__Original Research Article__

Design and Optimization of Intelligent Algae Interception Equipment for Rivers based on Orthogonal Analysis and Finite Element Analysis

ABSTRACT

This paper describes the process of designing an intelligent algae deterrent device that can stop algae and clean water, and the mechanical analysis and optimization of the key force parts of the device. The design of the equipment includes the design of the main structural frame and the transmission mechanism. The optimization process is mainly based on the orthogonal analysis experimental method, and ANSYS is used as the main calculation tool. The maximum stress of the chain is taken as the experimental result, the length of the tooth rake, the chain material and the transmission power are taken as three factors, and three levels are set for each factor, and a four-factor three-level orthogonal test table is selected. Finally, the optimized parameter values were obtained by simulated annealing algorithm.

Keywords: Algae interception equipment, orthogonal analysis, ANSYS, analysis of variance, simulated annealing algorithm.

1. INTRODUCTION

The use of algae interception equipment in the South-North Water Transfer Project has largely reduced the pollution of rivers, and with the development of science and technology, algae interception equipment has become more and more advanced. The main frame of the algae interception equipment is the barrage, the barrage in the water by the common action of many factors, in addition to consider the impact of water pressure on the stability of the barrage, the impact of vibration on the barrage is also not negligible, because the large barrage has a large volume, weak stiffness and complex hydraulic conditions and other factors appropriate to induce flow vibration, resulting in structural damage to the barrage, the actual engineering use of the barrage vibration damage is also relatively It is generally believed that the key to avoid the vibration of the barrage is to keep the self-oscillation frequency of the fence leaves and bars away from the main frequency of the high-energy pulsation of the water [1]. The rotary intelligent algae barrier is mainly composed of two major parts: vertical barrier and cleaning machine [2], which drives the cleaning rake on the barrier to rotate around the barrier through the chain drive mechanism and scrape away the algae on the barrier, thus realizing the function of continuous algae cleaning [3].

2. STRUCTURAL MODEL

2.1 Interceptor Structure

The working river water surface width of the algae interceptor equipment is 9 meters, the river bottom width is 9 meters, the depth is 6 meters, and the highest water level is 1 meter away from the dike. The barrage frame is the supporting part of the algae stopping equipment, and its top should be higher than the operation platform established on the river to facilitate the staff to observe the inspection and maintenance work. The head drive part of the barrage should be made horizontal, with a smooth transition between the overall barrage, so that the algae hooked up by the rotating tooth rake is easier to fall off. The height of the river table is set to 6.5 meters, the vertical height of the fence is set to 5.5 meters, the bottom of the fence is installed 18 small sprockets, the uppermost drive shaft is installed 18 large sprockets corresponding to it, each two sprockets for a group, each group spacing is 1 meter, a total of 9 groups. In order to avoid excessive torque of the sprocket shaft, each group of sprockets is installed with a motor.

According to the design dimensions, use solidworks to draw and assemble the part drawing, and the generated assembly is shown in Fig.1-2.

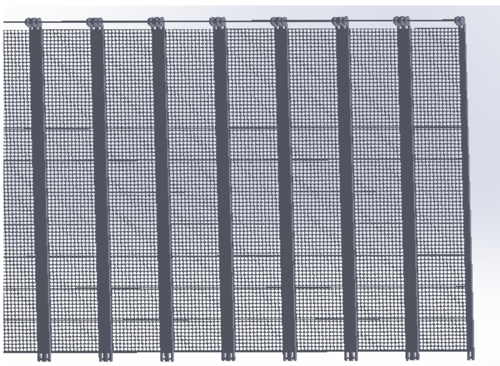


Fig.1. Assembly diagram of interceptor Fig.2. Interception network and tooth rake local combination diagram

2.2 Interceptor Mesh

Copper alloy interceptor mesh is the best material, which can meet various working conditions such as corrosion resistance, bending performance and tensile strength. The interceptor net is fixed on the interceptor fence, allowing the river water to flow through while blocking the algae through, and when the algae attached to the net surface reaches a certain amount, the machine starts and scrapes away the algae on the net surface. Its working mechanism diagram is shown in Fig.2.

2.3 Sprocket Drive Mechanism Design

Head drive part of the sprocket shaft diameter is designed for 300 mm, sprocket selection 17 teeth 16A standard sprocket, according to the size of the sprocket and the center distance between the sprocket design non-standard chain, in order to make the chain drive to drive the tooth rake to move in the interceptor network, the connection between the inner and outer links of the chain part of the pin to do some long, convenient and tooth rake welding. Every 0.5 m distance in the chain pin shaft welding a group of tooth rake, tooth rake structure and connection partial enlarged view as shown in Fig.3, 4.

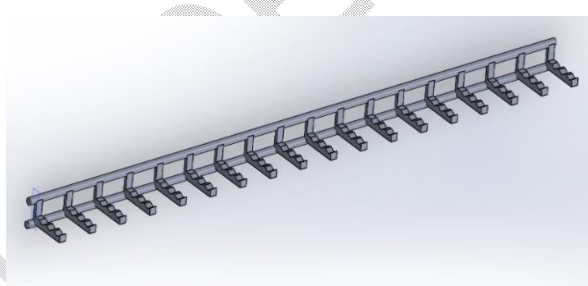


Fig.3. Tooth rake structure diagram

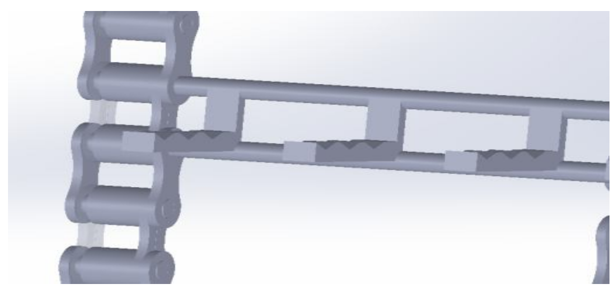


Fig.4.Tooth rake and conveyor chain partial connection view

2.4 Final Assembly Design

All the parts are assembled into a large assembly diagram as shown in Fig.5,6.

Fig.5. Front view of algae interception mechanism

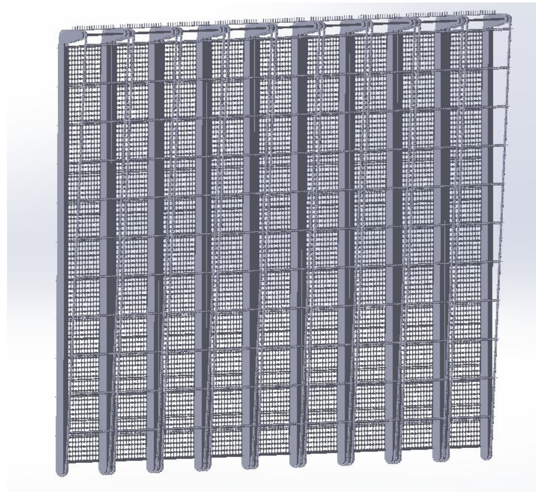


Fig.6. Reverse view of algae interception mechanism

It can be seen that the equipment has a total of nine groups of transmission mechanism, and each group of transmission mechanism is independent of each other, but also can be combined together, with couplings to connect the nine sprocket shafts together. From the model of the equipment can be seen, the biggest advantage of this algae stopping equipment is that it can achieve the function of the tooth rake uninterruptedly from the river to retrieve algae and garbage, and high efficiency, suitable for algae and garbage more river.

3. STRESS ANALYSIS OF KEY PARTS OF THE EQUIPMENT

3.1 Analysis Overview

From the above design, it can be seen that the transmission part of the equipment uses chain transmission, each set of transmission mechanism contains six sprockets, so the chain transmission in addition to considering its own self-weight, there is also the force from the rake teeth welded together with the chain, and this force is mainly applied to the connection pin between the outer and inner links, so the design of this chain is non-standard chain, and the diameter size of this part is increased to 9mm, and the diameter of the inner link roller remains unchanged The diameter of the inner link roller remains the same, but it is still 15.88mm according to the national standard.

Because the machine works in water, the chain should be treated with anti-corrosion treatment. Because the river is deeper, the size of the chain in the chain drive is longer, there are more links, and the self-weight and load are larger, the chain drive is easy to form fatigue cracks at the stress concentration, and it is easy to form fatigue fracture for a long time, so the mechanical analysis should be conducted before the machine test run, and the maximum stress should be calculated.

3.2 Design of Orthogonal Test

Ansys workbench is commonly used stress analysis software, before the stress analysis, display the various factors affecting the size of the stress, where the material of the chain is the main influencing factor, in order to explore the stability of the chain in the work under different material properties, set three different materials, select the three models of 45 steel, 45cr, 45mn as the three levels of the material. Because the length of the tooth rake directly determines the amount of algae or garbage hooked up at one time, will directly or indirectly affect the size of the load, set the length of the tooth rake 4cm, 5cm, 6cm as its three levels, plus the previous design of the tooth rake, make a model, measure the length of the tooth rake in the maximum weight of algae hooked up under each level, repeat the experiment, measured the experimental data as Table 1.

Table 1. toothed rake weight measurement experimental data table

Experimental number (1 level)	1	2	3	4
Weight/kg	17.5	15.8	16.7	18.4
Average value/kg	17.1			
Experimental number (2 level)	1	2	3	4
Weight/kg	25.9	26.6	27.2	24.3
Average value/kg	26			

Experimental number (3 level)	1	2	3	4
Weight/kg	36.6	38.2	35.1	37
Average value/kg	36.7			

The average value of the experimental data of each group under each level is used as the corresponding level parameter of the tooth rake. Motor power as the last influencing factor, the greater the motor power, the greater the starting torque, the greater the impact load on the chain, first calculate the total weight, and then determine the power of the motor.

When the equipment is working, the algae is fished by the tooth rake in front of the barrage to increase the load, and the tooth rake behind the barrage will unload the hooked algae and other things to reduce the load, so it can be judged that the greatest force in the whole chain is on the front side of the barrage, and the back half of the chain is removed to keep only the front half for simplified analysis.

The analysis model is drawn in solidworks software as Fig.7, and the partial view as Fig.8.

Fig.7. Analytical model

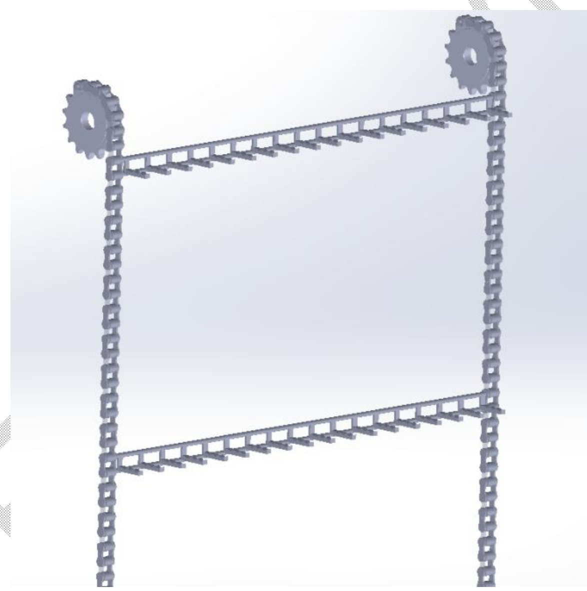


Fig. 8. Partial view

According to this model to calculate the full load force value, in solidworks under the evaluation command to call out the mass properties command, the mass of the tooth rake parts is 1291.65 grams. Similarly, the mass properties of the inner and outer chain links are called out, and the mass of a single inner link is 80 grams, the mass of a single outer link is 10 grams, and the total mass of a single chain is 100 grams.

From the model, it can be seen that the chain between the two adjacent tooth rakes has a total of 11 sections with a total weight of 1100 g. The total weight of the analyzed chain and tooth rake can be calculated as 37.1 kg. In accordance with the water surface and sprocket vertical distance of 1 m, at this time there are two groups of tooth rake bearing heavy, the maximum load of tooth rake is 36.7 kg × 2 = 75.2 kg, assuming that the interceptor is installed vertically, ignoring the effect of friction, the total force driven by the motor is 112.3 kg.

By the formula $p = f * v$ (1)

Where p is the motor power

f is the motor lifting load

v is the lifting speed

According to the lifting speed is estimated between 0.4m/s and 0.7m/s, the three levels of motor power are set as 500w, 650w and 800w.

In summary, design a three-factor three-level orthogonal test, the factors and their levels are shown in Table 2, choose four-factor three-level orthogonal test table, the orthogonal test table is shown in Table 3.

Table 2. The factors and their levels

Factors / Level	Material of the chain	Tooth rake length/mm	Motor power/w
1	45	4	500
2	45mn	5	650
3	45cr	6	800

Table 3. Orthogonal test table

Experiment NO.	Material of the chain	Tooth rake length/mm	Motor power/w	Empty column	Maximum stress/Mp
1	45	4	500		
2	45	5	650		
3	45	6	800		
4	45mn	4	650		
5	45mn	5	800		
6	45mn	6	500		
7	45cr	4	800		
8	45cr	5	500		
9	45cr	6	650		

In order to improve the running speed of the software, the model is considered to be symmetrical, so half of the model is kept for analysis, and considering that the maximum stress of the chain is concentrated in the uppermost links, the uppermost links are selected for the analysis model in Ansys as Fig.9.

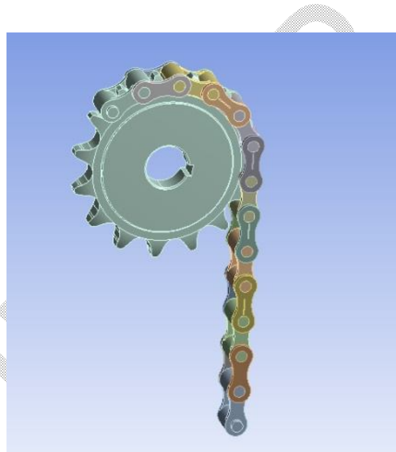
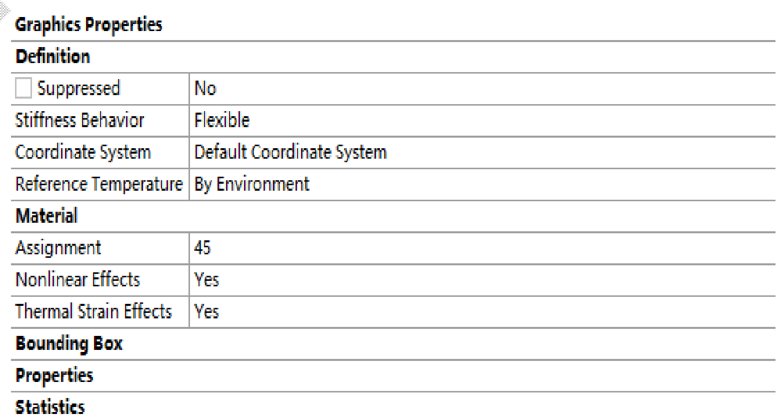


Fig. 9. Ansys analysis model



Graphics Properties	
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	45
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Properties	
Statistics	

Fig. 10. Material setup

Define the contact between chain and sprocket as friction contact, hide the other parts, name the selected surface of the sprocket, select all other surfaces except the contact surface of the sprocket and chain, name it g1, select the surface of several links in contact with the sprocket, name it g2, as in Fig.11. after setting, define the contact type of the chain and sprocket, select the contact surface, after that select g1, g2, change the binding contact to Friction contact, and the friction coefficient is set to 0.2. define the contact between chain links as friction contact, and the friction coefficient is 0.2. define the material as 45, perform meshing, and the minimum mesh is set to 1 mm, use mapped meshing and keep the intermediate nodes to improve the calculation accuracy [5], as in Fig.12.

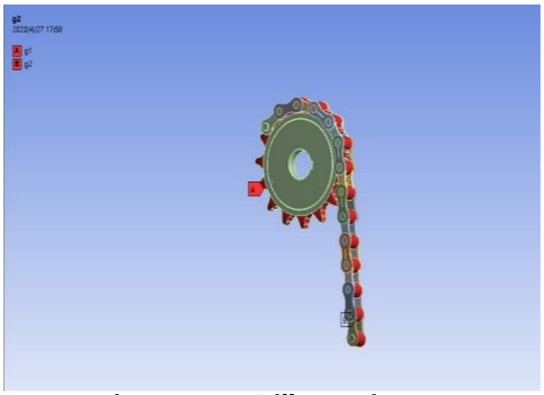


Fig.11. g1, g2 illustration

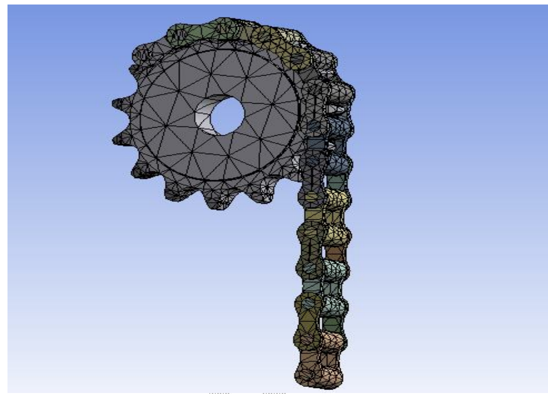


Fig.12. Meshing of the model

The load on the topmost link in the nine sets of experiments was calculated from the original model, as shown in Table 4.

Table 4. Topmost chain link load

Experimental number	1	2	3	4	5	6	7	8	9
Load /kg	71.3	89.1	110.5	72.3	90.3	112	70.7	88.3	109.5

According to Equation (1) and the motor power and load corresponding to each group of experiments, the drive speed of the chain in each group of experiments can be calculated as shown in Table 5.

Table 5. Chain drive speed

Experimental number	1	2	3	4	5	6	7	8	9
Speed m/s	0.70	0.73	0.72	0.90	0.88	0.45	1.1	0.57	0.59

RPM calculation based on the root formula $w=v/2\pi r$ (2)

Where w is the rotational speed

V is the linear velocity

R is the radius of the pitch circle

The pitch circle radius of the sprocket in this model is 0.06m, and the speed of the sprocket under each experiment is calculated as shown in Table 6.

Table 6. Rotational speed

Experimental number	1	2	3	4	5	6	7	8	9
Rotational Speed r\s	1.86	1.94	1.91	2.39	2.34	1.19	2.92	1.51	1.57

From the formula T = 9550P/N (3)

Where T is the motor output torque(n/m)

P is the motor power(kw)

N is the rotational speed(r/min)

According to Table 3. and Table 6, the torque of the sprocket in each group of experiments is calculated as Table 7.

Table 7. Sprocket torque

Experimental number	1	2	3	4	5	6	7	8	9
Torque n/m	42.8	53.3	66.7	43.3	54.4	66.9	43.6	52.7	65.9

The finite element analysis was performed for each group of experiments separately, and the results of the nine groups of experiments are shown in the order from top to bottom and from left to right in Fig.13.

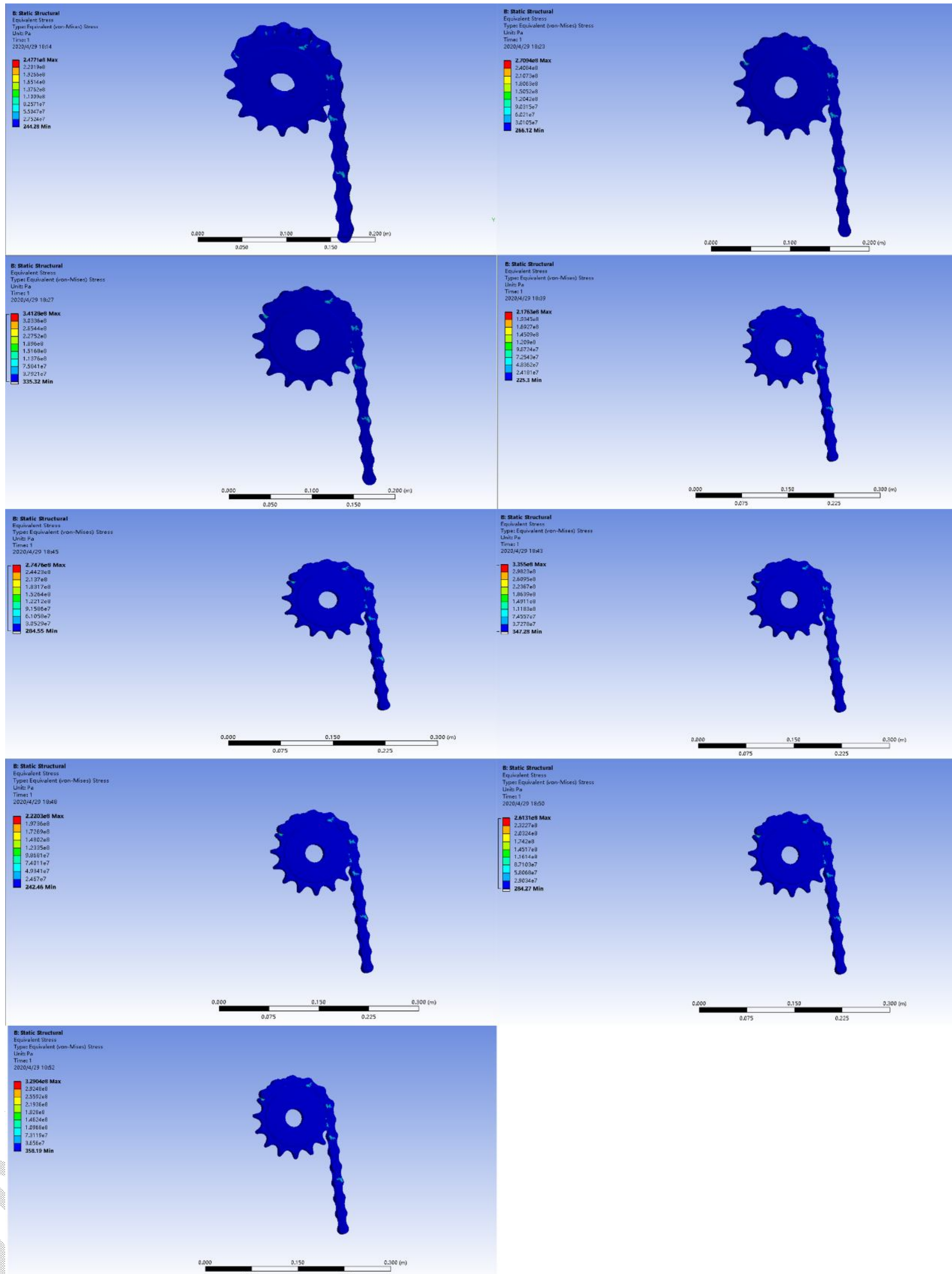


Fig.13. Maximum stress

Using the knowledge of material mechanics to calculate the maximum contact stress of the chain, it is known from the knowledge of elastic mechanics that when the chain link roller is in contact with the sprocket, its initial contact is a line contact, but due to the influence of elastic modulus, its contact part will be deformed elastically, and the line contact will become a surface contact, and its maximum contact stress is in the midline of the contact surface, and the theory of its maximum contact stress can be calculated using the Hertz formula[4] .That is:

$$\sigma_{max} = \sqrt{\frac{P}{\pi b}\left(\frac{\frac{1}{\rho_1} \pm \frac{1}{\rho_2}}{\frac{1-\mu_1}{E_1} + \frac{1-\mu_2}{E_2}}\right)} \qquad (4)$$

Where: p is the normal force of two objects in contact, ρ1, ρ2 is the radius of curvature of two contact surfaces, E1,E2 is the modulus of elasticity of two contacting objects, μ1, μ2 is the Poisson's ratio of two contacting objects, and b is the contact length.

Substituting the design values of the chain and sprocket into the formula, the maximum stress is found to be similar to the experimental results and meets the requirements. Fill in the maximum stress of the sprocket in Fig.13 into Table 8.

Table 8. Maximum stress of chain wheel

Experimental number	1	2	3	4	5	6	7	8	9
Maximum stress /Mp	248	271	341	218	275	336	222	261	329

Table 9. Orthogonal test scheme and results analysis table

Table head design	**Material of the chain**	**Tooth rake length /mm**	**Motor power /w**	**Empty column**	**Experimental results**
Column No. Experimental NO.	1	2	3	4	**Maximum stress/Mp**
1	45	4	500	Level1	248
2	45	5	650	Level2	271
3	45	6	800	Level3	341
4	45mn	4	650	Level3	231
5	45mn	5	800	Level1	275
6	45mn	6	500	Level2	336
7	45cr	4	800	Level2	222
8	45cr	5	500	Level3	261
9	45cr	6	650	Level1	329
K_1	860	691	845	852	T=2514
K_2	839	807	831	829	
K_3	812	1006	838	833	
R	48	315	14	377	
R-value sorting	2	1	3	4	

Table 10. Analysis of variance table

Source of variance	Deviation sum of squares	Degree of freedom	Variance	F-value	Fa	Significance
Materials A	768.55	2	384.275	0.60	$F_{0.05}$（	
Length B	3240.22	2	1620.11	2.54	2,2）	
Power C	436.22	2	218.11	0.34	=19.0	
Error e	1275.33	2	637.665			
Total	5720.32	8	2860.16	3.48		

The results of ANOVA show that the F values of A, B, and C are less than F0.05 (2,2) = 19.0, but it can be seen that Fb>Fa>Fc, the most significant effect of factor B, the more significant effect of factor A, and the least significant factor C. The results of ANOVA are consistent with those obtained by the analysis of extreme variance.

From the material yield stress ≥ 355mp, the safety factor between 1.2-1.5, according to the safety factor of 1.3, the maximum stress is 273mp, then according to the comprehensive balance method, the experimental A1B2C2 group is the optimal combination, the maximum stress of the chain is 271mpa, to meet the requirements, according to the optimal level of experiments, it is found that the operating speed of algae interception equipment and Load capacity are in line with the requirements, and the operating stability is also better.

4. OPTIMIZATION OF PARAMETERS

Analysis of variance Table 9 shows that the length of the tooth rake and the power of the motor in the mechanism have an impact on the maximum stress of the drive chain, which has a greater impact on the length of the tooth rake, the length of the tooth rake is defined between 4-6 cm, the motor power is defined between 500-800 watts, according to the optimization algorithm to calculate the optimal combination of this parameter on the value interval, this problem is a nonlinear multi-parameter optimization problem, the current solution to such This problem is a nonlinear multi-parameter optimization problem, and the current methods for solving such practical problems are mostly based on multi-objective intelligent optimization algorithms, such as: artificial neural networks, simulated annealing algorithms, ant colony algorithms, fuzzy algorithms and so on. The idea of intelligent optimization algorithm originates from the operation principle of some biological mechanism or the principle of a natural phenomenon, which is a theoretical bionic breakthrough, suitable for highly parallel, self-organizing, self-learning and self-adaptive characteristics, providing a new way to solve complex problems.

The BP algorithm has the process of examining the difference between the output solution and the ideal solution, assuming that the difference is w. The purpose of adjusting the weights is to minimize w. This again includes the "minimum" problem mentioned above. The general BP algorithm uses local search, such as the most rapid descent method, Newton's method, etc., while the simulated annealing algorithm has a good ability to search for the global optimal solution, but its search process relies on a state generating function, so first calculate the equation of the fitted curve based on experimental data.

The curve fitting tool is used in the matlab toolbox to fit the experimental data, and the equation of this fitting function is z=93-4.814e-12*x+0.31*y, where x belongs to [4,6] and y belongs to [500, 800].

The simulated annealing algorithm is used in matlab to calculate the values of x and y when the function value z is equal to 273mp, and the function is transformed into w=93-4.814e-12*x+0.31*y-273 with the constraints $4<x<6,500<y<800,0<w$. The minimum value of w under this constraint is found, and the annealing number is set to 150, resulting in the results in Fig.14. When the length of the tooth rake is 4.62cm, the motor power is 580w, the experimental results are closest to 273mp. using ansys to verify the size of the maximum stress value under this parameter, the experimental results and the predicted results are the same.

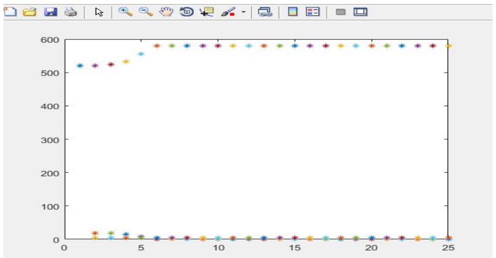


Fig. 14. Iterative process of x and y

5. CONCLUSION

In this paper, an intelligent algae interception equipment is designed to solve the river pollution problem, and finite element analysis is performed on the parts of the equipment that are prone to failure, and a set of optimal experimental parameters is selected by orthogonal experiments on the degree of influence of each factor on the value of the analysis results, under which the stable operation of the equipment is ensured and the efficiency is improved at the same time, and finally a set of exact optimal parameters is derived using simulated annealing algorithm to verify that the experimental results are the same as the predicted values.

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