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ABSTRACT

The parts optimization are very important for scroll compressor design. According to existing problems of current optimization algorithm and actual optimization problems, the improved optimization algorithm—genetic-particle swarm optimization (GA-PSO) is proposed for scroll plate optimization. The optimization method integrates crossover of genetic algorithm (GA) and evolutionary mechanism of particle swarm optimization (PSO), the main structure parameters are been as control variable, the optimization mathematics model is developed, making use of crossover of GA and evolutionary mechanism of PSO, GA-PSO realizes the purpose of minimizing value of objective function. GA-PSO is applied to scroll plate optimization on computer, it is shown that the improved approach converges to better solution much faster than the earlier reported approaches through compared with other methods and tested of prototype performance. All the results supply theory and technology support for wide application of GA-PSO in engineering.

1. INTRODUCTION

The scroll compressor is a kind of simple structure, high-efficient, low noise, high dependability, low vibration new-type displacement compressor, it has already extensively applied to refrigeration, air conditioner, various kinds of gas compression, and pressurized pump etc. But at present friction loss and leakage are the main barriers that affect the mechanical efficiency of scroll compressor, finally lead to the low refrigeration quantity and EER. The key component - fixed scroll and orbiting scroll form a series of crescent-shaped working pockets, its basic parameters decide the friction loss and leakage, also affect the compressor performance, so parameters optimization design is very important to enhance the entire machine performance of scroll compressor. At present there have many optimization research about scroll compressor, Fan Ling et al. [1] established the optimization mathematical model of scroll compressor and used the improved Runge-Kutta method to solve the model; Zhang Liqun and Liu Yongbo [2] used the SWIFT to optimize to the main design parameters, it improved the machine performance; Chen Jin et al. [3] used the multiobjective genetic algorithm to optimize the scroll shape; Particle swarm optimization (PSO) is an evolutionary computation technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. PSO is a population based optimization tool, the system is initialized with a population of random solutions and searches for optima by updating generations. In PSO, the potential solutions, called particles, are "flown" through the problem space by following the current optimum particles. It seeks the optimal solution through individual cooperation and information sharing. The new algorithm provides the very good tool for present optimization domain, Zhou Chi et al. [4] talked about origin, development and application of PSO, HPSO was developed by Lovbjerg, Rasmussen and Krink in 2000 [5]. But at present the optimization methods of scroll compressor exist the shortcoming of low precision, low efficiency and optimal solution is not ideal, according to structure, performance characteristics of scroll compressor and GA, PSO characteristics GA-PSO optimization method which combines merits of two algorithms is developed, the performance of scroll compressor is improved by using the optimized scroll plate, the test results indicate that the new optimization method has the obvious superiority for scroll plate optimization, it also provides the theory and practice basis for the application of intelligent algorithm in the project.

2. GA-PSO

2.1 GA

GA was developed by american Professor John H Hoolland, GA is global optimization reconnaissance method which simulates crossover and mutation of biology, it transforms optimization problem from the solution space of policy-making to the search space of heredity gene, eliminates inferior gene individual and develops the high quality gene individual, gradually enhances the quality of entire population, until the solution parameters reach convergence condition and the optimal solution of policy-making variable is obtained. GA gets relevant fitness according to optimization question, does not request continuous fitness function etc. so it gets wide application, GA is a process of search characteristic character string space, the goal is that gets the characteristic character string with high fitness, The characteristic of GA is that it works in turn in the code space and solution space, it carries on GA operation in the code space for chromosome, appraisal and choice in solution space for the solution, the process of choice, crossover and mutation is unceasing circulated from an initial population, until reaches a termination criterion and obtains the optimal solution.

2.2 PSO

PSO is an evolutionary computation technique, PSO simulates the behaviors of bird flocking. In the model community's individual has the ability to control oneself behavior based on the certain internal information and exterior information, it means that each individual has a certain sensation ability and it can apperceive individual position of local best and globe best, particle adjusts its next action according to the current condition and obtained information, so the whole community displays a certain intelligence. When solving optimization question each individual position is correspondingly regarded as a latent solution, according to the above rule the globe optimal solution can be gotten through repeated adjusting these latent solutions. For the nth iteration the particle of PSO changes according to the under two formulas:

$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1} \tag{1}$$

$$v_{id}^{n+1} = w \cdot v_{id}^{n} + c_1 \cdot rand() \cdot (p_{id} - x_{id}^{n}) + c_2 \cdot rand() \cdot (p_{gd} - x_{id}^{n}) \qquad i=1,2,\ldots,M \tag{2}$$

Where M is the particle sum; v_{id}^{n} is the dth weight of flight velocity vector for the nth iteration particle i; x_{id}^{n} is the dth weight of position vector for the nth iteration particle i; p_{id} is the dth weight of *Pbest* for particle i; p_{gd} is the dth weight of *Gbest* for particle i; *Pbest* is the best of particle; *Gbest* is the best of all particles; c_1 and c_2 are learning factors; *rand()* is a random number between (0,1); w is inertia weight function. The formula (2) computes new velocity of particle i through three parts:

①The first is the previous time velocity of particle i, it shows the present condition, can balance globe and local search ability;

②The second is cognition part, it indicates the particle thought, enables the particle to have the enough strong globe search ability and avoid local minimum;

③The third is society part, it incarnates information sharing between particles.

Under function of the three parts, the particles adjust position based on history experience and information sharing mechanism, finally the globe best solution can be obtained.

2.3 GA-PSO

GA and PSO are all based on iteration optimization tool, the system is initialized with a population of random solutions and searches for optima by updating generations. The general characters of two algorithms: Two algorithms are both the heuristic algorithms, establish on research foundation of the complex system, the low level element forms the complex structure through the simple organization in the high level, thus algorithm displays the intelligent characteristic, auto-organized, auto-adapted and auto-studied to solve the complex optimization problem; Two algorithms are both based on the probability algorithm, are parallel in essence and belong to the community search algorithm; Two algorithms do not request non-differentiable or other assistance knowledge, only need objective function and the fitness function of search direction. The different characteristics of two algorithms: GA needs to realize from the phenotype to the gene image, it is the code work, each individual is the chromosome with characteristic entity in fact, after initial generation of population produces, the better approximate solution is produced through survival of the fittest and superior win and the inferior wash out principle. PSO directly carries on processing on the question territory, each individual has the corresponding nature, particle do not wither away in the iterative process; the information transmission of GA is hidden and completes by crossover and mutation. PSO is displayed by two fundamental equations and is dominant; the final solution of GA is obtained through competition and the final solution of PSO is obtained through cooperation. Although GA has successful application in many optimization questions, but it also has some insufficiencies, GA has many parameters to adjust, the local search ability is bad, it has the phenomenon of immaturely constringency and stochastically roams and so on, thus causes the bad astringency and needs long time to find the optimal solution. Compared with the genetic algorithm and other optimized algorithms, PSO has no evolution operators such as crossover and mutation, in PSO, the potential solutions, called particles, are "flown" through the problem space by following the current optimum particles. the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. At present PSO has been successfully applied in many areas, such as function optimization, artificial neural network training, fuzzy system control and other areas where GA can be applied, but PSO also exists shortcoming of not high constringency precision, is easy to fall into the local extreme value[6][7]。

The article combines the advantages of GA and PSO, puts forward GA-PSO, the crossover is melted into PSO in improved algorithm, when the new solution produces, crossover is applied to it, produced new descendant substitutes for the parents particles, it can produce better solution, the descendant particles inherit the parents particles merits through crossover, it can enhance the search ability for solution and region between particles in theory, because crossover can reorganize the existing solutions, it is very possible to discover a better solution, simultaneously when PSO fell into the partial extreme value, Particles may jump out the local extreme point through crossover and very quickly achieve the globe best position, the crossover principle is that crossover particles are chosen by a certain crossover probability from all particles, random two particles carries on the crossover to produce the descendant particle, the position radius vector of descendant particle can be expressed as follows:

$$child_1(\bar{x}) = p * parent_1(\bar{x}) + (1-\bar{p}) * parent_2(\bar{x}) \tag{3}$$

$$child_2(\bar{x}) = p * parent_2(\bar{x}) + (1-\bar{p}) * parent_1(\bar{x}) \tag{4}$$

where $\bar{x}$ is the position vector of *d* dimensions, $child_k(\bar{x})$ and $parent_k(\bar{x})$ (*k=1*，*2*) are position of child particle and parents particle； $\bar{p}$ is *d* dimensions random number weight between [0, 1].

The velocity vector of descendant particles is obtained by the under formulas:

$$child_1(\bar{v}) = \frac{parent_1(\bar{v}) + parent_2(\bar{v})}{\left|parent_1(\bar{v}) + parent_2(\bar{v})\right|}\left|parent_1(\bar{v})\right| \tag{5}$$

$$child_2(\bar{v}) = \frac{parent_1(\bar{v}) + parent_2(\bar{v})}{\left|parent_1(\bar{v}) + parent_2(\bar{v})\right|}\left|parent_2(\bar{v})\right| \tag{6}$$

where $\bar{v}$ is the velocity vector of *d* dimensions, $child_k(\bar{v})$ and $parent_k(\bar{v})$ (*k=1*，*2*) are velocity of child particle and parents particle, each generation individual exchanges its part genes according to a certain probability and produces the new gene combination, each solution has the opportunity to exchange its outstanding gene, the better solution structure can be obtained, simultaneously the inertia weight *w* uses the linear function in training, firstly the great inertia weight is used, then the smaller inertia weight is gradually used, the phenomenon of slow training speed in the beginning and stochastically roams in the end is solved. The method overcomes the original algorithm shortcoming and is applied to scroll plate optimization, the satisfactory results obtained[8].

3. OPTIMIZATION DESIGN OF SCROLL PLATE

The scroll compressor is regarded as the new generation displacement compressor, its application prospect is more and more extensive. The main structure of scroll compressor shows in Figure1, it makes up of fixed scroll, orbiting scroll, crank shaft, frame, Oldham ring, main balance weight and assistant balance weigh etc. The fixed scroll and orbiting scroll are assembled at a relative angle of 180^0, so that they touch at several points and form a series of crescent-shaped pockets. One of the scroll plate is fixed and the other orbits around the centre of the fixed scroll wrap. The orbiting scroll is driven by a simple short-throw crank mechanism. The pair of contact points between the two spiral walls are shifted along the spiral curves. The relative angle of the two scroll plates are maintained by means of an anti-rotation coupling mechanism located between the back of the orbiting scroll plate and the frame. The fixed scroll and orbiting scroll are the most key parts, its design and manufacture influences the working

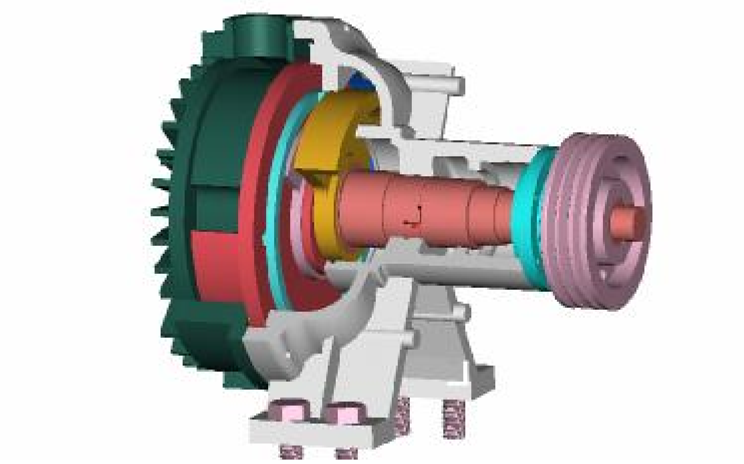

Figure 1: Structure of scroll compressor

performance in a great extent, the suction-compress-exhaust course of scroll compressor goes on at the same time, the whole course is repeated continuously and steadily, so the vibration and noise of the scroll compressor are low compared with other compressors [9]. In order to improve the performance of the scroll compressor, the scroll plates should guarantee own high precision and scroll plate optimization is very important, in the article the mathematical model of scroll plate is established according to the optimization design, then GA-PSO is applied to solve the model according to restraint condition, the optimized design parameters are gotten, it guide design of scroll compressor.

3.1 Design Variable

The basic parameters of fixed scroll and orbiting scroll are the key factors for compressor performance and the optimization main variables, the basic variables have:
(1) Pitch scroll: *P*; (2) Radius of basic circle: *a*; (3) Scroll width: t; (4) Scroll height: *H*; (5) Scroll turns:*N*;
The four parameters are been as design variables:

$$X = [x_1, x_2, x_3, x_4] = [a, t, H, N] \tag{7}$$

The change of five parameters affects performance index of delivery, compression ratio, mechanical loss and efficiency etc.

3.2 Objective Function

The optimization objective function of scroll compressor can be determined according to design request, such as manufacture cost, entire machine life and reliability, thermal characteristic, ratio power, EER or multi- goals and so on. Ratio power is chosen as the objective function of scroll compressor, the ratio power P_e of scroll compressor is given by:

$$P_e = P_S / V_S \tag{8}$$

Where P_S is shaft power; V_S is actual delivery.

$$P = 2pa \tag{9}$$

$$t = 2aa \tag{10}$$

$$r = P/2 - t \tag{11}$$

Where a is radius of basic circle; a is origination angle of involutes of the circle; r is basic circle center distance of fixed scroll and orbiting scroll.

Compression internal work W_i for compression 1m^3 gas is expressed as follows:

$$W_i = \frac{m_2}{m_2 - 1} p_s \left(t_i^{\frac{m_2 - 1}{m_2}} - 1 \right) + t_i^{-\frac{1}{m_2}} (p_d - p_i) + p_s \left(\frac{k}{k-1} - \frac{m_1}{m_1 - 1} \right) \left(t_i^{\frac{m_1 - 1}{m_1}} - 1 \right) \tag{12}$$

Where W_i is compression internal work; t_i is inner pressure ratio; m_1 is muti-stage compression index without cooling; m_2 is course muti-stage index; p_i is inner pressure; p_d is discharge pressure; p_s is suction pressure. (considering heat exchange of compression gas with outside, affixation loss of different inner and outer pressure ratio)

The shaft power of scroll compressor is :

$$W = W_i + W_s + W_d \tag{13}$$

Where W_s is mechanical loss of compressor; W_d is motor loss.

3.3 Restraint Condition

The restraint conditions of scroll compressor mainly include intensity, rigidity condition, processing condition, the thermal performance and dynamic performance etc. The boundary restraint conditions are established as follows for scroll plate optimization design:

(1) Big scroll circle number *N* will produce over compression loss and small *N* will produce under compression loss, circle number influences outline size of scroll plate, according experience *N* satisfies restriction $2.75 \le N \le 4.5$;

(2) For a fixed design scroll compressor, compression ratio e should guarantee fixedness $e = e_c$, the restriction of e is: $e_c \le e \le 1.02 e_c$;

(3) For a fixed design scroll compressor, delivery V should guarantee fixedness $V = V_c$, the restriction of V is: $V_c \le V \le 1.02 V_c$;

(4) In order to guarantee rigidity of process cutter and consider precision of scroll plate, the restriction is: $2 \le \frac{H}{P - t} \le 6$;

(5) The size of scroll tooth thick t influences intension, rigidity, radial leakage, volume, weight of whole machine and seal performance in work, so the t satisfies restriction: $2.5 \le t \le 5.5$;

(6) Big scroll height H will reduce leakage, but produce big overturn moment of orbiting scroll, big friction loss, instability movement and hard manufacture; small H can reduce overturn moment, but add scroll plate size under a certain delivery, H satisfies restriction: $H_{\min} \le H \le H_{\max}$;

3.3 Optimization Results and Analysis

Because each design variable has the different physics significance, the variable magnitude and the variation range are inconsistent, zero dimension scale transformation is applied to variable, it makes their change scope under the close magnitude, does not produce the serious error. Through the scale transformation it can also improve the condition of objective function in a certain degree, the convergence rate of optimized computation and the value stability, the scale transformation is given as follows:

$$x_i' = x_i / x_{i0} \quad i = 1, 2, 3, 4 \tag{14}$$

Where x_{i0} is original value of design variable;

Scale transformation of restriction condition can get same magnitude restriction function and satisfy restriction condition, GA-PSO is applied to solve objective variable $X = [x_1, x_2, x_3, x_4] = [a, t, H, N]$ through mathematical model under restriction condition, it makes P_e reach minimum, figure 2 is the algorithm process, the program of improved arithmetic is realized by *MATLAB*, GA, PSO and GA-PAO are compared through objective function, the basic optimization parameters of scroll compressor is $X = [a, t, H, N] =$ [3, 4, 38, 3.2]; three algorithms are applied to optimize the scroll plate mathematical model, each algorithm runs 80 times, in the optimization process, GA falls into local extreme value 10 times, PSO falls into local extreme value 7 times, GA-PSO falls into local extreme value 1 time, simultaneously two methods is applied to compare three algorithms. The first kind method uses fixed iteration times, table 1 is the optimized results of three kinds of algorithms when the iteration times are 400; The second kind method uses fixed objective function precision, when the objective function reached 5.5, GA needs iteration 250 generations, PSO needs iteration 190 times and improved algorithm need iteration 200 times, the results indicate that the improved algorithm can obtain the quite ideal optimal solution. The iteration times of improved algorithm are more than PSO, it is because that the improved algorithm used crossover operation, but the improved algorithm falls into the local extreme value just 1 time, simultaneously obtained better solution compared with two algorithms. The author uses the optimized result to guide the scroll compressor design, the prototype is carried on 400 hours life tests, ratio power reduces from 5.7 KW/m^{3}min^{-1} to 5.2-5.3KW/m^{3}min^{-1}, the performance test results indicated that the improved algorithm had high quality solution, good restrained characteristic and quick speed for scroll plate optimization. The improved method solved the parameters optimization question, reduced ratio power, obtained the satisfying results, provided a new thought and method for the development high performance scroll air compressor [10]. Now we are engaged in the improved mathematic model and better algorithm, if the problem can be ideally solved, I think that P_e can be reduced under 5.2.

Table 1: Optimization results (iteration times=400)

Design parameter	Initial value	GA	PSO	GA-PSO
a	3	3.3	3.5	3.52
t	4	4.3	4.2	4.46
H	38	37.5	39.2	40
N	3.2	3.18	3.25	3.04
P_e	5.7	5.38	5.33	5.26

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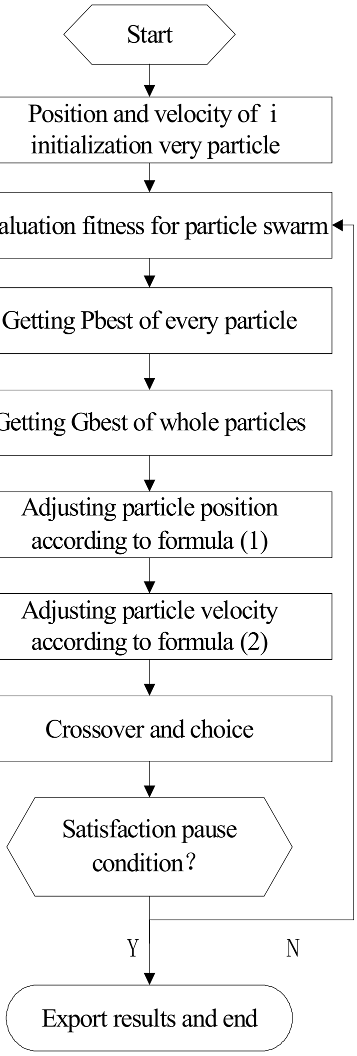

Figure 2 Algorithm flow chart