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POWER TAKE-OFF SYSTEMS OF OFFSHORE RIG POWER PLANTS

Wieslaw Tarelko

Gdynia Maritime University
ul. Morska 81-87, 81-225 Gdynia, Poland
tel.: +48 58 6901331
e-mail: tar@am.gdynia.pl

Abstract

The growing demand for subsea energy resources forces developing the various structural designs of offshore units destined for oil and gas exploration. Their more and more complicated power plants have to produce energy necessary for power supply of all drilling and production systems. This paper presents offshore structures for oil and gas exploration as one of tendencies in design of large technical systems. They are compared with the biggest structures whenever have been developed by mankind. Moreover, classification and application of the considered types of oil rigs, types of machinery supplied by their power plants, and key problems appearing during their operation are presented.

Keywords: oil rigs, power plant, power take-off systems

1. Introduction

The key challenge for designers of the contemporary technical objects is to gain their greatest achievements (quicker, larger, stronger, etc.). In some degree, this is in accordance with the human nature, which was expressed in the Olympic maxim in Latin: *citius, altius, fortius* – what means quicker, higher and stronger. And tendencies in the present day design are similarly. They could be expressed, *inter alia*, in precise steering of the machine movements, in precise processing of the machine element surfaces, reaching high reliability of technical systems, developing machines operated in severe conditions, developing machines with miniature or immense sizes.

Today, we are able to produce robots, for example surgical ones, with the steering accuracy of their movements nearly 10 microns; manufacture optical mirrors and lens with roughness of their surfaces nearly $Ra = 5\text{nm}$; make miniature air bearings with rotation speed nearly 300000rpm. We are also able to construct safe machines with a high level of their reliability, for example means of air transportation. High expenses for operational use of some of technical systems causes to their high reliability. For example, cost of operational use of continuous casting and rolling lines and continuous car body painting lines are 10000 €/h and 100000 €/h, respectively. Current nanotechnology allows to develop microscopic machines 1000 times less than thickness of human hair, for instance steam engine which pistons have 5 μm diameter.

Regarding the structures with immense sizes, the highest building standing on shore is a skyscraper Burj Dubai in United Arab Emirates. Unquestionably, the tallest free-standing structure in the world, until surpassed by the Burj Dubai in January 2008, was offshore oil rig Petronius named after Petronius, the Roman writer. This is very complex and expensive

construction 609,9 meters high, two times higher than Eiffel Tower and almost three times higher than Palace of Culture and Science in Warsaw (Figure 1).

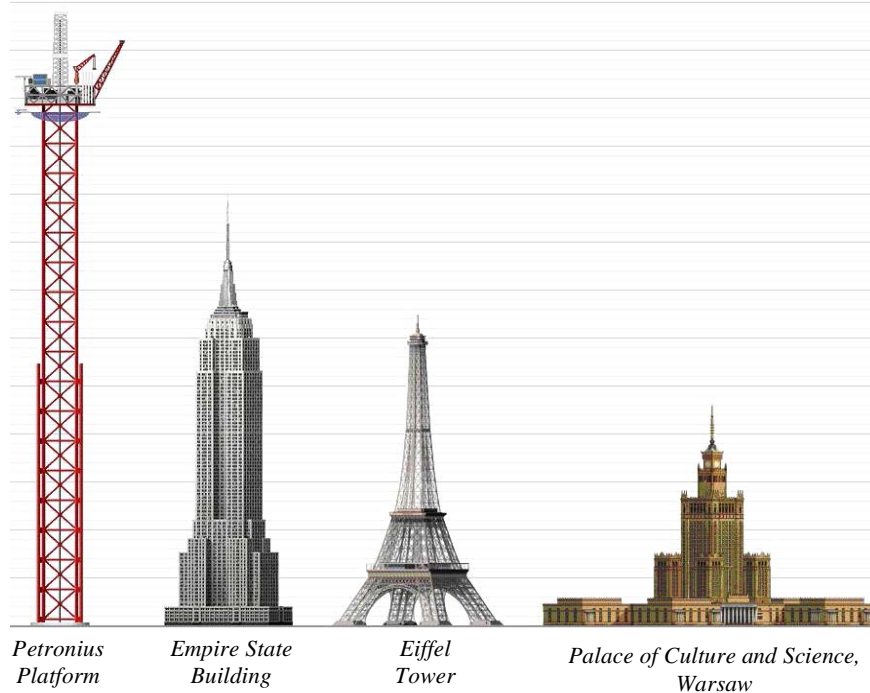


Fig. 1. The comparison of the Petronius Platform with well-known buildings

Except Petronius platform, the tallest off-shore oil rigs in the world (Figure 2) are Baldpate Platform, 579,1 m; Bullwinkle Platform, 529,1 m; Troll A Platform, 472 m; and Gullfaks C, 380 m, respectively.

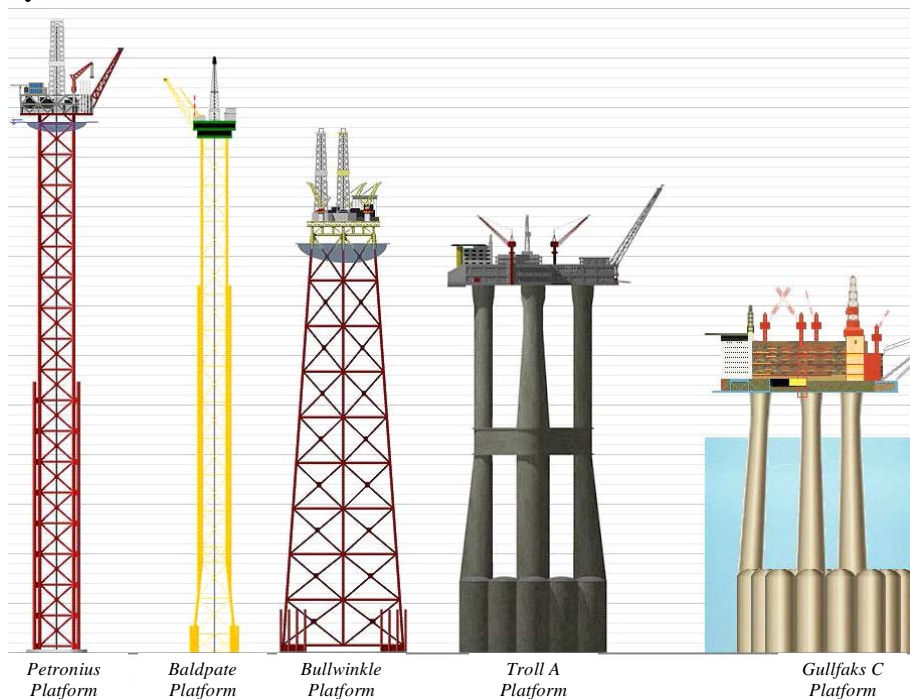


Fig. 2. The tallest offshore oil rigs

Power plants of offshore rigs should assure energy for different purposes, for example propulsion for mobile rigs, bit rotation for drilling rigs, oil and gas transportation for production rigs. This paper deals with issues concerned types of drilling and production systems supplied in

energy produced by offshore rig plants, various structures of offshore rigs and key problems appearing during their operation.

2. Structures of offshore oil and production units

Discovery of oil and natural gas fields under the sea bottom has forced the development of the special technologies for their operation and transportation. Offshore structures are large units used to house workers and machinery needed to drill and then produce oil and natural gas in the ocean. Their various structural design placed on these fields are intended to many purposes [3], such as for search and operation of oil-wells, for getting out oil and gas, for preliminary processing (for example for separation of water and gases from oil), for storage of the extracted oil and gas. The general classification of offshore structures according to the selected aspects is presented in Figure 3.

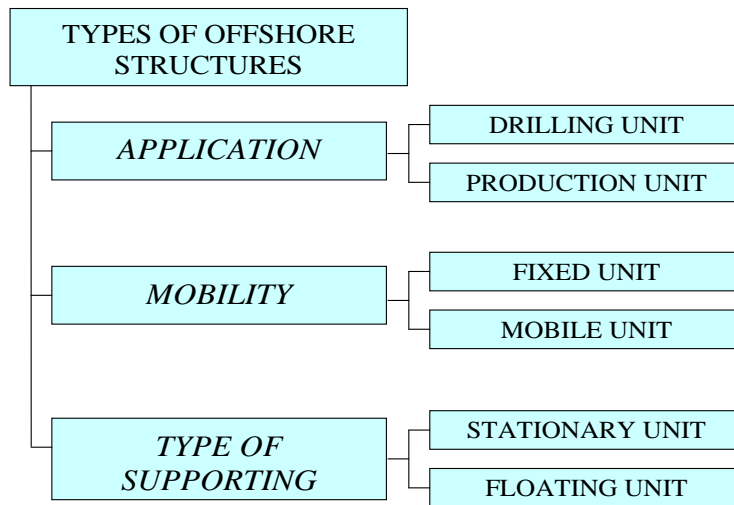


Fig. 3. General classification of offshore structures

According to application, the offshore structures may be used for drilling or for production of oil and/or natural gas, they can be fixed that cannot be moved from one place to another or mobile allowing for their dislocation.

Depending on the circumstances (Figure 4), these units may be attached to the ocean floor, consist of an artificial island (stationary units), or be floating (floating units).

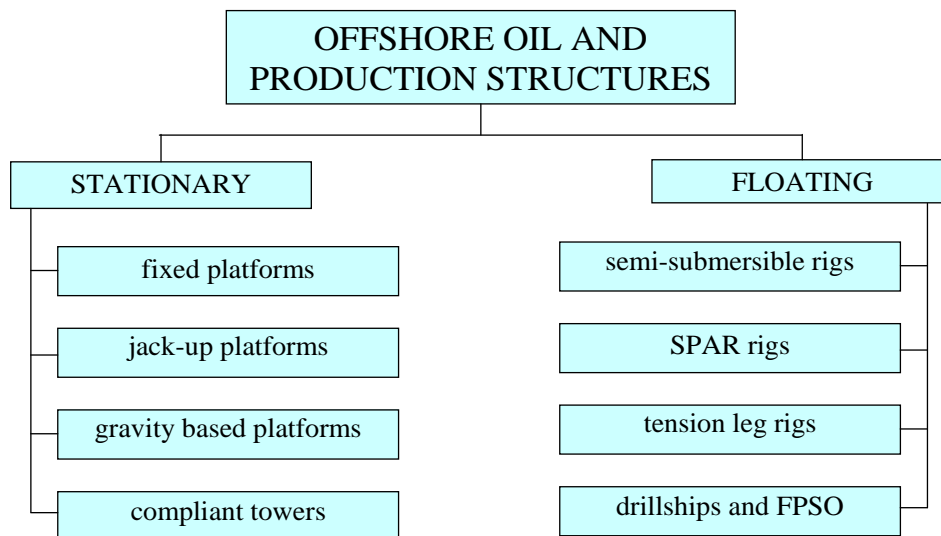
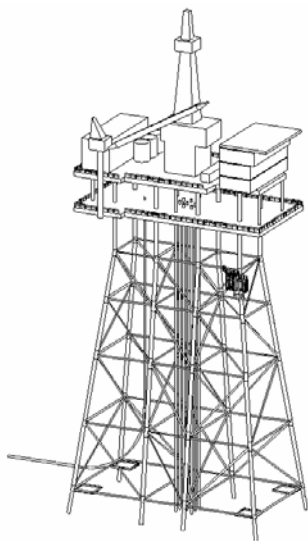


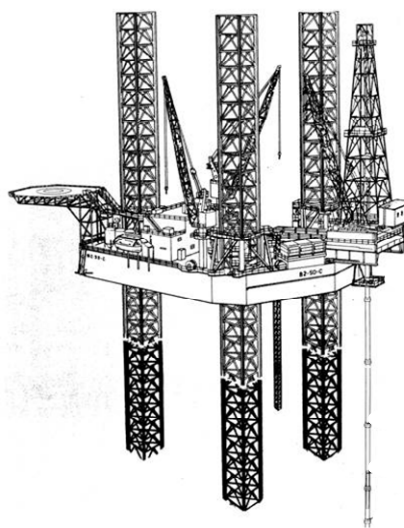
Fig. 4. Types of offshore units

In shallow waters, it is physically possible to fix an offshore structure to the sea floor. This is what is called stationary units. The advantages of stationary units are their good stability, as they are permanently fixed to the sea floor and there is no movement due to wind and water forces.

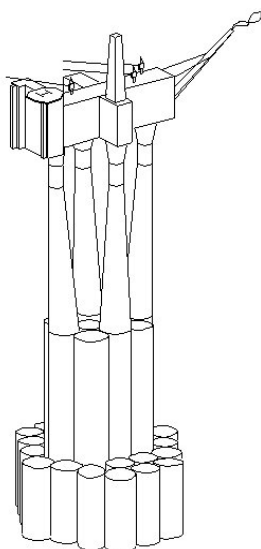
a)



b)



c)



d)



Fig. 5. Stationary offshore structures: a) fixed platform; b) jack-up platform; c) gravity based platform; d) compliant tower

A fixed platform (Figure 5a) is built on concrete and/or steel legs anchored directly onto the seabed, supporting a deck with space for drilling rigs, production facilities and crew quarters. Such platforms are designed for very long term use. Steel jackets are vertical sections made of tubular steel members, and are usually piled into the seabed.

A jack-up platform (Figure 5b), as the name suggests, is a platform that can be jacked up above the sea, thanks to legs which can be lowered like jacks. Its steel body is designed to float. These platforms, used in relatively low depths, are designed to move from place to place, and then anchor themselves by deploying the jack-like legs.

Another type of bottom-supported structure is a gravity based platform (Figure 5d), where its stability ensures its own weight. The substructure is usually built from concrete in deep, protected water near shore. Deck is usually built in one piece, brought on a barge or barges over to and then mated with almost completely submerged substructure. The completely assembled

platform is then towed to the installation site and ballasted down to seafloor. Because of this unique way of construction, geographical locations to which this type is applicable are limited. This type is inevitably massive and suitable for self-contained drilling and production role. Storage capability can be easily incorporated, making this type suitable for situations where pipeline transportation is not readily available.

An alternative of gravity based platform is a submersible rig (Figure 6) consists of upper and lower hulls connected by a network of posts or beams. The equipment and living quarters are installed on the upper hull deck. The lower hull has the buoyancy capacity to float and support the upper hull and equipment. When water is pumped into the lower hull, the rig submerges and rests on the seabed to provide a working place for the drilling. Movement and drilling operations proceed as that of the jack-up rig.

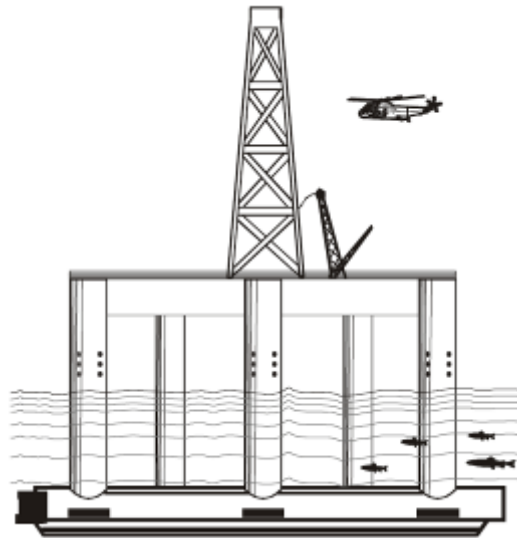


Fig. 6. Submersible rig

A compliant tower (Figure 5d) is constructed similar as a fixed platform. It consists of a narrow tower, mounted to a foundation on the seabed extended up to the platform. The offshore compliant tower is flexible, as opposed to the relatively rigid legs of a fixed platform. This structural flexibility allows it to operate in much deeper water, as the construction can take much of the loads exerted on it by the wind and waves. The compliant tower design is more flexible than conventional land structures to cope better with sea forces. It can deflect (sway) in excess of 2% of height. Most buildings are kept to within 0,5% of height in order to have occupants not feel uneasy during periods of movement. Despite its flexibility, the compliant tower is strong enough to withstand even hurricane conditions. In some cases, several guy wires and clumps weights can support the fixed and compliant towers.

Floating offshore units for oil and gas exploration float on pontoons or other buoyant chambers and can be moved to the exploration site. They can be towed by boats, and sometimes can have self-propelled capacity.

A semi-submersible rig has submerged pontoons (lower hulls) that are interconnected to the deck by vertical columns as shown in Figure 7. The lower hulls provide improved stability for the vessel. Also, the open area between the vertical columns of the semi-submersible rig provides a reduced area on which the environment can act. In drilling operations, the lower hulls are submerged in the water about half-length of the column, but do not rest on the seabed. When a semi-submersible rig moves to a new location, the lower hulls float on the sea surface.

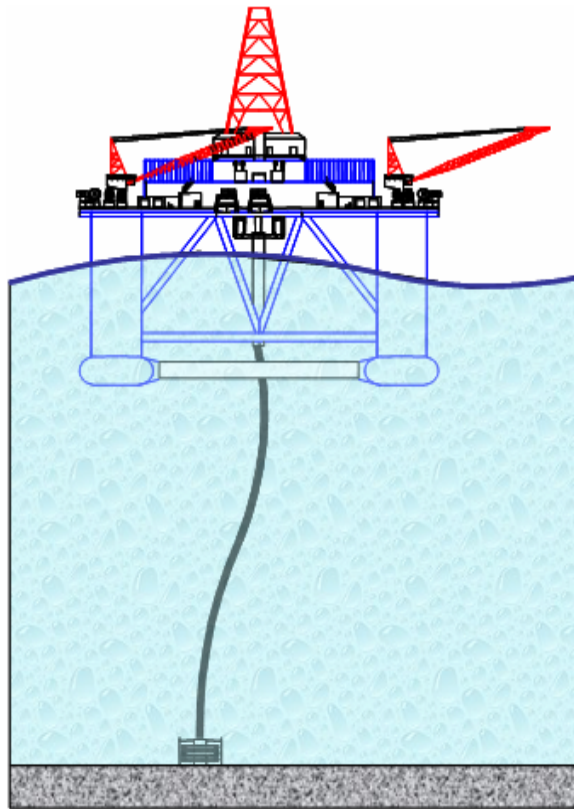


Fig. 7. Semi-submersible rig

A SPAR rig is among the largest offshore structures in use. These huge rigs consist of a large cylinder supporting a typical fixed rig platform (Figure 8a). The cylinder however does not extend all the way to the seafloor, but instead is tethered to the bottom by a series of cables and lines. The large cylinder serves to stabilize the platform in the water, and allows for movement to absorb the force of potential hurricanes.



Fig. 8. Floating offshore structures: a) SPAR rig; b) Tension Leg Platform (TLP)

One of the floating structures specifically developed for deepwater application is the Tension Leg Platform (TLP). It is essentially a semi-submersible rig attached to the seabed by vertical members called tendons, which are usually made of steel tubular and tensioned by excess buoyancy of the platform hull as shown in Figure 8b. Tendons are pinned to the seabed directly or indirectly by piles. Motion characteristics of the TLP allows wells to be completed on its deck, a big advantage because wells are one of the most important and expensive components of a petroleum production system and ease of access to them is a matter of prime concern in field development planning.

An alternative of the tension leg platforms are SEASTAR platforms. They are basically smaller tension leg platforms and consist of a floating rig, as for the semisubmersible drilling rigs. A lower hull is ballasted with water when drilling, which increases the stability of the platform movement from environmental loads. In addition to this semisubmersible rig type of features, SEASTAR platforms also incorporate the tension leg system found in larger platforms. SEASTAR platforms are typically used for smaller deepwater reservoirs, were it is not economical or practical to develop a larger platform.

A drillship (Figure 9) is the most mobile, self-sufficient and durable kind of the mobile exploratory rig, designed to drill in very deep water. Drillships contain all of the equipment and material needed to drill and complete the well. An opening called a moon pool is equipped in the center of the ship from the main deck to the water. Drilling assembly, a riser pipe, wellhead equipment, and so forth are lowered through the moon pool to the sea floor. They are easily moved by wind and waves, which puts excessive fatigue on the drilling equipment. The DPS is the most common technique used to combat excessive movement but is expensive to install and operate.

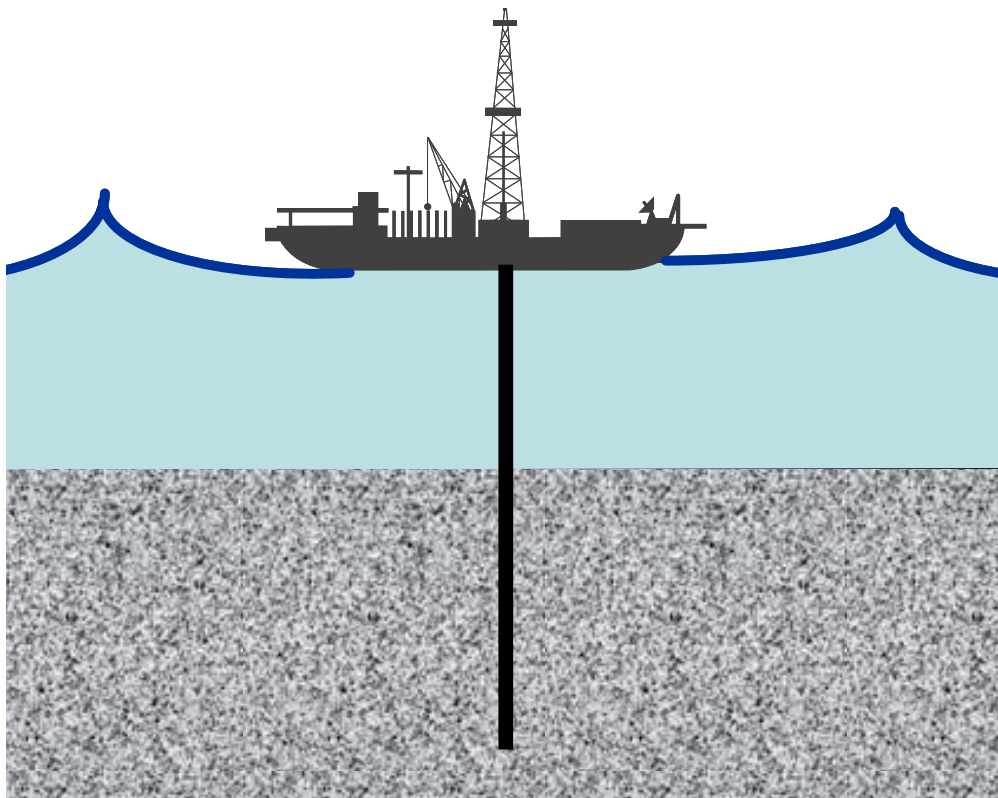


Fig. 9. Drillship

Floating Production Storage and Offloading (FPSO) units are essentially semi-submersible drilling rigs, except that they contain petroleum production equipment, as well as drilling equipment (Figure 10). Ships can also be used as floating production systems. The platforms can be kept in place through large, heavy anchors, or through the DPS used by drillships. With a

floating production system, once the drilling has been completed, the wellhead is actually attached to the seafloor, instead of up on the platform. The extracted petroleum is transported via risers from this wellhead to the production facilities on the semi-submersible platform.

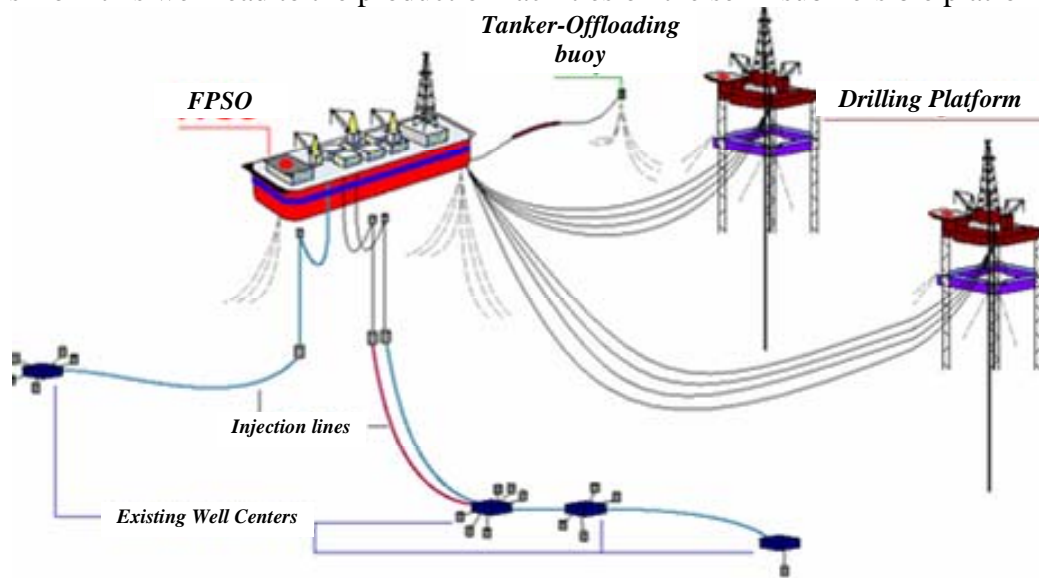


Fig. 10. Floating Production Storage and Offloading (FPSO) unit

To keep the position of semi-submersible rigs and drillships, DPS (acronym of **D**ynamic **P**ositioning **S**ystem) is used (Figure 11). In simple terms, a DP system consists of a central processor linked to a number of position reference and environment reference systems.

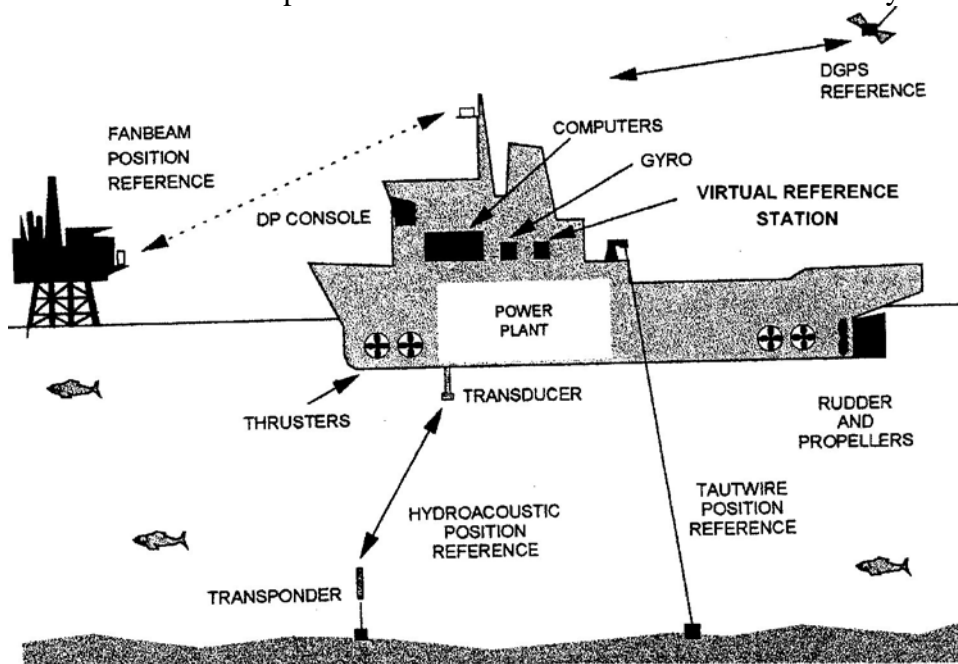


Fig. 11. Dynamic Positioning System

The semi-submersible rigs and drillships are provided with sufficient power and maneuverability by means of a variety of thrusters and propellers. The measured position of the vessel is compared to the desired or set point position, the computers then generate appropriate thruster commands to maintain or restore vessel position. Effects of wind forces and other environmental forces are taken into account. A bridge control console allows the operator to communicate with the system and vice versa, and vessel control to be effected. Often the only alternative positioning technique is the use of an anchor spread, but this is limited by depth of water. If this exceeds around 500m then cost, time and space considerations may preclude it.

Often the amount of hardware on the seabed renders it impossible to run anchors safely, if at all. The presence of anchor cables may prevent the vessel from positioning close to platform structures, and may also provide obstructions to other vessels.

3. Power take-off systems

Power plants of offshore drilling units can provide energy for various purposes, for example power supply of navigational devices, operation of rescue appliances, working of cranes and lifts, operation of mooring and anchoring, power supply for crew facilities. In some structural design of mobile units, their power plants supply of energy necessary for propulsion and steering.

Diesel engines compose the majority of power sources on offshore drilling units. Diesel engines drive large electric generators. The generators, in turn, produce electricity that is sent through cables to electric switch and control gear.

The following essential systems are supplied in energy produced by power plants of offshore drilling units:

- a hoisting system,
- a rotating system,
- a circulation system.

The hoisting system is used to raise and lower pipe in and out of the hole and to support the drill string to control the weight on the drill bit during drilling. The hoisting system consists of derrick, traveling and crown blocks, a drilling line, and drawworks. The derrick is a steel tower that is used to support the traveling and crown blocks and the drill string. The drawworks consists of a revolving drum around which the wire rope called drilling line is spooled or wrapped. The crown and traveling blocks are a set of pulleys that raise and lower the drill string.

The rotary system includes all the equipment used to achieve bit rotation. The main parts of the rotary system are: a swivel, a kelly, a rotary drive, a rotary table, a drill pipe, and drill collars.

The swivel supports the weight of the drill string and permits rotation. The swivel is attached to the bottom of the traveling block and permits the drill string to rotate. The kelly is the first section of pipe below the swivel. The outside cross section of the kelly is square or hexagonal to permit it to be gripped easily for turning. Torque is transmitted to the kelly through kelly bushings, which fit inside the master bushing of the rotary table (Figure 12). A kelly saver sub is used between the kelly and the first joint of drill pipe. As the rotary table turns the kelly is also turned. The movement of the kelly rotates the drill string and the drill bit. The major portion of the drill string is composed of drill pipe. Drill pipe is round steel tubes. The lower section of the rotary drill string is composed of drill collars. The drill collars are thick-walled heavy steel tubulars used to apply weight to the bit and prevent buckling of the drillpipes. The process of drilling a hole in the ground requires the use of drilling bits. Drill bits set up the drill end that actually cuts up the rock. They come in many shapes and materials (tungsten carbide steel, diamond) that are specialized for various drilling tasks and rock formations. Rotary drilling bits usually are classified according to their design as:

- drag bits: fixed cutter blades, rotate as a unit with the drill string.
- rolling cutter bits: usually three cones that are free to turn as bit rotates.

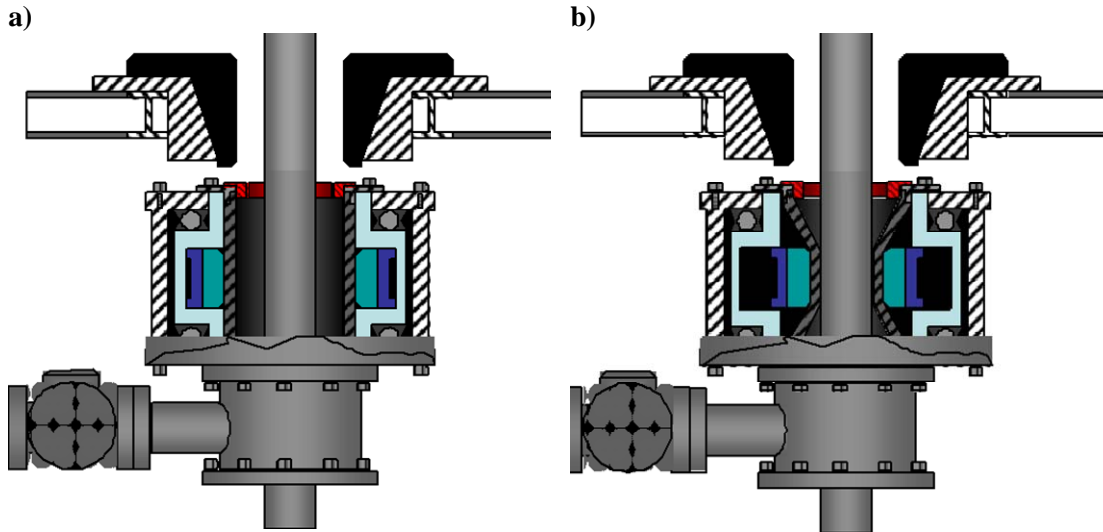


Fig. 12. Kelly and kelly bushings of rotating head: a) with-out torque transmission; b) with torque transmission

The circulating system replaces drilling fluid. The drilling fluid is most commonly a suspension of clay and other materials in water and is called drilling mud. Drilling mud removes cuttings from the hole and cools and lubricates the drilling bit. The principal components of the circulating system include:

- mud pumps and mud pits,
- mud-mixing equipment,
- contaminant-removal equipment.

The drilling mud travels through the following elements: steel tanks, a mud pump, a drill string, a bit, annular space between the drill string and hole to the surface, contaminant-removal equipment, and back to the suction tank.

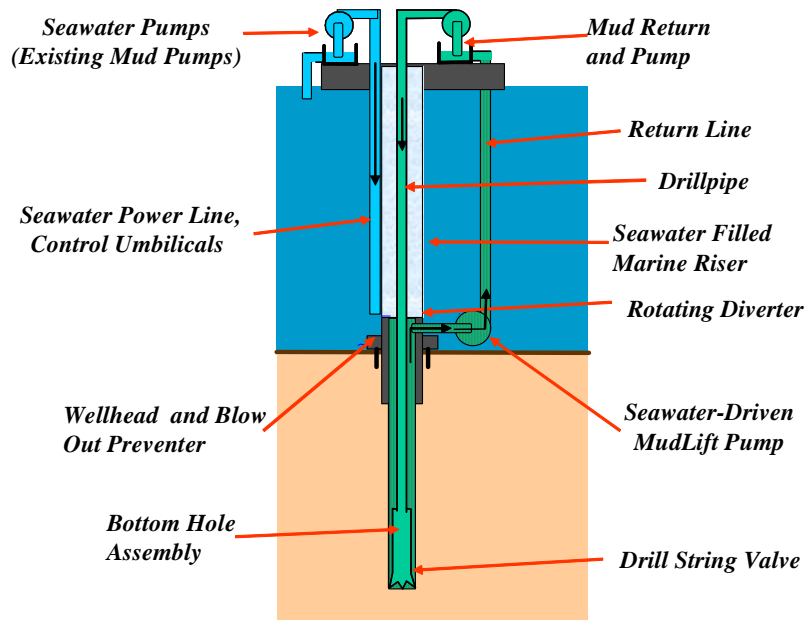


Fig. 13. Subsea mudlift configuration

Subsea mudlift configuration is presented in Figure 13. The mud pump takes in mud from the mud pits and sends it out a discharge line to a standpipe. The standpipe is a steel pipe mounted vertically on one leg of the mast or derrick. The mud is pumped up the standpipe and into a flexible, very strong, reinforced rubber hose called the rotary hose or kelly hose. The rotary hose is connected to the swivel. The mud enters the swivel, goes down the kelly, drill

pipe and drill collars and the bit. It then does a sharp U-turn and heads back up the hole in the annulus. Finally the mud leaves the hole through a steel pipe called the mud return line and falls over a vibrating, screen like device called the shale shaker. Agitators installed on the mud pits help maintain a uniform mixture of liquids and solids in the mud. If any fine silt or sand is being drilled, then devices called desilters or desanders may be added. If there are small amounts of gas in the formation, a device called degasser is also added.

For example, main problems of 3 000 meters deep drilling are the following:

- the typical riser with 533 mm diameter has an internal capacity about 650 m³,
- weight of the riser itself is about 900 ton,
- weight of mud inside the riser is about 1 200 ton,
- away from tectonic plate boundaries, the geothermal gradient is 25-30°C per km of depth.

According to the technical specification description of the semisubmersible rig LEIV EIRIKSSON (Figure 14), its machinery guarantees the following operating parameters [1]:

- water depth of drilling - 2300 meters,
- transit speed - 7 knots.

The rig machinery consists of:

- 6 x Wartsila Vasa 18V32 diesel engines, rated 7500 kW each,
- 6 x ABB ASG 900 XUB generators, rated 7300 kW each,
- 6 x KaMeWa Aquamaster UUC 7001 fixed pitch variable speed thrusters, rated 5 500 kW each, 157 rpm, 4,09 m diameter.



Fig. 14. Semisubmersible rig LEIV EIRIKSSON [1]

Moreover, this rig is equipped in the following drilling equipment:

- derrick: Hydralift 51,8 x 12,2 x 12,2 m; 680 tons,
- motion compensators: Hydralift Crown rating 680 tons, compensating: 362,9 tons; 7,62 m stroke,
- drawworks: Continental Emsco Electrohoist III, 2206,2 kW,
- rotary: Varco BJ RSTT, 984,2 tons,
- top drive: Hydralift HPS 750 2E ac electric drive, 680 tons; speed: 0 - 280 rpm,
- riser tensioners: 6 x Hydralift double, 90,7 tons each;
- mud pumps: 3 x Continental Emsco FC-2200, 1617,9 kW, 51,7 MPa.

The ultra-deep water drillship (Figure 15) new developed by OCEAN RIG should ensure the following operating parameters [2]:

- water depth of drilling - 3048 meters,

- transit speed - 12 knots.

The drillship machinery consists of:

- 6 x STX_B&W 16V32 diesel engines, rated 8000 kW each,
- 6 x ABB AMG 900 XU10 LSE generators, rated 7000 kW each,
- 6 x Rolls Royce AQM UUC455 fixed pitch variable speed under water demountable azimuth thrusters, rated 5 500 kW each.



Fig. 15. Ultra-deep water drillship [2]

The ultra-deep water drillship is equipped in the following drilling equipment:

- derrick: NOV 61 x 18,3 x 24, 4 m; 1200 tons,
- motion compensators: NOV AHC, rating 907 tons, compensating: 454 tons; 7,62 m stroke,
- drawworks: NOV SSGD, 4228,5 kW,
- rotary: NOV VBJ RTS hydraulic operated, static 6,4 tons,
- top drive: NOV HPS, 6,4 tons; speed: 0 - 300 rpm,
- riser tensioners: 6 x NOV DWRT, 544,3 tons each,
- mud pumps: 5 x NOV 14 P-220, 1617,9 kW, 51,7 MPa.

4. Conclusion

The growing demand for subsea energy resources forces developing the various structural designs of offshore units destined for oil and gas exploration. Their more and more complicated power plants have to produce energy necessary for power supply of all drilling and production systems.

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