll compressor is the number N and the starting angle of the involute increase. It can be seen that S3 has the largest internal volume ratio. The reason is that the larger number of scrolls N, which makes its compression stroke longer, which leads to a decrease in its suction volume. When the exhaust volume is not much different, it can be reduced. The content-to-volume ratio increases. Compared with S1, the internal volume ratio of S3 increased by 40.9%.

5. CONCLUSION

This paper optimizes the scroll compressor profile based on the genetic annealing algorithm, and compares the optimized results with the theoretical performance of the scroll compressor with initial profile parameters. The conclusions are as follows:

1. Through specific example calculations, the annealing algorithm is introduced into the genetic algorithm to improve the optimization performance of the traditional algorithm, so that it is not easy to get into the local optimal solution, and the calculation speed is fast. It effectively avoids the shortcomings of using a single genetic algorithm or annealing algorithm, and proves that the genetic annealing algorithm is an effective new algorithm for multi-objective optimization.

2. Build a mathematical model with the structural parameters of the scroll compressor of Guangzhou Guihong SHS-33H4203 scroll compressor as the optimized parameters. Taking the energy efficiency ratio as the objective function is conducive to convenient and accurate analysis of the volume characteristics and changes in the energy efficiency ratio in the thermal process. Make the compressor achieve the purpose of energy saving.

3. Through theoretical calculation and accurate analysis of the local optimal solutions of the four parameters p, t, N, and h, compared with the other three parameters, the pitch p has a significant impact on the compressor energy efficiency ratio and discharge volume. The number of turns N has a significant effect on the suction volume, and these parameters are of great significance for improving the working efficiency of the scroll compressor. At the same time, the model line S4 with the best comprehensive performance is obtained, and its energy efficiency ratio, suction volume, exhaust volume, and internal volume are increased by 49.68%, 73.9%, 50% and 16.0% respectively from the initial value S1.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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