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Permanent versus disconnectable FPSOs

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Abstract: Floating production storage and offloading (FPSO) vessels offer a cost-effective field development solution, especially in deepwater areas lacking an adequate pipeline network. Most FPSOs are permanently moored, i.e. the complete system is designed to withstand any kind of extreme environment at the field location. FPSOs that can be quickly disconnected from their moorings and risers have also been designed and deployed. The key feature of this type of disconnectable FPSO is that it can be disconnect and so avoid dangerous environmental conditions such as icebergs, hurricanes in the Gulf of Mexico and typhoons in the South China Sea. In this paper, the concept of disconnectable FPSOs for deepwater field development is presented. Key technologies and their engineering analyses are highlighted. The merits and demerits of disconnectable vs permanent FPSOs are then evaluated. The paper concludes that both permanent and disconnectable FPSOs are versatile floating systems and their selection depends on safety, technological, cost and operational considerations.
Keywords: disconnectable FPSO; permanent FPSO; deepwater; mooring system
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1 Introduction

From its humble beginning as a mobile well testing/production unit, the FPSO has evolved to dominate today's floating production systems (FPS) landscape. There are over 100 FPSOs in service in almost every major oil-producing region in the world, exceeding the total number of all other floating production systems combined.

Over the years, the FPSO[1] has proven itself as a versatile production system. The FPSOs currently in operation cover a wide arrange of environment conditions, vessel sizes, production rates, operating water depths and number of risers

FPSOs have been deployed in benign environment such as Offshore West of Africa[2] and in extreme hostile environment such as North Atlantic Margin; FPSOs operate in water depths ranging from 20 meters (Chang Qing Hao) in South China Sea to 1 853 meters (Seillean) Offshore Brazil. The vessel size varies with storage capacities ranging from a mere 50 000 bbl to 2 000 000 bbl (barrel). The maximum production rates range from 11 000 bbl/d to 200 000 bbl/d (barrel/day).

Studies have shown that the FPSO has cost advantages over other floating production systems for a wide range of water depths.

The majorities of the FPSOs deployed worldwide are permanently moored, i.e. the FPSOs with their moorings and riser systems are capable of withstanding the extreme storms at the field location. On the other hand, the disconnectable FPSOs have attracted more attention recently. The damage to the offshore units and pipeline systems caused by hurricanes Ivan, Katrina, and Rita in the year 2005, plus the continuing exploration success in the ultra deep water beyond the continental shelf, are two of the main drivers.

Fig.1 Turret moored permanent FPSO

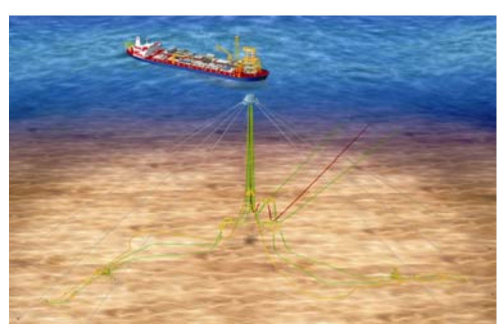

Fig.2 Turret moored disconnectable FPSO

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2 Why disconnectable

There are a number of drivers for a disconnectable FPSO[3].

1) Environmental and regulatory requirements.
Sometimes the regulatory body determines the FPSO has to be disconnectable. A typical example is for application in the US GOM. There are hundreds of offshore platforms in the vicinity and in case of hurricane, a drifting platform can potentially clash with the FPSO that has a large amount of crude storage.

2) Special design constraints.
A number of disconnectable FPSOs have been deployed in east coast of offshore Canada. The main drive is to avoid large icebergs. The only measure to survive an iceberg impact is to disconnect the FPSO and sail away. Also for a location with extremely severe storms that prohibit the safe design of mooring systems.

3) Cost trade off.
Sometimes, the disconnectable FPSO allows the reduction of the size/cost of moorings and risers because they only need to be designed against a less severe storm.

4) Operating considerations.
Due to operating consideration for example, if the FPSO is for early production/well tests, it is required to be highly mobile. When the early production is on-going, the permanent FPSO is being built. The temporary FPSO can disconnect to move to another location and the permanent FPSO can be connected to continue production.

3 Disconnectable FPSO

The disconnectable FPSO is typically turret moored and the disconnection of the FPSO with its moorings and risers is achieved through the specially designed disconnectable turret.

The primary function of the turret is to allow the FPSO to weather-vane without disrupting the transfer of production fluid between the FPSO and subsea wells. Turret types may be external or internal. External turrets are typically cantilevered off the bow or stern of the vessel. Internal turrets penetrate the body of the vessel between the bow and midship. For the deepwater application, this is considered to be the most suitable option as it integrates with the hull structure and capable of supporting large vertical mooring and riser loads.

Disconnectable turret is designed for FPSO to be able to disconnect to avoid certain extreme environments. The lower part of the turret (lower turret buoy) which connects the mooring lines and risers can be disconnected to allow the FPSO to sail away prior to the approaching of the storm, see Fig.3. After disconnection, the lower turret with anchoring legs and riser terminations sinks to 50~100 m below the water surface and thus clears off the wave zone. When the extreme environment passes, the FPSO can come back and pick the submerged mooring/riser buoy to get it reconnected.

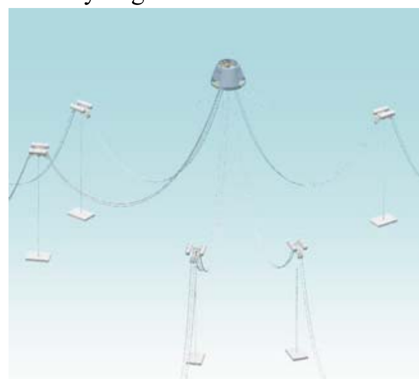

Fig.3 Moorings and risers with lower turret buoy

There are a number of diconnectable turret designs. Two commonly used types are BTM for internal turret type and RTM for external turret type as illustrated by Fig.4.

Fig.4 Buoy turret mooring (BTM) for internal turret

The general procedures to connect and disconnect an FPSO are as follows:

1) Turret buoy disconnection procedure:
Start marine systems;
Stop production;
Prepare risers for disconnection;
Disconnect risers;
Lower risers onto the buoy;
Disconnect structural connector;
Drop the low turret mooring buoy below surface;
Sail away;
Approximate time: 18 hours.

2) Turret buoy reconnection procedure:
Position FPSO in reconnection watch circle;
Retrieve hook-up line to pick reconnection chain;
Engage chain jack.

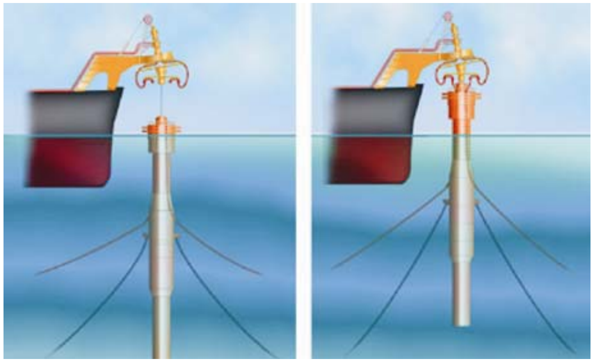

Fig.5 Riser turret mooring (RTM) for external turret

Lift mooring buoy into the turret (rotate turret for correct orientation):
Engage structural connector;
Retrieve risers from buoy;
Connect risers;
Approximate time: 24 hours.

The disconnectable FPSO offers the following attractive features.
1) The environmental hazard is minimized because the platform with crude storage can be disconnected and go to shielded area in the event of severe storm.

2) The lower turret with moorings and riser connections goes below the wave zone and is not significantly impacted by the storm.

3) The mooring system (and its associated turret components) can be of smaller size as it only needs to be designed against the less severe storm when the FPSO stay connected.

4) It safeguards against platform damage and liability to the operator in the storm event.

4 Key technologies

If we compare the disconnectable FPSO with conventional permanently moored FPSO, it is not difficult to notice that the FPSO hull and topsides are identical among the two. The key technologies therefore reside with the turret, moorings and risers.

1) Turret.
Turret itself is the key technology of an FPSO. It allows the FPSO to weather vane and in this case, it allows the FPSO to disconnect with its moorings and risers via a disconnectable low turret buoy.

Prior to the disconnection of the lower turret buoy, the risers are to be disconnected first. They can be done through the quick disconnectable valves (QC/DC valves) or manual valves. The QC/DC valves allow the disconnection to realize in a short time span, while the manual valves takes much more time to operate, see Fig.6.

Fig.6 Hydraulically operated riser QC/DC valves

Disconnection of the lower turret buoy is achieved through a specially designed structural connector, see Fig.7. The key feature is that the connector can be hydraulically actuated under large loads.

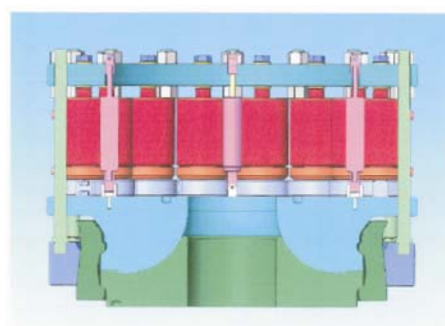

Fig.7 Structural connector

2) State of the art mooring design.
In a disconnectable FPSO, the mooring (and the riser) system is specially designed and fine tuned by many iteration procedures. The main consideration is that as the lower turret buoy is disconnected, it submerges under the vertical load of the moorings and risers to a depth where the equilibrium of buoy buoyancy and mooring riser vertical load is reached. This equilibrium depth is well controlled to be around 50 m to 100 m below the surface. If it’s too close to the surface, the buoy can be impacted

by the surface waves, and if it's too deep, the structural design of the buoy is a challenge, see Fig.8.

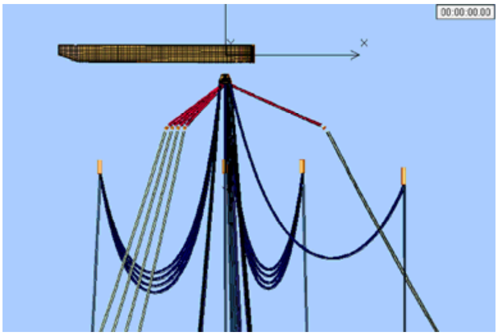

Fig.8 Disconnected lower turret buoy at equilibrium

3) Lower turret buoy design.
The design of the lower turret buoy is also challenging. In deep water, the vertical loads of the moorings and risers are very large and in order to support the large vertical load in the disconnected status, the net buoyancy of the buoy can also be large. A large buoy faces many problems of handling and also during the re-connection stage, large re-connection load can be expected. During the design, it is very important to minimize the buoy size/weight and to optimize its shape to minimize the hydrodynamic drag and added mass.

4) Riser design.
The riser system probably represents the most challenging task to any deepwater FPSO design. Flexible risers have been installed successfully in deepwater fields in offshore Brazil. However, as the water depth increases, the available riser diameters for non-banded flexible risers reduce significantly and as a result, more risers are required to fulfill the same production function.

Steel catenary risers (SCRs)[4] would be the preferred deep water riser solution due to its high resistance to hydrostatic load and relatively low cost. However, FPSOs will experience large motion responses under the wave environment. The large motion can cause excessive fatigue damage that could make the free hanging simple SCR concept not feasible.

For disconnectable FPSO, the riser design has special constraints as it has to cope with both connected and disconnected status. Plus it is vital to reduce the riser vertical load acting on the lower turret buoy. SLOR type of riser design has been proposed to achieve the riser stability and to reduce the vertical load on the lower turret buoy, see Fig.9.

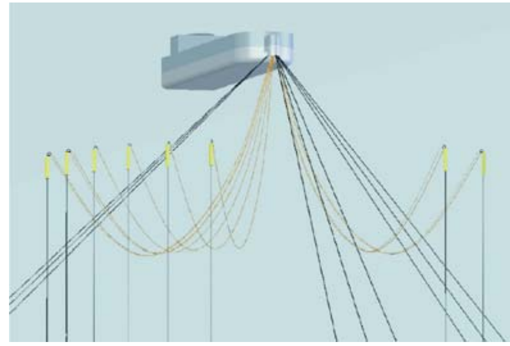

Fig.9 SLOR risers

5 Engineering analysis and design

The engineering analysis of a disconnectable FPSO is much more challenging than that of a permanently moored FPSO.

1) Mooring design.
The mooring system design has to consider both the connected mode and disconnected mode. Especially, the mooring system is fine tuned to control the dropped depth of the lower turret buoy. In both cases, the designer has to watch for the change of mooring profile and possible touching of seabed by wire rope or polyester deployed.

2) Disconnection analysis.
In the disconnection analysis, engineering analysis is to be conducted to simulate the dropping trajectory of the lower turret buoy to make sure there is no clash between the moving FPSO and the dropping buoy.

3) Disconnected analysis.
When the lower turret buoy is disconnected from the FPSO, it will submerge below the wave zone. However, the complete system still subject to current load and engineering analysis is to be conducted to make sure it's hydrostatically and hydrodynamically stable.

4) Re-connection analysis.
Re-connection analysis is usually conducted to confirm that the reconnection process is feasible. When the lower turret buoy is pulled into the vessel moonpool and close to the FPSO keel, there are significant hydrodynamic interactions between the tow bodies and the pulling tension can be very high. Advanced engineering analysis would be required to optimize the re-connection process.

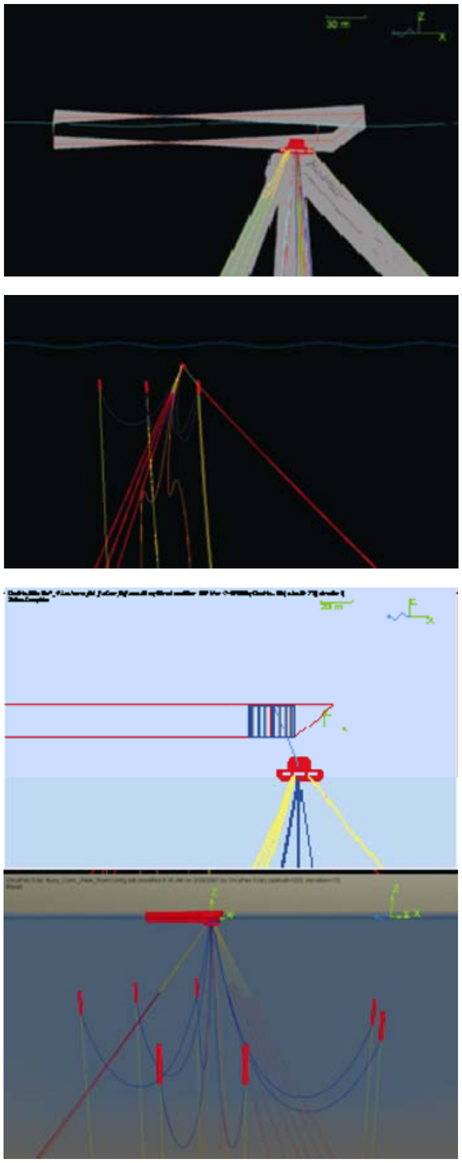

Fig.10 Challenging engineering analysis

6 Comparisons of disconnectable and permanently moored FPSOs

The comparisons of disconnectable and permanent FPSOs should be conducted from safety, cost and operation viewpoints.

1) Safety
The disconnectable FPSO is widely perceived to have a better safety standard. The main reason is that the FPSO can effectively avoid the storm by disconnecting from its moorings and risers. The onboard crude storage is moved offsite away from the extreme environment.

In addition, the disconnected mooring lines and risers stay with the lower turret buoy which submerges below the wave zone (50~100 m below the surface), so the complete system is very stable.

In the environment that subjects to icebergs, this is probably the only solution to survival.

2) Costs
In terms of cost, the turret system of a disconnectable FPSO is quite more complex than that of a permanent FPSO. The riser disconnectable valves and the main structural connector are all costly items. The lower turret buoy is also heavier because it's designed to withstand high hydrostatic pressure during the disconnected submerged mode. In addition, the installation procedures are more complex and more onboard equipment would be required for the disconnectable system.

The cost of a disconnectable turret can easily double that of a non-disconnectable turret.

On the other hand, the mooring system of a disconnectable FPSO can reduce in size substantially depending on the disconnection environment. For example, the mooring system of a permanent FPSO has to be designed against the 100 year hurricane environment in the GOM which has a significant wave height of 14 m while the counterpart moorings of a disconnectable FPSO only need to be designed against the 100 year return wind storm which has a significant wave height of 8 m. The mooring system weight and cost of the disconnectable system is probable less than half of the permanent system.

Even though it's a trade off between the turret cost and mooring cost, it is expected that the overall cost of a disconnectable system will still be higher.

3) Operations
In general, operating a disconnectable FPSO is more challenging than that of a permanent FPSO. The connection and disconnection mechanical components are to be maintained on regular basis, and when it comes to disconnection, extra care should be exercised to avoid damaging any components.

Adjustments of installed mooring lines and risers are much more difficult as they are only connected to the lower turret buoy. This in many cases prevents the use of polyester mooring lines in a disconnected system because polyester lines need regular maintenance due to mooring line creep.

4) Green water
There is another aspect of the FPSO operation in which the disconnectable system has an advantage. For green

water effect, the disconnectable FPSO only experiences smaller design environment when the FPSO is connected. For extreme tropical storms, the FPSO is disconnected and away from the storm location. A permanent FPSO has to withstand the extreme storm and experience the worst green water impact. A study has shown that even though the mooring system is capable of withstand the storm impact, the tropical storm such as the hurricane in the GOM can quickly change the wind direction in its eye. As the change of wave direction takes much longer time, the FPSO may potentially weather vane to the direction of the changing wind and expose the beam to waves. In such a case, the green water impact is much more significant and the topsides foundation should be reinforced to survive such an impact.

7 Concluding remarks

The present presentation outlines the disconnectable FPSO concept. The design features of the disconnectable turret are highlighted and the study concludes that the large size disconnectable FPSO can be successfully developed for application in deepwater areas that are subject to severe storms. The system saves mooring cost and enhances the safety features of the floating structure.

With a complex turret system and operation wise, the disconnectable FPSO is more challenging. The overall cost of a disconnectable FPSO is also expected to be higher.

Both permanent and disconnected FPSOs are versatile floating system concepts that have been deployed in many deepwater areas worldwide. The selection of the system depends on technology, safety, regulatory, cost and operation considerations.

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永久式与可解脱式 FPSO

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摘 要：浮式生产储卸油系统(FPSO)是一种经济有效的浮式平台方案，特别是在缺乏足够的输油管道系统的深海领域. 大多数 FPSO 是永久系泊的，即整个系统能够抵抗工作海域内的各种极值环境条件. 目前，能够将 FPSO 与其系泊及立管系统快速解脱的装置已经设计并发展了. 可解脱式 FPSO 的主要特点是可解脱性，并能避免一定的环境条件，如冰山，美国摩西哥湾的飓风，中国南海的台风. 本文将针对深水海域可解脱式 FPSO，提出其主要技术和工程分析与设计思路，评估可解脱式 FPSO 与永久式 FPSO 的优缺点，等等. 可见可解脱式 FPSO 与永久式 FPSO 都是十分有效的浮式系统，并根据平台设计的安全性、技术、成本和运行要求，来决定选择何种系泊方式.

关键词：可解脱式 FPSO；永久式 FPSO；深海；系泊系统