Research on the Integration Design of Double Well Head Drilling System for Semi-submersible Drilling Platform

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Abstract. In order to upgrade the capability in offshore drilling and exploring, it is imperative to design and study deep water drilling system. Firstly, surveying and researching the present situation and development status of deep water drilling system. Secondly, analysing the characteristics and configuration of the deep water drilling rig used for semi-submersible drilling platform, also selecting key equipment. Finally, designing and coming up with a dual-frame derrick drilling system with 3660 meters water depth and 15250 meters drilling depth, compared with the trade technology, its advantage: achieving top drive core and realizing continuous drilling, allowing duplex main wellhead operation, the two wellhead could be working at the same time, and a well is being used to piping, and another well is being used for drilling. As a result of saving the non-drilling time and increasing the drilling efficiency. It is of great significance to the development of marine energy sources.

Keywords: double wellhead operation; ocean drilling system; double derrick drilling rig; drilling rig selection; semi-submersible drilling platform.

1. Introduction
With the rapid development of global economy, the demand for Marine oil and gas is increasing sharply, but nearly 20 years, with the exhaustion of the oil and gas resources of the land, the world's deepwater oil and gas field exploration and development results emerge in endlessly, of which more than 70% in the northern gulf, southeast of Brazil and west Africa three deep waters, the deepwater oil and gas recoverable resources in three major areas of global deepwater oil and gas is 40\%-50\% of the total recoverable resources\textsuperscript{[1]}.

As the development of deepwater oil and gas field size and water depth increasing, the deep ocean engineering equipment and technology rapid development, accelerating the development process of Marine resources. For a long period of time, Marine oil and gas resources development around the world has become the important development goals and it is effective powerful weapon and the important sign of Marine oil and gas resources development. And the shallow sea exploration and development means has become increasingly mature, the development of deepwater drilling equipment is imperative\textsuperscript{[2][3]}. Deepwater drilling equipment can provide technical support for the design, construction and application of deepwater drilling platforms, and the main factor affecting the efficiency of deepwater drilling system is the form of derrick. Currently, most ultra-deepwater drilling platforms with operating water depth greater than 5000ft in the world adopt semi-derrick and dual-derrick rigs, while those with operating water depth less than 5000ft basically adopt single derrick. This drilling system with double derrick drilling rig can improve drilling efficiency\textsuperscript{[4]}.
2. Drilling System Design Process
Taking the needs of ultra-deep water drilling operations as the goal, the key parameters of drilling modules, circulation systems, solid control systems, etc. of the drilling system and the matching calculation of the system are carried out, then the configuration and selection of drilling systems are completed. Establish modular dynamic system, circulation system, solid control system and other equipment performance, structure parameter configuration database. Combined with the analysis of the mechanical behavior of the ultra-deep water riser under various working conditions, it provides theoretical basis for the type selection, design and operation of the drilling system equipment [5]-[7].
Calculating the equipment layout and completing the layout design of the drilling system. According to the optimization strategy of function zone module planning, operation cost planning and reducing the barycenter of the platform.
Carrying out analysis of the interface system between drilling systems and drilling platforms, and comprehensively analysing the man-machine interface, electro-mechanical interface, intelligent interface, and gas-liquid interface between drilling systems and drilling platforms or drilling vessels. Achieving the matching analysis and control channel requirement design for power module and hydraulic module of drilling system. In order to determine the demand of power, hydraulic and control signals for the equipment matching under different operating conditions, analysing the correlation between the input interface of drilling system and the output interface of drilling platform, and studying the interconnection relationship.
Finishing the functional design of the drilling system input interface and the drilling platform output interface, including the performance design of the power interface, human-machine interface, and gas-liquid interface, and the study of the communication interface protocols and standards.
The overall design technical route of the drilling system is shown in Figure 1.

Figure 1. General design technical route of drilling system.
3. Drilling Rig System Configuration and Equipment Options
At present, the ocean deep water rig refers to a floating ocean platform rig that is used for operating water depth of more than 500 meters. At present, there are three types of deep water rig [7]: AC inverter rig, Ram rig (hydraulic rig) and DMPT rig (double column multifunctional tower rig). The DMPT rig is a new type of rig.

Due to the high power of deep water rig equipment and the limitation of deck load and deck space, the low volume and high power AC frequency converter equipment is used in deep water rig. For AC frequency conversion drilling rig, the compensation device (such as crown block, travelling block, drawworks, dead rope compensation device, etc.) must be used to compensate the sinking motion of the drill string. The AC frequency rigs are widely used [8][9]. Most of the new ocean rigs use this type and have good experience in installation, commissioning, use and maintenance. The first deep-water semi-submersible drilling rig HYSY981 also adopts this type of rig to adapt to the working water depth of 3,660 meters. A semi-submersible drilling rig with a drilling depth of 15,250 metres is recommended for this type of rig.

The main systems of the rig include: lifting system, compensation system, circulatory system, rotating system, underwater system and solid control system. The selection of mast type and compensation device has a relatively large impact on the drilling system and is the main influence factor for the rig configuration selection, especially the mast type. It is one of the most important effecting factors on the cost, weight and working efficiency of deep water drilling rig.

3.1. Hoist System
Used for completing drilling, lifting, rising and dropping systems such as drilling, casing, tubing, riser, BOP (blowout preventer) or pumping rod string, including key equipment such as derrick, travelling system, and drawworks, etc. The derrick used on the semi-submersible drilling platform is an ocean dynamic derrick. The derrick is used of placing crown block, travelling block, hook, and top drive, installing top drive guide rail and storing pipe string.

At present, there are three types of derrick, such as single derrick, double derrick and one half derrick, which are suitable for deep water semi-submersible drilling rig. Among them, the double derrick rig on the deep water semi-submersible drilling platform has two types of operating system: main auxiliary wellhead and double main wellhead. Deeper water drilling platforms should use double derrick deep water drilling rigs. For example, for deep water semi-submersible drilling platforms with a maximum operating depth of 3,660 meters, the time for landing riser and BOP are longer. In order to improve operational efficiency, double derrick should be used.

The vital equipment of the lifting system is the derrick and drawworks. The selection of the height of the derrick and the input power of the drawworks is the most critical choice index of the system.

3.2. Rotation System
Used for rotating the drilling tool in the well to continuously break the rock, including a rotary table and top drive device. A new generation of high torque AC frequency top drive is commonly used in deep water drilling rigs. The top drive lifting load is matched with the maximum hook load of the drill rig, and the scooter can have telescopic function. The diameter of the rotary table opening shall not be less than 1536.7 mm, so that when the pipe is decentralized, the unilateral gap between the rotary table opening and the outer wall of the pontoon shall not be less than 76.2 mm to 127 mm. For the seventh-generation deep-water semi-submersible drilling platform, due to its operating depth of 3,660 m, riser with a diameter greater than 1371.6 mm will be deployed, so an open diameter 1917.7 mm rotary table should be used.

3.3. Drilling String Compensation System
The semi-submersible drilling platform must be equipped with compensation system to eliminate the impact of the platform sinking movement on the drill string to ensure constant drilling pressure and ensure that the drill tool can continue to drill during the platform sinking movement and improve drilling efficiency. The compensation system is divided into passive compensation type and active compensation type. In addition, according to the different installment locations of the compensation mechanism, the
drilling compensation is divided into crown block model, travel block model and hoisted model compensation. At present, there are two kinds of commonly used lifting compensation methods for deep-water drilling rigs: active lifting compensation for sky models, and compensation for hoisted models (active compensation drawworks). Both ultra-deep water semi-submersible drilling platforms can choose two compensation types of them. When using a double derrick, if you need to reduce the barycenter of the entire platform, you can use an active compensation drawworks to compensate for the trip.

3.4. Circulatory System
The circulatory system mainly includes high-pressure mud pumps and low-pressure centrifugal pumps. Deep water drilling systems are generally equipped with 3 to 4 high-pressure mud pumps with 2,200 hp, which are driven by AC frequency Motors. Deep water drilling systems use mud pumps with a power of 2,200 hp and a pump pressure of 7,500 psi (mud pumps with gemstone machinery can be used to realize equipment localization). The deep water semi-submersible drilling platform has large operating depth and hook load, and is equipped with dual-frame derrick. Equipped 5 to 6 mud pumps. The semi-submersible drilling platform with working water depth of 3,660 meters and drilling depth of 15,250 meters is recommended to be equipped with 6 mud pumps. Four pumps used and two pumps reserved.

3.5. Pipe String Handling System
Composed of a number of mechanized, automated and intelligent equipment. It completely or partially replaces manual operations during the drilling string processing operation. It is used to complete all or part of the transportation, connection, placement, etc. of drilling pipe string such as drill pipe, drill collar, or casing, and is divided into pile field area equipment and drill platform area equipment. Pipe string yard equipment mainly includes pipe crane, power cat walk, and requires maximum operating area of the crane cover pipe pillar yard area. And its maximum processing capacity should be extended to be suit for riser. The equipment of the drilling area includes iron roughneck, racking pipe devices, pipe string lifting devices, support devices, and clamping devices.

3.6. BOP and X-mas Tree Handling System
At present, the diameter of the deep-water blowout preventer group (following abbreviation, BOP) is 476.25 mm, and the rated working pressure is (15000 to 20000) psi. Deep water semi-submersible drilling platforms can be equipped with universal BOP with 10000 psi pressure level or 7 to 8 gate blowouts with 20000 psi pressure. The BOP includes the LMRP (lower marine riser package), the middle connector, the lower blowout preventer group, and the blowout preventer combination frame. According to the different spatial arrangements, BOP and the X-mas tree processing system can share the same processing system, or use two separate systems. When a common system takes into account, its maximum processing capacity is designed according to the weight of BOP. When two sets of independent systems are used, one set is used for processing BOP and another set is used for processing X-mas trees.

3.7. Solid Control
Deep water drilling rigs generally adopt solid control systems of level 5 or above: scrapers, shale shaker, degasser, mud cleaner desander (generally configured according to specific circumstances), desilter, centrifugal pumps, etc.. The parameters and configuration of the solid control system are mainly determined by the drilling rig cycle displacement (mud pump maximum displacement) and mud treatment process.

4. Designing a Deep Water Drilling System
4.1. Major Equipment Arrangement
The drilling system of the platform is centered on the rig module, and the entire rig module is arranged in the central position of the platform. For dual-frame derrick rig, the center position of the platform adopt the center position of the derrick or the center position of the main rotary table. The central part
of the platform is monthly pool, for the decentralization and recovery operation of underwater equipment. The mud pump, daily mud pool, pulp distribution equipment, bag store, BOP control system equipment, etc. are set in the special cabin of the hull on the platform. Drilling equipment is mainly arranged in several areas \cite{10}–\cite{13}: tube yard deck (upper deck), drilling platform area, moon pool area, lower deck and other areas.

4.1.1. Pipe Deck /Upper Deck Area
Upper deck area have a large number of drilling equipment \cite{14}, including riser crane, BOP crane, X-mas tree crane, solid control equipment rooms, power catwalk (should be part of the automated pipe handling system), folded crane, piping machine, and pipe yards, etc..

4.1.2. Drill Floor Area
The drilling floor area include drillers’ cabin, local instrument rooms, derrick frame, lifting systems, rotary table, chock and kill manifold, standpipe manifold, and drill platform equipment such as iron roughneck, Iron derrick man, power Slip and mud stuffing box, etc.. The drawworks is also generally arranged in the drill floor area.

4.1.3. Moon Pool Area
Moon pool area placement of moon pool equipment: riser tensioner, high pressure air accumulator, accumulator, nitrogen tank, control skid, moon pool winch, blowout preventer and X-mas tree pulley, slide and lower blowout preventer guide device (mounted on the bottom of the moon pool).

4.1.4. Lower Deck
Lower deck set up high pressure mud pumping room, small pit, mud purification equipment, power system equipment are all arranged on the.

4.2. Drilling Pipe Pile Layout

4.2.1. Drilling Pipe and Casing
The horizontal pipes are laid on the upper deck, and the verticals are on the setback area. The pipe string pile is placed in the stern area of the main deck. Both the pipes are stacked on the pile in a horizontal storage manner. When used, the pipes can be transported, connected and placed into the setback area by using the horizontal and vertical string processing system equipment\cite{10}.

4.2.2. Riser
The marine riser has three arrangement ways for semi-submersible drilling platforms: horizontal separately, both of horizontal and vertical, vertical separately. Different placement methods affect the layout of the platform, the riser handling project and its flowing and operating efficiency.
Firstly, the riser is level. The horizontal riser need to be changed to the vertical state by the conveyor device before it will be sent to the rotary table wellhead. The horizontal placement riser is generally located on the main deck, and its area can be used in combination with the casing storage area. Secondly, some is horizontal and another is vertical. The horizontal risers are placed on the main deck pipe yard. When used, they need to be connected and transported to the wellhead through treatment equipment. The vertical risers can be placed in the vertical placement area, when used, they are directly transported to the wellhead. Finally, the riser is vertical, it can improve the efficiency of the riser landing and even the overall operation, so that the riser can be laid down the upper deck below, is placed on the lower deck, reducing the barycenter. Recommending to use the finally arrangement for the semi-submersible platform.

4.3. The Drilling System Configuration Designing
Based on the above, designing the configuration of the deep-water drilling system for ultra-deep water semi-submersible drilling platforms with a depth of 3,660 meters and a depth of 15,250 meters, Compared with trade technology as shown in table 1, layout scheme as shown in Figure 2.
Table 1. Comparison table with designing and trade technology.

| Name                          | Designing schema     | others          | Comparative result |
|-------------------------------|----------------------|-----------------|--------------------|
| Projected depth               | 3660 m               | 3660 m          | equivalence        |
| Depth-drilled                 | 15250 m              | 15250 m         | equivalence        |
| Maximum hook load             | 1150 t               | 1134 t          | equivalence        |
| Table opening Dia             | 1917.7mm(75.5 in)    | 1917.7mm(75.5 in) | equivalence        |
| Mud pump                      | quantity and power:  | 4+2(reserved), 2200 hp | equivalence |
|                               | 4+2(reserved), 2200 hp |                 |                    |
| BOP/X-tree handling system    | BOP crane: 600 t     | BOP crane: 550 t | precedence         |
|                               | X-tree crane: 150 t  | X-tree crane: 120 t |                    |
| Drill string handling system  | Drill string transport capacity, | Drill string transport capacity, | equivalence |
|                               | 2-7/8 in≤D≤36 in     | 2-7/8 in≤D≤36 in |                    |
|                               | Piping capacity,     | Piping capacity, |                    |
|                               | 2-7/8 in≤D≤14 in     | 2-7/8 in≤D≤14 in |                    |
| Riser handling system         | Verticality place,   | Verticality place, | precedence         |
|                               | single height 130 ft  | single height 110 ft |                |
| Subsea BOP stack              | Rated working pressure: | Rated working pressure: | precedence         |
|                               | 20000 psi            | 15000 psi       |                    |

4.3.1. Dual-frame Derrick

The derrick adopts a dual-frame, which adopts a large-span structure to separate the drilling operation area on both sides of the derrick from the maintenance of the equipment in the middle. This facilitates drilling operations and equipment maintenance. Its structural performance is approved, and the dual-frame derrick structure is as shown in Figure 3.

As equation (1), the effective height $H_M$ of the derrick mainly depends on the drilling operation of the rig. When the travelling block is up to the highest position, it can still ensure sufficient safety height, which is closely related to the height of the standpipe, the length of the travelling block and the top drive, the compensation displacement, and the collision protection distance.

$$H_M = h_{TP} + l_{TL} + h_{CPD} + h_{CPH}$$

\[ \text{Figure 2. Distribution of drilling system.} \]  
\[ \text{Figure 3. Dual-frame derrick.} \]
In the above formula:
- $T_{Ph}$, The effective height of the standpipe, take 41.15 metres.
- $T_{Lh}$, The actual height between travelling block and top drive, take 13 metres.
- $C_{PDh}$, Top safety anti-collision space, take 4.5 metres (including 3.81 metres compensation trip).
- $C_{PHh}$, The bottom safety anti-collision space, take 4.5 metres (including 3.81 metres compensation trip).

So, $H_{e} = 63.15 \, m$, determine the effective height of the derrick 64 metres.

### 4.3.2. Substructure Height

The substructure height is one of the most important parameters for substructure design. The factors to be considered include: mud backflow pipe angle, riser tensioner swing angle, the BOP and X-max tree handling net space, etc. At the same time, the substructure height has a greater influence on the barycenter for the drilling system. As equation (2), the substructure height $H$ can be obtained.

$$H = h_1 + h_2 + h_3$$  \hspace{1cm} (2)

In the above formula:
- $h_1$, The height of mud diverter inlet, $h_1 = 3 \, m$ in figure 2,
- $h_2$, Vertical height difference between the mud outlet and the mud diverter inlet. The length of the backflow pipe between the mud outlet and the mud diverter inlet is $L$, and the tilt angle $\phi$ is generally not less than 5°, so, $h_2 = L \times \sin \phi = 2.62 \, m$.
- $h_3$, The height difference from Mud outlet to the drill floor. Taking into account the actual dimensions of rotary table, rotary table beam and diverter, the height difference $h_3$ is not less than 3 m.

Therefore, the drill floor height $H = 3 + 3 + 3 + 3 = 8.62 \, m$, so, it is reasonable to determine a 9 metres high drill floor height.

In addition, need to further verify when the riser tensioner is fully extended and the swing angle is 3°, guarantee to have sufficient safety space between the tensioner and the side wall of the moon pool.

### 4.3.3. Lifting System

The lifting system adopts variable frequency drawworks and travelling system with compensation, and the drawworks placed on the outside of the derrick, and its performance is reliable.

The main technical parameters of Semi-active crown block compensation device for drilling system include maximum static load and maximum compensation load. The maximum static load of the drilling system should not be less than the maximum hook load of the drilling system.

The maximum compensation load of the crown block compensation device during drilling as equation (3) below.

$$Q_{\text{max}} = Q_{ST} + Q_{TR} - F_{FL}$$  \hspace{1cm} (3)

In the above formula:
- $Q_{ST}$, maximum string weight, 7250 kN
- $Q_{TR}$, travelling system weight, 700 kN
- $F_{FL}$, pipe string flotation, $F_{FL} = \rho g V = 1500 \times 9.8 \times 70.24 \approx 1030 \, kN$

So, $Q_{\text{max}} = 7250 + 700 - 1030 = 6920 \, kN$

So, The maximum static load of the crown block compensation device is 11500 kN and the maximum compensation load is 6920 kN.

### 4.3.4. Rotation System

Mainly includes rotary table and top drive.

- Rotary table
The rotary table is the main load-bearing and rotating part of ocean rig equipment. Bearing the weight of all the drill pipe string when lifting the drill pipe string. Bearing the weight of BOP and underwater equipment when decentralizing BOP and underwater equipment. It can be used for the rotation of drilling tools when dealing with underground accidents in emergency situations. When choosing a rotary table, it mainly considers the opening diameter and the maximum static load of the rotary table. The rotary table opening diameter must ensure the smoothly handling the riser. At present, the rotary table diameter of the deep water drilling platform is more than 60.5 in (1536.7 mm), with the operation depth increasing, the rotary table opening diameter will continue to increase. The outer diameter of the floating material of the riser supporting exceeds 60 in (1524 mm). The safe operating gap is usually 5" (127 mm) when decentralizing the riser. So the rotary table opening diameter is 75.5 in (1727.2 mm). The maximum static load of the rotary table is the maximum axial load that the rotary table can withstand, and its value should not be less than the maximum hook load 11,500 kN.

The rotary table is driven directly by a hydraulic motor, which has the characteristics of integrating mechanical, electrical and hydraulic design, small size, light weight and strong function.

- Top drive

The cost of offshore drilling is high. In order to improve drilling efficiency, the top drive is used instead of the swivel and rotary table. And the main parameters of the top drive include continuous working torque and maximum hook load. Having telescopic capability.

Continuous operating torque of the top drive should be equation as (4).

$$M_{\text{max}} \geq 10^2 \cdot L_{\text{max}} - 5$$

In the above formula, $L_{\text{max}}$ is the upper limit of the nominal well depth, which is 15250 metres. So, Continuous operating torque of the top drive should be equation as (5).

$$M_{\text{max}} \geq 10^2 \times 15250 - 5 = 147.5 \, \text{kN} \cdot \text{m}$$

The top drive maximum static load is the maximum lifting capacity that the top drive can withstand. The maximum static load of the top drive is the same as the hook load, which is 11,500 kN.

In order to further improve the working efficiency of the rig travelling system, the pipe string automatic processing system can realize the continuous operation. During the top drive moving upwards from the drill floor, the top drive needs a retractable guide rail frame to effectively avoid the wellhead.

4.3.5. BOP and X-max Tree Handling Systems

The equipment of the BOP and X-max tree handling system is deployed on the upper deck.

**Figure 4.** BOP handling system layout.

Equipped with two sets of BOP, sharing one LMRP, reserving with each other, with a maximum working pressure of 20000 psi, using the BOP platform design with self-guided function and hydraulic step slider, having the advantages of simple operation and high reliability. The layout is as shown in figure 4.

**Figure 5.** X-max tree handling system layout.

Equipped with 5-6 sets of X-max trees, X-Y two-way sliding and steering systems, hydraulic systems, electronic control systems, etc. to achieve a series of operations such as removing and transporting ultra-
large X-max trees from the storage area to the wellhead. The X-max tree treatment equipment can realize the X-Y two-way slip. The layout plan is as shown in figure 5.

4.3.6. Automatic Handling System
Specially equipped with fingerboard for storing riser, bridge crane and pallet for transporting riser. Two risers for one string, through the cabinet standing on the lower deck.
Drilling standpipe placed on the inside of the derrick, it can save space and reduce the piping requirements.
The drilling system is efficiently operated by the automatic treatment system and drill integrated control system, etc. Realizing automatic handling system.

5. Conclusion
Describing the general design technical route of the drilling system, analysing the deep water drilling rig, determining the type of deep water drilling rig, and expounding the characteristics of the key equipment, finally determining a drilling system design and layout scheme as shown in figure 2. To design and deploy the drilling system of the deep water rig in the platform precise shift and steering ability, riser column safety monitoring ability, automatic pipe processing and storage capacity, monthly pool opening and heavy equipment transportation capacity, mud pool storage capacity, etc.. The development of marine exploration is changing rapidly, and the localization of marine equipment highlights its importance. In the design of offshore platform drilling systems, the superiority of high-end localized equipment is highlighted. The innovation and upgrade of localized equipment will lead to a new technological breakthrough in marine oil exploration and development.

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