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Analysis of Fatigue Performance and Parameter Optimization of Single-turn Crankshaft of Submersible Diaphragm Pump

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Abstract: In order to improve and optimize the structure and performance of the submersible diaphragm pump, make the pump work more efficient and stable, and reduce the energy loss and noise, take the single-turn crankshaft of the submersible diaphragm pump as the research object, analyze the force of the single-turn crankshaft, establish a three-dimensional model of the single-turn crankshaft, and parameterize the key design dimensions, find the force change of the single-turn crankshaft by changing the size, and bring the changed value into the software for further analysis, and obtain the influence relationship between the key size parameters of the single-turn crankshaft on performance and stability. Finally, the single-turn crankshaft is optimized by finite element software. The results show that the force of the single-turn crankshaft can be changed through parameter optimization, which can reduce the maximum stress of the single-turn crankshaft and improve the overall safety factor, and the maximum stress of the optimized single-turn crankshaft is reduced by 16.28%, the total deformation is reduced by 15.81%, and the optimized state is more stable, and the bearing capacity and life are improved. It is believed that the parameter optimization of finite elements is obviously helpful for the improvement of single-turn crankshaft.

Keywords: Submersible diaphragm pump, Single-turn crankshaft, Fatigue analysis, Parameter optimization.

1. Introduction

In the industrial field, media need to treat corrosive, high temperature, high viscosity or solid particles, and traditional pumps are difficult to meet the requirements of these special conditions. Therefore, the latent oil diaphragm pump came into being. Potential oil diaphragm pump is widely used in petroleum, chemical, pharmaceutical and other industrial fields, and has the advantages of simple structure and high performance. As one of the key components, the crankshaft of diaphragm pump has an important influence on the efficiency and stability of the submersible pump. Therefore, this study of the fatigue performance of the single-turn crankshaft of the diaphragm pump and the parameter analysis, to further obtain the relationship between the crankshaft performance and parameters, in order to obtain a more stable and durable structure.

The single turn crankshaft of the diaphragm pump is faced with a complex stress environment in the process of work. In the long time of work, due to the influence of vibration, impact and pressure, the single turn crankshaft will have the risk of fatigue and damage, which leads to the decline of the pump performance, shortened life and even equipment failure. Therefore, it has important theoretical significance and practical application value of the submersible diaphragm pump. By studying the fatigue performance of single-turn crankshaft, the fatigue life and failure mechanism in the working process can be revealed, so as to provide scientific basis for avoiding pump failure in operation. During the research, the structural characteristics, stress distribution and deformation should analyze the fatigue failure mechanism in detail. At the same time, the complexity of the working environment, including the influence of the medium characteristics, working temperature and pressure change on the single turn crankshaft, is also considered to evaluate the fatigue performance more comprehensively.[1-2]

Zhang Tao et al. [3] designed the geometry with similar theory and realized the rapid design of the crankshaft. After workbench conducted modal analysis, but did not reach the best design structure of the crankshaft.

In this paper, we conduct fatigue performance analysis and parameter optimization for the single crankshaft of diaphragm pump, study the influence of design parameters on the performance of single crankshaft, and further optimize the crankshaft structure to improve the working efficiency and reliability of diaphragm pump.

2. Theoretical Analysis

2.1. Material characteristic analysis of single-turn crankshaft

As one of the important components of the pump, the single-turn crankshaft needs to bear a lot of load and rotating torque in the working process, and there are certain technical requirements for the selection of the single-turn crankshaft material. The standard 45 steel was used as the material for the single turn crankshaft. The S-N curve of the material represents the relationship between the stress and cyclic life of the material, and is an important tool to assess the fatigue characteristics and life of the material under cyclic load.

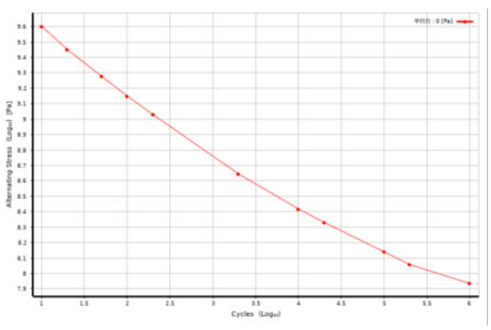


Figure 1. S-N curve

45 steel has a high yield strength and tensile strength, can withstand a large load and stress, has a better strength guarantee. At the same time, easy processing and heat treatment, with high castability. At the same time, it has high hardness and wear resistance and good toughness after proper heat treatment, which can prevent the wear caused by friction and improve the life of the crankshaft.

2.2. Analysis of crankshaft force

The crankshaft force, mainly includes gas pressure, inertia force and friction force generated by the movement of the crank and connecting rod mechanism. The calculation of each force is described in detail in the literature, as shown in Fig.

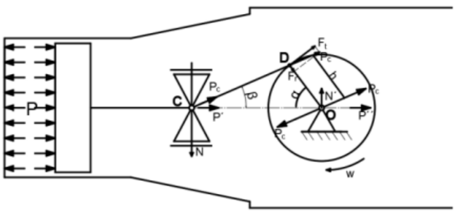


Figure 2. Crankshaft force diagram

he gas force acting on the piston is called the piston force the piston force along the piston, the piston rod, the crosshead to the cross pin (i. e. C point). At point C, it is also subjected to the recurrent inertia I. Because both P and I act along the direction of the cylinder center line, the resultant force of the two forces is

$$P' = P + I \tag{1}$$

$$I = m_p r \omega^2 (\cos\alpha + \lambda\cos 2\alpha) \tag{2}$$

The force P'at C may be divided into two forces, one force N perpendicular to the crosshead slide is called the lateral force, the other force P c along the center line of the link is called the link force. Their numerical values are, respectively, respectively:

$$N = P' tg\beta \tag{3}$$

$$P_c = \frac{P'}{\cos\beta} \tag{4}$$

The force acting on the crank pin can be divided into two directions: the tangential force F ι perpendicular to the crank and the radial force Fr along the radius of the crank. From the triangle relation of Figure 2:

$$F_\iota = P' \frac{\sin（\alpha+\beta）}{\cos\beta} \tag{5}$$

$$F_r = P' \frac{\sin（\alpha+\beta）}{\cos\beta} \tag{6}$$

The β—— -link swing angle in Eq.

The link force Pc is transmitted along the link to the crank pin (point D), and the moment M is formed on the spindle neck (point O). The M value is calculated according to the following equation:

$$M = P_c h = P' r \frac{\sin(a+\beta)}{\cos\beta} \tag{7}$$

In the vertical distance between the center line of the h —— link and the center line of the spindle, its value is:

$$h = r\sin(\alpha + \beta) \tag{8}$$

M is the rotational resistance moment on the compressor shaft. In addition to the moment M, the force Pc, which can be decomposed into a force P 'acting along the center line of the cylinder and a force N' acting perpendicular to the center line of the cylinder:

$$P'' = P_c \cos\beta = P' \tag{9}$$

$$N' = P_c \sin\beta = P' \frac{\sin\beta}{\cos\beta} = P' tg\beta = N \tag{10}$$

It can be seen from the geometric relationship of the figure that the force N'at the neck O of the main axis is equal to the lateral crosshead force N in the opposite direction, and the distance between each other is A, so the force couple NA is in the opposite direction to the resistance moment M of the machine, and has a tendency to dump the machine, which is called the tilt complex moment. The arm length of the force coupling is A=lcos β + rcos α =rsin (α + β) / sin β. So the value of the recovery moment is:

$$NA = P' r \frac{\sin(\alpha+\beta)}{\cos\beta} \tag{11}$$

3. Fatigue Performance Analysis and Parameter Optimization

3.1. Crankshaft fatigue performance analysis

According to the theoretical analysis section, the initial data of the crankshaft is shown in the table:

Table 1. Initial crankshaft data

r	m_p	ω	Total deformation-maximum	Safety factor-minimum	Life-Minimum	Equal effect force- - the maximum	maximum pressure; maximum stress
0.14mm	0.22kg	40π	0.0013872mm	1.519	1E+06	34.423MPa	2500N

The force curve of the crankshaft was obtained by substituting the initial data into the formula with matlab.

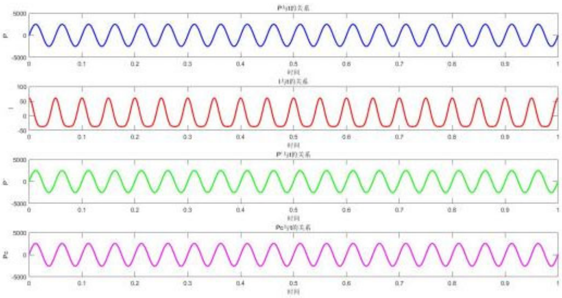


Figure 3. Force curve

It can be seen that the reciprocating inertial force has a limited influence on the crankshaft. To facilitate the analysis, the crankshaft load amplitude is set to a fixed value of 2500N. Computing the force of the crankshaft according to the fixed value can accurately calculate the stress change law of the axis at a specific amplitude and frequency. This helps to assess the strength and fatigue life of the crankshaft as well as the parameter optimization.

3.2. Design parameters

The design parameters of single turn crankshaft of diaphragm pump mainly include the size of crank pin, spindle diameter, size of crank, etc. In this study, according to the empirical formula and the research results in the existing literature, we set the partial design dimensions as parameters, the input parameters include the spindle diameter P 1, the crank thickness P 2, the diameter of the crank pin is set to P 3 length P 4, the output parameters include solid-mass P 5, total deformation-maximum P 6, safety factor-minimum P 7, life-minimum P 8, etc-effect force-maximum P 9

Table 2. Design parameters and initial values

input parameter	Spindle diameterP_1	Crank thicknessP_2	Quickpin diameterP_3	Crank pin lengthP_4
initial value	20mm	12mm	20mm	12mm
input parameter	Crank pin lengthP_4	Solid-massP_5		
initial value	12mm	0.50252kg		
out parameter	Total deformation-maximumP_6	Safety factor-minimumP_7	Life-MinimumP_8	Equal effect force- -the maximumP_9
initial value	0.0013872mm	1.519	1E+06	34.423MPa

3.3. Crankshaft setting and solution solving

3.3.1. Grid division

The workbench is used to mesh the model. The mesh structure is triperihedral. In order to ensure the quality of the mesh, the size of the mesh is adjusted, and encryption and surface mesh division are used to further improve the quality of the mesh. Before fatigue analysis, the grid is tested to verify the grid relevance, and the grid of different sizes is simulated. When the results almost never change, the current grid size can be used for simulation. At this time, the simulation results obtained are relatively accurate, and the division result diagram is shown in Fig.

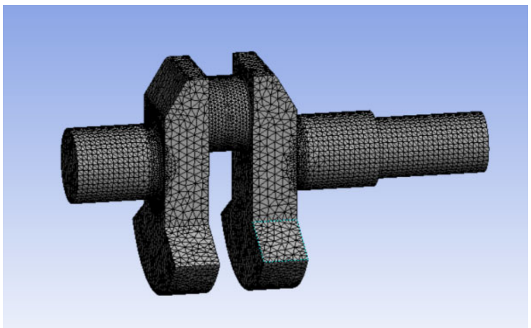


Figure 4. Single-turn crankshaft meshing

3.3.2. Boundary condition setting

The force position of the single turn crankshaft is in the crank pin, fixed position on the spindle diameter, and fixed support is set at both ends.

3.3.3. Solve the setting

The output of the solution scheme is that the force convergence Newton-Raphson residue is set to 0. The fatigue tool domain type selection time, the material fatigue strength factor (kf) is 0.8, the loading type is completely opposite, the scale factor is 1, the analysis type is selected stress life.

3.3.4. Fatigue performance analysis results

The total deformation results are shown in Figure 5. It can be seen that the deformation of the crankshaft is mainly concentrated on the crank pin, which is in line with the theoretical analysis. The stress distribution is shown in Figure 6. The maximum value is at the intersection of the main shaft and the crank, and the maximum stress is 34.423MPa.

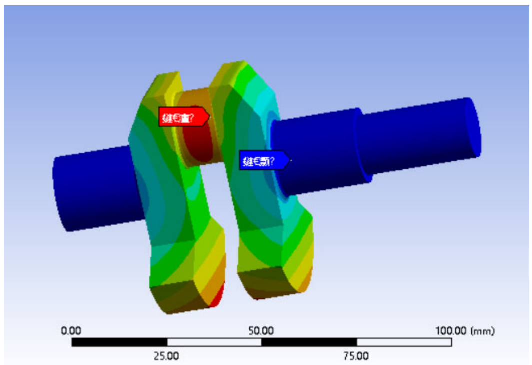


Figure 5. Total deformation

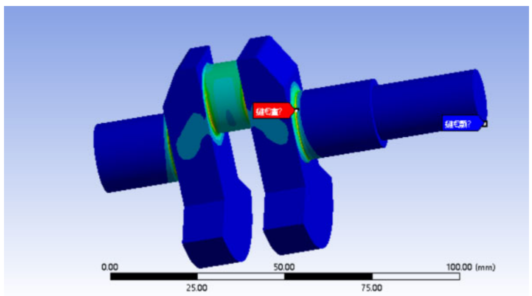


Figure 6. Stress distribution

3.4. Parameter optimization

The stress distribution of the single turn crankshaft of the diaphragm pump is uneven in actual use. Due to the force, the single turn crankshaft of the diaphragm pump often exceeds the limit, which will lead to the fatigue failure and even damage of the single turn crankshaft of the diaphragm pump. Therefore, in the design and optimization of the single turn crankshaft of diaphragm pump, attention should be paid to controlling the maximum stress value to minimize the impact of the maximum stress on the fatigue life of the single turn crankshaft of diaphragm pump.

The MOGA method (multi-target genetic algorithm) is a variant of the NSGA- (non-dominant ranked genetic algorithm) based on the popular controlled elite concept. It supports multiple targets and constraints, aiming to find the globally optimal solution. The optimization target is chosen to minimize the effect force and minimize the total deformation, and to restrict the safety factor. According to the literature, the minimum safety factor is equal to 1.8.

The response point is definitely an indispensable function for parameter optimization using Workbench. The relationship between the input parameters and the output parameters can be judged by the response point, and the reasonable value range can be determined, so as to determine the optimal parameter combination and improve the optimization speed.

The response point can adaptively adjust the parameter search area according to the input parameters, and quickly find the optimal parameter combination, so as to shorten the optimization time and improve the optimization efficiency. At the same time, the response points also support the restriction and screening of the parameters to ensure the stability and feasibility of the parameters.

The changes obtained from changing the structural parameters are shown in the table:

Table 3. Table of parameter changes

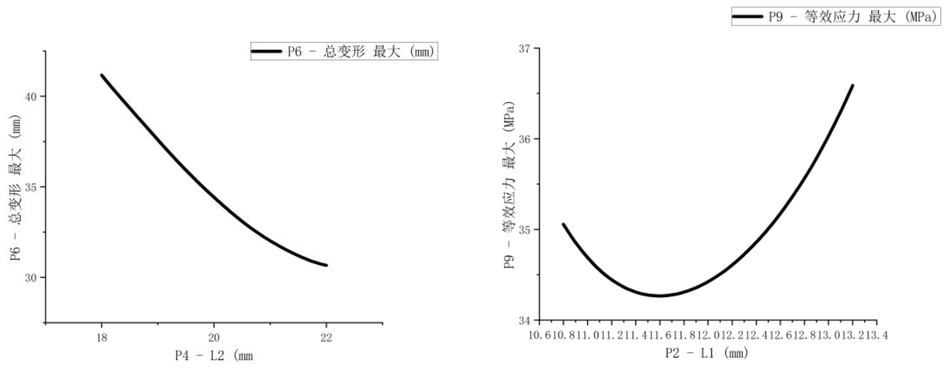
P_1 (mm)	Stress (MPa)	Deformation (mm)
18	41.166	0.001587
19	37.59	0.001473
20	34.423	0.001387
21	32.017	0.00134
22	30.663	0.001326

P_2 (mm)	Stress (MPa)	Deformation (mm)
11	34.689	0.001327
11.5	34.277	0.001357
12	34.423	0.001387
12.5	35.008	0.001418
13	36.03	0.001452

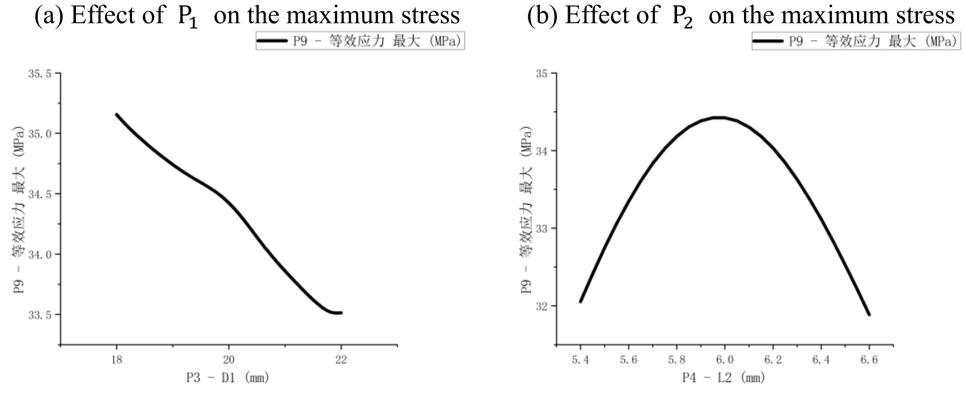
P_3 (mm)	Stress (MPa)	Deformation (mm)
18	35.156	0.001563
19	34.741	0.001467
20	34.423	0.001387
21	33.86	0.00133
22	33.514	0.001298

P_4 (mm)	Stress (MPa)	Deformation (mm)
5.4	32.054	0.001352
5.7	33.834	0.001369
6	34.423	0.001387
6.3	33.692	0.001406
6.6	31.885	0.001424

The tabular data is imported into the response module, and the result of each input parameter and equal effect force-maximum response curve based on the response point is shown in Fig



(a) Effect of P_1 on the maximum stress (b) Effect of P_2 on the maximum stress



(c) P_3Effect of P_3 on the maximum stress (d) Effect of P_4 on the maximum stress

Figure 7. Influence of input parameters on stress

As can be seen from the figure, the maximum stress decreases with p1, then increases with p2, decreases with p3, and then decreases with p4.

It can be seen that the combination of each parameter has a great impact on the performance of the single-turn crankshaft, so a comprehensive analysis should be made in the parameter optimization process to obtain a complete parameter relationship.

Based on the previous experimental design and response surface optimization, the optimization initially generated 4000 samples, generated 800 samples in each iteration, and found 3 candidates in a maximum of 20 iterations. Convergence after 11334 assessment.

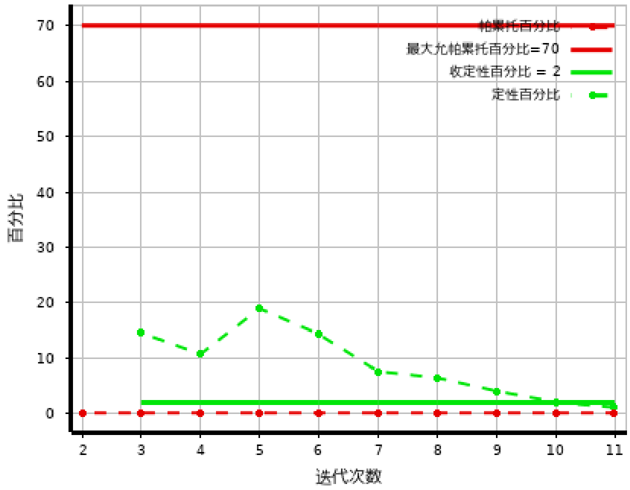


Figure 8. Iteration diagram

The final optimization result candidates are shown in the table:

Table 4. Candidate points

	Candidate points1	Candidate points2	Candidate points3
P_1(mm)	21.797	21.863	21.692
P_2(mm)	11.276	11.245	11.305
P_3(mm)	21.711	21.73	21.693
P_4(mm)	5.4038	5.4036	5.4015
Maximum equal effect force (MPa)	1.7933	1.8	1.8
The minimum safety factor	28.683	28.938	28.818

4. Conclusion

Consider the selection of candidate point 3 comprehensively. After parameter optimization, the minimum safety factor reaches the minimum value of 1.8, which improves the reliability and durability level of the single-turn crankshaft of the diaphragm pump under the working load. At the same time, the maximum value of the isoeffect force is 28.818MPa, which is reduced by 16.28%, indicating that the optimized crankshaft is more stable and reasonable in stress distribution, which helps to reduce the phenomenon of concentration of crankshaft force and prolong the service life of the crankshaft. Moreover, the total deformation maximum was 0.0011679mm, decreasing by 15.81%, indicating that the crankshaft is more stable in the optimized state and its carrying capacity is improved to a certain extent.

In conclusion, the optimized results show that by reasonably adjusting the design parameters of the crankshaft, we can not only improve the minimum safety factor, but also make the stress distribution of the crankshaft more stable and reasonable, so as to effectively improve the performance of the crankshaft in the working state. This provides a useful reference for the optimal design of the single-turn crankshaft of the diaphragm pump.

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