THREE-DIMENSIONAL MULTI-PIPE ROUTE OPTIMIZATION BASED ON GENETIC ALGORITHMS

Huanlong Wang[1],Cuilian Zhao[1] ,Weichun Yan[2] ,Xiaowei Feng[1]
[1]College of Mechanicals Engineering and Automation, Shanghai University, Shanghai 200072, China;Email:whllenny-2000@163.com; [2]Shanghai Turbine CO.,LTD. Shanghai 200240,China

Abstract: To optimize the design of three-dimensional multi-pipe, multi-constraint and multi-objective path planning, an approach based on Genetic Algorithms (GA) is presented in this paper, which includes definition of genes to deal with pipe routes, definition and application of fitness functions, and definition of punishing function set by constraints. An example and good simulation results are also presented to show the validity of this approach.

Key words: route optimization; GA; Encapsulated Oil Pipes (EOP).

1. INTRODUCTION

In the system of ships, aeroengines and turbines, which has complicated pipe system, the route optimization is always a research hotspot. The route optimization not only releases burden of manual design, but also enhances efficiency of design and reduces cost of design and manufacturing. Though having function of general pipe design, some commercial CAD softwares, such as UG, SOLIDWORKS and CATIA etc., don't have function of the route optimization for some special industries. And researchers mainly focused on the route optimization of two-dimensional pipes or three-dimensional and single one, but relatively less in the multi-pipe, multi-constraint and multi-objective route optimization previously. Taking the route optimization of the EOP[1] of turbine as an example, this paper will present an approach for the "three-multi" optimization problem, which may be useful to other route optimization.

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A lot of works have been done in the route optimization of three-dimensional pipes, and relative study is developing from the simple two-dimensional route optimization in the early days to the three-dimensional multi-pipe, multi-constraints and multi-objective route optimization now.

In 1976, sprout method adopted "Depth-First Search" to optimize route [2], which needed more information. In 1985, Dijstra adopted weighted graph (G=(V,E,W) where: V : a group of connecting points; E: cyclometer of connecting points; W; weighted value)to describe pipe space and solve the route optimization problem [3].And then some developed methods, such as adjoining nodes algorithm, the shortest route rapid algorithm and Dijkstra algorithm with evaluating function [4], were proposed, which were only to solve the single pipe problem, instead of considering the multi-pipe one just like the kind of route optimization problems of EOP of turbine. In 2003, Fan jiang proposed the path planning in the pipe system based on coevolution, which was only suitable to the two-dimensional pipe system [5].

Now the main algorithms of path planning are as follows:

- Lee Routing Algorithm [6]: it is a kind of maze algorithm, which is one of the oldest Lee Routing Algorithms. M.Dorigo proposed Ant Colony Algorithm [7] based on maze algorithm.
- Method based on AI and KBE: the process of pipe design is a kind of sequent one, which agglomerates designers' intelligence and experience. So the pipe planning and expert system can be developed to enhance the design efficiency by the technology of AI and KBE.
- Path planning based on Simulated Annealing (SA)[8].
- Path planning based on GA: it is quite useful to the route optimization, and can be applied to solve the multi-pipe, multi-constraint route optimization problem.

2. ALGORITHM OF THE ROUTE OPTIMIZATION UNDER KNOWN CONDITON

2.1 Condition setting

Supposed that the relative position of entrance and exit section of each pipe has been known. Data are transited to Excel as an initial data frame from an outer system by data transition (Fig.1). And then the route can be optimized by GA. Followed the flow chart (Fig. 2).

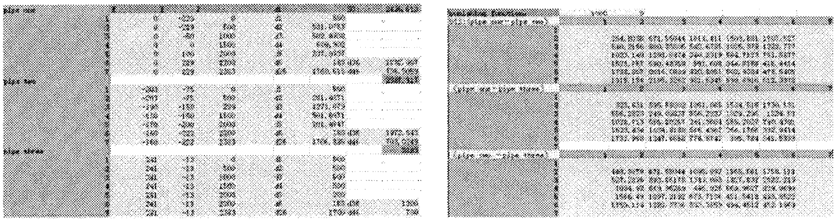


Figure 1. Data frame

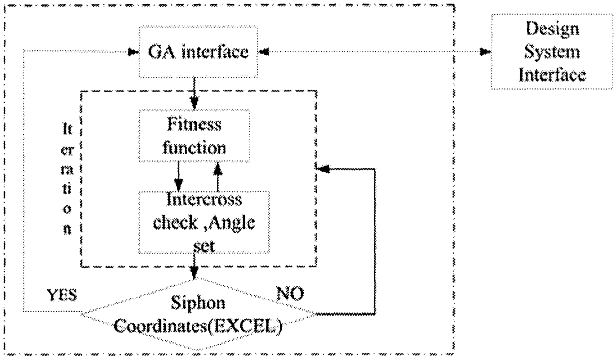


Figure 2. Flow chart

2.2 Coding method

Encoding is a chief aspect of designing and applying GA. Considering the three-dimensional and big data, the coordinate parameters are encoded by floating number, number of bend pipes by integer, the whole variable by coupling multi-parameter. And the code length of each individual "p" is changed with the variable "N" (the number of bend pipes). It is as follows:

$$x_{1,3}\cdots\cdots x_{1,m-2}x_{1,m-1}x_{2,3}\cdots\cdots x_{2,m-2}x_{2,m-1}x_{3,3}\cdots\cdots x_{3,m-2}x_{3,m-1}y_{1,3}\cdots\cdots y_{1,m-2}y_{1,m-1}y_{2,3}\cdots\cdots y_{2,m-2}y_{2,m-1}y_{3,3}\cdots\cdots y_{3,m-2}y_{3,m-1}$$
$$z_{1,2}\cdots\cdots z_{1,m-2}z_{1,m-1}z_{1,m}z_{2,2}\cdots\cdots z_{2,m-2}z_{2,m-1}z_{2,m}z_{3,2}\cdots\cdots z_{3,m-2}z_{3,m-1}z_{3,m}N_1N_2N_3$$

Where:

$x_{i,j}y_{i,j}z_{i,j}$: the coordinates of each pipe; $i=1$:oil pipe one; $i=2$:oil pipe two; $i=3$:oil pipe three; j : 1～m; and $z_{i,j+1} \geq z_{i,j}$;

N_k: the number of each bend pipe; $k=1$: oil pipe one; $k=2$: oil pipe two; $k=3$: oil pipe three; m : the number of strait pipe; m =N+1;

2.3 Selection of fitness function

The selection of fitness function is very important. For the optimization problem with constraints, it can be performance index, or be transformed from the performance index. This paper is about the shortest path, and constraint is that pipes can't be intersected, and bend pipe angle can't be over 60°. Although GA is the algorithm that deals with the maximum problem., the minimum problem with constraints can be transformed from the maximum problem with the punishing function.

According to pressure loss of fluid in the pipe, the shortest length of pipes and the least number of bend pipes are taken as performance index to form the fitness function F_i.(Each pipe has the same fitness function).

$$F_i = w_1 \times \left(1 + \frac{S_i}{\sum_{j=1}^{m} d_j} \right) + w_2 \times \left(\frac{N_{\max} - N_i}{N_{\max} - N_{\min}} \right) + R_p$$

Where:

i :suffix, its meaning is the same to the upper one;

S_i :the straight distance between the exit and the entrance section of each pipe;

f_i: the objective function of each pipe; F_i: the fitness function of each pipe; N_i: the number of bend pipes of each pipe;

w_1 : the weight value of pipe length in the fitness function; w_2 : the weight value of the number of bend pipes in the fitness function

d_i :the length of the single straight pipe; $N_{\min}$: the mini number of bend pipes; $N_{\max}$: the max number of bend pipes;

R_p : the punishing function, which is defined in case of the intersection between pipes and the bend pipe angle.

2.4 Selection of the punishing function R_p

It is a basic principle for the multiple pipes to avoid intersection and the bigger bend pipe angle. Hence, the intersection points must be deleted in order to the route optimization. And the bend pipe angle also needs restricting to reduce the searching space. For every pipe, the punishing function is added to the fitness function to reduce the fitness to delete the bad points when pipes intersect between each other and the bend pipe angle goes beyond the set one. Formula is as follows:

$$\sqrt{(x_{ij}-x_{kg})^2+(y_{ij}-y_{kg})^2+(z_{ij}-z_{kg})^2}>R_i+R_k$$

The bend pipe angle is limited between 0° and 60°, so the formula is as follows:

$$-1\le\frac{d_{i,(j-1,j)}^2+d_{i,(j,j+1)}^2-d_{i,(j-1,j+1)}^2}{2\cdot d_{i,(j-1,j)}\cdot d_{i,(j,j+1)}}\le-0.5$$

Where:

$$d_{i,(j-1,j)}=\sqrt{(x_{i,j}-x_{i,j-1})^2+(y_{i,j}-y_{i,j-1})^2+(z_{i,j}-z_{i,j-1})^2}$$

$$d_{i,(j,j+1)}=\sqrt{(x_{i,j+1}-x_{i,j})^2+(y_{i,j+1}-y_{i,j})^2+(z_{j+1}-z_{j})^2}$$

$$d_{i,(j-1,j+1)}=\sqrt{(x_{i,j+1}-x_{i,j-1})^2+(y_{i,j+1}-y_{i,j-1})^2+(z_{i,j+1}-z_{i,j-1})^2}$$

i , k: $1\le i,k\le3$,and $i\ne k$, the symbol of pipe, its meaning is the same to the upper ones; R_1: radius of oil pipe one; R_2 : radius of oil pipe two; R_3 : radius of oil pipe three ;j, g : $1\le j,g\le m$, symbol of the bend pipe coordinates .

For the punishing function, formula is as follows according to the upper rules:

$$R_p=\begin{cases}0\\1000\end{cases}\text{(if interference :0 ; otherwise: 1000)}$$

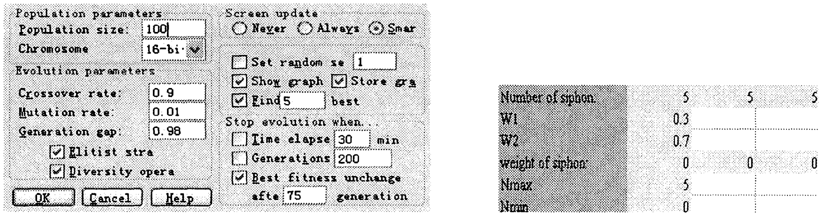
3. TRIAL ANALYSIS

The trial analysis of this algorithm is applied to one part of the EOP system, According to the design experience, the max number of the bend pipes is five. The pipe coordinates are as follows:

Table 1. The coordinates of entrance and exit

	Entrance X	Y	Z	Exit X	Y	Z	Diameter ¢
Sucker for bearing	-229.0	0.0	0.0	0.0	229.0	2383.0	219.0
Sucker for primary oil pump	-75.0	203.0	0.0	-160.0	-222.0	2383.0	168.0
Cream pipe for primary oil pipe	-13.0	-241.0	0.0	241.0	-13.0	2383.0	168.0

Set: population size M=100, cross rate Pc=0.9, mutation rate Pm=0.01, generation gap G=0.98, the weight value of length of the pipe w_1=0.3, the weight value of the number of the bend pipe w_2=0.7, the setting is as follows:



Population parameters
Population size: 100
Chromosome 16-bi·
Evolution parameters
Crossover rate: 0.9
Mutation rate: 0.01
Generation gap: 0.98
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☐ Generations 200
☑ Best fitness unchange afte 75 generation

Number of siphon	5	5	5
W1	0.3		
W2	0.7		
weight of siphon:	0	0	0
Nmax	5		
Nmin	0		

Figure 3. Parameter and weight value setting

Results are as follows after optimization.

Table 2. Optimization results

	X	Y	Z	Number of siphon
Sucker for bearing:	-229.00	0.00	812. 00	2
	0.00	229.00	1533.00	
Sucker for primary oil pump:	-75. 00	203. 00	299.00	4
	63. 00	122. 06	521.20	
	128. 12	84. 00	1138.74	
	-82. 88	-140. 09	1434.14	
	-160. 00	-222. 00	1629.00	
Cream pipe for primary oil Pump:	-13. 00	-241. 00	1021.24	5
	36. 33	-196. 72	1196.34	
	130. 32	-183. 48	1332.80	
	180. 55	-116. 79	1481.65	
	218. 57	-33. 19	1620.50	
	241. 00	-13. 00	1733.00	

The 3D modeling is as follows:

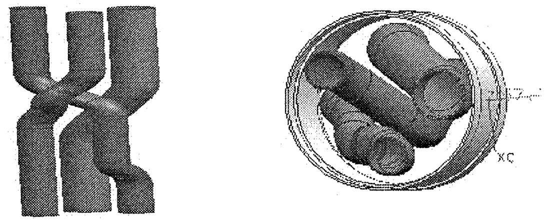

Figure 4. 3D modeling

4. CONCLUSION

Faced to the multi-pipe, multi-constraint and multi-objective optimization problem, a method based on GA is presented to deal with the pipe route planning. One part of the EOP system is also optimized and its result is quite satisfied. However, some further study is needed as following:

- The weight value is only set by the design experience, which may be thoughtless.
- There is only one part of the EOP system optimized, and the optimization of whole system needs improving.

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