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Principal optimization of semi-submersible support platform based on multi-island genetic algorithm

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ABSTRACT

Aiming at the conceptual design stage of semi-submersible support platform, the optimal primary scale scheme is designed. Latin hypercube design is adopted to sample the sample space. At the same time, SESAM software is used for parametric modeling based on sample point parameters to obtain the model of all schemes. According to the existing data of semi-submersible platforms, the main scale constraints of platforms are determined, and the mathematical model with the minimum heave, trim and roll response as the objective function is established. The multi-island genetic algorithm was used to optimize the main scale of the supporting platform model, and the scheme with the highest stability and suitable displacement was selected. The results show that the model and algorithm are feasible, and the smallest scale scheme of each response can be obtained under the constraint conditions. The multi-island genetic algorithm is proposed to optimize the primary scale of the platform, which has a strong reference value for the determination of the primary scale scheme in the conceptual design stage of the platform.

Keywords: Multi-island genetic algorithm; Latin hypercube design; Principal dimensions; Optimize

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1. Introduction

The semi-submersible platform has relatively small environmental loads due to its small waterline, and its movement performance is better in severe sea conditions. At the same time, because of the large deck area and the advantages of large variable load [1, 2], it has gradually become one of the mainstream devices for deep-sea oil exploration and development. Due to the complex sea environment, the platform has to be affected by wind, waves, currents, and even earthquakes, which puts forward higher requirements for the safety and stability of the supporting platform. In order to make the overall performance of the semi-submersible support platform better, researches on platform optimization are endless. This article discusses the influence of factors such as sports performance, stability, positioning performance, and general layout on the principal dimensions of the platform. A method of using the multi-island genetic algorithm to optimize the three conditions of heave response, roll response and trim response respectively to find the optimal plan is proposed.

2. Platform structure

The platform selected in this study is a standard semi-submersible support platform, and its main scale elements are:

Table 1 The principal dimensions of the parent platform

Lower floating body length	Main deck length	Main deck width	Lower float width	Lower float height
98m	66m	67m	14m	9m

The operating condition adopted is the self-storage condition：

Table 2 Working condition data

Draft	Displacement	Center of gravity height	Rx	Ry	Ry
13.5m	27650.01t	22.04m	29.17m	30.37	33.87

The semi-submersible platform structure is mainly composed of three major structures: a lower floating body, a column and an upper deck [3]. Among them, the lower floating body provides the huge buoyancy required for relocation and operations, and its structure is shown in Figure 1 below.

In recent years, semi-submersible platforms have mostly adopted square cross-sections, making construction easier and increasing drainage and cabin capacity. The arrangement of the columns should try to make the platform have similar high horizontal stability and high vertical stability [4].

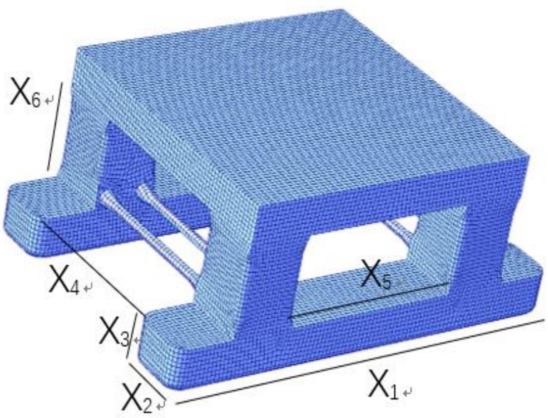

Fig.1. Semi-submersible platform

3. Main technical indicators of semi-submersible platform

3.1 The influence of sports performance on the selection of principal dimension

The design of the principal dimensions should take into account the adjustment of the center of gravity and the unchanged moment of inertia of the hull [5] to reduce the pitch and roll of the hull. Therefore, heave response is the primary consideration in the design of the platform's principal dimensions.

3.2 Influence of stability on principal dimension

Wind inclination moment, platform resilience, and weathertight integrity range are closely related to the complete stability of the supporting platform. The semi-submersible support platform has a vertical wind direction with its tilt axis, and the platform's wind tilt moment is the largest [6]. Regardless of the state of the platform, based on integrity considerations, the most dangerous overturning direction occurs at the agreed tilt axis.

3.3 The effect of positioning performance on principal dimension

The semi-submersible support platform needs to go to different sea areas for drilling operations, usually towed and buried anchors are used. This anchor cannot withstand the uplift force, and a longer steel connection is required to connect the anchor [7]. In harsh sea conditions, the steel that needs to be connected to tow the buried anchor needs to be longer, and the strength and rigidity of the cable need to be greater [8]. This also causes the weight of the cable to increase, which affects the variable load of the semi-submersible support platform.

3.4 The influence of the general layout on principal dimension

The upper hull deck has a double bottom height of 1.5m-1.7m, and both floors are about 3.5m high. Eight main engines with DP3 dynamic positioning are arranged in four engine rooms. This layout requires high hull length on the platform [9]. Moreover, the two engine rooms/switchboards in the first part are relatively close to the living area, so additional consideration should be given to the noise of the engine room and the safety of category A machinery spaces. In addition, the engine room can all be located in the stern area of the upper hull. The four engine rooms are equipped with longitudinal A60-class structural bulkheads and the internal equipment, pipelines and cables of the engine room are tightly arranged.

3.5 The influence of variable load on principal dimensions

The displacement of the semi-submersible support platform is composed of empty ship weight, variable deck weight, anchor and chain weight, fresh water and fuel oil, and ballast water weight [10]. Each state of the submersible platform has sufficient displacement and is closely related to the external dimensions of the supporting platform. The principal dimensions of the lower floating body are determined by the towing displacement [11].

4. Optimization method and optimization model establishment

4.1 Multi-island genetic optimization algorithm

M.KaneKo is improving the parallel distributed genetic algorithm to form a multi-island algorithm. The multi-island genetic algorithm uses fitness function as the standard, and basically does not use external information elements to search for the best in the current population. This genetic algorithm divides the population into several subgroups that are isolated from each other and evolve independently, but information is still exchanged between the subgroups to ensure the diversity of the population [8], so as to find the global optimal solution in the sample. Compared with other genetic algorithms, the multi-island genetic algorithm has stronger global solving capabilities and computing capabilities.

The multi-island genetic algorithm repeatedly uses operators to select, from parent generation to offspring to grandchildren to great-grandchildren and reproduces continuously, so that the adaptability of the population to the environment is continuously improved. The process is as follows [12]:

Step 1: Initialize the group;

Step 2: Calculate the individual fitness function value;

Step 3: Select individuals who enter the next generation according to a certain rule determined by the individual fitness value；

Step 4: Cross operation according to probability Pc;

Step 5: Mutation operation according to probability Pm;

Step 6: If the stop condition is not met, go to step2, otherwise go to step7;

Step 7: Output the chromosome with the best fitness value in the population as the satisfactory or optimal solution of the problem.

4.2 Optimization model establishment

4.2.1 Design variable

In this study, the six main dimensions of the floating body length, width, height, column horizontal spacing, vertical spacing, and column height are selected as design variables [13], which are $x_1, x_2, x_3, x_4, x_5, x_6$, as shown in Figure 1. The range of design variables and original parameters are as follows:

Table 3 The range of design variables and original parameters

Design variable	Unit	Variation range	Original parameters
X_1	m	88.2-107.8	98
X_2	m	12.6-15.4	14
X_3	m	8.1-9.9	9
X_4	m	35.1-42.9	39
X_5	m	35.1-42.9	39
X_6	m	16.65-20.35	18.5

4.2.2 Objective function

4.2.2.1 Heave response

The heave performance of the semi-submersible support platform is a performance that operators are very concerned about. Compared with other directions, the platform has less flexibility in the heave direction. The heave response of the semi-submersible support platform is much greater than that of other offshore platforms. Therefore, the limit of the heave motion range of the semi-submersible support platform is set to ensure the normal operation and safety of the platform. [14] Therefore, reducing the heave response of the semi-submersible support platform under severe working conditions is of great significance for ensuring the stability and safety of the support platform. This paper studies the influence of heave response under unit wave on the main scale of semi-submersible support platform. Through calculation, the heave response is the most significant under horizontal waves, so the maximum heave response value of all schemes under horizontal waves is selected to study.

4.2.2.2 Roll response and pitch response

The roll and pitch performance will affect the normal operation of the platform. If the roll and pitch are too large, it will cause many equipment on the deck to fail to operate normally and cause physical discomfort for the personnel. [14] The roll response is the largest when the wave is incident in the direction of 90°, so the maximum roll value of each plan of unit wave under horizontal wave is also adopted for research. The trim response has the largest response under heading waves, so the unit wave is selected as the maximum trim value of each scheme under heading waves.

4.2.3 Restrictions

4.2.3.1 The initial stability height

The initial stability of different schemes is different. In order to ensure the stability and safety of the platform, GM>2.0m is selected as the constraint standard.

4.2.3.2 Displacement

In order to ensure the cost, ±2% of the original platform displacement is taken as the constraint standard.

4.2.4 Mathematical model

$$\begin{aligned} &Find \quad x_1, x_2, x_3, x_4, x_5, x_6 \\ &Min \quad \text{heave}, \text{roll}, \text{pitch} \\ &\text{s.t} \quad 29598156 \geq \text{displacement} \geq 28437444 \end{aligned}$$

5. Optimization example of semi-submersible platform

Based on the information given in Table 3, using the optimized Latin Hypercube experimental design method to sample the sample space, [15] selected 200 sets of sample data, and Table 4 shows the first 20 sets of data:

Table 4 Sample data

	x_1	**x_2**	**x_3**	**x_4**	**x_5**	**x_6**
1	88.25	13.96	9.86	37.52	41.70	18.04
2	89.27	14.06	9.45	35.40	37.75	19.01
3	89.31	15.33	8.89	39.54	39.08	18.61
4	90.29	12.60	9.10	38.57	39.43	19.35
5	90.83	14.54	9.38	39.84	36.14	17.49
6	90.95	13.24	9.82	38.75	42.45	18.81
7	91.76	14.81	8.18	35.23	37.20	19.09
8	92.52	13.49	8.42	37.13	39.45	20.19
9	92.73	13.17	8.24	36.64	37.03	18.26
10	93.54	13.33	9.19	37.43	38.93	17.17
11	93.97	15.20	9.31	36.34	40.69	18.41
12	94.62	14.20	8.99	42.02	40.04	19.95
13	95.17	15.10	8.29	40.83	40.42	18.33
14	95.30	14.61	8.63	37.72	39.70	18.55
15	95.98	14.15	9.07	40.64	36.32	19.61

16	96.72	12.95	8.49	38.32	40.98	18.15
17	97.18	15.00	9.50	36.47	42.06	18.78
18	97.99	12.83	8.36	42.75	40.89	16.82
19	98.41	12.89	9.41	41.02	38.35	20.10
20	98.85	13.56	9.00	41.68	37.62	17.36

Based on the parameters of the sample points, parameter modeling is carried out in the GENIE section of the SESAM software [16], and a series of models of all methods are obtained.

5.1 Parameter settings

Table 5 Sample data

Option	**Value**
Sub-Population Size	10
Number of Islands	20
Number of Generation	50

5.2 Trim optimization results

Table 6 Trim optimization data

X_1	X_2	X_3	X_4	X_5	X_6	**Pitch**
100.44	13.919	8.515	42.412	38.433	16.718	0.0090316

The scale scheme is calculated with HydroD software for its trim response, displacement and initial stability height. The results are as follows:

Pitch	**Displacement**	**GM**
0.0128	2.84479E+07	2.725

The trim response value obtained by the optimized plan is smaller than the result of the smallest plan that satisfies the constraints among the 200 previously selected plans.

5.3 Roll optimization results

Table 6 Roll optimization data

X_1	X_2	X_3	X_4	X_5	X_6	**Pitch**
96.454	14.736	8.101	35.101	37.798	18.035	0.015256

The scale scheme is calculated with HydroD software for its roll response, displacement and initial stability height. The results are as follows:

Pitch	**Displacement**	**GM**
0.01729	2.85027E+07	5.232

The roll response value obtained by the optimized plan is smaller than the result of the smallest plan that satisfies the constraints among the 200 previously selected plans.

5.4 Heave optimization results

Table 7 Heave optimization data

X_1	X_2	X_3	X_4	X_5	X_6	Pitch
102.6	13.793	8.9399	40.066	39.122	17.1172	0.94261

The scale scheme is calculated with HydroD software for its heave response, displacement and initial stability height. The results are as follows:

Pitch	Displacement	GM
1.612	2.95743E+07	2.117

The heave response value obtained by the optimized plan is smaller than the result of the smallest plan that satisfies the constraints among the 200 previously selected plans.

6. Conclusion

This paper establishes a mathematical model of the main scale of the semi-submersible support platform. The multi-island genetic algorithm is used to target the heave, roll and pitch responses of the platform respectively, and realize the automatic optimization of all parameters [18], and obtain the global optimal solution. The results show that the effectiveness and feasibility of the multi-island genetic algorithm is suitable for the type optimization of semi-submersible platforms and can be used for the preliminary design of the platform.

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