Development status and trend analysis of anti-icing semi-submersible drilling platform

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Abstract. In order to speed up the development of Arctic resources, it is the focus of polar drilling equipment research and development to develop a new anti-ice drilling platform which adapts to the harsh environment of polar regions and reduces the construction and operation costs. By briefly analyzing the structure of the existing anti-ice drilling platform, the design points of the anti-ice semi-submersible drilling platform are obtained, and the development status of the anti-ice semi-submersible drilling platform is analyzed. Finally, the development trend of the anti-ice semi-submersible drilling platform structure is summarized.

1. Introduction
The Arctic contains about 22 per cent of the world's total untapped oil and gas, and huge oil and gas resources have made the Arctic the world's future energy hub [1-2] However, the development of oil and gas resources in the Arctic region is seriously restricted by the harsh working environment, the complex shallow strata, the difficult logistic support and the harsh environmental requirements [3] The development of a new type of polar drilling platform to solve the above major problems in the exploitation of polar resources is of great significance to the development of polar oil and gas resources.

The existing drilling equipment in the Arctic mainly includes egg drilling ship, wedge drilling ship, cylindrical drilling platform and semi-submersible drilling platform. Both the egg-shaped and wedge-shaped drilling rigs can use their own structure to bend and break the ice, reduce the ice load, and can quickly evacuate the operating site in the event of severe polar ice conditions; the cylindrical drilling platform uses the conical shape with vertical axis in the waterline area to improve its ice resistance; in addition, the wedge-shaped drilling rig can ensure the self-direction of the anti-ice device relative to the drift direction of the icefield and the steel consumption is low [4-5].

However, the polar application of semi-submersible drilling platform can effectively solve the problems of high steel consumption, high construction cost, low mobility and poor wave resistance under wind and waves [6] in particular:

1. The frame structure, the form is simple, the steel consumption cost is low;
2. Strong ability to resist storms, small response in waves, good wave resistance, good drilling stability;
3. Strong mobility, easy location, installation and evacuation in the operation site, can move freely to complete the development of multiple oil fields;
4. Adapt to a wide range of water depth (150 m-3000m), especially for deep water drilling operations.
Therefore, on the basis of analyzing the design requirements of polar drilling platform, this paper investigates the current design status of polar semi-submersible drilling platform, analyzes the design direction of polar semi-submersible drilling platform, and puts forward some relevant suggestions.

2. Main Points of Design of Semi-submersible Drilling Platform

Although semi-submersible drilling platforms dominate offshore exploration drilling equipment, semi-submersible drilling platforms are still rarely used in the Arctic. Even operational ice-resistant semi-submersible drilling platforms allow towing and operation only under relatively light ice and snow conditions, and the "window period" of platform operations needs to be assessed according to the climatic conditions and weather forecasts of the operating waters, mainly due to the sharp increase in the construction and operating costs of semi-submersible drilling platforms operating fully under extremely harsh ice and snow conditions. The cost increase is reflected not only in the need to strengthen the structure and positioning system in the ice zone, but also in the need to rent expensive nuclear-powered ice breakers to ensure continuous and safe operation under harsh ice and snow conditions.

Accordingly, the design of polar ice-resistant semi-submersible drilling platform (SSDP) should determine the ice resistance grade and anti-ice protection measures according to the ice condition, water depth, wind wave, port, infrastructure and regional ecological environment of its operating area, so as to ensure the maximum economic benefit under the specific operating environment. The optimization of the design scheme usually requires a trade-off between the anti-icing ability of the equipment, the anti-freezing performance of the equipment, the mobility, the wave resistance and the consumption of steel, which usually leads to the selection of two typical design schemes with obviously different anti-icing levels:

1. Limited ice resistance, evacuation from the site when there is a threat of severe ice conditions, e.g. Polar Star, the relatively low cost of construction and the design of no-load displacement of about 35000 tons, the difference from traditional semi-submersible drilling platforms is that: a. structural strengthening is carried out with support through water lines to reduce the impact of ice on the platform; ice belt strengthening is b. on structures interacting with ice and conical ice breaking structures are installed; c. riser is used [7] Or riser area design special central column to protect it.

2. Allow year-round operations (including under harsh ice and snow conditions), such as JBF ARCTIC, expensive, and design no-load displacement of about 70,000 tons.

3. Main forms of polar semi-submarine drilling platforms

The existing polar semi-submersible drilling platforms are divided into cylindrical stable semi-submersible drilling platforms and cylindrical semi-submersible drilling platforms [8] The concept of a new generation CS-50/60, polar semi-submersible drilling platform developed by the National Scientific Centre of the Russian Krylov, developed mainly by the Norwegian Company of Moss Maritime*, the Polar Star, of the Netherlands Huisman Equipment Company and the Russian National Scientific Centre[9-10].

3.1. CS-50/60

The CS-50/60 designed and developed by Norway's Moss Maritime* Company has extremely low ice resistance and operates only in frozen areas [11] (See Fig .1). CS-50’s length 117.6 m, width 69.7 m, draft 9.8 m, displacement is 31250t.

The CS-50/60 platform has two water-immersed pontoons with six vertical stabilization columns arranged on the pontoons. The first and last stabilization columns are connected to each other through a pair of tubular structures with a diameter of 3 m, and the vertical frame is formed in the form of a horizontal and vertical pipe with a diameter of 2 m, together with the stabilization column, to form the supporting base of the platform working deck [12].
To reduce the amount of steel used in the whole semi-submersible drilling platform, CS-50 project used a pair support device with a diameter of 2 m to support the central part of the platform and bear the weight of the drilling equipment. To effectively ensure the strength and stiffness of the equipment (achieved without a significant increase in metal consumption), four pairs of intermediate supports were used, which formed flat vertical trusses due to the presence of transverse horizontal supports. They primarily contribute to reliable connection of the semi-submersible rig buoys and stabilizers and ensure rig rigidity during lateral bending and torsion [13].

3.2. Polar Star
"Polar Star" is based on CS-50/60 improvements developed by the Russian Krylov National Science Center, the main purpose of which is to improve the "Polar Star" anti-ice class "and to meet the requirements of the Russian Classification Society for the" rules for graded construction of ice-resistant floating drilling platforms "," he said [14] In addition, the following improvements have been made:

1. The anti-ice layer of the riser is made of a special central pillar and fixed with a cross brace on the buoy (Fig. 2);
2. For the purpose of reducing the influence of ice on the platform, the oblique cross-supporting structure CS 50 crossing the working waterline is not used;
3. In order to increase rigidity, additional horizontal supports are provided, which are mounted below the working waterline and form horizontal frames together with columns and floating bridges;
4. "Polar Star" the buoy structure is arranged along the longitudinal direction and consists of longitudinal and transverse bulkheads to form an independent supporting frame to improve the ice resistance.

"The Polar Star" length is 118.6 m, the top side width is 72.7 m, the support base width is 92, its main scale and CS-50 are not different, but "Polar Star" design draught 9.8 m displacement is 39300, because of the ice resistance grade has increased, resulting in the ice belt structure, stable column and support structure weight has increased [15]. The main structural material of the platform is steel with a yield strength of MPa 355. The platform is equipped with a winch serving 8 anchor cables, each with a length of 2200 m, consisting of 84 mmNV R5 of steel chains, each of which has a breaking force of 8381 kN [16].
CS-50/60 and Polar Star bulkhead design features vertical support tubes arranged along the entire height of the bulkhead, which can effectively form support in width and absorb the weight of the rig [17].

3.3. JBF ARCTIC

The design of traditional stable-column semi-submersible drilling platform has the following disadvantages:

1. Special intensive structures need to be designed to protect the riser from ice;
2. Crushed ice may be blocked between stable columns (and between columns and riser protection devices), thereby increasing the overall impact of ice on the platform.

The JBF ARCTIC™, developed by Dutch Huisman Company combined with the characteristics of cylindrical drilling platform and traditional stable column semi-submersible drilling platform can be used to operate in extreme ice conditions (about 2-3 m ice thickness) for the whole year [18] (Figure 3). The maximum depth of the water area of the JBF ARCTIC site shall not exceed 1500 m, and the drilling depth shall be 12000 m, and shall be secured by 20 anchor cables in the form of 162 anchor chains [19].

"JBF ARCTIC" consists of an annular buoy with a diameter of 116 m, eight inclined stabilization columns and an inverted conical platform deck box. A grid is arranged between the two stabilization columns. The grid prevents large pieces of breakable ice from penetrating into the space between the columns and provides a safe space for riser operation. There are four different draught types [20]:

1. When the inclined column crosses the water surface, it dissipates energy, which can suppress wave attack well and has good wave resistance;
2. When the ice interacts with the inclined column, the ice layer is destroyed by bending, thus reducing the ice load;
3. Drag transport in shallow draft, improve the drag transfer speed.

Figure 3. JBF ARCTIC rendering

Figure 4. Schematic diagram of JBF ARCTIC layout
By reasonably distributing the ice load, optimizing the ice belt structure and the parameters of the anchor cable, the JBF ARCTIC "can meet the operating conditions of extreme ice conditions and obtain better performance under severe ice and snow conditions. However, JBF ARCTIC" have avoided these shortcomings, it is still possible to form ice rings. A large number of structures form a heat transfer channel from the ring buoy support base to the upper working deck, which helps the structure located below the waterline to freeze easily, resulting in the formation of a strong block ice plug inside the support base. In addition, ice will be brought into the dome space formed by inclined columns and upper working decks under wind and wave conditions, and the formation of large ice blocks will be promoted [21].

3.4. New Generation Polar Semi-submarine Drilling Platform Concept
The National Science Center of the Russian Krylov has tested the wave resistance and ice resistance of three polar drilling platforms JBF ARCTIC"," Polar Star ", cylindrical drilling platforms, among which the JBF ARCTIC" performance is optimal [22].

A new generation of polar semi-submersible drilling platforms (as shown in 9) has been designed by the Krylov national science center of Russian to solve the problems existing in stable-column and cylindrical semi-submersible drilling platforms. A new generation of polar semi-submersible drilling platforms is suitable for Arctic waters up to a depth of 400-450 m, for all fields in the Barents and Okhotsk Seas, for most fields in the Kara and Chukchi Seas, and for deep water areas in the Laptef and Pechora Seas [23].

Figure 5. Schematic diagram of the layout of a new generation of polar semi-submersible drilling platform

The new generation of polar semi-submersible drilling platforms is derived from three-body vessels, including three floating vessels, three stabilization columns and an upper working deck, which are connected to the upper working deck through three stabilization columns, with a total length of about 114 m, and a width of about 68 m, and a displacement of about 21100 t. The structural features are as follows:

1. The head of the floating ship contains ice teeth, and the head of the stable column is wedge-shaped, which is beneficial to destroy the surrounding ice and hinder the production of large floating ice;
2. The floating ship has a circular tail, which is beneficial to improve the towing performance;
3. The stable column waterline area adopts the inclined design to ensure that it can bend and break the ice with the wave motion;
4. Compared with the stable column of the middle floating ship, the stability of the floating ship on both sides is relatively backward to the stern, which is beneficial to the passage of large ice cubes from it without clogging.
5. Because the unconventional wedge section of the stable column helps to reduce the influence of ice load on the structure, the platform structure and anchor positioning system have lower weight compared with the traditional semi-submersible drilling platform [24].

4. Trends
The design and long-term operation experience of anti-ice semi-submersible drilling platform shows that semi-submersible platform can meet the strict requirements of offshore drilling under Arctic conditions. Based on the principle of semi-submersible platform, various types of anti-ice platform can be further developed to meet the specific natural environment of polar regions, and to improve the performance and economy of platform ice area operation and wind and wave action.

Based on the investigation of the above anti-ice semi-submersible drilling platform, its overall layout and structure are as follows:
1. 1–3 simplified underwater floats with stable columns (one or two per float);
2. The underwater floating body is connected with each other through the support structure in the horizontal and vertical plane;
3. There is no support at the water line, which is helpful to reduce the response of wave and ice to platform motion;
4. Simplify the structural form of a stable column, such as a cylindrical to rectangular frame [25]. When a rectangular (square) column with oblique angles is used, one of the edges of the column is usually installed flat with the side guard plate, which makes it easier to ensure the strength of the whole structure;
5. Use of inclined stable columns or supporting structures [26], which can increase the damping of motion and reduce the ice load;
6. By setting various forms of ice teeth on stable columns and supporting structures, the bending or cutting damage to ice layer is increased.

By comparing various resistant semi-submersible platforms, it is found that inclined stable columns and optimized structural elements are used to reduce the ice load and the amount of structural steel [24]. The main direction to improve the anti-ice performance is to adjust the structure of the ice belt and reduce the area of the operating water line.

In the foreseeable future, the inclined stable column will become one of the most important features of the appearance of the anti-ice platform, and the number of stable columns will be further reduced, because a small number of stable columns will not only help to reduce the impact of ice on the platform. It can also reduce structural weight without reducing structural strength and stability.

During the process of improving the design of the CS-50/60, the semi-submersible platform with various structural forms is proposed, which aims to improve the ice resistance of the platform and reduce the thickness of the ice belt element. The [27] The importance of structural element optimization is not only to reduce construction costs, Moreover, when the thickness of welded structure ≥30 mm, it is very difficult to meet the cold tolerance requirements of classification society for platform structure [25].

The traditional and newly proposed architectural and layout solutions are designed to reduce the area of the operating waterline, which helps to reduce the impact of waves and ice on the facilities and maintain the "translucent" characteristics of the underwater structure of the semi-submersible platform. It is beneficial to reduce the operating amplitude of the platform under the action of wind and waves.
5. Conclusions
The research and development direction of anti-ice semi-submersible drilling platform mainly includes the following three aspects:

1. By optimizing the section and quantity of the stable column, the water surface of the working water line is reduced, the motion amplitude under the action of wind and wave is reduced, and the influence of ice on the working facilities is reduced;
2. The use of inclined stable columns to enhance the ice damage;
3. The anti-ice performance of the platform is improved by optimizing the ice band structure of the stable column;
4. By improving the supporting structure, the ice load of the platform and the amount of structural steel are reduced.

On this basis, the design of anti-ice drilling platform will occupy one of the leading positions in the world marine engineering market.

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