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Development Path of Offshore Drilling Equipment in China

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Abstract: China has made significant achievements in the development of offshore drilling equipment, and the nation can now develop shallow water drilling rigs independently. However, in the production of deepwater drilling equipment, there still exists a significant gap between China and other advanced countries, thereby inevitably hindering its deepwater oilfield development. To accelerate the development of China's offshore drilling equipment, in this study, the development status of the equipment in both China and abroad is first analyzed from three aspects: shallow water drilling machines, deepwater drilling machines, and new types of marine drilling machines. The development status in China, as well as the gap between China and other advanced nations, is then summarized. Subsequently, the key technologies for realizing the domestic development of deepwater drilling equipment are described, and corresponding countermeasures and suggestions are proposed. We also suggest that China should focus its efforts on making breakthroughs in the design, materials, technology, inspection, and sea testing of deepwater drilling rigs. To clarify the development path of offshore drilling equipment, China should establish and improve the standards and specifications regarding offshore drilling rigs, develop different types of deepwater drilling equipment at different stages and at different levels, establish an integrated testing platform and a sea testing base, strengthen its inter-industry cooperation, develop this sector in an innovation-driven mode, and promote diversified, serial, automated, and intelligent development.
Keywords: offshore drilling rig; deepwater drilling rig; development of equipment; test; sea test

1 Introduction

Specialized drilling equipment is required for offshore oil and gas development. After years of development, China's offshore oil industry has various types of drilling and completion equipment, such as submersible drilling platforms, jack-up drilling platforms, semi-submersible drilling platforms, and jacket platforms with modular drilling rigs, forming a series of differentiated offshore drilling and completion products [1]. Various platforms have been designed and built in China, and domestic drilling rig manufacturers have been able to independently manufacture drilling equipment for shallow water platforms. However, some technical problems remain to be solved in the design and manufacture of offshore drilling rigs. In particular, the technology used for the design and manufacturing of key equipment for deepwater drilling rigs is in the hands of a few foreign manufacturers. This leads to high construction costs, a long supply cycle, and high maintenance costs for deepwater drilling rigs, which, to some extent, restricts the development efficiency of deepwater and far-reaching offshore oil and gas use in China [2,3].

To accelerate the development of China's offshore drilling equipment to meet the needs of China's offshore oil and gas field development (particularly, its far-reaching offshore oil and gas field development) it is necessary to

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carry out research on the development path of China's offshore drilling equipment. In this paper, the development status of offshore drilling rigs, both in China and abroad, is investigated. The problems existing in the design and construction of offshore drilling rigs in China are analyzed, and the key technologies of offshore drilling rig equipment are summarized. Countermeasures and suggestions are put forward to promote the development of offshore drilling equipment in China.

2 Development status of offshore drilling rigs around the world

The equipment used to carry out offshore drilling and completion operations includes mobile drilling equipment, production platforms equipped with drilling rigs, floating drilling production storage and offloading equipment, and tender rigs [4–6]. The core equipment includes drilling rigs, which differ for different types of platforms, particularly for shallow water and deep water. According to the operating water depth, offshore drilling rigs can be divided into shallow water drilling rigs and deepwater drilling rigs. Surface blowout preventers (BOPs) are used in submersible drilling platforms, jack-up rig platforms, jacket platforms, and other shallow water drilling rigs. The drilling rigs on semi-submersible drilling platforms, drilling ships, and deepwater floating production platforms (tension leg platforms, single-column platforms, and semi-submersible production platforms) are deepwater drilling rigs, all of which are equipped with risers. Surface BOPs are used for drilling rigs on a tension leg platform and single-column platform, and subsea BOPs are used for drilling rigs on other deepwater platforms [4].

2.1 Shallow water drilling rigs

There is little difference between shallow water drilling rigs and land drilling rigs; thus, there are many manufacturers in China and abroad who can manufacture shallow water drilling rigs. According to different lifting methods, shallow water drilling rigs can be divided into conventional drilling rigs, hydraulic drilling rigs, and rack and pinion drilling rigs.

2.1.1 Conventional drilling rigs

Drawworks/crown-block/traveling-block lifting is a traditional lifting mode adopted by most shallow water drilling rigs (including production rigs and mobile drilling rigs). The rig configuration of the production platform is relatively simple; thus, there are many manufacturers of such rigs in the world. Most of the rigs on jack-up drilling platforms are produced by National Oilwell Varco (USA), Aker MH (Norway), and Cameron (USA).

2.1.2 Hydraulic drilling rigs

The lifting system of a hydraulic drilling rig is a hydraulic cylinder, which has no drawworks or traveling system. Hydraulic drilling rigs have some application in shallow water platforms (mainly used for jacket platforms, but also to a small degree in jack-up drilling platforms). The hook load of hydraulic drilling rigs used in shallow water is generally small [7]. The hydraulic drilling rigs used in shallow water platforms are primarily developed by Drillmec (Italy), WEI (Italy), and Herrenknecht (Germany). The lifting systems of the hydraulic drilling rigs of Drillmec and WEI adopt a single hydraulic cylinder and pulley system, whereas the hydraulic drilling rigs of Herrenknecht adopt double hydraulic cylinders and no pulley system.

2.1.3 Rack and pinion drilling rig

The lifting system of a rack and pinion drilling rig consists of a gear and a rack. In one type of structure, the rack is fixed on the mast, and the gear box drives the top drive to move along the rack of the derrick, as in the VR series rack and pinion drilling rig from American Augers (USA), the VDD series rack and pinion drilling rig of Max Streicher (Germany), and the Ti-200 rack and pinion drilling rig of Herrenknecht. In another structure, the gear box is fixed, and the rack drives the top drive to move, as in TTS Sense's (Norway) Finder250 rack and pinion drilling rig. Rack and pinion rigs are seldom used offshore, and only a few of them are used in shallow water jacket platforms [8].

2.2 Deepwater drilling rigs

Most deepwater drilling rigs use a subsea BOP and a drilling riser, which is also the main difference between deepwater drilling rigs and shallow water drilling rigs. Typical deepwater drilling rigs include drilling equipment on the platform (referred to as surface drilling equipment) and underwater equipment. The rig equipment arranged on the platform includes derrick and auxiliary equipment, drill floor and auxiliary equipment, lifting systems, heave compensation devices, rotary systems, high-pressure mud systems, low-pressure mud conveying systems,

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solid control systems, bulk systems, drilling control systems, pipe handling systems (including riser conveying systems), BOP and Christmas tree conveying systems, well control systems, hydraulic systems, and third-party equipment (cementing units, well testing systems, and combustion arms). Subsea equipment mainly includes riser systems (including a telescope joint) and a subsea BOP stack (including a control system).

Because deepwater drilling rigs require a strong load capacity, power, high degree of automation, high reliability requirements, and a special application environment, few manufacturers in the world can manufacture such rigs.

2.2.1 Surface drilling equipment

The types of deepwater drilling rigs include alternating current (AC) variable-frequency drive drilling rigs, RamRigs, cylinder rigs, and dual multi-purpose tower (DMPT) drilling rigs. AC frequency conversion drilling rigs are the most commonly used. A DMPT drilling rig, a type of special drilling rig with a lifting system, is seldom used.

(1) AC variable-frequency drilling rig

AC variable-frequency drilling rigs have the advantages of good installation, commissioning, use, and maintenance experience; thus, they are the most widely applied rigs globally. Traditional lifting systems are used in AC variable-frequency drilling rigs, which are equipped with variable-frequency drawworks. The crown compensator or drawworks compensator must be used in deepwater AC variable-frequency drilling rigs to compensate the heave motion of the drill string.

The main manufacturers of deepwater AC variable-frequency drilling rigs are National Oilwell Varco and Aker MH; which have nearly monopolized the global deepwater drilling rig market.

(2) RamRig

A RamRig is a type of hydraulic rig. RamRig is currently on its third generation and adopts a lifting hydraulic cylinder instead of drawworks; the lifting hydraulic cylinder is equipped with a drill string motion compensator, and therefore does not need an additional heave compensator, and includes a hydraulic automatic drilling function. The derrick type RamRig mostly uses a double derrick. The lifting hydraulic cylinders of the first and second generation RamRig are on both sides of the derrick, and the top drive and hook are in the middle. The arrangement of the hydraulic cylinders of the third generation RamRig derrick has changed greatly, and the lifting hydraulic cylinder is placed in the middle of the derrick.

(3) Cylinder rig

Cylinder rigs are hydraulic rigs, adopting a fixed derrick, and the lifting system adopts multiple sets of hydraulic cylinders. The hydraulic cylinder is in the middle of the derrick. A cylinder rig is similar to third generation RamRig.

(4) DMPT drilling rig

A DMPT drilling rig is a new type of drilling rig specially designed for deep water. The derrick of the drilling rig is a dual operation multi-purpose tower. The dual operation multi-purpose tower is a welded box girder bearing structure. The tower covers a small area. A set of lifting systems is equipped on both sides. The active heave compensator drawworks is placed in the middle of the derrick, and the traveling system and setback are on the outside of the derrick. All of the main equipment of the drilling rig is installed in the closed tower, the lifting system has no truss derrick structure, and thus the large equipment can directly slide or lift to the wellhead center without the operation restriction of the traditional V-door of the derrick.

2.2.2. Subsea equipment

(1) Drilling riser

Only a few countries currently have offshore drilling riser manufacturing capabilities, including the US, Norway, France, and Russia. The main forms of riser structure are the flange type, clamp type, and buckle type. GE Vetco and Cameron are the largest offshore drilling riser manufacturers in the world. In France, the clip riser was developed by the French Petroleum Research Institute during the 1980s, and the aluminum alloy riser was developed by ZAO company in Russia. In addition, Aker and National Oilwell Varco produce drilling risers of different forms and specifications.

(2) Subsea BOP

The main manufacturers of subsea BOPs in the world are Cameron, National Oilwell Varco, and GE Vetco, all of which are American companies and dominate in terms of technology and market share. The mainstream subsea BOP product specifications are 476.25 mm, 105 MPa, and 6 rams with a MUX control system. The maximum working depth is more than 3000 m, and they can be used on deepwater drilling ships and deepwater semi-submersible drilling platforms. GE Vetco, Cameron, and other companies have launched 140 MPa BOP stacks with seven or eight rams, which can be used for next-generation ultra-deepwater semi-submersible drilling platforms.

The development of drilling rigs has undergone an evolution from land drilling rigs to shallow water drilling rigs and deepwater drilling rigs. From land drilling rigs to shallow water drilling rigs, the problems of modularization and salt spray corrosion at sea have mainly been solved, and the degree of automation has been increased. From shallow water drilling rigs to deepwater drilling rigs, the problems of harsh subsea environments, acceleration caused by platform motion, and higher automation have also been solved [9]. The main differences among land, shallow water, and deepwater rigs are shown in Table 1.

Table 1. Main differences among land, shallow water, and deepwater drilling rigs.

Features	Land	Shallow water	Deepwater
Arrangement	Large area and low integration	Modularization, high integration	Compact layout
Movement	Single equipment relocation or skid mounted relocation	Mobile as a whole	Move platform
Influence of platform motion	None	None	Has an influence on the lifting system, crane, pipe treatment system, and other moving equipment
Influence of special environmental conditions	None	High humidity and high salt fog corrosion environment, and typhoon influence	High humidity, high salt fog corrosion environment, and typhoon evacuation influence
Equipment in subsea environment	None	None	Riser, BOP
Subsea control	None	None	BOP
Heave motion compensation	None	None	Riser tension, drilling string heave compensator
Requirements for operation efficiency	Low day rate, low efficiency requirement	High day rate, high efficiency requirement	High efficiency and automation requirements

2.3 New offshore drilling rig

In addition to the abovementioned offshore drilling rigs, foreign manufacturers are continuing to innovate offshore drilling rig equipment, putting forward new concepts and carrying out new product research and development, and some new products are being used in offshore drilling rigs.

2.3.1 Continuous-motion drilling rigs

A continuous-motion drilling rig is a new type of rig proposed by the West Group of Norway. The characteristics of the rig include the following. During the process of tripping, the rig can makeup and break-out the pipe during the tripping process, and thus the rig can continuously trip in and trip out (without stopping to makeup and break-out at the rotary table), the tripping speed of the rig is greatly improved, and the wellbore accidents caused by a bottom hole pressure surge during the process of tripping can be greatly reduced [10, 11]. The working principle of West Group’s continuous-motion rig is reciprocating circulation and continuous makeup and break-out, thereby realizing a continuous-motion operation, and the maximum tripping speed can be as high as 3600 m/h. At present, the continuous-motion rig is still in the field-testing stage of an engineering prototype, and it has not been widely used in actual oil fields.

2.3.2. Dual drawworks drilling rig

The double drawworks lifting system uses two drawworks in a set of lifting systems of the drilling rig, one of which replaces the deadline anchor of the traditional lifting system and changes the deadline end into another fast line end. With the design of a double fast line, two drawworks can work at the same time to lift the top drive together, or lock one drawworks and use a single drawworks to lift the top drive. The double drawworks system has the advantages of high redundancy, low power of a single winch, and high efficiency of active heave compensation [12]. The double drawworks drilling rig with active compensation developed by National Oilwell

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Varco has been applied in a semi-submersible drilling platform.

2.3.3. Seabed drilling rig

During the 1990s, the concept of a seabed drilling rig was put forward internationally. In 2003, Maris (UK) completed a preliminary feasibility study of a seabed drilling rig and put forward a more detailed seabed drilling scheme. In 2005, Robotic Drilling Systems (Norway) began to design and develop a prototype seabed drilling rig system, and completed the trial production of the test prototype in 2010, representing the highest level of international seabed drilling rig development.

2.3.4. Badger explorer drilling device

In 1999, the concept of a badger explorer drilling device was proposed for the first time, which, to a great extent, can solve the problems of exploration wells in deep water, polar regions, and other special complex areas. In 2003, Norway successfully developed a prototype of the badger explorer drilling device, which, in 2011, has entered the experimental stage. The badger explorer drilling device can be used in deepwater drilling operations, and can greatly reduce the cost of offshore drilling. At sea, the drilling device can be installed using a working ship, and needs to be landed to the wellhead of the seabed using a remotely operated vehicle.

3 Development status of offshore drilling rigs in China

The drilling equipment used in China’s shallow water oilfields includes modular drilling rigs, submersible drilling platforms, and jack-up drilling platforms. Such equipment has been fully localized, from the hull design and construction to the supporting and drilling equipment. The application of these offshore drilling rigs has been effective.

After years of development, China’s semi-submersible drilling platforms have formed a series of fleets with operating water depths ranging from 300 m to 3600 m, which are in line with the world’s advanced levels in terms of quantity, operating water depth, and platform configuration, among other factors. The construction level of China’s semi-submersible drilling platforms has reached the advanced international level through the construction of advanced semi-submersible drilling platforms, including Endeavor and Blue Whale 1 [13]. However, the products of domestic manufacturers of drilling equipment mainly focus on the drilling for land and shallow water platforms. There is a large gap between the design and manufacturing level of domestic manufacturers of deepwater drilling equipment and the advanced level from countries abroad. In addition, there is a significant gap between domestic hydraulic drilling rigs and foreign-developed rigs. Thus, the drilling equipment used for the jacket platform, jack-up platform, and other shallow water platforms in China is primarily developed domestically, whereas the drilling equipment for deepwater platforms (including underwater equipment) is mostly imported.

During the process of using and maintaining deepwater drilling rigs in China, some localization has been gradually realized, including maintenance, and the development of spare parts, individual parts, and certain equipment. For example, Exploration 3, a semi-submersible drilling platform, and Nanhai Challenge, a semi-submersible production platform, are equipped with a number of domestically produced parts. The deepwater drilling rigs on the Tiger series drilling ships built by Shanghai Shipyard for Opus Offshore (Singapore) adopt a large amount of domestically produced equipment, including derricks, crown-blocks, traveling-blocks, rotary tables, drawworks, mud pumps, riser cranes, catwalks, knuckle boom cranes, Christmas tree trolleys, BOP trolleys, and driller’s rooms. The drilling rigs equipped on this series of drilling ships are deepwater drilling rigs with the highest equipment localization rate at present. Some key equipment of the rig, such as the riser system, BOP and control system, diverter, choke and kill manifold, crown block compensation system, riser tension, top drive, iron roughneck, driller’s chair, and control software, are all manufactured by foreign companies. In addition, Baoji Oilfield Machinery Co., (China) has carried out the development of key equipment, including a pipe handling system, 1536.7-mm rotary tables, drilling control systems, and drilling risers [14–16]. In addition, Hebei North China Petroleum Rongsheng Machinery Manufacturing Co., (China) has developed a subsea BOP and control system, and produced an engineering prototype [17,18].

In general, the level of domestic shallow water drilling rigs is not different from those of foreign countries, but the localization rate of deepwater drilling rigs is low. In particular, some key equipment of deepwater drilling rigs cannot be manufactured in China. Although engineering prototypes for some equipment have been developed, they have not been tested or applied on-site, and thus it is difficult to enter the domestic and foreign markets. Equipment requiring technological breakthroughs mainly includes the following categories: high-power equipment (mainly including high-power top drive and drawworks), subsea equipment (including risers, riser telescope joints, subsea BOPs, and control systems), heavy load heave compensation equipment (including drill string heave compensation and riser tension), automatic handling equipment (including pipe handling systems, BOPs and Christmas trees, and transportation systems), control system hardware and software (including driller's operating systems and control software), as well as other key equipment, such as dual-derricks, cementing systems, and combustion arms. In addition, most of the domestic offshore drilling rigs are AC frequency conversion drilling rigs. A deepwater heavy hook load drilling rig is more suitable as a hydraulic drilling rig; however, the design and development of high-power hydraulic drilling rigs remains lacking in China.

4 Analysis of key technology of deepwater drilling rig

4.1 Comparison of key technologies in China and abroad

A comparison of domestic and foreign technology levels is shown in Table 2. There is a certain gap between China and foreign countries in the design, materials, technology, inspection, field testing, standard specifications, services, and other aspects of deepwater drilling rigs. The main problems are as follows. The design level of deepwater drilling rigs, subsea systems, and heave compensation systems still needs to be further improved, as does the manufacturing level of the domestic materials. In addition, a small number of special materials (used for hydraulic equipment, well control equipment, and subsea and wellbore fluid contact equipment) for drilling rigs still need to be imported; the domestic product chain is incomplete, lacking the manufacturing capacity of key equipment, such as a heave compensator and subsea BOP. In addition, the manufacturing process, inspection, and testing of domestic manufacturers need to be further improved, and the enterprise standard of key equipment of deepwater drilling rigs is lacking.

4.2 Key technologies to be developed in China

4.2.1 Design and integration technologies

The complete set design of a drilling rig, the design of a subsea system, and the design technology of a heave compensation system pose difficulties in the design of deepwater drilling rigs. In addition, the design and integration technologies include the interface design between a deepwater drilling rig system and the platform, the interface design between different systems of deepwater drilling rigs, and the integration of various drilling equipment.

4.2.2 Special materials

These include metal materials with special requirements (high-temperature-resistant, corrosion-resistant, and erosion-resistant alloys) and high-temperature-resistant rubber materials, such as materials for manufacturing underwater BOPs and for manufacturing hydraulic sealing elements.

4.2.3 Special processing and heat treatment technologies

Examples of such technologies include the forging and heat treatment process for the manufacturing of large forgings of subsea BOPs, the precision machining process for the inner flow channels of the hydraulic components, and the precision machining and surface heat treatment process for large hydraulic cylinders.

4.2.4 Inspection during manufacturing process

During the manufacturing of deepwater drilling rigs, the basic detection methods and tests mainly carried out are the following: material qualification tests (corrosion resistance, high- and low-temperature resistance, tensile, impact, bending, and hardness tests), the welding process and performance qualification tests, the quality control process and non-destructive tests, and other basic tests, including a chemical and crystal phase analysis, creep and nonmetallic material tests, sacrificial anode tests, coating tests, and fire tests.

4.2.5 Integration testing and verification

Factory acceptance testing (FAT) and extended factory acceptance testing (EFAT) of the components, equipment, or systems of deepwater drilling equipment should also be carried out. System integration testing (SIT) should be conducted for some deepwater drilling equipment (such as a subsea BOP stack), and reliability tests should be carried out for newly developed or modified equipment. The test contents for different equipment are different. For example, the FAT contents of a subsea ram BOP mainly include the following: sealing, fatigue, pressure bearing trip, shear, suspension, ram disassembly, and ram locking tests. The purpose of an SIT test is to simulate the actual installation operation steps for on-site use, as well as to verify the matching of the interface of

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the drilling equipment, the effectiveness of the installation procedures, and the integrity of the functions. At present, there are no complete testing technologies, testing processes, or testing equipment for deepwater drilling equipment in China.

Table 2. Comparison of key technologies of deepwater drilling rigs in China and abroad.

Key technology		Foreign level	Domestic level
Design	Complete set	System integration design based on drilling technology	Imitation mainly, complete set design ability is insufficient
	Single equipment	Mature in all equipment	The design ability of underwater system and heave compensation system is insufficient
	New product	Strong ability of new product design	None
Material	Conventional metal materials	Mature	Mature
	Special alloy	Mature	High-temperature, corrosion and erosion resistant alloys need to be imported (materials for hydraulic equipment, well control equipment, subsea and wellbore fluid contact equipment)
	Special nonmetallic materials		Some materials need to be imported
Technological process	Processing technology	Mature	There is still a gap between metal seal and special heat treatment process
Testing	Equipment and process	Complete testing equipment and perfect process	Lack of some testing equipment
	Technical system	Materials, identification, FAT, EFAT, SIT	Imperfect systematization
Field test	Sea trial	The new product has passed the sea trial	Lack of sea trial
Standards and specification	Industrial standards and specifications	API, ISO, and DNV standards, covering all standards	The industry standards and national standards are relatively complete, but some of the key equipment lack standards
	Enterprise standards and specifications	All manufacturers have more stringent enterprise standards	Few enterprise specifications for deepwater drilling rigs
Service capability	Hardware service capability	Ability of installation, debugging, repair, and maintenance services	Insufficient
	Software service capability	Ability of software development, debugging, and upgrading	Insufficient
Others	System integration capability	Strong integration ability	Lack of integration capability
	Equipment automation control	Perfect software and hardware system	Lack of development testing system
	Equipment weight control	Small and light	Large and heavy
	Quality control	Strict quality control and high product reliability	Mediocre reliability
	Innovation ability	Strong originality	The ability of innovation and integrated innovation of single equipment

4.2.6 Sea trial for prototype equipment

In promoting the development of key equipment for deepwater drilling rigs, a large amount of equipment is first developed by domestic manufacturers. For prototype equipment, although the material test, performance appraisal test, FAT, SIT, and other tests are carried out, these tests cannot fully prove the reliability of the equipment. Therefore, for important equipment, it is often necessary to carry out tests or trials under the actual offshore conditions (for example, long-term offshore tests are carried out when a dual-gradient drilling system is developed in China or abroad) to ensure the reliability of the equipment, and whether the function and reliability meet the requirements of practical operation. It is necessary to make clear the sea trial content, operation procedure, sea trial outline, and resulting evaluation method for each piece of equipment.

4.2.7 Deepwater hydraulic drilling rig

In addition to the above key technologies, the deepwater hydraulic drilling rig also needs to break through the key technologies of the important hydraulic equipment, such as a high-speed hydraulic cylinder with a heavy load, a hydraulic cylinder heave compensation system, a high-precision hydraulic valve with a large flow, and a high-power hydraulic pump station.

5 Countermeasures and suggestions

5.1 Establish and improve standards and specifications

The level of standards and specifications can reflect the development level of an industry. Owing to the low level of domestic deepwater drilling rigs, the current domestic standards and specifications for the special equipment of such rigs, including the subsea BOP, the riser, the heave compensation device, the active heave compensation drawworks, and the riser tension, are essentially based on the API or ISO standards. To promote the development of the technical level of deepwater drilling rigs, we should independently formulate their standard specifications. Through the formulation and improvement of the standard specifications, we can summarize the existing maturity level, promote the improvement of the construction capabilities, and form our own design, manufacturing, inspection, and usage systems. Among the standards and specifications for the equipment, the focus should be on the design, materials, and testing standards and specifications. In addition, the standard specifications for sea trial and offshore application for prototype products should be established to promote localization of the equipment.

5.2 Localization of deepwater drilling equipment for different types, stages, and levels

The domestic technology maturity of each piece of equipment used in deepwater drilling rigs is different, and thus it is necessary to carry out the analysis of domestic technology maturity and divide the localization stage of the equipment. The equipment localization stage can be summarized using the following three categories. The first category, which is to avoid carrying out localization applications for the time being, requires a sea trial, engineering prototype construction, engineering prototype testing, and principle prototype research and development. The second category, which is carrying out localization (requiring testing), requires a sea trial or field trial. The third category can be applied directly for engineering applications or after carrying out an EFAT (or SIT). Due to the different levels of importance of deepwater drilling equipment, the possibilities and consequences of equipment failures are different. Therefore, it is necessary to carry out an evaluation and analysis according to the importance level, localization stage, technical difficulty, failure risk level, and other factors when dividing the types of drilling equipment. Different types of equipment, using different localization strategies, require different tasks. For example, for important equipment, high-power equipment, or equipment used in harsh environments, a large number of tests should be carried out to ensure reliability; for prototype equipment, research and development should be carried out from each stage of the principle, test, and engineering prototypes. In addition, not all deepwater drilling equipment require a sea trial; it depends on the importance and risk classification of deepwater drilling equipment.

5.3 Establish an integrated test and sea trial base

Strict testing is the key to the localization of deepwater drilling equipment, and testing is extremely important in the manufacture of such equipment. In particular, the risers, subsea BOPs, and other subsea equipment are used in harsh working environments, bear complex loads, and have high reliability requirements. Therefore, strict testing must be carried out to ensure the quality of the products. Domestic companies and research institutes have built some testing equipment; however, the distribution remains scattered and the utilization rate is not high. Therefore, we suggest conducting a plan at the national level, integrating the existing domestic test resources, establishing an integrated test base, carrying out an integrated test of the domestic equipment, and improving the utilization rate of the current test equipment. It is easier for the first domestic equipment to be recognized by users after a sea test, and problems can also be found and improved during the sea test. However, a sea trial is not only expensive, it is also difficult for domestic manufacturers to find supporting facilities and sea trial sites. Therefore, it is suggested that under the support and coordination at the national level, domestic manufacturers and users jointly build a special sea trial platform and open the user interface of the control system, which is used specifically for sea trials of domestic equipment.

5.4 Operational risk assessment of newly developed equipment

If the newly developed domestic deepwater drilling equipment is put into trial or application, a risk analysis

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during the operation process must be carried out before application to determine the high-risk points and to formulate an emergency plan. It is necessary to identify various risk factors that may exist in the drilling operation of deepwater drilling equipment and to carry out a risk assessment. In addition, the risk level can be judged according to the risk acceptance standard, and the risk control measures can be constructed to reduce the operation risk of domestic deepwater drilling equipment to a reasonable and acceptable level. Such work should be conducted by an organization with relevant qualifications and rich experience, such as a classification society in China or abroad.

5.5 Extensive cooperation in domestic industries

There are not many domestic manufacturers of offshore drilling equipment, and thus it is impossible for manufacturers to solve all key problems. Therefore, domestic drilling rig manufacturers need to cooperate with the domestic industry to seek help for the key technological breakthroughs in the design, materials, fine finishing, heat treatment, hydraulic components, control components, software development, and other aspects of offshore drilling rigs, thereby forming a complete product manufacturing chain. If necessary, we can cooperate with the world to carry out research and complete the research, development, and manufacturing of the whole set of drilling rig products through global procurement. The state has issued a system to create conditions for the development and application of key equipment, such as an insurance mechanism for the major technical equipment, as well as a domestic offshore industry alliance and other consortia, providing support for the localization of offshore drilling rigs. Domestic offshore drilling rig manufacturing companies, equipment application enterprises, universities, and scientific research institutes are cooperating to jointly establish a perfect standard system by building a high-level research, design, and construction team; forming an independent research and development innovation system, combining production, study, research, and application; and rapidly promoting the localization development process of offshore drilling rig equipment in China.

5.6 Innovation-driven development

The deepwater drilling rig market has been monopolized by a few manufacturers in the US and Norway for many years. Through long-term technology accumulation, these manufacturers are far ahead of other manufacturers in research and development and manufacturing capacity. Therefore, it is difficult to overstep the conventional technologies, and it is necessary to break the monopoly and enter the global deepwater drilling rig market through technological innovation. We should pay attention to and strengthen technological innovation, and carry out localization of deepwater drilling rigs according to the characteristics of the South China Sea, forming new products to break the monopoly of a few foreign manufacturers. The original innovation of individual equipment or tools can be carried out first, such as the first anti-typhoon riser soft suspension device in China [19]. In addition, we will continue to carry out the integrated innovation of drilling rigs in China, such as the design of dual derrick continuous tripping drilling rigs. Driven by innovation, we will steadily promote and expand the application of new deepwater drilling products in offshore oil and gas development.

5.7 Diversified, serialized, automated, and intelligent development

Domestic offshore drilling rig products are relatively undiversified. In the future, they should be further diversified and serialized to meet the needs of different conditions. For example, light hydraulic rigs are manufactured to meet the drilling and workover needs of small shallow water platforms, and hook-mounted rigs are developed to meet the needs of deepwater and ultra-deepwater drilling. Automation and intelligence are the development directions of future industry. In China, we should speed up the development of special rig floor manipulators, iron roughnecks, power catwalks, automatic pipe handling machines, and wellhead automation tools for offshore drilling rigs. In addition, the technologies of automatic drilling systems, data acquisition, closed-loop control, image recognition, remote monitoring, and fault recognition should be integrated into a drilling control system, thereby realizing the automation and intelligence of offshore drilling rigs.

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