Rotary Steering Spindle System Parameter Design Based on Fatigue Life

Xiaodong Zhang [a], Weibiao Zhu, Yi Zhang, Quan Zhou

School of Mechanical Engineering, Southwest Petroleum University, Chengdu 610500, China

[a]402231754@qq.com

Abstract

Point-the-bit Rotary Steerable drilling system(RSS) represents the future development direction of drilling system. At present, the study in point-the-bit RSS is still blank. Especially the location of center shaft parts on the system impacts on the fatigue life of mandrel directly. Through the finite element method to calculate the maximum equivalent strain of the dangerous local of the rotary steering spindle, and combining the calculation formula of life of nominal stress method and general method of slope central theoretical, the fatigue life of the shaft has been estimated. The life of the mandrel has been simulated by the finite element software fatigue. Finally, taking the fatigue life as the optimization goal, multi-parameter optimization with the shaft model has been done using orthogonal experiment method. The best combination with the 1mm offset has been given by analyzing, which can provide the principle for design of rotary steering spindle system.

Keywords

Point-the-bit; Rotary Steerable; Spindle System; Fatigue Life; Orthogonal Method.

1. Introduction

Rotary steering drilling technology refers to the drill string rotating in a state of real-time adjustment of hole deviation and azimuth, so as to realize to control the drilling direction and orientation of the drill, signifies the highest level in today's world the development of drilling technology [1-2]. Foreign oil companies on the key technology of our country of the rotary steering blockade, makes our country can only rely on high rental service to accomplish difficult well drilling, so domestic oil drilling industry must walk the path of independent research and development. Pointing to the rotary guide is the development direction of the future, but foreign field data shows that the fatigue of the spindle system is guidance tools is an important factor of failure of [3]. Point type rotary steering spindle system in the process of deflection, the spindle is not only to diamond under high pressure, while under the effect of bias force of rotating, so the spindle to bend under cycle load and the reverse cycle load combination [4]. This article on the basis of fatigue analysis, through the structure sensitivity central axis system changing parameters in the model to analyze the influence of life, in order to evaluate the change of design parameters life the influence of the central axis, provide the basis for the design of rotary steering spindle system.

2. Mandrel system analysis model

This article according to the drilling hole to establish finite element model of spindle system, the actual size bit simplified as spindle and wall contact, at the same time applying 5T axis at the bottom of the heart, can be converted into pressure on the bit plane, joint bearing, cantilever bearing outer ring set to fixed constraint, at the same time, cantilever bearing inner hole and shaft for the clearance fit, ensure mandrel axial freedom from the constraints. Analysis model is shown in figure 1, the center shaft diameter 72 mm, 30 mm offset ring width, drill joint bearing distance L1 = 600 mm, the distance bias ring L2 = 400 mm, the first cantilever bearing distance bias ring L3 = 400 mm, two cantilever bearing spacing for L4 = 400 mm.

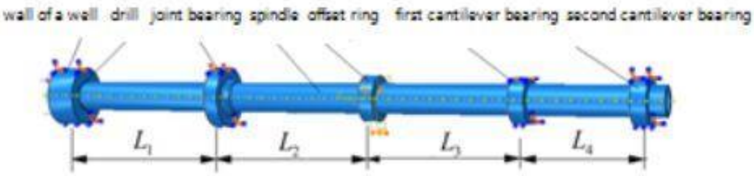

Fig.1 Initial analysis model of spindle system

3. Fatigue life calculation of mandrel system

Although there is no point to type rotary steering fatigue failure of spindle system of information, but according to the load characteristics of the spindle, the main damage form of spindle is a composite of bending fatigue or bending and twisting fatigue damage [5]. Spindle failure is a gradual process, the main crack initiation, propagation and fracture of three stages.

3.1 Single-shaft fatigue life calculation of mandrel system

Steering drilling process, the surface stress of bending mandrel, the surface properties of spindle cardiovascular and axial impact is bigger, the fatigue life of the spindle system in the underground actual loading condition is more complex, spindle offset point load is no longer continuous load, but in a combination condition. Think local stress strain gauge component fatigue damage is caused due to the danger zone of plastic deformation to crack initiation, and therefore should be used to calculate the local stress strain gauge mandrel fatigue life; the fatigue life calculation the Manson-Coffin strain fatigue life formula [6]:

$$\frac{\Delta\varepsilon_f}{2} = \frac{\Delta\varepsilon_\varepsilon}{2} + \frac{\Delta\varepsilon_p}{2} = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \tag{1}$$

Δεf is the total strain amplitude, Δεε and Δεp are the elastic and plastic strain amplitude, σ′f is the fatigue strength coefficient, ε′f is the fatigue elongation coefficient, b is the fatigue strength index, c is the extension fatigue index, E is the elastic modulus to determine the fatigue life of mandrel Nf. First of all, to determine the formula of the total strain amplitude, also known as spindle local maximum equivalent strain of the dangerous [7], in this paper, by using ABAQUS software central axis, elastic-plastic finite element analysis to calculate the strain value.

Elastic-plastic analysis select isotropic hardening model [8]. Mandrel material is the 42CrMo alloy, the tensile fatigue limit of the material is 513 MPa, and torsion fatigue limit is 310 MPa. Initial model, analysis model and axis offset are set to 2 mm, bit at the same time put 2KN.m torque. Maximum equivalent stress is obtained by the finite element analysis, in 18092 of node; the node on the maximum equivalent stress is 205.6 MPa. The maximum equivalent strain is also on the node 18092, its biggest effect such as 0.00398.

Table.1 Stress (MPa) and strain values of point 18092

Stress /MPa	σ_x	σ_y	σ_z	τ_{xy}	τ_{yz}	τ_{zx}
Value	40.25	203.5	70.49	49.52	51.53	22.58
Strain /10^{-4}	ε_x	ε_y	ε_z	γ_{xy}	γ_{yz}	γ_{zx}
Value	-7.11	10.4	2.17	37.3	-34.1	-10.09

Fatigue performance parameters with the conventional performance parameters of the material can be used to estimate, based on the general slope method to estimate, can find out the fatigue life of a spindle for 303321 times, total about 82 hours.

3.2 Fatigue life simulated analysis

Central axis combined with finite element design life fatigue analysis software system, analysis of the fatigue life with only acts on the drill bit and joint bearing of spindle, affect the stress of the spindle is not large, so don't consider the effect. First of all, establish finite element model of spindle system, the first load step is in the offset the 2 mm offset, the second load step is to apply 2KN.m. Central shaft m torque, through elastoplastic material Settings, get the Mises stress of two kinds of working conditions; then, the finite element analysis results file into the Design life.

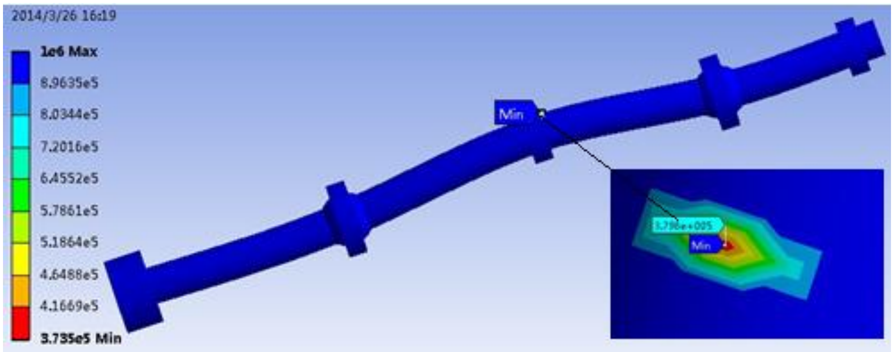

Fig.2 Fatigue life picture of spindle system

Reading spindle fatigue analysis results from the finite element software, the fatigue life of the spindle system available cloud image, as shown in figure 2, it can be seen that the life of the spindle offset position is the shortest, also know the dangerous point there minimum life of about 379600 times, total about 100 hours, longer than the single-shaft fatigue life of the theoretical calculation.

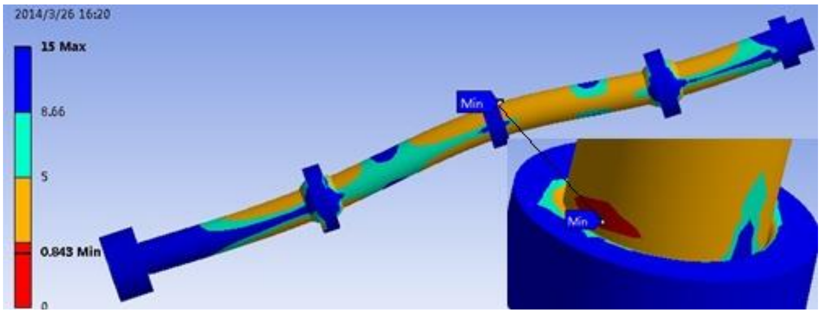

Fig.3 Safety factor picture of spindle system

Figure 3 is the spindle system cloud security coefficient, it can be seen that the bias in the safety factor of the spindle minimum, so you need to consider the stress of the spindle and the position of the offset ring, bearings, central axis, reasonable optimization of structural parameters of the system.

4. Mandrel system parameter design based on fatigue life

As a result of the spindle system parameters can be optimized, in this paper, using orthogonal experiment method to optimize the model, the orthogonal experiment method is designed based on the experimental model experiment scheme, then using orthogonal table for data analysis of a kind of optimization method; the advantage of the orthogonal design of experiment is part can only through the experimental results can predict the results of the experimental model, so as to reduce the experimental cost [9].

4.1 Mandrel system orthogonal experimental design

Spindle system model in the optimization of the factors include: the inner diameter of the mandrel A, offset B, offset ring width C, position offset ring D, cantilever bearing E and joint bearing position F. Orthogonal experiment design, first of all, study of factors and levels should be determined according to the actual working condition, the spindle system optimization factor value. Model assumes that the spindle system of bias and cantilever joint bearing, joint bearing ring to the drilling direction is positive, the orthogonal experiment of factors and levels as shown in table 2. Because of the factors in the orthogonal experiment for 6, level 5, so choose $L_{25}(5^6)$ as the orthogonal table, each factor in the experiment of five experiments are carried out in each level. From the results of the 25 groups of experiments can be life, the influence of each factor on cardiovascular axis system according to the combination of orthogonal experiment table 25 elastic-plastic analysis, and then the fatigue performance parameters in the Design life of each combination for the fatigue life of the results as shown in table 3, here just list the top 15 kinds of combination of the calculation results.

Table.2 Factors and levels of orthogonal in spindle system

Factor	Level				
A	66	69	72	75	78
B	1	1.5	2	2.5	3
C	20	25	30	35	40
D	-50	-25	0	25	50
E	-50	-25	0	25	50
F	-50	-25	0	25	50

Table.3 Analysis results of orthogonal trail in spindle system

Group	Mandrel inner diameter /mm	Offset /mm	Offset ring width /mm	Offset ring position/mm	Knuckle bearing position/mm	Cantilever bearing position /mm	Max effective strain /10-3	Fatigue life /times
1	66	1	20	-50	-50	-50	3.912	333271
2	66	1.5	25	-25	-25	-25	3.938	321465
3	66	2	30	0	0	0	3.975	305218
4	66	2.5	35	25	25	25	4.031	283241
5	66	3	40	50	50	50	4.087	263274
6	69	1	40	-25	0	25	3.994	297540
7	69	1.5	20	0	25	50	3.994	297536
8	69	2	25	25	50	-50	3.978	304210
9	69	2.5	30	50	-50	-25	3.992	298400
10	69	3	35	-50	-25	0	4.018	288217
11	72	1	35	0	50	-25	3.862	357281
12	72	1.5	40	25	-50	0	3.887	344781
13	72	2	20	50	-25	25	3.910	334128
14	72	2.5	25	-50	0	50	4.058	273541
15	72	3	30	-25	25	-50	4.115	253847

Sorts through orthogonal experiment results and be able to get the results in table 4, the mean 1 this line 6 digits, respectively factors A, B, C, D, E and F the life of the corresponding to the first level of experiments, the sum of the rest of the so on; the poor, the greater the spindle system of the parameter changes the greater the influence of central axis system lifetime [10]. So mandrel diameter and offset influence on the life of the spindle system is the biggest of all.

Table.4 Range analysis of orthogonal trail results in spindle system

------	Mandrel inner diameter（A）	Offset（B）	Offset ring width（C）	Offset ring position（D）	Knuckle bearing position（E）	Cantilever bearing position（F）
Mean 1/time	303293.8	332588.2	312170.8	317164	306704.8	314221
Mean 2/ time	297181.4	329704.4	303001.8	321189	322462.6	304160.3
Mean 3/ time	312715.6	318942.8	310306.8	302075.4	315042.8	308154
Mean 4/ time	341968	293893.2	315249.8	298125.4	307788.8	317761.6
Mean 5/ time	297712.8	277743	312142.4	314317.8	300872.6	307776
Range	44786.6	54845.2	12248	23063.6	21590	13601.35

At the same time, be able to get the best combination of spindle system solution for: A4-B1-C4-D2-E2-F4, namely: mandrel diameter 75 mm + offset 1 mm + offset ring width 35 mm + offset ring - 25 mm + joint bearing movement + cantilever bearing to 25 mm to 25 mm. Although this orthogonal experimental method only calculates the offset for the best combination of 1 mm, but through the calculation illustrates the orthogonal experimental method can indeed for good design basis for the design of the spindle system.

5. Conclusion

1) the fatigue life of the rotary steering spindle system model for 80-100 hours, seriously restrict the overall use of steering tool life, affect drilling efficiency;

2) the spindle system center shaft diameter and offset influence the life of a central axis system is one of the biggest, in the design process, in particular, attention should be paid to these two parameters change the influence of the central axis of life;

3) the spindle system optimal combination scheme for: A4-B1-C4-D2-E2-F4, i.e., the mandrel diameter 75 mm + offset 1 mm + offset ring width 35 mm + offset ring - 25 mm + joint bearing movement + cantilever bearing to 25 mm to 25 mm.

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