DESIGN & CONSTRUCTION OF A DISCONNECTABLE TURRET MOORING FOR A FSO IN SOUTH CHINA SEA

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ABSTRACT

One of the most important improvements in Single Point Mooring (SPM) technology in recent years is the development of a reliable disconnectable mooring capable of releasing during extreme sea conditions. The FSO/FPSO vessel is capable of disconnecting from its mooring when a major storm approaches and sailing out of the area. The vessel can then return, re-connect itself and resume production operations following the storm passage.

The concept is especially attractive in offshore areas of the world subjected to severe seasonal cyclonic weather systems but with characteristically mild environments throughout the remainder of the year. This disconnectable turret permits the mooring lines and the load bearing structural components to be designed for forces well below those that would be imposed by the 100 year cyclone. Hence, for many projects the mooring system cost (and the offshore installation cost) will be substantially reduced even though the disconnectable turret hardware is more complex than that for a permanent turret mooring. Additional savings will also be realized via reduced cost for structural modifications to the FSO/FPSO vessel including less strengthening in the turret well and lighter foundations for deck mounted process equipment than would be required were the vessel to remain on station and be subjected to typhoon conditions that could produce green water across the vessel deck.

This paper presents a summary description of the basis for design, construction and installation of a disconnectable turret mooring for an FSO vessel which will be installed in the "typhoon alley" area southeast of Hong Kong in Summer 1993.

The disconnectable turret provides an economical mooring for FSO/FPSO vessels in areas of the world such as Australia's Northwest Shelf, the Timor Sea, the South China Sea offshore the People's Republic of China and possibly the Gulf of Mexico. This sophisticated technology opens up the potential for the development of marginal offshore fields that would be uneconomical using conventional (permanent) SPM systems.

INTRODUCTION

The first turret moorings in the offshore industry were used on the "Discoverer" class drillships developed in the late 1960's by The Offshore Company. This background of experience combined with Single Point Mooring technology has led to the use of turret moored vessels for offshore production and storage applications.

Permanent mooring systems for floating storage and offloading (FSO) and floating production, storage and offloading (FPSO) vessels have been in use since the mid 1970's. These systems were designed for the 100 year storm conditions and have been employed in a wide variety of environments including the North Sea[1,2] and Australia's Northwest Shelf[3]. Two SPM's located at Shell Expro's "FULMAR" field and BHP's "CHALLIS" field respectfully are based on the articulated SALM-YOKE technology which provides a very functional but expensive solution. Turret mooring systems are now considered to offer an attractive alternate solution as evidenced by Shell Expro's decision to replace the "FULMAR" system with an internally mounted permanent system in 1995.

SALM-YOKE, SALS, CALM-YOKE and Fixed Towers (with a Cantilevered "Soft" Yoke) type SPM's are presently employed for FSO and FPSO applications in numerous locations worldwide but primarily in mild to moderate environments.

Turret moorings for floating storage/production applications were installed in the mid-1980's and quickly gained acceptance. These designs were mounted directly to the tanker structure and located either outboard of the tanker's lines or inboard usually on or immediately aft of the forecastle.

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Turrets eliminate the mooring buoy, hinges and articulated joints generally associated with other types of permanent tanker mooring systems and provide an economical station-keeping method for floating storage and production applications.

While economics undoubtedly played an important role in the acceptance of turret moorings for FSO/FPSO projects, the development of rugged and reliable hoses and flexible pipe for risers was certainly an important consideration. Turret moorings have virtually supplanted all other types of SPM designs for ongoing and future floating production and storage projects except in very shallow water where the fixed tower-yoke combination probably remains the optimum choice.

The first disconnectable turret was developed in the mid-1980's for the "JABIRU"[4] field in the Timor Sea between Australia and Indonesia, an area frequented by severe cyclones during part of the year. The decision to utilize a disconnectable system was driven by project economics after it was determined that a permanent system which was technically feasible and relatively straightforward to design was far more expensive that the lighter, more complex disconnectable design. Subsequent oil discoveries in Timor Sea and Northwest Shelf areas offshore Western Australia[5] and in the "typhoon alley" area offshore mainland China have generated an increased interest in disconnectable SPM's which provide an elegant solution and allow economical production from these fields.

GENERAL DESCRIPTION

The disconnectable turret system described herein is shown in Figure 1. This design is characterized by a large buoy (spider buoy) located beneath the keel of the vessel. When disconnected, the spider buoy submerges to a pre-determined depth about 35-40 meters below the surface where it stabilizes while supporting the mooring lines and the risers. Disconnectable systems are designed for a much lower environmental return period than permanent mooring-type SPM's because the vessel does not remain moored in extreme seas. When the warning for the imminent approach of a typhoon is given, the vessel disconnects the riser(s) and releases the spider buoy and sails to safe waters. After the storm passes, the vessel returns to site, recovers the floating retrieval line, re-connects and begins production operations.

The disconnectable turret mooring described herein is designed to moor a 128,000 DWT FSO vessel in 142 meters water depth. The FSO site is approximately 120 miles southeast of Hong Kong in the Lufeng 13-1 concession offshore the People's Republic of China. This area is subjected to frequent severe typhoons typically 4-6 each year. The field development scheme utilizes a fixed production platform which supports all the processing facilities and the downhole pumps required for producing the wells.

The characteristic restoring force for the disconnectable turret is developed by a symmetrical 8-leg composite wire-chain mooring system with high capacity drag embedment anchors. Fundamental to the design of the mooring legs is an evaluation of key parameters as follows:

- Mooring loads and excursions with FSO vessel connected.
- Survival loads with spider buoy submerged and FSO vessel disconnected.
- Forces to retrieve the spider buoy for re-connection of FSO vessel.
- Available installation techniques for spider buoy and anchor leg system.

Iterative design procedures are required to achieve an optimized design and model testing of the final configuration, especially the re-connection, is a necessity.

The elevation shown in Figure 2 illustrates several key features of the turret system:

- Location - Selected to provide optimal mooring system design, minimize retrieval forces, facilitate connection to the tanker and be compatible with marine operations of the tanker when underway.

- Deck Mounted Main Bearing - This arrangement permits the main roller bearing to be located above the main deck and minimize overturning moment by having a flexible mount under the bearing to reduce any moment that might be induced due to elastic deflections in the turret and deck structure.

- Connector Tensioner - The connection between the turret and the disconnectable spider buoy is achieved by a Cameron collet connector. The collet connector is mounted in series with a hydraulic tensioner which preloads the connector and the mating structure. Thus, all moments are transferred through surfaces preloaded in compression at the o.d. of the turret shaft and its interface with the spider buoy.

- Mooring Winch Location - The mooring winch is located on the turret to avoid retrieval line entanglement during re-connection operations.

- Riser Connection - The riser termination is located on the winch deck 10 meters above the main deck level. The piping is fitted with special connectors that may be easily disconnected and reconnected. When disconnected the riser is lowered by means of its handling winch into a receptacle in the spider buoy.

MAJOR DESIGN CONSIDERATIONS[6]

The design matrix for a disconnectable turret mooring includes numerous key items. Multiple design iterations are normally required to achieve an optimized mooring system where a change in one variable affects other aspects of the system.

Water Depth - Water depth is a major factor in determining the make up of the mooring legs (chain, wire or a combination of chain and wire). This in turn determines the amount of buoyancy required to hold up the detached mooring system and whether or not the buoyancy will be concentrated in a single module or if additional buoyancy will be necessary as distributed units attached to the mooring legs. Due to the impact on installation costs, use of distributed buoyancy is to be avoided if possible.

Connected Environment (Vessel Moored) - For a given size vessel and load condition, the performance and sizing of the mooring system is controlled by the forces acting on the vessel due to the maximum connected environment. The combination of wind, waves, and current, both in-line and crossed, determine maximum system motions and forces. System forces determine the size and strength of the mooring legs and turret structure. Maximum system motions determine, in part, the configuration of the flow lines (riser system). Interference between the mooring legs and the riser system must be addressed.

Disconnected Environment (No Vessel Moored) - When disconnected, the mooring system descends to a depth of between 35 and 40 meters. The exact depth is a trade off determined by the amount of weight (mooring legs, risers and buoyancy module construction) that the unit must support, the restoring force characteristics (both horizontal and vertical) of the detached system; and the severity of the survival storm. Mooring leg forces are generally of low order, however, motions of the spider buoy are an influence in design of the riser system. Damaged cases (anchor leg damage or buoyancy loss) must also be analyzed in order to determine maximum excursions and, more importantly, the maximum head for which the buoyancy unit must be designed.

Soil Conditions - The condition of the sea floor determines the type of anchoring required (piles or drag anchors) and the accuracy to which the anchor point can actually be set to avoid the need for further adjustments during anchor leg installation. For accuracy of placement, piles are preferred. However, cost and available installation equipment may dictate use of drag anchors in many cases.

Anchor Leg Configuration - Optimization of the anchor legs is the most significant factor in achieving an efficient disconnectable turret mooring. This element must have adequate strength and safety factors to satisfy code requirements in addition to having a spring constant that will be compatible with the system motions while not adversely affecting the loads. The anchor leg configuration will also have a significant effect on the installation costs and the necessity of set point accuracy for the anchors or piles.

Lifting Force For Re-connection - Minimization of the lifting force is imperative in order to have an optimized system. All marine operations and equipment necessary on the storage/process vessel are heavily influenced by this variable. The vertical force versus displacement characteristics of the anchor leg system as well as the shape and location of the buoyancy of the anchor leg support system will have a major effect upon the lifting requirements for re-connection of the mooring system to the storage/process vessel. Lift force requirements are depicted in Figure 3 and may be referenced to the spider buoy positions shown in Figure 4.

Riser Connection - It is necessary to place the connection point for the risers at a location that is easily accessible for operational and maintenance personnel. Handling aids must be provided in order to facilitate connection operations. Operators should endeavor to minimize the size and number of flow lines since accommodating large lines into the disconnectable system will have a major cost impact.

Storage/Process Vessel Interface - The turret should be located on the storage/process vessel at a location where the existing structure is accessible for structural connection. This allows the best control of vessel stresses and greatest fatigue life of the existing vessel structure. Additionally, the loads and motions for the mooring system and recovery system can be quite dramatically influenced by the location of the turret on the vessel. If the turret is located too far forward, large hydrodynamic forces can be experienced. If it is too far back, low-frequency surge and yaw motions and their associated forces can increase.

Fatigue of Anchor Legs - Fatigue characteristics of a permanently moored system are usually dominated by significantly lower sea states than those for which the system is ultimately designed. In a disconnectable mooring, this is not the case since the sea states to produce maximum anchor leg loads are only slightly greater than the conditions that occur on a much more frequent basis. As a result, design of all components of the disconnectable turret mooring are more likely to be controlled by fatigue.

Arrangement of Handling Gear - To minimize costs, especially on conversion installations, it is desirable to leave the mooring winches and their associated chain lockers undisturbed. Relocation is expensive and this equipment must remain completely operational during periods of disconnection. Compromises must be investigated early to establish the structural arrangement while considering location of cargo tanks, mechanical equipment and sea-keeping or hydrodynamic characteristics of the vessel. In the case of new built vessels the freedom to optimize arrangements on the storage/process vessel is much greater and may perhaps result in savings in the final overall system design.

Inspection and Maintenance - Because of the added complexity of the mechanical components of a disconnectable turret mooring system, inspection and maintenance requirements will of necessity be greater than for a "typical" permanent system. Of course, a trade-off to the added effort is the ability to perform major inspection and maintenance during times of disconnection when the vessel and the key components for connecting to the mooring system can be brought alongside a quay where added facilities may be readily available for assistance.

Manufacturing Considerations - Because of the size and weights of the major components to be manufactured into the tanker structure, careful attention must be paid to the machinability, handling and heat treatment of each component. Elimination of machining of bearing foundations on the tanker or storage vessel structure is a major opportunity for cost savings. To facilitate the mounting of the system on the storage or process vessel, all needs for cradling, transporting and lifting must be manufactured into the hardware. It is desirable that these aids be arranged to avoid fatigue prone "hot spots" and also be a permanent part of the mechanical assembly where possible.

Failure Modes Effects Analysis and Design Reliability - Operators are continually requiring more utilization of their equipment and manpower during the life of a floating production and/or storage system. In order to accomplish re-connection and disconnection satisfactorily and maintain a high degree of safety, more complex mechanical equipment is necessary. Because of this, and the potential for extensive damage and loss of life as a result of untimely failure on this type of equipment, it is necessary that the highest degree of reliability be designed into and included in the budget for these installations. Performing a failure modes and effects analysis of the system and its operation is recommended in order to fully evaluate conceivable situations that may potentially occur during the life of a mooring system. When performed properly at the appropriate early time in the project, the cost and schedule impact of this effort will be minimized and the results be more useful to achieve operating success.

The LUFENG 13-1 disconnectable turret system and the FSO are designed and constructed in accordance with ABS "General Procedures for the Classification/Certification of Floating Production Systems" and will be classified +A1 Floating Storage System.

MOORING SYSTEM

Model Tests

Over a one year period, two comprehensive sets of model tests were conducted at the Maritime Research Institute Netherlands (MARIN) before arriving at the final mooring and re-connection systems design. The objectives of the first model tests included verification of a preliminary mooring legs configuration and an investigation of the performance of an external bow mounted turret compared to an internal turret. The second set of tests involved a refined mooring legs configuration and a comparison of hydrodynamic loads on the connected spider buoy for two internal turret locations relative to the FSO forward perpendicular. Table 1 contains a summary of the key design environmental conditions simulated in the model tests.

Table 2 gives the ratio of experimentally measured to computer predicted maxima of key forces and motions for the connected FSO. *F-xy* and *F-xyz* are the resultant turret forces in the horizontal plane and horizontal and vertical planes, respectively, and *Anchor Leg* is the tension in the most loaded line. *Turret-xy* is the resultant turret motion in the horizontal plane and *Turret-z* is turret vertical motion. Considering the time and expense required to conduct model tests, the ability to accurately predict the overall force and motion response of systems as complex as a disconnectable turret mooring is critical for the timely design and optimization of the numerous sub-system components.

RISER SYSTEM

The riser system must be optimized for both the FSO connected and FSO disconnected configurations. Based on the site water depth and the extreme severity of the environment, a basic 'Lazy-S' configuration was identified as the most stable and economical design. The critical design parameters monitored in the survival analyses of the riser system are summarized as follows:

- Maximum tension at riser end connections
- Minimum riser bend radius near spider entry, mid-water arch and seabed
- Maximum angles between riser and spider and riser and mid-water arch
- Minimum length of lower riser section on seabed
- Seabed contact with upper riser section
- Interference between upper riser section and mooring legs

After the selection of a flexible riser structure with hydraulic, thermodynamic and corrosion properties that satisfy the site production requirements, optimization of the Lazy-S configuration subject to the above design criteria was carried out by varying the following physical parameters:

- Length of upper and lower riser sections
- Horizontal location of dynamic riser/static bottom line interface
- Mid-water arch support radius and net buoyancy
- Length of mid-water arch tether and horizontal location of clump weight

Numerous analytical cases governing the survivability of the riser system were derived in consideration of the global orientation and strength of the environmental conditions at the Lufeng 13-1 site (Table 1), and the maximum vessel/spider excursions observed from model tests and numerical simulations. Static and dynamic simulations were conducted for the following environmental conditions and system configurations:

FSO CONNECTED

- Maximum environment: 8.0 meter significant wave height, 1.2 meter/second current
- FSO vessel 50% or 100% loaded
- Environment parallel or transverse to plan view riser layout
- Maximum vessel offset towards or away from mid-water arch
- Intact mooring or one leg broken
- Riser connected or disconnected from turret

FSO DISCONNECTED

- Maximum environment: 14.4 meter significant wave height, 2.4 meter/second current
- Environment parallel or transverse to plan view riser layout
- Maximum spider buoy offset towards or away from mid-water arch
- Intact mooring, one leg broken or one compartment flooded

Static and dynamic analyses were performed using the three-dimensional, non-linear finite element program FLEXCOM-3D™, which fully accounts for axial, bending and torsional stiffnesses. Static analysis, which included loads due to current and maximum vessel/spider excursions, represented the majority of the analytical effort during system optimization. Subsequent dynamic analyses simulated the additional external loadings due to wave kinematics and vessel/buoy wave-frequency motions, and were primarily used for fine tuning and final system design verification. The mean plus maximum wave drift force induced low-frequency vessel offsets were treated quasi-statically for all analyses.

MAJOR TURRET COMPONENTS

The turret system design emphasizes high reliability, ease of maintenance and low technical risk. The overall objectives were achieved by locating critical mechanical components above the water line to the maximum extent possible, providing ease of access for preventive maintenance and utilizing construction methods and components that are proven in existing SPM systems. The procedure for installing the turret into the FSO vessel eliminates any machining of large diameter support structures which are pre-welded into the vessel.

- The turret shaft is a stiffened steel cylinder 27.4 meters high and 4.7 meters inside diameter which is inserted through the ship's hull just aft of the forecastle. Precision machined weldments provide interfaces with the bearings. Located at keel level is the structural connector and tensioner assembly which latches the spider buoy and the mooring lines onto the turret shaft. The turret shaft may be rotated for final alignment prior to re-connection by means of dual hydraulic drive units which power the gear ring on the main bearing.

  When the spider buoy is re-connected, a water tight seal is achieved by means of dual seals at the interface with the turret shaft. Two submersible pumps are employed to pump the turret shaft dry and thus provide access for inspection and maintenance.

  The interior of the turret shaft is fully ventilated and lighted at all times and fire and gas detection sensors are strategically placed in the disconnect area and at intervals up the shaft.

- The spider buoy is a multi compartmented cylindrical structure with a hull 10.3 meters in diameter and 8 meters high. This component provides the interface between the mooring legs and the turret and it incorporates the male part of the structural connector and the landing seat for the production riser. The eight chain support assemblies for the mooring legs are located around the lower periphery of the buoy. Buoyancy and stability requirements are satisfied by a combination of syntactic foam modules installed around the upper hull and permanent ballast in the lower hull. Provisions are included to add weights for trim and depth adjustment following installation. Guide pin receptacles are provided to insure proper alignment of the riser during re-connection operations.

  A fendering system of rubber fenders is provided around the re-connection area to cushion any impact forces and preclude the potential for damage during re-connection.

- The mooring system is a symmetric 8-leg chain and wire rope composite design. Each mooring leg is made up of eight elements including an adjustment section, a weighted excursion limiter, a section for attachment to the chain stoppers and a high capacity drag embedment anchor. The composite anchor legs produce a characteristic force-displacement curve that is nearly linear (Fig. 5). The majority of each mooring leg is composed of 4 inch drawn and galvanized wire rope.

  Mooring System Safety factors are in accordance with ABS "General Procedures for the Classification/Certification of Floating Production Systems". The system design results in motions and excursions of the FSO that are very satisfactory. The dynamics of the spider buoy while disconnected and during re-connection are well within acceptable limits and the lifting requirement for re-connection is minimized.

- The connector tensioner assembly is located just above keel level. The upper part of the spider buoy and the lower part of the turret shaft incorporate machined interfaces that bring the spider buoy in register to the turret. These components are joined by a Cameron collet connector which is designed to produce and resist only axial loads.

After connection of the collet connector, the tensioner is hydraulically actuated to produce a compressive load at the turret shaft/spider buoy interface. This load is mechanically locked and monitored to maintain preload and prevent separation of interface surfaces during occurrence of maximum design mooring forces. Thus, the collect connector is subjected to a nearly constant axial tensile load condition and is resistant to fatigue, a significant design advantage. The connector incorporates two sensors which detect the locked and unlocked position of the collet ring and fully redundant independent hydraulic cylinder operating systems. The entire connector tensioner assembly may be released and raised for inspection and maintenance. This operation is restricted to the minimal environmental conditions.

- The main bearing system for the turret shaft consists of a 6.5 meter diameter three row roller bearing located at main deck level. This bearing arrangement provides a highly reliable and low maintenance system. The design eliminates machining operations on the large diameter turret support structures welded into the tanker. The roller bearing at the main deck is protected by elastomeric seals. Bearing supports are designed to preclude unfavorable deflections. On the ship side, the bearing is mounted to a large circular steel ring which is supported by a series of energy absorbing elements which will reduce the effect of unfavorable deflections at the tanker's main deck. Retainer fittings on the turret side are stiffened to avoid deflections. An automatic lubrication system injects grease at specific programmed intervals.

- The fluid swivel stack consists of a single six inch, 600 lb. ANSI rated, piggable swivel, a two inch air swivel and an annular electrical swivel for electrical power and control service. The production swivel is sealed by multiple reinforced PTFE seals and the bearing is lubricated by the automatic system used primarily for main bearing lubrication. The electrical swivel is equipped with safety devices to warn of any anomalies.

- The spider buoy retrieval system is comprised of a hydraulically powered winch and a chain jack mounted in series. The retrieval winch, hydraulic power unit, accumulator bank and control console are mounted on the winch deck 10 meters above the top deck of the tanker. The chain jack is located on the centerline of the turret shaft immediately above the top deck. During disconnection, the accumulators are utilized to power the hydraulic cylinders which release the collet connector.

  During re-connection, a hawser rope spooled on the retrieval winch pulls the spider buoy into a position near the keel of the tanker. During this operation, a stud link chain stored in a locker in the bottom of the spider buoy is deployed. When the winch has pulled the chain into the upper clamp of the chain jack, the winch is placed in the low pull, constant tension mode and the chain jack assumes the task of pulling the spider buoy into register with the turret shaft. When the spider buoy is docked with the tanker, the turret shaft is rotated into final alignment, the securing pins are hydraulically driven into receptacles in the spider buoy and the collet connector is locked and tensioned.

  The winch and chain jack combination was selected over a dual drum winch because it provides a positive locking mechanism, better control, ease of operation and maximizes the safety of personnel and equipment.

- The riser handling winch and control console is located on the same deck as the retrieval winch and is dedicated for riser deployment and retrieval operations. Following purging operations prior to disconnection of the riser, isolation ball valves are closed and the piping spool above the riser is disconnected by removing two Grayloc™ connectors. A fishing tool guide and jar centralizer are installed atop the riser and the riser is run down the riser guide tube using an Otis type SB pulling tool. After the riser is landed in its seating receptacle in the spider buoy, the pulling tool is removed using the jar and recovered to the winch deck. Riser retrieval utilizes the same SB pulling tool. Air power tools are available on the winch deck to facilitate removal and re-connection operations.

CONSTRUCTION

To facilitate the handling, testing and mounting of the disconnectable turret mooring system onto the FSO vessel, the design maximizes the use of sub-assemblies. All mechanical components are shop tested to verify performance prior to mounting into the turret system. Commissioning or functional testing is carried out during the final assembly onto the vessel.

The turret shaft has been fabricated in Japan and will be transported to Singapore for installation onto the tanker. Other mechanical components were manufactured in the United States, Newfoundland, Europe and Canada and transported to the respective assembly sites.

The spider buoy, anchor leg assemblies, anchors and risers are being transported to Hong Kong from where the offshore installation will be staged by the Client.

The FSO vessel is being converted from the 128,000 DWT motor tanker "Sea Queen". Preparation of the tanker for installation of the turret begins prior to the tanker being placed into drydock. To have efficient use of the drydock, the tanker structure is cut away except for the lower hull prior to the vessel's entering the drydock.

Installation of the turret begins by mounting the lower support ring in the keel of the tanker. The remainder of the watertight tube that surrounds the turret shaft is inserted and welded out sufficiently to support the weight of the turret shaft. The upper bearing foundation is also installed and welded out.

The turret shaft is lifted and inserted into the tanker with temporary supports. The upper bearing assembly is mounted in place and stud bolts torqued to the proper pretension. The turret shaft is rotated to check runout on critical assemblies. After a satisfactory rotational test of the turret, the tanker can be removed from the drydock. A temporary closure plate is installed on the lower end of the turret to maintain dry working conditions inside the shaft. The tanker is now relocated alongside a dock with access to heavy lift equipment. Other subassemblies are installed sequentially beginning with the connector tensioner assembly at the lower end and continuing to the fluid swivel assembly atop the pipe deck on the turret superstructure. Each component is tested following installation. After all equipment is mounted in place, pressure testing of the piping and fluid swivel and rigorous testing of the hydraulic systems and controls is conducted. It is important to note that one of the major subassembly tests involved the mating of the lower turret structure and connector tensioner assembly with the spider buoy. This test verified proper fit-up between the components and the function of the collet connector and tensioner. This test was conducted in Japan prior to final weld out of the turret shaft.

OFFSHORE INSTALLATION

Installation of the spider buoy, anchor legs and riser is scheduled for June 1993. The FSO vessel will sail from the conversion yard in Singapore in early July for connection to the spider buoy in late July 1993.

Prior to commencement of work in the field, a survey vessel equipped with a Differential Geographic Positioning System (DGPS) will set a long baseline (LBL) acoustic array on the seabed in the vicinity of the installation site.

A pre-installation survey will be conducted using side scan sonar along a 200 meter corridor for the full length of each mooring leg route and the flowline riser route.

Installation of the anchor legs will be done by laying and tensioning diametrically opposed legs using a crane barge and a Bruce Tensioner. Each anchor is equipped with a transponder to accurately fix the anchor touchdown location. An ROV will verify location and anchor orientation after touchdown.

After tensioning, length adjustments of up to 20 meters can be made in a special chain section. The excursion limiter section, the wire rope section that comprises the catenary and the short chain section that connects to the spider buoy chain stoppers are now installed and buoyed for pick-up.

Installation of the spider buoy is similar in many respects to that of a standard CALM buoy. The main difference is that the initial pull-in wires are configured with pre-determined hang-off points to expedite final tensioning which will cause the buoy to submerge.

The riser and flowline are installed as a single line with a flange connection between them and with no PLEM. Installation begins by connecting the riser to the spider buoy then installing the mid-water arch. A temporary net-type pig trap is installed at the spider buoy end which is replaced by the pressure test end gear following pigging. The flowline section is laid away from the mid-water arch to the production platform where it is pulled through a J-tube to the process deck.

The spider buoy is trimmed with weights to the proper elevation and orientation following riser hook-up.

The final stage of the installation is the retrieval and connection of the spider buoy to the FSO tanker. There will be a trial disconnect and re-connect operation as part of the final acceptance criteria.

CONCLUSIONS

The disconnectable turret mooring system provides a means of mooring storage/production vessels in areas of the world where it is not economically feasible to employ a permanent mooring system. This technology may permit marginal field developments that were not previously considered practical. In addition to this perceived primary application, disconnectable turret technology can provide a method for mooring specially outfitted shuttle tankers in extremely hostile areas such as the North Sea, the Bering Sea and the North Atlantic where acceptable operational efficiencies cannot be achieved with loading systems that rely solely on dynamic positioning of the tanker for station keeping. The system may also have utilization for shuttle tanker operations in areas subject to significant ice floes. The development of the disconnectable turret mooring system illustrates that SPM technology is available to design, build and install innovative solutions for hydrocarbon production anywhere in the world.

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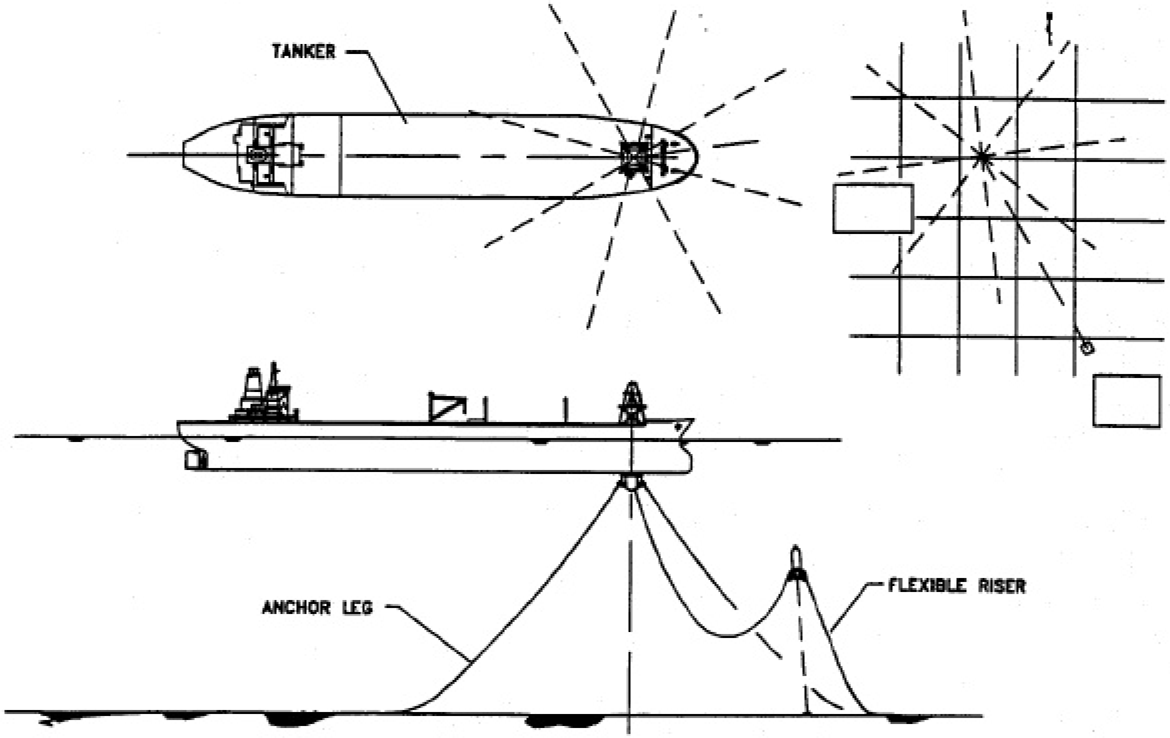

FIGURE 1

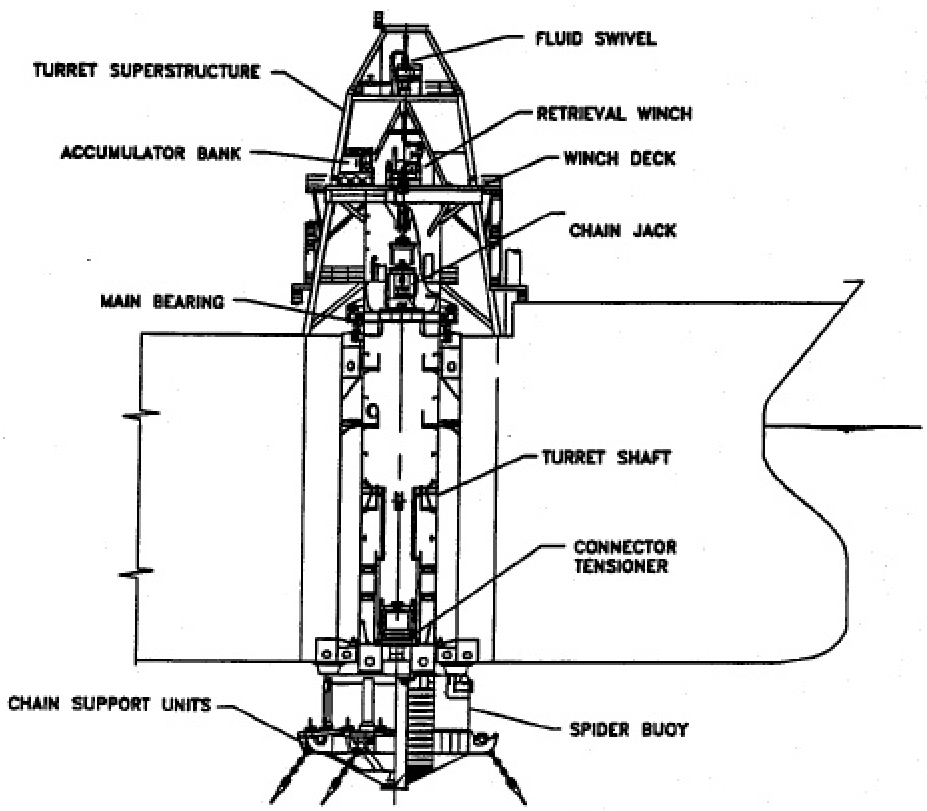

FIGURE 2

TABLE 1 Lufeng 13-1 maximum design environmental conditions.

	RE-CONNECT	OFFLOAD	DISCONNECT	CONNECTED	DISCONNECTED	
WAVES						
Spectrum	P-M	P-M	P-M	P-M	P-M	
Maximum Height	6.50	7.40	13.80	15.00	24.20	meters
Significant Height	3.50	4.00	7.40	8.00	14.40	meters
Peak Period	8.80	9.10	10.40	11.62	15.80	sec
WIND						
10 minute mean	22.5	26.9	43.1	49.5	126.8	knots
CURRENT						
@ Surface	0.97	1.56	1.94	2.33	4.65	knots
@ buoy depth of 35 meters	0.93	1.50	1.86	2.16	3.85	knots
@ Riser arch	0.90	1.45	1.80	2.04	3.54	knots
DIRECTIONALITY						
Co-linear	yes	yes	yes	yes	yes	
Crossed	no	no	no	yes	no	

Note: Crossed condition defined as wind and current at 30 degrees to wave direction.

TABLE 2 Ratios of measured to predicted maxima for connected FSO.

	CO-LINEAR ENVIRONMENT		CROSSED ENVIRONMENT	
	100% Loaded	50% Loaded	100% Loaded	50% Loaded
FORCES				
F-xy	1.09	1.06	1.02	1.10
F-xyz	1.03	1.14	0.93	0.96
Anchor Leg	1.02	1.01	1.03	0.90
MOTIONS				
Turret-xy	1.15	0.91	0.99	0.80
Turret-z	0.96	1.10	1.02	0.91

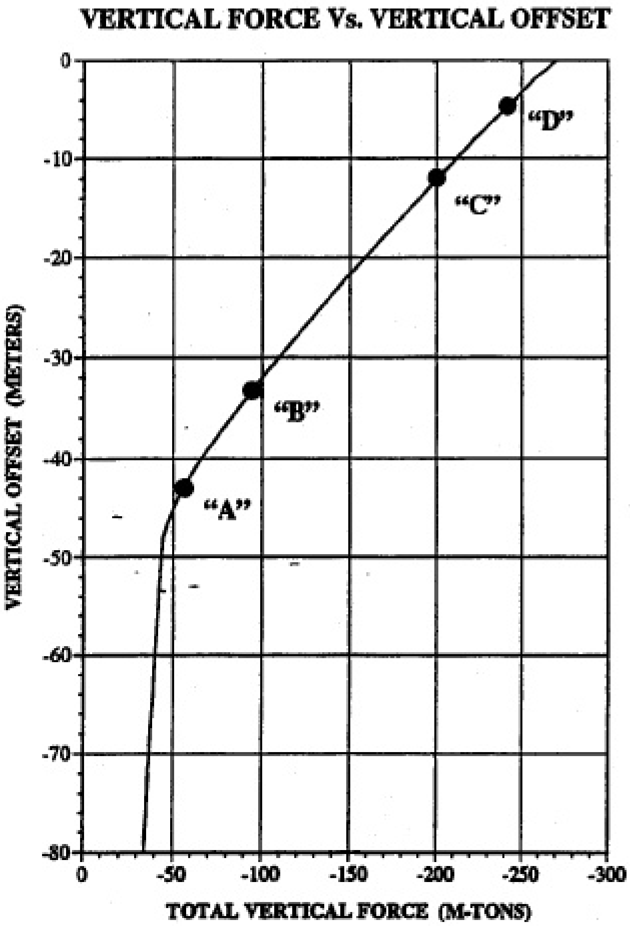

Fig. 3 Vertical force deflection characteristics.

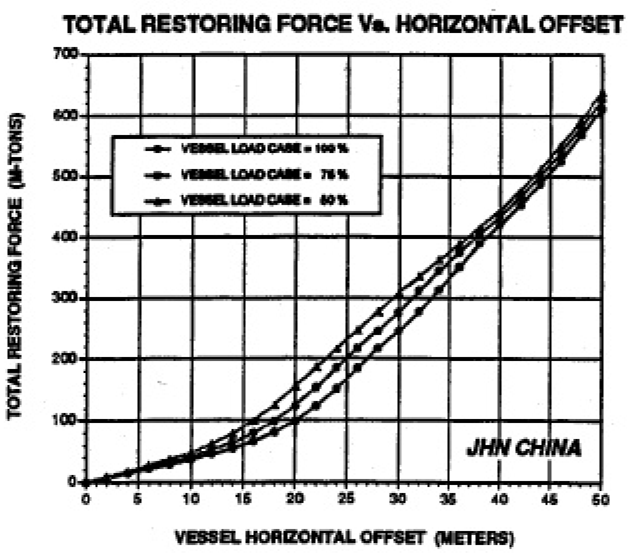

Fig. 5 Horizontal force deflection characteristics.

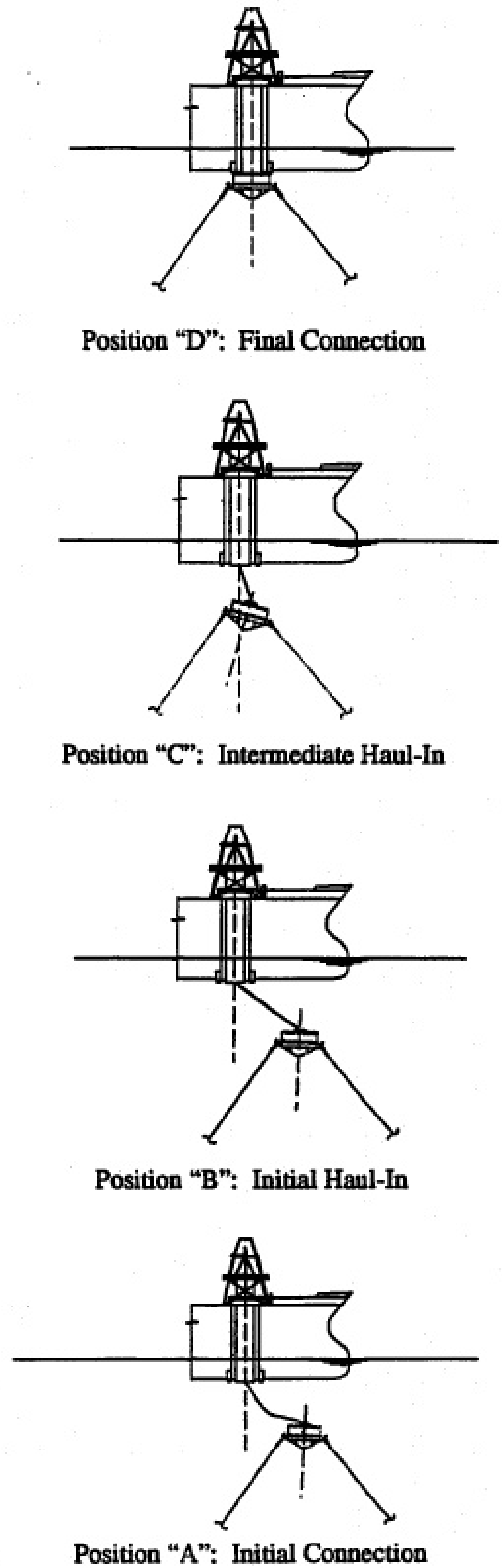

Fig. 4 Re-connection of the mooring system.