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Faulty of Science and Technology

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Author	Tieli Li
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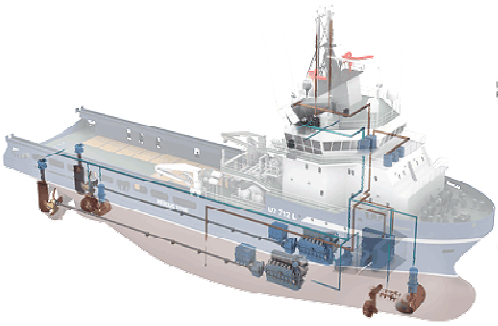
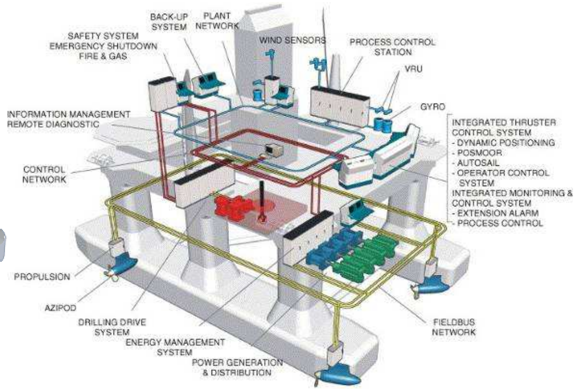
DP systems for offshore vessel positioning in deep water

Master thesis

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Tieli Li

ABSTRACT

Current industry practices and the suggestions from the literature are that offshore oil exploration and production activities will move into deeper water further from shore. To achieve that, dynamic positioning systems are indispensible. In the past 5 years, there has been a dramatic increase in the number of offshore installations equipped with DP systems.

This thesis is focused on comprehensive characteristics, utilities, risk analysis and future trends regarding positioning systems in the offshore oil industry, and figures out the most suitable methods for keeping an offshore installation on location (traditional anchor mooring system, lightweight mooring system, dynamic positioning system). Specifically, this thesis emphasizes on the offshore dynamic positioning system. This method will be investigations to improve the accuracy and reliability of different types of rigs and vessels, as well as improving the safety and efficiency of DP operations.

Safe operations of the dynamic positioning of offshore drilling units and support vessels are dominated by two parameters, the resistance against drift-off from position and the robustness of position recovery. The operational facts tell us that DP vessels' loss of position during operations is not rare. Effective ways will be illustrated by evaluating the two parameters and improve the safety accordingly. HAZOPs and FMEA risk analysis methods will be used to evaluate the reliability of the system.

ABSTRCT IN CHINESE

从目前的行业惯例和相关文献可知，近海石油的勘探和生产活动将进入更深的水域，更加远离海岸。实现由浅水到深水的石油开发，动力定位系统是不可或缺的。在过去的 5 年里，配有动力定位系统的海上石油开采设施的数量显著增加。

本文重点强调动力定位系统在海洋石油工业中的综合特性、相关应用、风险分析及其未来的发展趋势。同时指出了近岸石油开采装置最适合的定位系统（传统的锚泊定位系统、轻质的张力索定位系统、动力定位系统）。研究提高不同类型的钻井平台及船舶动力定位系统的可靠性的方法，以及安全高效的进行系统操作的方法。

对海上钻井装置及海洋石油支持船动力定位系统的安全运行主要由两个参数决定，位置偏离的抵抗能力及原始位置的复原能力。事实告诉我们，动力定位装置在运行过程中丢失船位并不少见。如何通过对这两个参数的有效评估，来提高系统运行的安全性将会在文章中阐释。危险和可行性分析及故障模式和效应分析将会评价系统的可靠性。

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ABS	American Bureau of Shipping
AHTS	Anchor Handling Tug Supply vessel
BOP	Blow-out Preventer
CCS	China Classification Society
CNOOC	China National Offshore Oil Corporation
COSL	China Oilfield Service Limited
DGPS	Differential Global Position System
DNV	Det Norske Veritas
DP	Dynamic Positioning
DPO	Dynamic positioning operator
EQD	Emergency Quick Disconnect
FMEA	Failure Mode and Effects Analysis
FPSO	Floating Production Storage Offloading
GOM	Golf of Mexico
GPS	Global Positioning System
IMCA	International Marine Contractor Association
IMV	Ice Management Vessel
LR	Lloyd's register
MODU	Mobile Offshore Drilling Unit
NCS	Norwegian Continental Shelf
OSV	Offshore Support Vessel
PMS	Power Management System
PSV	Platform Supply Vessel
ROV	Remote Operated Vehicle

Chapter 1 Deepwater floating structures' station keeping systems

1.1 Various deepwater offshore floating structures

Many kinds of deepwater floating structures engage in the offshore oil and gas industry through more than 50 years of development. This thesis will more focus on the floating structures which could be equipped with DP system as an alternative of position keeping technology. The following floating structures will be used to illustrate the utility, operation, limitation and associated risk of the DP system.

1.1.1 Semi-submersible drilling rigs

A semi-submersible drilling rig shown by figure 1-1 is composed of horizontal underwater pontoons supporting vertical columns on top of which is the drilling platform. It is used in deep waters where a fix platform resting on the sea bed or a jack-up rig lifted over the water with long leg structures would be impractical. In the shallower waters it can be moored with a set of anchors, but in deeper waters it is initially held in a GPS position by a number of thrusters through DP system.
The use of DP system rather than a mooring system means in the event of a hurricane, that the drill pipe can be lifted from the BOP and the rig moved to safety place. Also the depth of the waters makes mooring a complex and expensive task. The dynamically positioned ultra-deepwater semi-submersible rig has the capability of working in water depths of up to 3,000 m.

Figure 1-1 Semi-submersible drilling rig Ocean oil 981

1.1.2 Ultra deep water drilling ship

Drilling ships showing in figure1-2 work in water depths ranging from 600 to more than 3000 meters. Drilling equipment pass through the vessel's moon pool and connected to the well equipment below with riser pipe, which extends from the top of the subsea well to the bottom of the drillship.

A proper mooring system on a drilling ship is integral to drilling successful wells. In shallower waters, drilling ships are moored to the seafloor with anywhere from 6 to twelve anchors. Once the water depth becomes too deep, drilling ships depend on DPS to keep the vessel in place while drilling. DP system relies on several thrusters located on the fore, aft and mid sections of the ship, which are activated by an onboard computer that constantly monitors winds and waves to adjust the thrusters to compensate for these changes.

Figure 1-2 Ultra deepwater drilling ship
(http://www.rigzone.com/training/insight.asp?insight_id=306&c_id=24)

1.1.3 FPSO (floating production, storage and offloading unit)

A Floating Production Storage and Offloading vessel shown in figure 1-3 produces oil using a flexible riser from the oil field beneath the seabed. It also has the capability to store vast quantities of oil in a similar way to an oil tanker. The oil is transported from the FPSO by a Shuttle tanker for transportation to the mainland. In the processes, the FPSO is required to maintain her position under external forces such as current, wind and wave. Especially, during the offloading phase, the two vessels should keep their position because they are coupled by a hawser, leading to complex dynamic interaction.

DP system is used in a FPSO to keep her positional stability in deep waters where the use of conventional mooring systems is generally not available (Ahn, et al., 2002).

Figure 1-3 FPSO with dynamic positioning system
(http://www.dps-global.com/news-press/2011/jordbaer)

1.1.4 Deepwater offshore supply vessels

As the offshore oil industry develops from the shallow to deeper water gradually, an increasing number of supply and anchor handling vessel are equipped with DP system and designed bigger and more powerful than in the past to meet the associated requirements.

Figure 1-4 North Sea deepwater support vessel
(http://www.stxosv.com/offshore/anchor/Pages/default.aspx)

Traditional anchor mooring supply operations could not be conducted due to the depth of deepwater. Further, the captain could not insist on 2or3 day’s continuously manual operation. Deepwater OSVs shown by figure 1-4 are therefore always equipped with DP systems. Deepwater OSVs are not only being built but are also being operated by DP2 standards, and some companies are already requiring DP3 OSVs. Table1-1 below shows the characteristics of OSV from shallow to deepwater.

Table 1-1 The characteristics of OSV from shallow to deepwater

Comparison		Shallow water	Medium water	Deepwater
PSV	Length	60m	70m	90m
	Deadweight	1000t	3000t	4500t
	Liquid mud	$100m^3$	$1000m^3$	$1200m^3$
	Deck space	$300m^2$	$700m^2$	$1000m^2$
	Propulsion	2 fixed pitch propellers	2 azimuth thrusters	2 azimuth thrusters
		1 bow thruster	2 bow thrusters	3 bow thrusters
	DPS	nil	DP2	DP2
AHTS	Length	60m	70m	90m
	Power	4000HP	15000BHP	20000BHP
	Bollard pull	70t	400t	500t
	Liquid mud	nil	$400m^3$	$600m^3$
	Propulsion	2 fixed pitch propellers	2 azimuth thrusters	2 azimuth thrusters
		1 bow thruster	2 bow thrusters	3 bow thrusters
	DPS	nil	DP2	DP2

1.2 Offshore deepwater floating structures' station keeping system

1.2.1 Overall introductions

Fundamentally, there are two means of deepwater station keeping methods. The first method which has been used for centuries is traditional anchor mooring system by physically securing the vessel to bottom of the seafloor. As technology in advance, chain or wire used in the traditional mooring system are instead by the Lightweight synthetic mooring materials, which extends the domain of the traditional method in term of water depth.

The second method is the dynamic positioning method which is widely used in the offshore deepwater area. DP system is an active method by using the vessel's thrusters to maintain its position and heading. It is not restricted by the water depth as comparing with traditional methods.

In order to decide on most suitable method for keeping an offshore vessel on location, different methods will be investigated:

- Use of traditional deepwater mooring system
- Use of lightweight deepwater mooring system
- Dynamic Positioning

1.2.2 Deepwater mooring systems

Installing deepwater moorings for Spars, floating production units, FPSOs and drilling rigs is proving to be increasingly time-consuming and costly, as mooring equipment and practices developed for shallow water are applied to deepwater environments (Green, 2010). Currently, the number of the deepwater mooring projects is increasing. For instance, Atlantia's Thunder Hawk Floating Production Unit showing by figure 1-5 is moored in 1,800m of water depth; and a submerged turret production buoy was moored in 2,500m of water depth of GOM in 2010.

Figure 1-5 Polyester rope mooring Thunder Hawk Floating Production Unit (http://www.offspringinternational.com/caseStudy/14/Polyester_Rope_Mooring_for_Thunder_Hawk_DeepDraft_Semi.html)

The mooring system used for deepwater station keeping is typically either a catenary system or taut-leg system. Conventional catenary mooring systems become progressively ineffective as water depth increases to 800m, due to the heavier mooring loads, generated by traditional chain and wire rope mooring systems (Klaoudatos, 2006). In order to get the desired mooring tension as well as less weight, synthetic fiber ropes are widely used in the deepwater mooring system.
Comparing with a catenary system, synthetic fiber ropes have more advantages. They are much lighter than the steel spiral strand wire; they can provide much more horizontal forces to resist the external condition bring back the installation to the original location; they have lower cost in terms of price than the catenary system. Thus they are much more used for the deepwater installations compared with the catenary system. Figure 1-6 gives an illustration of the polyester rope taut leg and the conventional catenary mooring scope.

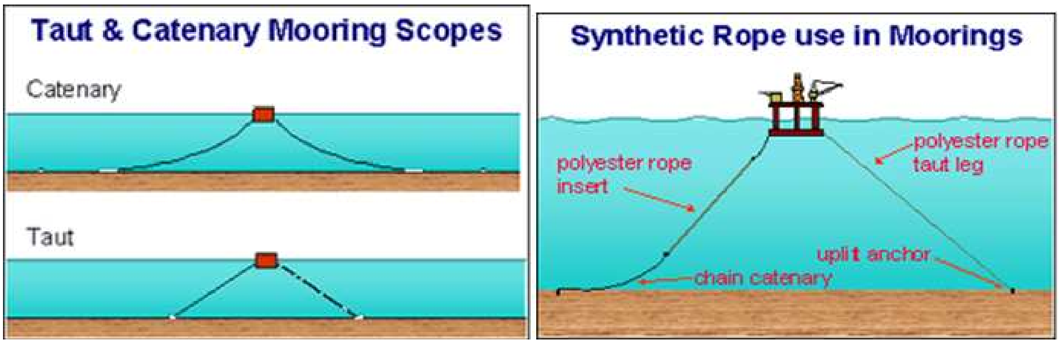


Figure 1-6 Demonstration of the catenary/ polyester rope moorings
(http://www.tensiontech.com/services/mooring.html)

1.2.3 Dynamic positioning systems

Dynamic positioning is a station keeping technique consisting of on-board thrusters that are automatically controlled to maintain a floating structure's position and/or heading. The propulsive force produced by the thrusters/rudders counteract the mean and slowly varying actions due to wind, waves and current so as to maintain the structure within pre-set tolerances at a desired point above the sea floor and on a pre-defined heading (ISO19901-7,2005). Many people think that DP is more risky than manual operation. It seems for them impossible to position the vessel or floating installations only through automatic propulsion control. On the contrary, the advanced DP technology can provide enough safety and reliable position control for the vessels or the offshore floating installations.

1.3 Station keeping methods comparison

1.3.1 Equipment cost perspective

The equipment cost of the DP system is more expensive than the traditional deepwater mooring system, as there are a lot of regulatory requirements for the DP system. The need for separate engine room is the main cost of the DP system. Engines need to be equipped to power the thrusters in order to maintain the position of the offshore floating installations. The electronic components of the DP control system also greatly add up the cost of the system.
The main cost of the mooring system including winches, anchors, mooring chains, anchor handling devices. Usually, the mechanical devices are less expensive than the electronic devices. The mooring system does not need separate room used for locating engines, as well as fuel consumptions.

1.3.2 Positioning perspective

For positioning perspective, DP system need to constantly running to keep the rig or other floating installation in position with a great deal of fuel consumption. For the mooring system, once the anchors have been deployed, engines are not needed constantly operation, which is a great advantage comparing with DP system.
On the other aspect, DP system does not need to use large AHTS for anchor handling. Mooring system on the contrary need to used large AHTS for anchor handling and they must be used at each time when the rig is changing position. Great risk will be increased during anchor handling operation and may lead to plenty of downtime to the rig, as well as the daily rate is very high for AHTS renting.

1.3.3 Maintenance perspective

DP system uses computer program which needs upgrade at a certain intervals when the new version software developed, and associated cost need to be paid to the manufacturers, but it is not great deal.
The chain, wire, or synthetic rope of the mooring system need to inspection according the specific regulations, as well as the winches, anchors and anchor handling devices, this add up cost as comparing with DP system. However, the repair of the mooring system equipment is much easier than the equipment of the DP system, as the equipments in the mooring system are relatively simple than the DP equipment.

1.3.4 Reliability perspective

The DP system today is very reliable compare with old system used several decades' ago. Much more redundancies have been established to make sure the positioning keeping ability of the system. Most of failures we record today are not the system itself; actually they are the failure of the sensors and human errors. The risk of DP system drift-off remains at a low level nowadays. However, the reliability of the DP system still does not exceed the mooring system, although mooring system could not provide 100 percentages reliability. Even with great technology development, DP system still has less reliability than the traditional mooring system.

1.3.5 Sea condition perspective

For the offshore floating installations equipped with DP systems, can be operated at a water depth up to 3000m, or even deeper for the ultra deepwater drilling ship. In terms of a coming storm or hurricane, they could navigate themselves to the safe area after disconnecting the risers down below. For the mooring system, AHTS will be used to heave up all the anchors several days before the big storm or hurricane passing, and redeploy the anchors again after the bad weather passing, which increase the downtime significantly relative to the DP system. Mooring systems are usually adopted in the relative shallow area. The deepest mooring system being used nowadays is in 1800m which we mentioned above. Table 1-2 shows a simple comparison of the two station keeping methods.

Table 1-2 Station keeping method comparison

Anchoring	Dynamic Positioning
Advantages: • No complex systems with thrusters, extra generators and controllers. • No chance of running off position by system failures or blackouts. • No underwater hazards from thrusters.	**Advantages:** • Maneuverability is excellent; it is easy to change position. • No anchor handling tugs are required. • Not dependent on waterdepth. • Quick set-up. • Not limited by obstructed seabed.
Disadvantages: • Limited maneuverability once anchored. • Anchor handling tugs are required. • Less suitable in deep water. • Time to anchor out varies between several hours to several days. • Limited by obstructed seabed (pipelines, seabed).	**Disadvantages:** • Complex systems with thrusters, extra generators and controllers. • High initial costs of installation. • High fuel costs. • Chance of running off position by system failures or blackouts. • Underwater hazards from thrusters for divers and ROVs. • Higher maintenance of the mechanical systems.

(Ref: http://en.wikipedia.org/wiki/Dynamic_positioning)

1.4 Selection between DP system and mooring system

In general, the choice between the two systems is depend on the requirements to be met.

In the past, it is widely accepted that for shallow water traditional mooring system is the better choice than a DP system; for deep water DP system is the better choice than the mooring system. However, suspicion is generally arising with the development of new technology for the offshore oil industry.

With respective to get more position accuracy, the DP system is generally superior to mooring system. And the relative accuracy of position keeping for the DP system is increasing with the depth of the water.

With respective to financial aspect, the cost due to the consumption of the fuel by the DP system can offset the cost of renting an AHTS for towing and anchor handling. Thus the two position keeping systems are often competitive on term of financial aspect.

How to get the advantages of both systems?

Dynamic positioning combined with shallow water mooring system is the optimized choice for the operators and contractors in today’s offshore industry, which could get the advantages of the two systems. The shallow water mooring system is much less expensive than the deepwater mooring system. The ability of connection with a pre-set subsea anchoring system, ensures that the shallow mooring system can be used in deeper water area, as well as anchor deploying time saving. And the DP system could be used occasionally to make sure quality of position keeping satisfied.

For this combination concept, the DP system can help to increase heading and position keeping accuracy, increase safety during anchor dragging, balance the tension of the mooring line during harsh weather condition, and help anchor handling through self maneuvering; on the contrary, the mooring system could provide position keeping ability in case failure of the DP system, and also increase the ability of DP system use in harsh environment, such as the Arctic area.

Chapter 2 Dynamic positioning systems

2.1 DP systems introduction

2.1.1 The history of DP systems

DP system is a technology development of the offshore oil and gas industry. Bjørneset et al. (2008) have defined a dynamic positioning system as: A computer controlled system to automatically maintain a ship's position and heading by using her own propellers and thrusters.

"Eureka" built in 1961 was the first vessel equipped with the system compliance with the definition of DP. "Eureka" with thrusters both bow and stern enabled her to keep the position automatically. Figure 2-1 illustrates the vessel "Eureka". As the reliability and availability of the system at that time was not high enough, the DP system was only used for simple offshore activities.

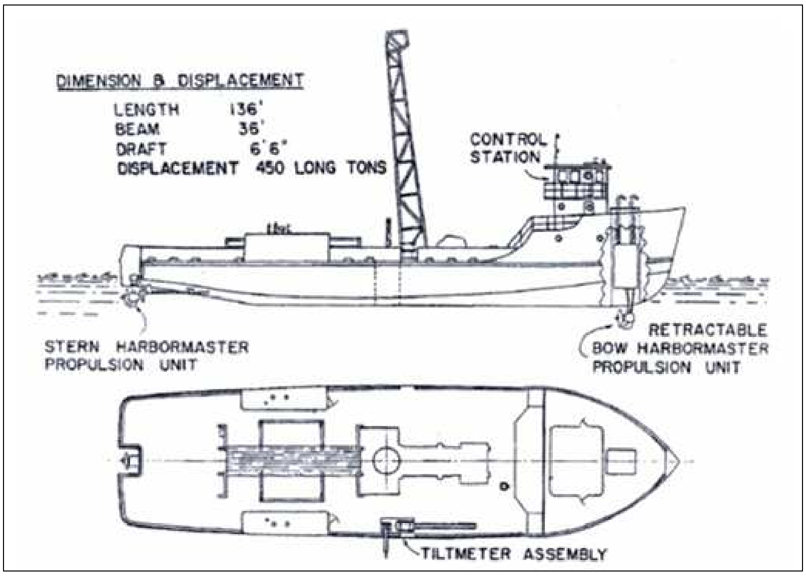


Figure 2-1 The first DP vessel "Eureka"
(http://gcaptain.com/history/)

For several decades of developments, dynamic positioning technology has become mature. Nowadays, the offshore oil and gas industry is gradually moving into deeper water and harsh environment locations, which has brought a great development of dynamic positioning technique.

2.1.2 DP systems Classification

Different classification societies each give out their DP system classification. Table 2-1 lists the DP classification from different classification societies, including LR, DNV, ABS, and CCS. DP classifications are all in compliance with the requirements of IMO concerning equipment and redundancy.

Table 2-1 DP system classification

NO.	IMO require	Classification of different society			
		LR	DNV	ABS	CCS
1	/	CM	T	DPS-0	/
2	Class1	AM	AUT/AUTS	DPS-1	DP-1
3	Class2	AA	AUTR	DPS-2	DP-2
4	Class3	AAA	AUTRO	DPS-3	DP-3

We take ABS (American Bureau of Shipping) DP classification as an example to describe the differences between each level of DP class. The ABS divide the DP system into four classes, they are DPS-0, DPS-1, DPS-2, and DPS-3.

For DPS-0, manual position control and automatic heading control is required. There is no redundancy requirement for this DP class. For DPS-1, there is also no redundancy requirement for this DP class. But the position and heading could be automatically controlled by the system. For DPS-2, it has the ability of automatic and manual position and heading control. Furthermore, it will not lose position keeping ability in the case of failure of any single components. Two independent DP control systems could automatically shift to the other in the case of failure. This DP class has fully redundancy system, thus it is much more reliable, available and safe compared with DPS-1 class. For DPS-3, on the basis of DPS-2, it could withstand the loss of single compartments of the vessel or the floating installation caused by fire or flooding.

2.1.3 Basic principles and elements of DP systems

Basic principles

The fundamental purpose of DP system is automatic control of the vessel or the offshore floating installation to maintain their position and heading by using the propellers, rudders and thrusters. The vessel or the installation on the sea is subject to forces from wind, current, wave and the forces generated from the propulsion system.

The external and internal forces act on the vessel or the installation, which lead them to generate six freedoms of movements, including roll, pitch, yaw, surge, sway , as well as heave. Figure 2-2 illustrates the forces both external and internal which act on an OSV and the associated motions generated.

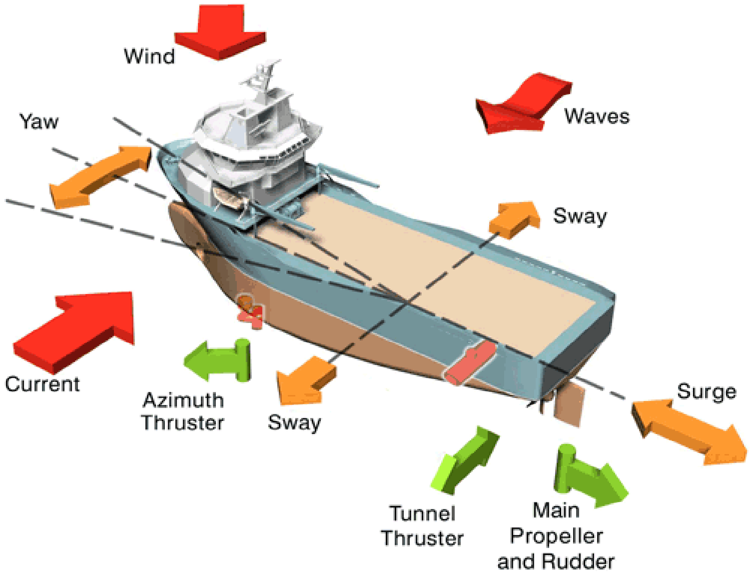


Figure 2-2 DP system basis forces and motions (http://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/BD306BBB3E7DA73FC1256DAB00353083?OpenDocument)

The DP system contains a computer program which allows the motion surge, sway and yaw can be automatic controlled, keeping the position of the vessel or installation. Position reference systems provide the position data; heading sensors such as gyro compass provide heading data of the vessel. The computers will get the data from the references and sensors and compare them with the pre-set data. Then the DP control system will control the propulsion system to take action eliminating the errors between the actual positions and heading data and the pre-set data. A simple working procedure for the DP system is illustrated by figure 2-3 below.

Elements of the DP system:

The entire DP system includes the following equipment and systems: Computer; control console; position reference system (hydro acoustic, taut Wire, DGPS, laser-based); heading reference; environment reference; power system; and propulsion system.

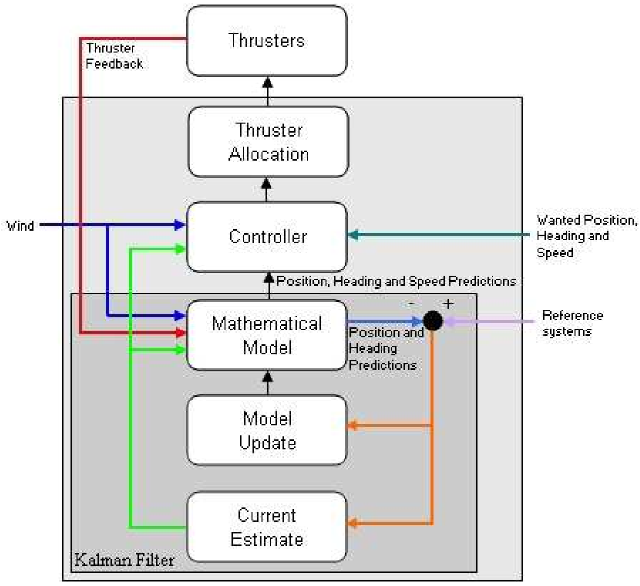


Figure 2-3 Dynamic positioning system control
(http://en.wikipedia.org/wiki/Dynamic_positioning)

2.1.4 The advantages and disadvantages of DP systems

Comparing with an anchor mooring system, some advantages are mentioned as follows:
The offshore floating installations with DP systems can maneuver to new worksites with more time saving and no needs to hire powerful AHTS for anchor handling; they can provide rapid response to harsh weather such as hurricanes or tropical storms, emergency disconnect the risers and selfnavigate to asafe place; adapt to water depths up to 3000 meter or even make it possible to exploit more oil and gas resources in deep seas; there is no risk for the system to damage the subsea facilities without using the mooring line and anchors.

On the contrary to the advantages, there are also some disadvantages concerning a DP system: more relevant personnel are needed to operate and maintain the system, and the position control operations rely on operators, which may cause human errors during the operation and increase the risk of losing position; as the system needs to continuously operate during drilling activities on the sea, much more fuel will be consumed as compared with a mooring system, thus the daily rate will increase accordingly which may affect the choice of the oil company; the failure of the electrical components, can generate great risk for the whole system, especially the failure of the position reference system; it is not a very mature technology being used in the harsh environment, such as the Arctic area and an area with extreme weather.

2.2 Activities executed by DP vessel

2.2.1The use of DP systems on OSV

An OSV equipped with DP system (Figure 2-4) could provide the following operations: diving and ROV Support Operations; offshore supplying support; cable Lay and Repair Operations; seabed tractors and trenchers operations; survey and ROV support operations; pipe laying operations; rock dumping operations; dredging operations and so on. With the help of DP system, the efficiency of the operations increases dramatically, as there is no need for manual operations.

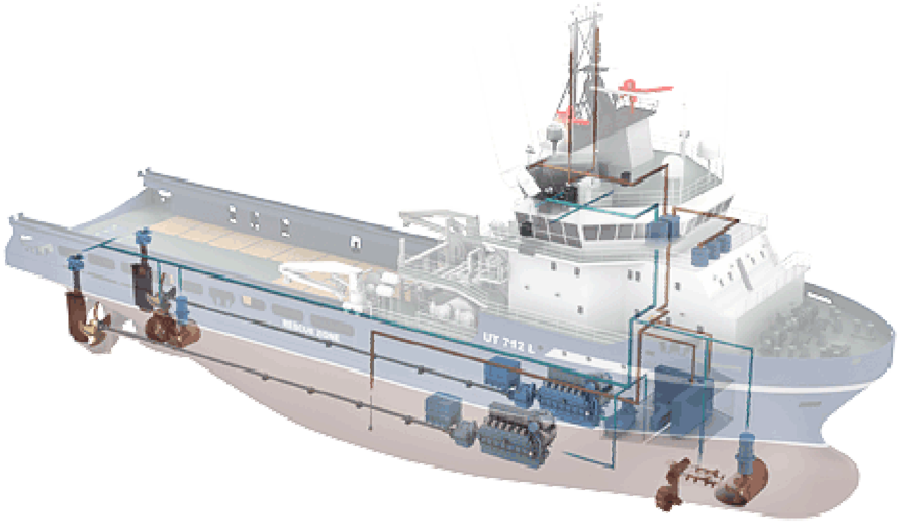


Figure 2-4 Illustration of the DP system on OSV
(http://www.rolls-royce.com/marine/products/automation_control/positioning_systems/)

2.2.2 The use of DP systems on the drilling rigs

A semi-submersible drilling rig is a floating offshore drilling installation with hulls submerged under the sea surface but not standing on the seafloor. As the development of the offshore oil industry gradually goes into deepwater, most of the semisubmersible drilling rigs are outfitted with DPS-3 system instead of traditional anchor mooring systems. Much more equipment redundancy has been established making the DPS-3 more reliable and available with high position holding accuracy. Even in the shallow water, DP system is used combine with anchor mooring system to provide position keeping ability in the case of anchor dragging. With a DP system on board, the drilling rig or drilling vessel could position to the worksite automatically, keep and change heading according to the operation requirement, would not necessary hire large power AHTS, as well as obtaining time saving. Figure 2-5 gives an illustration of the DP system arrangement on the drilling rig.

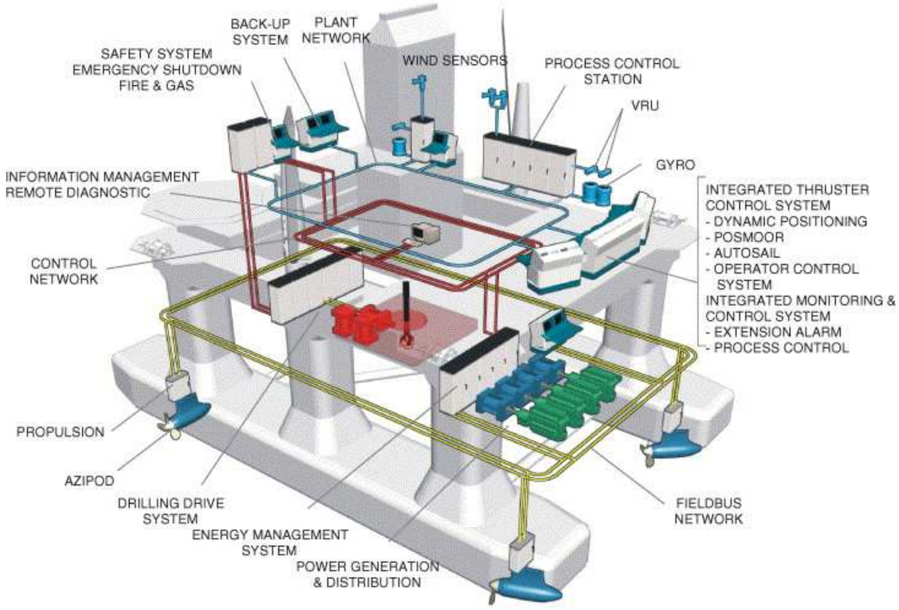


Figure 2-5 Illustration of the DP system on drilling rig (Sørensen, 2005)

2.3 The accuracy and reliability of the DP systems

2.3.1 Reliability of DP systems

Forsthoffer has said that the reliability is the ability of the equipment unit to perform its stated duty without a forced (unscheduled) outage in a given period of time (Forsthoffer, 2006). As the exploration and exploitation of oil and gas is further shifting to deepwater area, the requirements to the reliability of the DP system become significant important. In order to increase the availability and the reliability of the DP system, multiple redundancy hardware and software were designed and developed. The offshore industry currently measures DP reliability through a general classification system. Nowadays the DPS-3 class is widely equipped on deepwater drilling rigs and offshore supports vessels in order to get high reliability. The hardware redundancy takes the form of triple-redundancy including three operation stations. Both the hardware and software development widely increase the reliability of the system.

2.3.2 Methods to improve the DP systems' reliability

There are several methods that could be used to assess the reliability of the DP system:

- **Failure mode and effects analysis**

Failure mode and effects analysis (FMEA) belonging to qualitative analysis is most frequently used to assess and improve the reliability of the DP system. FMEA often the first step of the reliability assessment, it contains assessing as many components as possible to identify causes, and effects of the failure (IMCA M166).

The benefits of FMEA assessment

The benefits of FMEA are including the follows:

- Assurance that all failure modes and their effects are taken into consideration;
- Generating a list of potential failures accompanied with their effects;
- Assistance in developing the operation procedures and trouble-shorting direction;
- Basis for establish corrective actions;
- Developing early criteria for test planning and checkout system;

- **Fault tree reliability assessment**

A fault tree is a graphical technique that is used by operators to identify the chain of events leading to a specific event, normally a fault or failure. The fault tree is tailored to a particular failure of interest and models the probability of that failure. For a vessel with a DP system, the design worst case failure is normally fairly simple to identify and is commonly a switchboard failure (Reilly and Hensley, 2011).

2.4 The future trends of the DP systems

2.4.1 DP technology development

As the development of information technology, especially computer software represents a significant advantage for DP capacity calculations, according the environmental conditions which the vessel is facing during operation.

Following the development in DP hardware, software, weather reference systems, position reference systems, redundancy and FMEA and so on, the downtime of the DP system due to the weather is easy to be predicted. And the vessel's true excursion could be monitored by the DP operator, which could give advance warning to the operator.

With the demands of the DP vessel owner and its operator, thruster technology makes rapid developments. Comparing with the tunnel thruster, azimuth thrusters provide added advantages for DP vessels, which could provide 360 degrees of propulsion for the vessel both at bow and stern.

For decades of years passing, DP systems have become much more sophisticated, however the higher reliability and safety characteristics are provided by a sophisticated system at the same time.

2.4.2 Main challenges affect future design of DP systema

Green DP-system design

Many efforts have been made on the DP technology in order to get the vessel "greener". The environment compensator and the predictive controller have been designed by Kongsberg, and employed on an experimental vessel; the fuel could be saved 20% as approved.

Bulb-bow, X-bow and Axe-bow, etc, i.e. multiple special hull designs have been used by modern DP vessels in the North Sea, which could release the resistance generated by the air and water.

Two engines instead of four engines, steaming fix at 80% or even lower, moreover, LNG propulsion systems have been used by some DP vessels instead of diesel engine propulsion systems. All of these above, make the DP vessel cleaner and greener.

Deepwater and arctic adaption

With the offshore oil and gas industry shifting to deepwater and even the harsh sea areas like arctic area, this generates more requirements on the DP system. Loads from the big waves, drift ice and ice floes, which will further complicate vessel motions, requiring more complex dynamics (Dev, 2012). They generate big challenges for DP vessel operations in those areas, which require continuous improvements of DP control systems, hardware and software systems, reference systems, thruster technology, power management system and so on.

2.4.3 Prospect of the DP system in the future

Over the decades of years (and which will also continue in the future years) efforts have been made to make sure that the reliable and safe operations of the offshore domain take place from various aspects. The DP system still remains vulnerable, indicating that power generation, power management, sensors, reference systems, control systems and other relevant parts have to possess a certain degree of standard and accuracy (Dev, 2012). DP technology is developing while it to some extent becomes more complicated. The market demands, the industry needs, as well as the stakeholder's requirements give the direction of safe and reliable DP technology development.

Chapter 3 DP system operations

3.1 Operations of DP systems on drilling rigs

3.1.1 DP drilling operations

DP rigs currently have the ability of operating in water depths of up to 3000m. DGPS is the most reliable form of position reference in this water depth. Two or three DGPS systems provide redundancy. Further position-reference is obtained from deep water Long Baseline acoustic systems or other reference systems.

A DP drilling rig which performs a drilling operation is illustrated in figure 3-1. Generally, there are four major components involved in DP operations, including power system, thruster system, DP control system, and DP operator. In normal operations the drilling rig should be positioned inside the yellow zone within a green zone area. When the rig loses the capacity to keep its position by thrusters, it may drift beyond the yellow zone or even reaching the edge of red zone and then drift-off occurs. At this circumstance, the drilling operation must be stopped and the drillers should prepare for disconnection, otherwise the DP operator could operate the rig back within the yellow zone. Emergency disconnection must be initiated in order to disconnect the risers and shutdown the well if the rig drifts off the red zone limit. If the disconnection is not a success, the riser, wellhead or the BOP will be damaged, which causes significant financial losses and rig downtime.

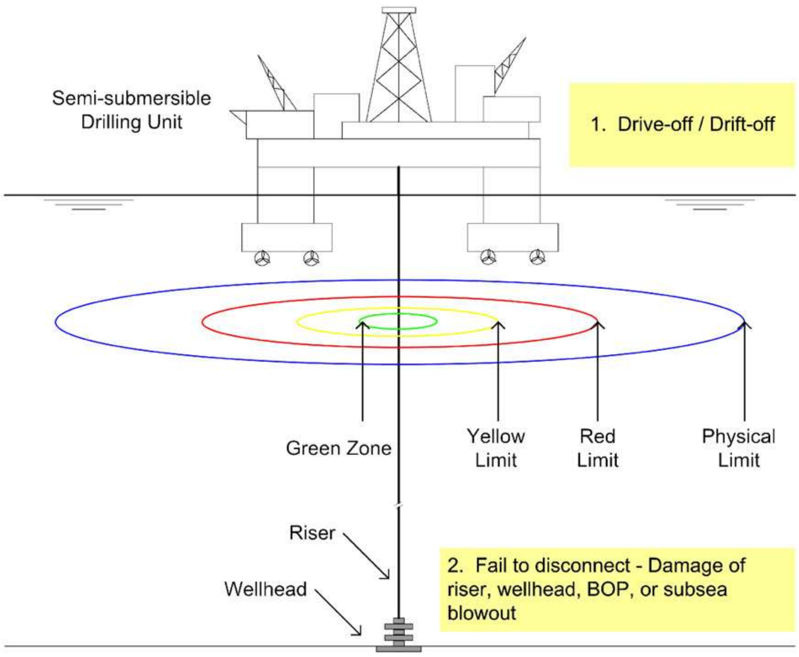


Figure 3-1 DP Drill rig operation limit zone
(Ref: Chen, Moan and Verhoeven, 2006)

3.1.2 Matters needing attention

The resistance to loss of position and the robustness of the recovery are the key parameters for safe dynamic positioning operation of a drilling rig. In order to find the effective way to improve the reliability of the DP system, both of the two parameters should be evaluated, especially during dynamic positioning operation in harsh water.

The relationship of the two parameters is shown in figure 3-2; there are two curves in the figure which show the acceptable and preferable safety level of a DP drilling operation. The low/medium/high levels of the two parameters are determined by a lot of factors, like the operational condition, the competence of the operator, and the condition of the associated equipment and so on.

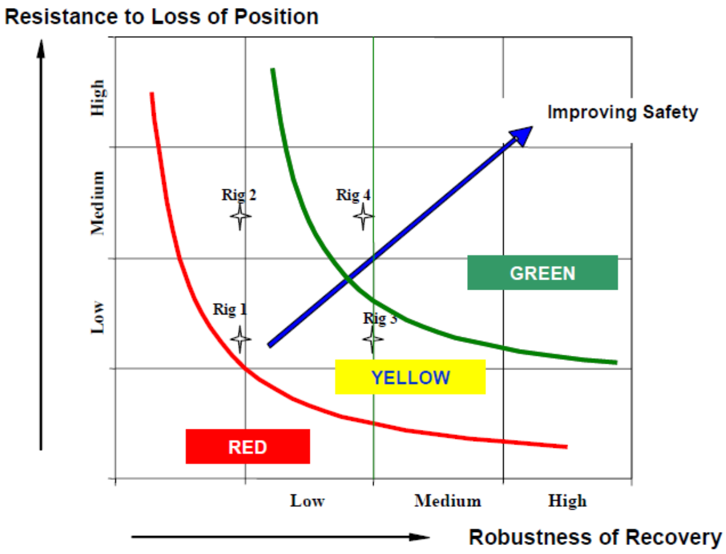


Figure 3-2 The relationship of two parameters (Ref: Chen, et al., 2006)

The DP system is actually a human-machine system, including control system, reference system, thruster system, power system, as well as the DP operator. For improving the safety operation of the system all these systems should be taken into account. The Rig4 shown in figure 3-2 is safer than the others, because she has more ability to resist loss of position and she has more ability to recover to her original position.

3.2 Operations of DP systems on OSVs

3.2.1 Diving and ROV support operations

The OSVs engage in diving and ROV support operations are always equipped with DP system. As these operations need the OSV one has to continuous keep the same

position for a long time, 3 to 4 days, sometimes even longer. The Captain could not manually operate the vessel for long time continuously at the same position. Thus the DP system is the most suitable system to settle this problem.
Although the task itself may be relatively less hazardous, to stay on location especially close to an offshore structure may be hazardous. A ROV or the diving system may directly deploy from a frame at the side or astern of the OSV. After the ROV or the diving system is deployed over side, then great care must be taken to ensure that the thrusters or the propellers are not fouled by the umbilical. To avoid this accident, DP operation mode could follow the target mode, using the ROV as the position reference.

3.2.2 Seabed tractors and trenchers

Before a pipe laying operation, the seabed needs to be trenched for a certain depth which is decided by the dimension of the pipeline to avoid damage by fishing nets or anchors dropped by other vessels. After the trencher has been lowered down to the seabed, attention must be paid to avoid the thrusters or the propellers being fouled by the umbilical attached on the trencher. The rotation center of the vessel could be aligned with the trencher in order to keep the pipeline deployed in the direction designed.

3.2.3 Pipe laying operations

Pipe laying operations are always to be conducted by an OSV equipped with a DP system. Generally, there are three methods for pipe laying, J-lay, S-lay, and reel-lay. For all of these methods, it is essential that tension is maintained on the pipeline. The DPO (DP operator) should operate the vessel carefully so that the distance moved ahead is equivalent to the length of the jointed pipeline being laid down. Once moving ahead, the pipeline joining operation on board could be conducted again. The tension on the pipe is used to prevent the pipe from buckling. If the tension in the pipe is lost, then the pipe situated at the touchdown area with the seabed will be damaged.
The DP system communicates with the pipe tension value to continuously provide commands to the thrusters to maintain tension, heading and position. As it not allows the vessel to weathervane, the DP system must be able to effectively cope with the weather condition and the sea state.

3.2.4 Rock dumping operations

Rock dumping vessels always have DP systems in order to accurately dump the rock on the seabed for some reasons. All these kinds of vessels working in the offshore industry are fitted with DP systems, because this operation requires that the vessel is having effective speed control so that a uniform distribution of the rock is possible. The Auto-track function of the DP system is commonly used in this operation, so that the vessel could track accurately along the direction of the pipeline route surveyed previously.

3.3 Integrated operations of drilling rigs and OSVs using DP

3.3.1 Introduction to operational situations

It is very common for dynamic positioning offshore vessels to operate and position themselves close to other vessels. For instance, an OSV conducts transfer of fluids and solids to drilling rigs, FPSOs; or shift personnel from the OSV to offshore facilities. Figure 3-3 shows a PSV using a DP system alongside a drilling rig which also has positioned itself by using DP system.

Figure3-3 Integrated DP operation between an OSV and a drilling rig

3.3.2 General requirement of integrated operation situation

When DP vessels are operating on DP close to one another, they are potentially subject to several forms of mutual interference. These include thruster wash, acoustic and radio position reference sensor signal interference and intermittent shelter from wind and sea. These factors should be considered when planning such operations.

This may take the form of assuming a less accurate position keeping tolerance than normally be expected. Co-ordination or choice of position reference sensors and frequencies and careful choice of the relative positions of the vessels are essential. One DP vessel should be given the co-ordination responsibility. (IMCA M 125).

3.3.3 DP OSV general operation procedures

The following DP OSV operation procedures will greatly reduce the risk of DP OSV loss of position. Normally it could be used in all operation circumstances. And the following procedures take an OSV approaching a drilling rig as the example.

- Arrival check: Before the OSV comes within 500m of the drilling rig the arrival check should be carried out to make sure that DP operation is satisfactory.
- Communication: Communications should be tested and verified prior to begin alongside operations.
- Approaching the drilling rig: The OSV should not approach the drilling rig without authorization.
- DP location check: These checks should be carried out at a safe distance from the drilling rig. The objectives are to assess the vessel's station keeping performance.
- Close alongside Time: Close alongside time at the working location should be kept as short as possible.
- Separate distance: The distance should be agreed between the vessel and the rig. The safe distance should be carefully selected.
- Safety working location: Every supply operation should select a safety working location. It is much more safe working on the lee side of the rig than the on the weather side.
- Safety working heading: The most suitable OSV heading to be selected should give the chance of the OSV to make a rapid escape from the drilling rig.
- Escape route: An escape route should be identified before conducting transfer operations.
- Critical and allowable excursion: The critical limit should not exceed half of the distance between the OSV and the drilling rig; and the allowable limit should not exceed half of the critical limit.
- Changes of position and heading: DPO should be aware of the dangers during the operation, small changes of heading and position are preferred (IMCA M182).

3.4 Dynamic positioning in ice covered water

3.4.1 The existing concepts and designs

In recent years, offshore oil and gas exploration and field development are increasingly focused on the Arctic waters. The U.S. Geological Survey (USGS) estimated that as much as 25 percent of all recoverable resources (oil, natural gas and natural gas liquids) yet to be discovered are to be found north of the Arctic Circle, see also the figure 3-4 below (Wassink, 2011).

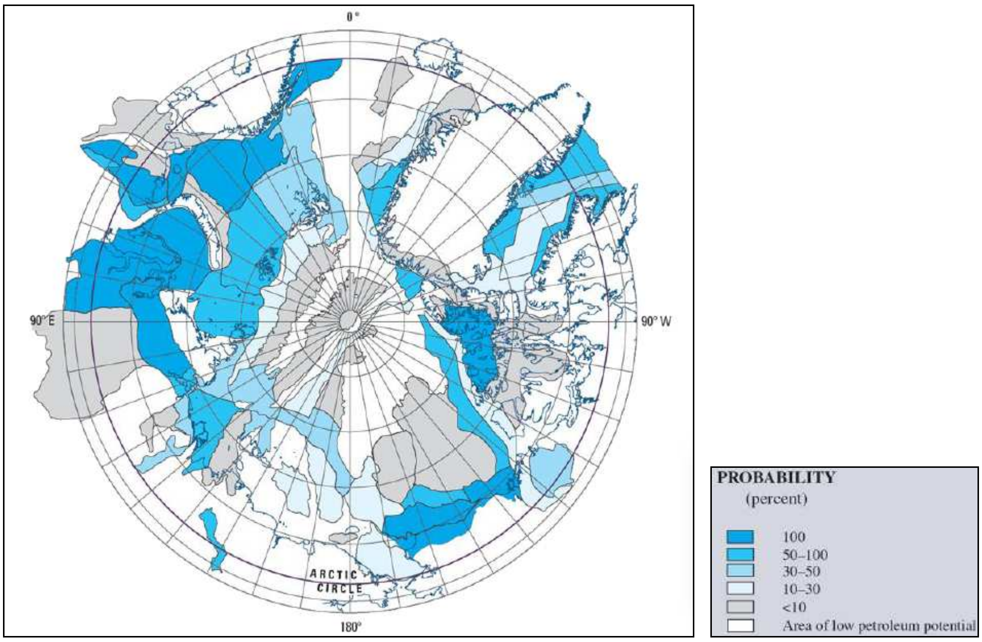


Figure 3-4 Potential of Arctic oil & gas reserves
(Ref: Wassink, 2011)

Others estimate that the Arctic contains more than one third of the world's undiscovered oil and gas reserves (Kuehnlein, 2009). At the same time, the Arctic also has the harshest environmental condition for offshore activities, for instance, the remoteness, extreme cold, dangerous sea ice, and a fragile environment.

There have been some examples of moored offshore installations in ice. However, there is very little operational experience regarding DP operation in ice. Even up to now, DP concept for continuous operation in ice dose not exists. Although the DP system is a mature technology widely used in the offshore industry in the open water, it is difficult to adopt this system for operating in ice covered area. Figure 3-5 shows an OSV operating in light ice covered area using DP system.

Figure 3-5 OSV conducts operation in ice covered area using DP system
(Ref: Jenssen et al., 2009)

3.4.2 Main challenges for dynamic position keeping in ice

There are several challenges for dynamic positioning system to be used in ice.
How to accurately predict the ice force is one of the most significant challenges. Ice thickness, concentration, size distribution of ice floes and drift velocity are known to be important factors regarding ice loads (Jenssen et al., 2009). The dynamics of the ice and the vessel's dynamics interact with each other, which makes the force of the ice on the vessel difficult to predict. In DP mode, and assuming the vessel is aligned with the ice drift direction, the thrust created by the propulsion of the vessel has to resist all the forces caused by the ice drift, which include not only the mean and oscillating force in the longitudinal x-direction, but also an oscillating force in the transverse y-direction and an oscillating yaw moment (Wilkman et al., 2009). That makes the vessel easily to drift off the position. The following figure 3-6 shows the forces in ice.

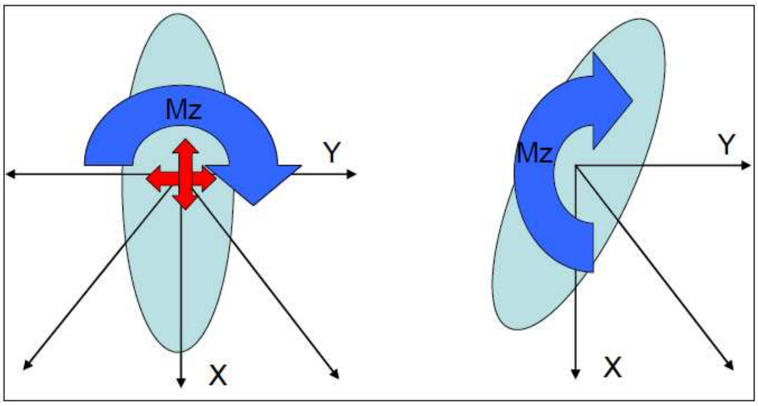


Figure 3-6 Force in ice (Ref: Wilkman et al., 2009)

Another challenge for DP system operation in ice is that rotating the vessel on the spot is not possible. Vessels in ice are not able to rotate on the spot, like would be possible in open waters. Figure3-7 illustrates the turning of a vessel in ice. As it can be seen the vessel has to move forward and backwards in order to rotate (Kuehnlein, 2009). For the vessel with bad design, much more space is required in order to rotate the vessel.

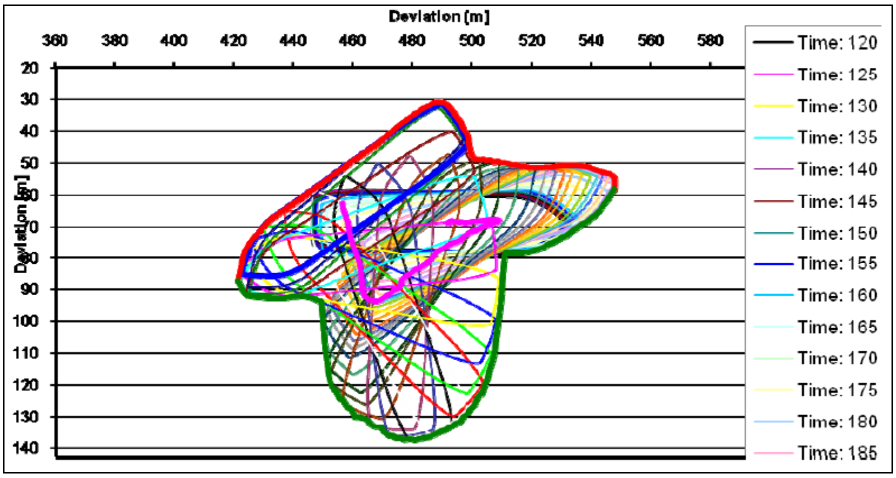


Figure 3-7 vessel rotating in ice with DP system (Ref: Kuehnlein, 2009)

Ice under the hull of the vessel is also a big challenge for DP system operating in ice. The ice floes propelled by the thrusters with high speed could create great harm to the hull of the vessel, as well as the equipment under the hull of the vessel, such as the acoustic transducers. Thus a well shape design of the hull is essential.

Even the cold temperature and the wind chill, will damage the wind sensor and other equipment of the DP system on deck, which may lead to the holistic system being out of work. Those challenges make DP concept for continuous operation in ice is not achieved.

3.4.3 New concept developments

Ice conditions vary from light to heavy, both speed and direction of drifting ice may change rapidly, as well as the challenges mentioned above, should be taken into account for a new concept DP system design. A new conceptual design includes the following features:

- Low ice resistance of the vessel at both bow and stern. This was achieved by optimizing the icebreaking hull shape, similar to the ones found on icebreakers.
- High ability to turn the vessel in ice in order to follow changes in ice drift. This was achieved by implementing a strong slope at the side of the vessel. This hull shape allows the vessel to break ice over the entire ship length. The azimuth propellers deliver the required thrust for turning the drill ship.
- The vessel is able to operate in ice without icebreaker assistance up to very severe ice conditions (Kuehnlein, 2009). With icebreaker assistance, the operational limits of the vessel can be extended even further.

3.4.4 Logistic of ice management

A DP vessel's station keeping capability can be increased through ice management. The aim of ice management operation is to decrease the severity of ice condition level which the DP vessel is operable. In practice, before the ice approaching the DP vessel the blocks should be broken into small ones, which could prevent the DP vessel from drifting off position due to the collision of the big block of ice.

The role of ice management is critical, because the station keeping capability of the DP vessel is limited in ice. In order to provide sufficient ice management intensity and effect, normally more than one ice management vessel is needed. The bigger ice management vessel will be arranged further from the DP vessel, and the small or equal large ice management vessel will be arranged near the DP vessel. The ice management vessels cooperate to break the ice smaller, and decrease the dynamical behavior of the ice against the DP vessel. Figure 3-8 illustrates the arrangement of the ice management vessels.

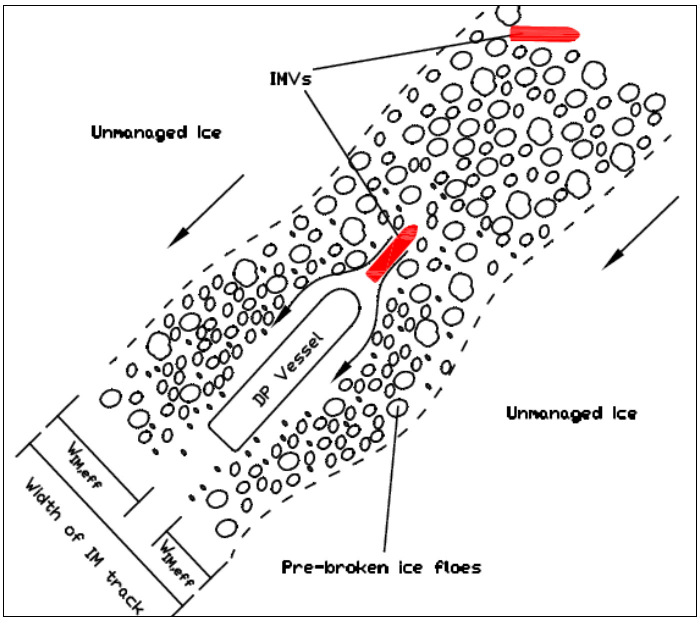


Figure 3-8 Ice management performed by two IMVs (Ref: Wilkman, et al., 2009)

Chapter 4 DP system management

4.1 Associated DP systems

4.1.1 The definitions of the components of DP systems

- DP control system：The DP-control system consists of the following sub systems: dynamic positioning control system; sensor system; display system; positioning reference system; and associated cabling (Lloyd rules).
- Positioning reference system: This system provides the whole DP system position reference data, which the DP system use for relative position calculation, such as DGPS system, taut wire position reference system, and acoustic position reference system.
- Power system: All components and systems necessary to supply the DP-system with power. The power system includes the followings: prime movers with necessary auxiliary systems; generators; Switchboards; uninterruptible power supplies and batteries; distribution system; power management system (Lloyd rules).
- Thruster system: Generally, there are two kinds of thrusters used by the DP system: tunnel thruster and azimuth thruster. An azimuth thruster could provide forces in 360 degrees. Besides the thruster itself, the thruster system also includes the control part, and power supply part.

4.1.2 Operational requirements of DP system

The DP system should be checked before every DP operation in order to make sure the system is working correctly. During the DP operation, the system should be checked periodically. When the external weather condition forces the vessel or the installation off the position continuously, then DP operation should be terminated. During the DP operation, the DP operator should fulfill the location check list and watch the check list. If for long term positioning, the position check should periodically be carried out. Annual tests should also be fulfilled to make sure the normal working status of the whole DP system.

4.1.3 DP system testing

Normally, a DP system test is including initial survey, interval survey, and annual survey.

Initial survey includes the complete test of all components and systems and the

ability to keep position after single failure associated with the assigned equipment class; the interval of periodical surveys should not exceed five years to make sure the system is in good working condition; the annual survey should be carried out within three months before or after each anniversary date of the initial survey (IMCA M113).
All this tests should be documented and approved by the authorities. These tests are carried out to make sure that the system is properly maintained and that all the components are in a good operating status.

4.2 Emergency situations during the DP operation

4.2.1 OSV/MODU off the position

The most significant risk relevant to DP operations is loss of the position control ability. For the MODU, loss of position without safe disconnection could result in critical damage not only to the well, but also to the subsea equipment. For an OSV (offshore support vessel), loss of position will lead to collision with the installation nearby during operation or damage to the subsea facilities. Figure 4-1 shows the proportion of the loss of position incidents from year 1994-2003. From the figure below, we can clearly get the information that failure of the position reference system and human errors are the main causes for DP incidents.

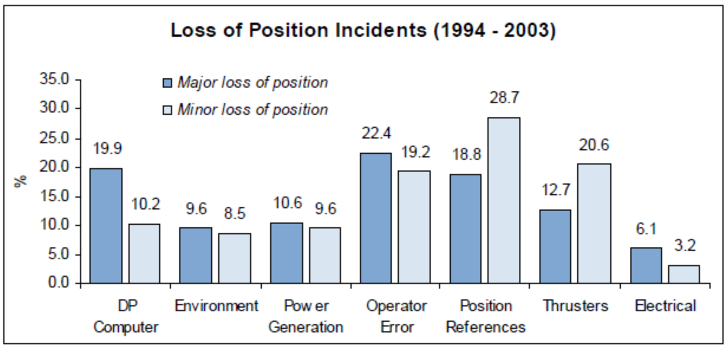


Figure 4-1 DP incidents causes (Tjallema, 2007)

Normally, there are two basic failure modes for loss of positions; they are drive-off and drift-off. For drive off, the OSV/MODUs go off position by their own thrusters force, because inaccurate position data are received, which lead to the DP system drives the installation to the wrong position. For drift off, the force generated by thrusters could not resist the external environmental force; the installation will drift off its original position by the force of the wind, waves as well as the currents.

4.2.2 Influence factors for loss of position

There are three main influence factors that will significantly influence the position keeping ability of the DP system. They are environmental factors, the dynamic positioning system, and the DP operation associated personal.

The environmental condition: The environmental factors of wind, wave, and current, directly influence DP vessels' resistance to loss of position. Possibility of sudden changes of wind and current direction, and possibility of certain atmospheric conditions that influence the GPS, these are at least the factors to evaluate (Verhoeven et al., 2004).

Dynamic positioning systems: The characteristics of the DP control system; the status of the positioning reference system, the status of vessel sensors play significant contributions to resistance of loss of position.

DP associated person: Verhoeven said that the action of DP personnel may directly lead to loss of position of the DP system, or they may interact with the technical failure both contributing to loss of position. The following elements affect the human actions: training, certification, operation experiences, knowledge about the DP system, work attitude, teamwork spirit and so on. Besides, lack of competence may also lead to wrong system operation.

4.2.3 Emergency quick disconnect of the MODU

Normally the rig manager, according the information provided by the DP operator, decides whether or not to initiate the EQD (Emergency quick disconnect), manually or automatically. In most of the situations, automatic is the first choice. However, in order to get more time for response and increase the reliability of the disconnection system, the manager may also decide to initiate the EDQ manually.
The time from initiating the EQD to completely disconnect is critical important (Bakken and Smedvig, 2001). To reduce the disconnection time is significantly important for a successful disconnect operation. An improved disconnection system has been developed in order to reduce the time of the disconnection.

4.2.4 OSV response when the rig looses position

Most DP OSV shall be equipped with DP class 2 or DP class 3 systems. And almost all the MODUs are equipped with DP class3. However, for the highest safety the DP system must be available all the time for all operations.
Great care must be paid when operating DP OSV in close proximity to a drilling rig which also is positioning herself by a DP system. Thruster wash, environmental

sensors, and positioning reference signals will interact with each other significantly. This circumstance causes less accurate position-keeping than expected normally. Coordinated and careful choice of relative position between the OSV and the drilling rig are important. The movement of both the OSV and the drilling rig may be unsynchronized due to movements of the DP reference sensors, which may lead to an increased risk of collision.

The Captain or the DP Operator on the OSV should be familiar with the special conditions during operations and great precaution should also be taken. Especially during the moment that the drilling rig is losing the position. The following actions should be taken by the OSV under this circumstance：Terminate operations and move away from the drilling rig; safely moving in joystick or manual control when the position is lost during the supply operations.

4.3 Safety assurance for the OSV/MODU and the personnel

4.3.1 Methods to protect the DP OSV/MODU

System redundancy: Redundancy is designed to ensure that the DP related equipment are always being available, which reduces the probability of the DP installation's loss of position and protect the installation from damage (DNV-RP-E306). The minimum redundancy requirements of the DP systems are shown in table 4-1.

Table 4-1 Minimum requirements for DP systems

(Lloyd rules: Rules for classification and construction)

<table>
<tr><th colspan="3" rowspan="2">Subsystem or component</th><th colspan="5">Minimum requirements for Class Notation</th></tr>
<tr><th>DP 0</th><th>DP 1</th><th>DP 2</th><th colspan="2">DP 3</th></tr>
<tr><td rowspan="6">Power system</td><td colspan="2">Generators and prime mover</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="2">Main switchboards</td><td colspan="2">1</td><td>2</td><td colspan="2">2 in separate compartments</td></tr>
<tr><td colspan="2">Bus-tie breaker</td><td colspan="2">–</td><td>2 NO [1]</td><td colspan="2">2 NO</td></tr>
<tr><td colspan="2">Distribution system</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, through separate compartments</td></tr>
<tr><td colspan="2">Power management (see 2.5)</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="2">UPS for DP control system</td><td>–</td><td>1</td><td>2</td><td colspan="2">2+1 in separate compartments</td></tr>
<tr><td>Thruster system</td><td colspan="2">Arrangement of thruster</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments, provided WCF is not exceeded</td></tr>
<tr><td colspan="3">DP-relevant Auxiliary Systems</td><td colspan="2"></td><td>Redundant [2]</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td rowspan="2">DP-Control system</td><td colspan="2">No. of computer systems</td><td colspan="2">1</td><td>2</td><td colspan="2">2+1 in separate compartments</td></tr>
<tr><td colspan="2">Independent joystick with auto heading</td><td>–</td><td>1</td><td>1</td><td colspan="2">1</td></tr>
<tr><td rowspan="4">Sensors</td><td colspan="2">Position reference systems</td><td>1</td><td>2</td><td>3</td><td colspan="2">3 whereof 1 connected to back-up control system</td></tr>
<tr><td rowspan="3">Vessel's sensors</td><td>Wind</td><td colspan="2">1</td><td>2</td><td>2</td><td rowspan="3">One of each connected to back-up control system</td></tr>
<tr><td>VRS</td><td colspan="2">1</td><td>2</td><td>2</td></tr>
<tr><td>Gyro</td><td colspan="2">1</td><td>3</td><td>3</td></tr>
<tr><td colspan="3">Essential non-DP systems [3]</td><td colspan="2">–</td><td>Redundant</td><td colspan="2">Redundant, separate compartments</td></tr>
<tr><td colspan="3">Printer</td><td colspan="2">Yes</td><td>Yes</td><td colspan="2">Yes</td></tr>
<tr><td colspan="8">[1] NC bus-tie breakers may be accepted depending on the findings of the FMEA and additional testing (NO = normally open, NC = normally closed)
[2] when active components are used
[3] see Section 2, B.6</td></tr>
</table>

Safe working limit: When determining safe working limits, OSV shall consider the time necessary to change the mode of operation from DP to manual and/or joystick control while bearing in mind that position loss is always possible, the likely speed of position loss and the increased position excursion after the worst known failure condition (UKCS-MAL-001, 2010).
Safe working limit must be kept to prevent collision and other incidents.

A safe working location and working limit should be kept between the OSV and the installation. The distance may change according to the operational environment and other external factors. The location should be at the lee side of the installation if possible. The OSV should be operated at a safe speed when inside the 500m zone of the installation. And the speed should not exceed 0.5knot in the 500m zone to avoid collision.

4.3.2 Methods to protect personnel

Keeping communication: It is very important to keep effective communication between all the responsible parties during DP operations. This communication should be available at all the time. The parties should involve: DP operator, deck crew, engine control room; offshore installation; crane operator; as well as the other vessels or installations nearby. In the case of the emergency, all the personnel involved during the supply operation should be informed at once. The deck crew should first move to a safe place and then take associated actions according to the order from the OSV and the installation to avoid injury.

Associated responsibility: All the personnel who works on the OSV or the installations associated with DP operations should be aware their responsibility. The following personnel's responsibility should be defined in the safety management system of the company: master, chief engineer, DP operator, watch keeping engineers and DP technician. Those personnel should be responsible for the duty of both the DP OSV and the installation. The responsibility of those personnel should be monitored by the company's manager of the DP department to ensure that all the personnel fulfill their responsibility properly. It is fundamental for safe operations of the DP vessels.

Personnel certificated: All personnel involved in DP operations shall as a minimum meet the minimum competence requirements. The personnel who conduct DP operations within the 500m zone of the installation should hold a valid certification issued by the relevant authority. The DP operator first on board a DP OSV or installation should get familiar with the DP system on board this OSV or installation before they conduct supply or positioning operations.

4.4 Improve the reliability and availability of DP systems

4.4.1 FMEA analysis methods

The guideline of IMCA M166 define FMEA as "a systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them" (IMCA M166).

When talking about DP systems on board the OSV or other installations, the objective is to develop such a system which can not only keep position when meeting with the undesired circumstances, but also can allow the faults be corrected when they occur.
The FMEA can be carried out either by starting from the components level and then expending to system level, which can be called the bottom up approach, or be starting from the system level downward to the components level which can be called top down approach.

It is a general rule to expand the analysis down to a level at which there is a good understanding of the failure mechanisms, the failure rates and the failure impacts. However, it is often necessary to make compromises regarding the detail to which the analysis should be conducted, since the workload could be overwhelming even for a system of moderate size if the details of the approach are taken to the individual part level (Eriksen et al., 1999).

4.4.2 Power and thruster reliability and availability

An FMEA of a power system on board an OSV or a mobile installation, especially when it is done at the design phase can lead to better reliability and availability of the power system (Fougere, 2005). And the benefits can be achieved from the followings measures:
The system arrangement of the system can be optimized through FMEA. Taking the power supply to the thruster auxiliaries for example, the design of the right one in figure 4-2 is more secure than the left one concerning the power supply to the auxiliaries of the thruster.
A FMEA can identify the common causes of failure for the system, thus providing an easy way to identify which components of the system need to be redundant, according to the failure frequency of the component.

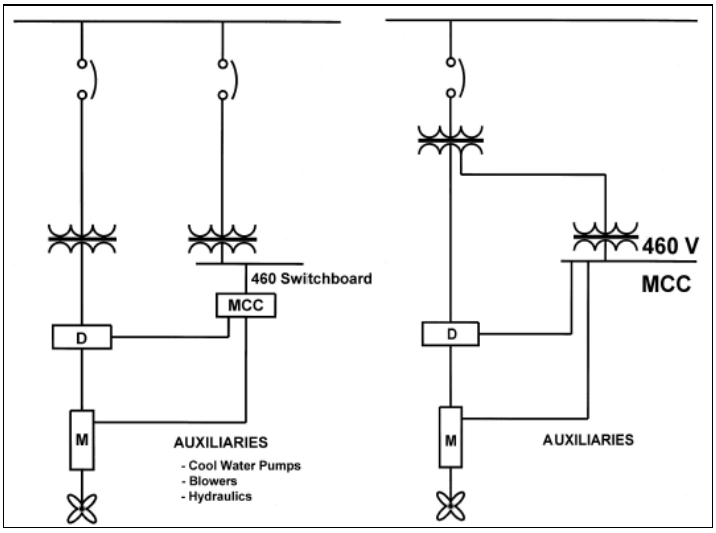


Figure 4-2 Two different design of the power supply to the thruster (Fougere, 2005)

However, some issues concerning the robustness of the DP system for example the operational features and the system performance criteria could not be reflected through FMEA (Fougere, 2005). During DP operations, equipment working parameters should be logged, with a smart analysis software, the data could be analyzed to detect the working condition or fault causes of the equipment. Monitoring and periodically testing the redundancy system can also help to reduce the down time of the system.

4.4.3 DP operators

A competent DPO or a well-trained DPO could be able to quickly react on a failure event and take measures to stabilize the OSV or the MODU to avoid a more serious situation.

The competent DPO should hold the following skills: Understanding the performance limit of the OSV or the rig, and how to operate the OSV or the rig at the limiting situation; understanding how to quickly and accurately identify signals, and mitigate the negative effects to the position keeping ability of the OSV or drilling rig. In order to perform correctly, a DPO requires a broad range of knowledge. The DPO must have detailed understanding of the equipment and systems which affect the DP system or are affected by the DP system.

4.4.4 Weather effects on reliability

As oil exploration moves into the harsh environment, deepwater, ultra deepwater, and even the Arctic area, failures to hold position in bad weather have been an occasional problem.

A heavy weather condition creates a big challenge for the DP system keeping positioning of the OSV or the drilling rig, even equipped with DP3. Strong wind associated with big waves pushes the vessel or the rig off the position, when the force generated by the thrusters is less than the force created by the outside environment.

The position reference sensor or the local position reference system will also be affected by the bad weather condition. The effect of the vessel motion means that the bearing and distance measured by the local position reference system is suffering constant changes. As for the heave motion of the vessel, the compensation action will be delayed, which leads to the position reference system becoming less accurate or even fail to function normally.

When operating the OSV or the drilling rig in an ice covered area which have been mentioned above, the forces generated by the ice acting on the hull generate a big challenge for the position keeping system.

The equipment of the DP system should be more redundant when operated in a heavy weather condition to increase the reliability of the system. An accurate position reference system should be used and even a motion reference unit to reduce the time lag of the compensation. Detailed risk analysis should be conducted before and during the DP operation. If the vessel could not keep the position no longer, safety measures should be taking as early as possible to avoid collision with the installations; and emergency disconnection should also be taken into consideration by a drilling rig.

Chapter 5 Risk analysis of DP operations

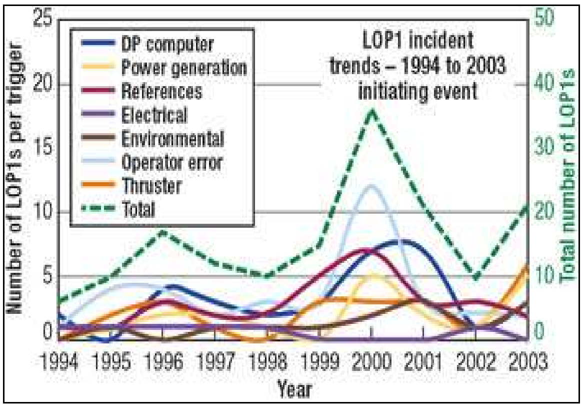
5.1 DP incident introduction

5.1.1 DP incident category

Dynamic positioning operations have been performed from the 1960s and during more than 50 years of DP operations, there has been much knowledge about the operation and the associated risk. During these decades, there also have occurred many incidents, which provide us lots of experiences that can be learned from to avoid those same incidents occurring again.
The incident data can be divided into two categories according to their severity level: major and minor loss of position.
And the causes that lead to loss of position are divided into the following: DP computer fail; Reference sensors fail; Power generation fail; Thruster system fail; Environment (wind, wave, current); Operator error (DPO, electrician, master).

5.1.2 DP incident statistics

There are a total of 371 incident data occurring over a period of about ten years from 1994 to 2003, with 158 major and 213 minor position losses (IMCA M181). And the causes' distributions are shown in figure 5-1.



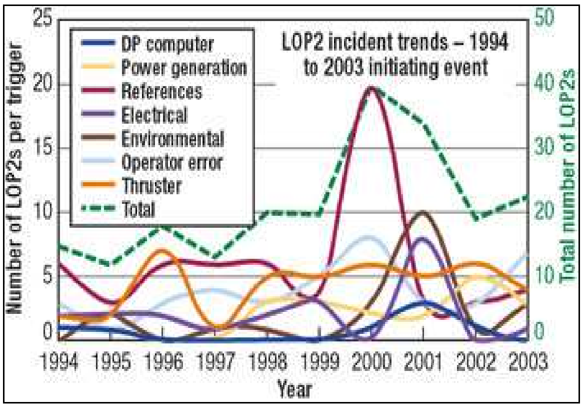


Figure 5-1 Number of the DP incidents causes by different reasons (IMCA M181)

For the total number of accidents which is indicated by the green dashed line, the number of less serious accidents is more than the number of the serious accidents. The figure also shows that the total number of the accident no matter major or minor is slowly increaseing, that because the increase in the number of DP vessels. The number around the year 1999-2001 is high, mainly caused by operator errors and the failure of the reference system (DGPS). The large number of operator errors in DP incidents means that reducing the amount of operator related DP incidents would significantly increase the safety and reliability of DP operations (Tjallema et al., 2007). Through normalization of the data for various activity levels, we find that operator error, fault of reference system and fault of DP computer are the dominating causes for the accidents.

5.2 DP Operation alert

5.2.1 DP operation alert status

Commonly the concept of red, yellow, and green operation status is used in the offshore industry. The operator, master or other relevant crew will be alerted when the operational status level changes, then an appropriate reaction should be taken to resume the DP system to normal operation status (green), otherwise an incident will be generated.

5.2.2 DP alert response

When the operation status is green which indicates that the system is normal, no actions need to be taken. When the operation status shows yellow that indicates the system is being degraded, then a risk assessment needs to be carried out and actions need to be taken.

When the operation status shows red status, this indicates an emergency situation and saving actions should be taken to prevent persons from injury, avoid collision, environment pollution as well as structure damaged. Figure 5-2 shows the operator reaction model when loss of position.

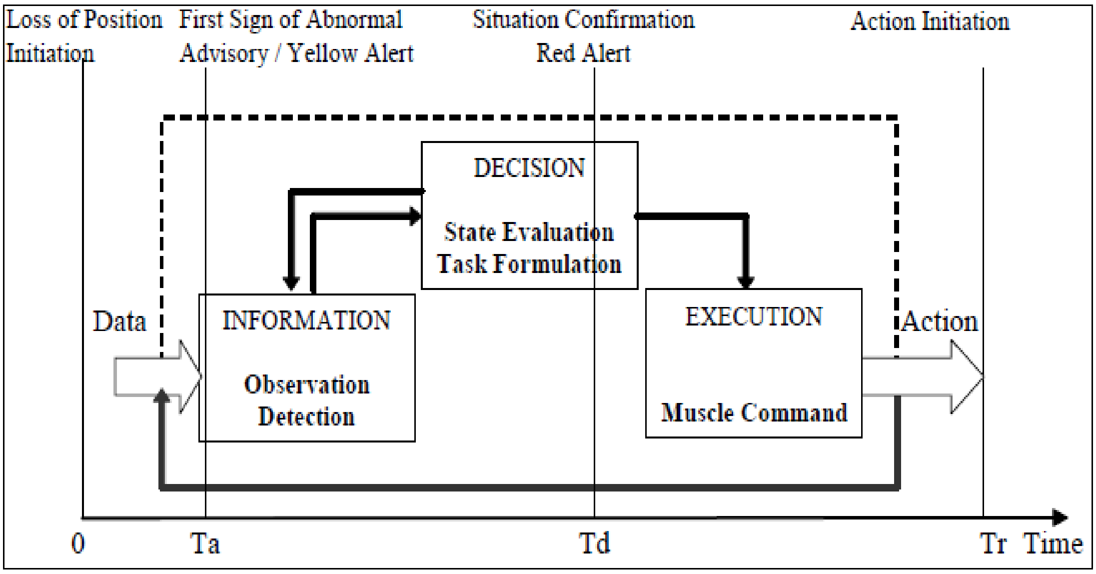


Figure 5-2 Operator reaction model when loss of position (Verhoeven, et al., 2006)

5.3 DP operational risk assessment

5.3.1 Risk assessment introduction

Every DP vessel or installation should have its own risk assessment procedure, and risk assessments should be carried out for all DP operations. For the DP OSV or the installation operating at the same offshore location, risk assessment should be carried out for every operation. Factors that are affecting the risk during the close situation (OSV alongside the installation) should especially be taken into full considerations.

The factors needed to be taken into consideration when carrying out risk assessment during the close situation are including: capability of the DP OSV; size of DP OSV and the offshore installation; supply operation; sea state conditions; current conditions; visibility; other installations nearby, and so on. Consideration of these factors could dramatically reduce the collision risk with the installation.

5.3.2 DP operation risk identification

Risk identification is the first step in risk assessment process.

Identification example: one of the bow thrusters of a DP OSV is in failure, which

causes degradation of the system. The OSV is alongside (at the weather side) of the drilling rig. The most significant point of this situation is that there is only one bow thruster providing force to push the bow of the OSV against the force of the external condition. The thruster redundancy is lost, thus there is a significant risk for the OSV at this situation.
Identification example: the DP control onboard a DP OSV is in failure during the transfer operation. The most significant point of this situation is that the vessel could no longer be controlled in a DP mode. Then the conventional OSV control model (manual or joystick) should be considered as the alternative to the DP control. The loss of DP capability is a significant risk for the OSV at this situation.

5.3.3 Hazard severity

The severity of the risk can be divided into the following categories, shown in table 5-1.

Table 5-1 Risk severity categories and associated consequences

Severity	Consequence
high	Major damage to the facilities /environment; people death
medium	Minor damage to the facilities / environment; people inquired
low	No damage to the facilities / environment; no people injured

The failure of the bow thrusters leads to the OSV being unable to control the heading and its position. Finally the OSV will loose the position with the risk of collision with the drilling rig. The severity of this risk could be medium or high. The failure of the DP control is likely to lead to OSV auto positioning failure, however the vessel still can be controlled manually, and moving the vessel clear of the drilling rig could be possible. The severity of this risk likely could be low.

5.3.4 DP operation risk matrix

The risk ranking for the DP vessel position keeping ability can be determined by the risk matrix below, which divides the risk into three ranks, they are: acceptable risk, risks where it is required to take actions, and unacceptable risk. The ranks are determined by both the severity and the likelihood of the risk associated. Figure 5-3 shows the matrix of the risk.

Severity	Likelihood		
	unlikely	possible	probable
high			
medium			
low			

Figure 5-3 Risk matrix illustration

When the severity is high and the likelihood is possible, the associated risk is considered unacceptable. Then, risk reduction measures should be carried out to reduce the risk to the acceptable level. For OSV loss of one of its two bow thrusters, this is an unacceptable risk, it should move clear from the drilling rig to reduce the risk to acceptable level. With the severity being low and the likelihood being possible, the associated risk is considered acceptable; however reasonable measures should also be taken to reduce the risk as low as possible.

5.4 Barriers prevent loss of position

5.4.1 Barrier mode concept

Barriers should be established to reduce the possibility of the occurrence of a failure, a hazard, and the accident. The barriers could prevent the occurrence of the next event in the event chain, and thus reduce the occurrence probability of the accidents.

Normally, the function of the barrier include: reduce the likelihood of the hazard; limit the duration of the hazard; reduce the severity of the hazard (Chen et al, 2009).

5.4.2 The elements of the barrier mode

Barrier elements are used to fulfill the required barrier function. The barrier elements contain technical aspects and operator aspects. The technical factors, human factors, and organization factors influence on the elements of the barriers. Figure 5-4 gives an illustration of the barrier concept.

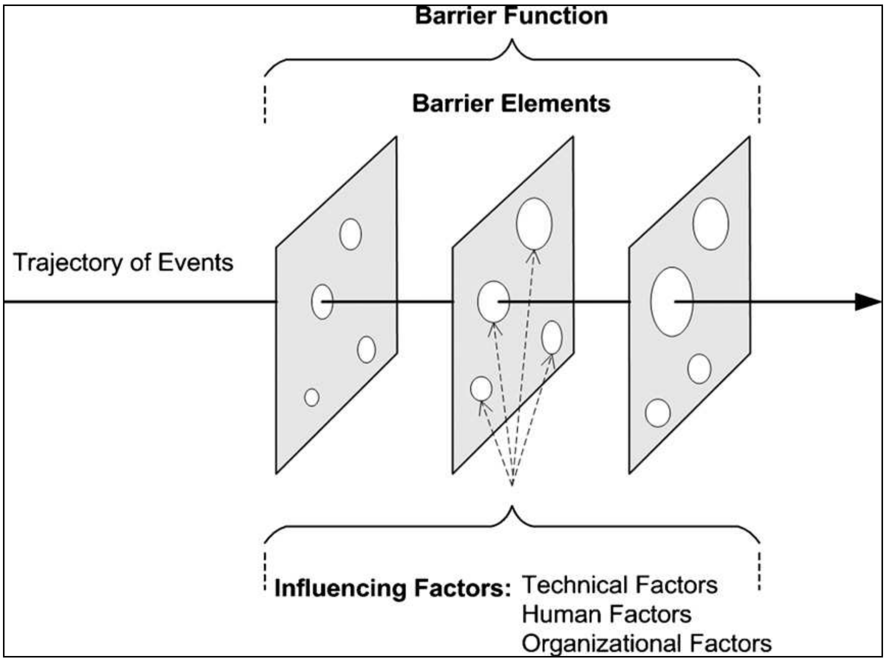


Figure 5-4 Barrier function, barrier elements and influencing factors (Chen et al., 2009)

5.4.3 Barriers to be established to enhance position keeping

Critical causes lead to loss of position.
The failure of the position reference system (DGPS) is found to be the most critical cause leading to the DP OSV or DP drilling rig loss of their position keeping capability according to the DP incident statistic from the NCS (Chen et al, 2009). DGPS (differential global position system) sometimes generates inaccurate position data, which are sent to the DP software. DP software uses this mistaken data for position calculation, which leads the DP OSV or DP drilling rig to move to the wrong position and exceeding out of the yellow limitation eventually. Thus, barriers should be established to prevent DGPS generate inaccurate data, further prevent those inaccurate data being used by the DP software, and finally prevent the vessel or the rig from moving out of the yellow limitation. Figure 5-5 shows the barrier function and events needed to prevent a failure.

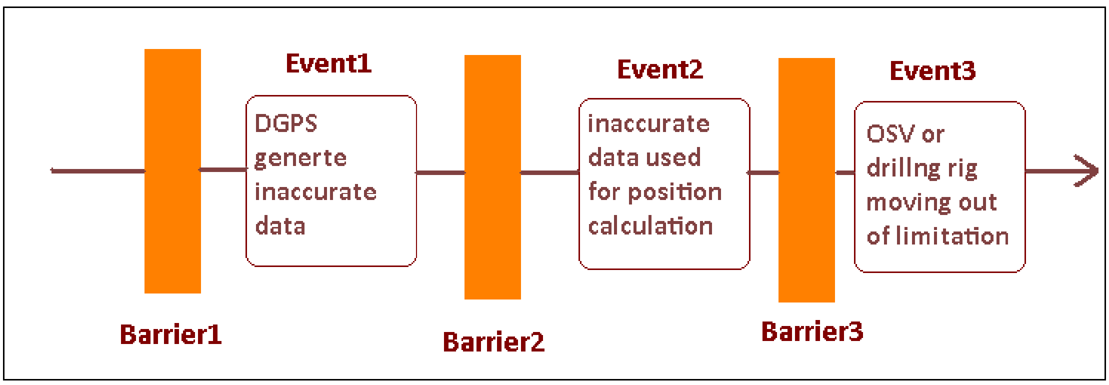


Figure 5-5 Barriers used to prevent the events

Barriers to prevent DGPS generate inaccurate data.
Independence between two DGPS data is important to prevent the DGPS generate inaccurate data. The lack of independence between two DGPS data in the DP system, may lead to the system loss of position reference redundancy, when one of the two or both of the two DGPS data are generated in error. Regular inspection and analysis should be carried out to make sure that the two DGPS are independent. The independence between two or more DGPS data in the DP system could reduce the probability of the DGPS generating inaccurate position data. Proper antenna position could also improve the accuracy of the data used for position calculation. If the location of the antenna is not proper, interference will occur, which generates errors into the DGPS. Then inaccurate position data will be output by the DGPS. Corrections need to be carried out to optimize the antenna location.

Barriers to prevent inaccurate date being used for position calculation.
Data output quality control function is widely used to increase the accuracy of the data being used by the DP software (Chen et al, 2009). If one or more quality control parameters are out of limitation, the DGPS would stop output data to the DP software for position calculation. And the DGPS will alert the DP operator through vision or sound alarm if accurate data output are terminated. Besides, More than one position reference system should be used at the same time with different working principles. Taut wire position reference system and acoustic position reference system could be used together with the GPS system to increase the validation of the data for position calculation.

Barriers preventing OSV or drilling rig moving out of limitation.
If the DP software uses inaccurate data for position calculation, the vessel or the drilling rig may have the potential risk of moving out of the green circle to the yellow limitation. Thus barriers should be established to prevent the movement of the installation exceeding the yellow limitation. The DP operator should get enough training so that they can react quickly when drive-off appear. The operator should be trained to be very familiar with information used to judge the installation’s loss of position or not. Base on the judgment, the DP operator could take associate reaction procedures to prevent the movements. On the other hand, the DP operators shall be given systematic training on various system alarms to increase the ability to evaluate what actions need to be taken to deal with the alarms.

5.5 Loss position HAZOP analysis

HAZOP is a risk analysis method used for identifying hazards and problems which will prevent efficient and safe operations. It was initially developed to analysis chemical process systems, but it has been extended to be used for other systems and operations. The HAZOP analysis procedure is shown by figure 5-6 below:

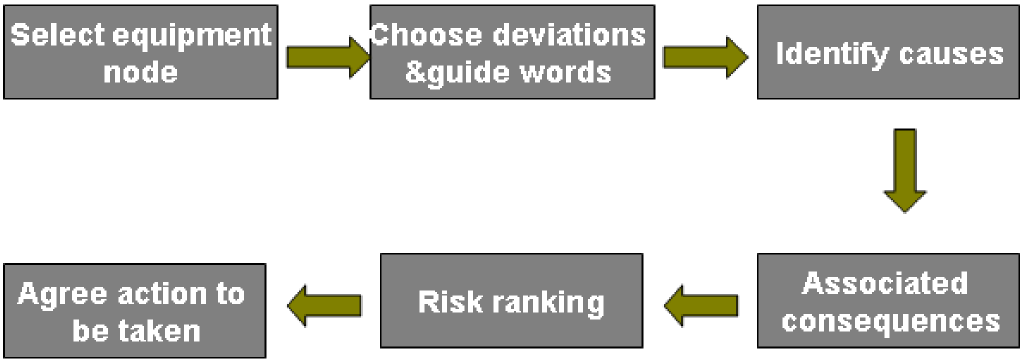


Figure 5-6 HAZOP analysis procedure

Loss of position of a floating installation would easily lead to collision with the other installations nearby, or lead to damage to the risers and wells, and may further lead to severe pollution accidents. Thus, it is very important to analysis the position keeping system in order to take pre-actions to prevent loss of position.

HAZOP is one of the most commonly used techniques in the offshore industry (Ambion, 1997). Dynamic positioning system can be analyzed through HAZOPs to identify the potential risk during a normal operation. For example, the risk of loss of position for the DP vessels could be analyzed as shown in table 5-2 below.

Table 5-2 DP loss of position HAZOP analysis

Equipment node	Guide word	Deviation	Possible causes	Consequence	Recommendation
Position reference	none	Total failed	1)Power supply off; 2)satellite failure; 3)device out of work; 4)device damaged	1)Loss of position; 2)environment pollution	1)more position reference; redundancy with different work principle; 2)properly protect outer part of the device from damaging; 3)emergency power supply
	less	Position data with large error	1)antenna signal damped; 2) calculation part error; 3)interrupted with each other	Moving out of limitation	1)check the antenna regularly 2)regularly system self test; 3)proper satellite or transponder position
	more	Do not get proper signal occasionally	1)Maintenance defect; 2)transponder	1)Large thrusters load; 2)high fuel	1)regularly maintenance by specialist;

			contaminated; 3)system disorders; 4)system setup error	consumption; 3)less position control accuracy; 4)degradation of DP operation status	2)check the satellite and transponder working condition; 3)restart the system; 4)properly system setup
Power station	less	No power supply	1)Fuel run out; 2)Fire alarm generate; 3)switch-board burn out; 4)All generators out of work	1)loss of position; 2)collision with other installations; 3)environment pollution	1)enough fuel for daily consumption; 2)establish emergency response procedure; 3)the emergency generator available at any moment
	more	Insufficient power supply	1)damaged of power cable; 2)one of the generator shut down; 3)one or more power route blocked up	1)moving out of limitation due to insufficient thrusters force; 2)lower position keeping accuracy and reliability	1)regularly power supply system checkup; 2) generator maintenance regularly according to the PMS
Thruster	Almost none	All thrusters shut down	1)no power supply; 2)control station error; 3)power switch board out of work; 4)main power cable erosion	1)loss of position; 2)collision with other installations adjacent; 3)environment damage	1)regularly thruster system check up; 2)establish thruster working status monitoring system; 3)redundancy power route setup
	less	One or two thruster out	1)partly power route blocked up;	1)lower position	1)fulfill the check list before

		of work	2)electrical signal blocked from input to control station	keeping ability and reliability; 2)loss of position may occur	operation; 2)redundancy power route setup; 3)electrical signal checkup before input to DP control station
	more	Thrusters working abnormal	mechanic part fail of the thruster itself	1)out of work of the thruster; 2)lower DP system position keeping capacity	1)thruster maintenance according to the requirement; 2)get ready of the spare part
Sensor	less	1)sensors not working in system 2)heading indicating error 3)thrusters force output hardly balance with the external force	1) Failed of the sensors signal input 2)gyro compass working abnormally or failed	1)lower DP position keeping ability 2)loss of heading keeping ability 3)loss of position	1)regularly sensors working condition checkup 2)redundancy of the gyro compass 3)equip sensors with different working principles
	more	1)Wind sensor damaged 2) electrical signal could not receive by DP control station 3)sensors working disorder	1)hash external weather condition 2)wrong sensor signal cable connection 3)long time sensor working	1)loss sensors signal occasionally 2)DP system alarm sound out 3)degradation of DP operation status	1)proper sensor protection and examination 2)sensor restart , self diagnose and test 3)replaced by new ones
Computer software	less	1)System paralysis 2)software incompatible	1)original design problem 2)old version software	1)loss the ability of system control 2)loss of	1)software debug or redesign of the software 2)update the old

		with hardware 3)wrong command for hardware	3)wrong software for specific hardware drive	position 3)degradation of DP operation status	software for the new one
	more	1)Button input invalidation 2)operation station shift invalidation	1)poor contact 2)software disorder 3)signal cable damaged 4)wrong software operation	1)system out of control 2)emergency status may occur 3)degradation of DP operation status	1)computer system properly protected, and examination regularly according to maintenance plan 2) operation panel test timely

Chapter 6 DP operation in South China Sea

6.1 Deepwater oil fields in South China Sea

Offshore oil and gas resources represent almost 40 percentages of the global oil and gas reserves. In recent years, the major exploration discoveries (almost 50 percentages) come from deep sea areas. Nowadays, the world's total deep water proven oil and gas reservoirs are about 20 billion cubic meters.

South China Sea shown in figure 6-1 is the deepest and widest sea in China, with the richest oil and gas resource down below. The petroleum geological resources are about 20-30 billion tons; gas geological resources are about 16 billion cubic meters contained in South China Sea Basin, accounting for 1/3 of China's total oil gas resources of which 70% are in deep sea area.

Figure 6-1 South China Sea (Haveman, et al., 2006)

China offshore oil industry's exploration and development of offshore oil fields is generally in less than 300 meters, oil and gas exploration and development of more than 300 meters water depth are at the initial stage. In 2006, CNOOC (China National Offshore Oil Corporation) and Husky completed a deep water drilling in China which was the first in depths over 1000m in Pearl River Mouth Basin. Then Liwan 3-1 gas field was found. This discovery is a great milestone in Chinese petroleum industry. It also proved that in the South China Sea area has the basic geological condition of forming large sized oil and gas fields.

Ocean oil 981 is the world's latest sixth generation semi-submersible drilling platform built by COSL (China Oilfield Service Limited) which is a subsidiary company of

CNOOC. It is designed to resist the 200 years intervals wave in the South China Sea, which is greatly improving the system's ability to resist disasters. Integrated positioning system of the DP type and an anchor mooring system are adopted; the anchor system can be used when the water depth less than 1500 meters, the full DP model can be used when the water depth more than 1500 meters, this greatly saves the fuel. Figure 6-2 below is ocean oil 981 during operation at the Liwan oil field in South China Sea.

Figure 6-2 The sixth generation of semi-submersible drilling rig 'ocean oil 981'
(Ref:http://szb.xgrb.cn:9999/epaper/xgrb/html/2012/05/08/03/03_76.htm)

6.2 Weather conditions of South China Sea

The Liwan oilfield is situated in block 29/26 in South China Sea, 180 nautical miles from the mouth of the Pearl River southeast of the Hong Kong. The average water depth around this area is 1400m. On May 9, 2012 China's first deep-water drilling platform "Ocean oil 981" equipped with DPS-3 was successful for her first drilling at the Liwan oil field. In order to keep the position at the well location, she has to overcome the special external conditions such as monsoon, cold fronts, soliton currents and typhoons in the South China Sea.

The monsoon and the cold front

The general weather pattern for this location is that of a monsoon, where there is a rainy season and a dry season. During the monsoon the directionality of the environment changes and heavier rainfall occurs (Haveman, et al, 2006). Besides heavier rainfall, there is always strong wind accompanied. The occurrence of the directionality of the monsoon is generally from March to April and October to November. The cold fronts appearance in winter frequently bring wind with force at least 7-8, which generate risk for the offshore installations especially the installations positioned by DP systems. Generally, the wave height is changing monthly in the South China Sea, and we will get the highest wave height in winter. Figure 6-3 gives the statistics of the significant wave heights monthly, we can see that the wave height is around 3 meters during winter.

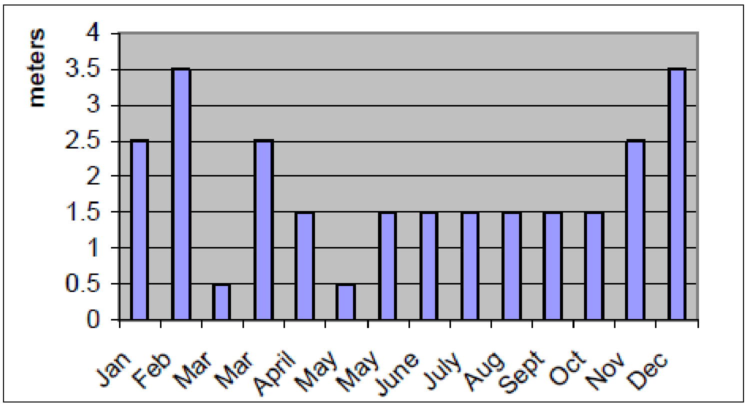


Figure 6-3 Significant wave heights in South China Sea (Haveman, et al, 2006)

The soliton current

Soliton current is a special phenomenon which occurs in South China Sea during the summer season. It is generated at the different temperatures and depths of the sea water. The speed of the soliton current is usually up to 3-4knots with the tide current, which will generate ripples on the sea surface. It will easy be detected by RADAR when the sea state is calm. Figure 6-4 is a radar imagine of the coming of a soliton.

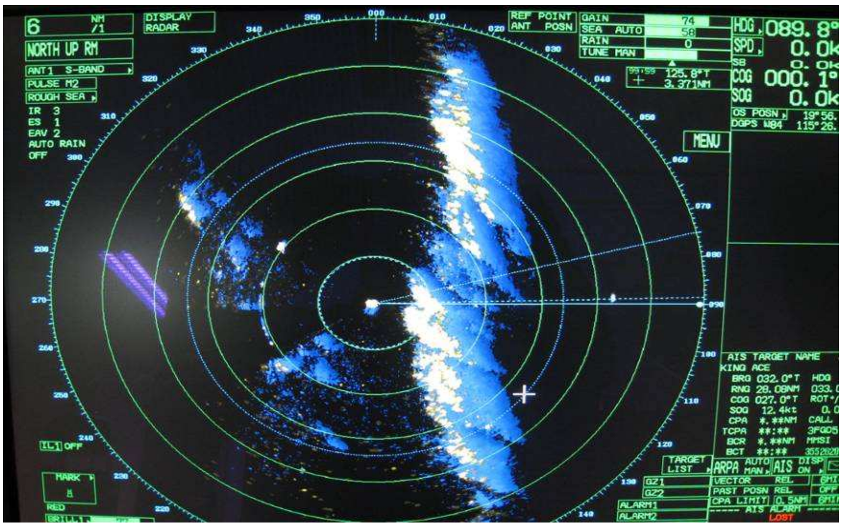


Figure 6-4 Radar imagine of soliton current

In high sea states or during heavy rainfall the solitons cannot be detected at all, as the whole sea surface will then be covered with ripples (Tjallema and Stapersma, 2010). Generally, the soliton current is hundred meters width, 50 nautical miles long, with strong energy in it. It also creates a significant risk for the DP system's position keeping ability due to their high speed and rapid direction changing. Thus, it is very important for the DP operator to detect the soliton early and take pre-actions to resist it from losing position.

The typhoons

In the South China Sea typhoons are generated from east of Luzon Island in the Philippines Ocean, and are then moving into the South China Sea. The most predominant characteristics of this kind of typhoons are the high strength, large affection area, but with enough warning time.

There is another kind of typhoons that occurs on the east central part of the South China Sea. It develops from the tropical low pressure generated at the South China Sea and the tropical low pressure coming from the Pacific. Commonly it is known as “local typhoon”. The characteristics of this kind of typhoons are less horizontal domain, low vertical height, and relatively low intensity. The diameter of the local typhoon is generally 600-1000 kilometers. The central pressure is general 980-990 HPa. They are generated fast, are difficult to prevent and are usually destructive to the offshore facilities.

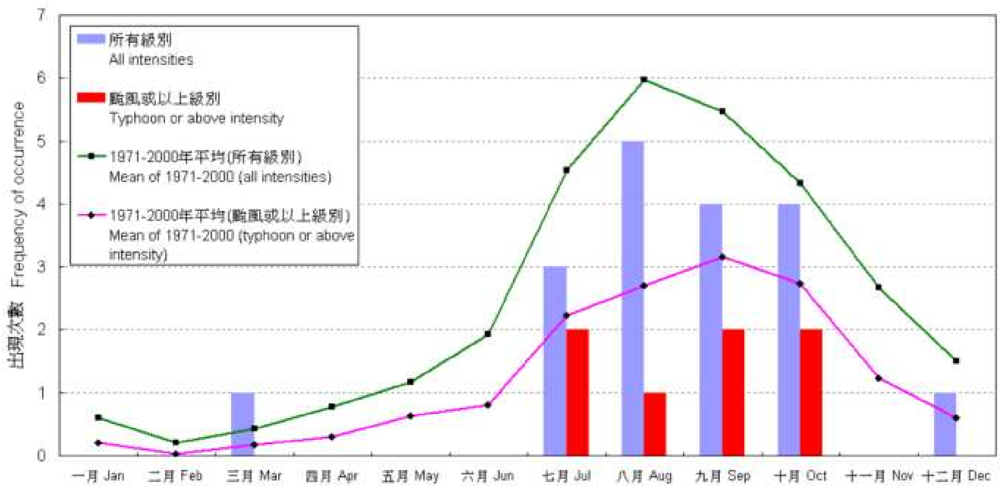


Figure 6-5 The occurrence frequency of typhoon in 2010 South China Sea (http://gb.weather.gov.hk/publica/tc/tc2010/chinese/figure21_uc.htm)

The occurrences of the typhoons in South China Sea focus on July to October. Figure 6-5 shows the occurrence frequency of typhoon in 2010, the data were collected by Hong Kong weather bureau. Most of the oil fields in the South China Sea will be affected during the typhoon season; the general paths of typhoons are shown in figure 6-6. Pre-actions will be taken when comes a typhoon, especially for the floating installation positioned by DP system.

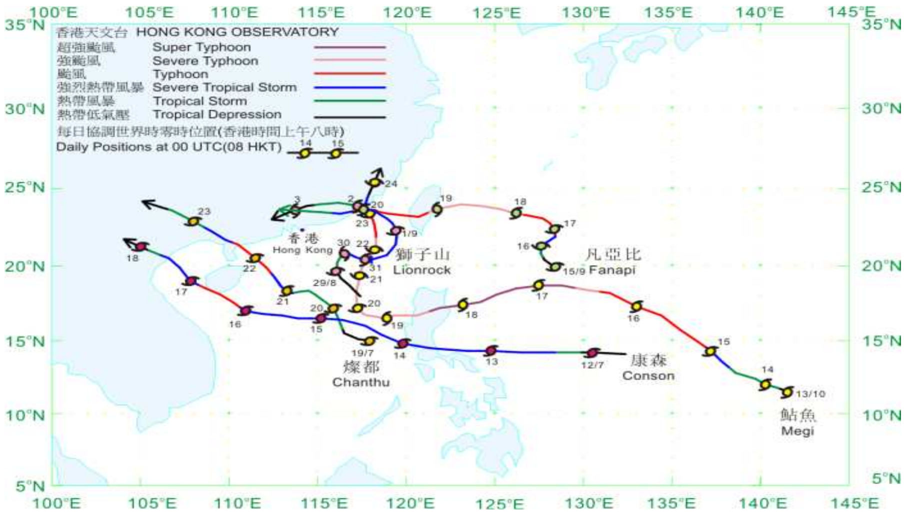


Figure 6-6 The paths of 5 typhoons in 2010 South China Sea
(http://gb.weather.gov.hk/publica/tc/tc2010/chinese/figure22_uc.htm)

6.3 Eliminate the effects of soliton to the DP system

Risk of soliton to Ocean Oil 981's position keeping

The Liwan oil field occasionally suffers from the attacks of solitons. As large energy is contained in the soliton current, thisincreases the probability of the drilling rig Ocean Oil 981 being forced off the position. If the forces acting on the hull of the Ocean Oil 981 exceed the power of the thrusters equipped on the rig, the rig will lose the ability of keeping position. On the other hand, the rapid change of speed and direction will lead to a certain delay for the DP system to react to the environment changes, causing the rig drift off the original position even out of the warning limits.

Soliton anticipation

The first step of eliminating the effects of soliton to the DP system is anticipation of solitons; warning system.

Solitons occur all year round, especially in June and July. The tTide is the original cause for the generation of the soliton, thus the occurrence of the soliton can be more or less predicted. Their intensity cannot be estimated but there may be measures to provide an advance warning of their impending arrival. With advance warning the rig activities can be scheduled around solitons until passage is complete (Millmaker, et al., 1997).

Radar could be used to detect the solitons. Solitons will generate ripples on the sea surface, so shipboard radar could be used to detect them. The speed and the wave length of the soliton could be accurately measured by radar.

For the drilling rig Ocean Oil 981, data from the riser could represent useful information concerning time and effect of the coming soliton. Since the data directly yield from the effects of the solitons on the riser, these data are very useful for soliton detection. This information should be accompanied with visual observations or other detection methods, as sometimes it is difficult to distinguish the data from other environmental conditions.

Actions taken to resist solitons

The DP operator should use various means including visual and radar to detect the soliton and it strength. Otherwise, the suddenly attack will force the drilling rig off the original position and damage the subsea facilities further.

All the power generators should be keept at good working conditions to resist the effects of the solitons， especially the ones that are not detected in time, in order to provide efficient forces by the thrusters to resist the attack of the soliton currents.

After a warning that the solitons are coming, the DP operator should get ready all the thrusters (all of eight thrusters for the Ocean Oil 981) and generators, in order to cope with the coming soliton impact.

One shall adjust the heading of the drilling rig directly against the soliton before the soliton arrival as far as possible to avoid the soliton attack the side of the rig. There are two pontoons at each side of the Ocean oil 981; they will suffer more force when attacked by the soliton because of the larger transverse section.

One shall also adjust the DP control system to quickly response to the changes of the environment. The quick mode could be used in this circumstance to cope with the rapid speed and direction changes of the soliton. Thus, enough time could be obtained for the thrusts to resist the external force before the rig being forced off the green limitation or even the yellow limitation that we have mentioned in the above.

One shall also notify the relevant parties to take associate actions, according to the intensity of the soliton to decide whether to start the emergency plan or not. The OSV along sides the rig should navigate to a safe area outside the 500 meters zone of the rig. All the production actions should be ceased if the soliton is defined as at a serious level.

6.4 Eliminate the effect of typhoon to the DP system

Real cases in South China Sea

In October 23rd 1983, the drilling rig “Java sea” leased by Arco oil company from Global offshore drilling company of USA, was capsized in South China Sea due to the attack of NO.16 typhoon in 1983. All 81 people on board were dead, and the total economic loss was 350 million US dollars. The root cause for this disaster was that people in charged did not pay enough attention on the local typhoon in South China Sea, and it was too late when the actions were taken.

In September 14th 2009, the drilling rig “West Hercules” leased by Husky Oil Company from Seadrill drilling company, operated on the Liuhua oil field in South China Sea. The water depth was about 1100 meters; the rig was being forced off the original well position due to the attack of the NO.15 typhoon in 2009. The root causes were that the people in charge were too confident about the ability of the rig to resist the typhoon attack, and the actions were taken too late to resist the typhoon.

Risk of typhoon to Ocean oil 981 position keeping

The drilling rig Ocean oil 981 operates at the Liwan oil field, which is frequently attacked by typhoons, as the oilfield is situated at the general route of typhoons during the typhoon season. Typhoons increase the risk for the rig being force off the position, due to the external extremely high wave forces which may be exceeding the force generated by the 8 thrusters of the rig.

Loss of position may occur as drift-off. And associated well damage, equipment damage, and even person injury accidents may occur. Additional measures should be taken for Ocean oil 981 to minimize the risk generated by typhoons in the South China Sea, and make sure that the wind speed and wave do not exceed the rig's operation standards shown in table 6-1.

Table 6-1 Ocean oil 981 operation standards

Activity	Wind speed		Hs	Surface current		Flex joint angle
	knots	m/s	m	knots	m/s	degree
Vessel design	100	51	17	3.1	1.7	7
DP operation	70	36	10.7	3.1	1.7	7
Anchor thruster assist	80	41	17	3.1	1.7	7
Supply boat operation	40	21	4	2.0	2.0	/

Actions taken to resist typhoons

Ocean oil 981 has been successfully operated in the South China Sea. The DP system accompanied by a mooring system for station keeping is a proven concept in typhoon areas. However, for some areas the shallow mooring system could not be accompanied with the DP system, because of the depth of the water. Thus, much more additional actions should be taken to cope with the coming typhoon.

Weather forecast:

Normally, the shore base will sent the weather information to the rig at regular intervals in the South China Sea, and the rig could receive the weather information through weather fax, as well as other methods. The routine report will be more frequent when there is a typhoon or tropical low pressure warning. Then the rig will decide whether to keep position at the original position or disconnect the risers and navigate to safe area according to the weather severity. However, there must remain enough time for the rig to navigate to the safe area when deciding to disconnect, otherwise the rig may be trapped by the typhoon.

Preparation for typhoon:

When there is a typhoon or tropical warming, the rig should get fully preparation for the coming severe weather and prevent the rig from directly encounter with the typhoon. Firstly, the rig should relief and recovers all the risers and subsea facilities timely before the approach of typhoon near to the area limited by the recovery time. Secondly, all the moving equipment or materials should be lashed tightly, and all the watertight openings should be checked. Thirdly, enough maneuvering space should remain for dynamic positioning to avoid collision with other installations nearby. Fourthly, the generators and the thrusters should be used reasonably, avoid continuous use at full load condition. Fifthly, reasonable heading should be adjusted to avoid the rig being directly exposed to the heavy wind and waves generated by typhoon. Sixthly, continuous tracking the moving path of the center of the typhoon by plotting the typhoon forecast position on the typhoon plotting map, avoiding to enter into the dangerous semicircle of the typhoon.

Typhoon navigation:
If the rig manager decides to disconnect the risers and navigate to the safe area, then suitable navigation methods should be selected. By receiving the moving path information of the typhoon from the shore base or received by the rig itself, then the rig manager or the OIM could justify the rig's relative position with the typhoon eye. Figure 6-7 shows the relationship of wind and the typhoon eye in the north hemisphere.

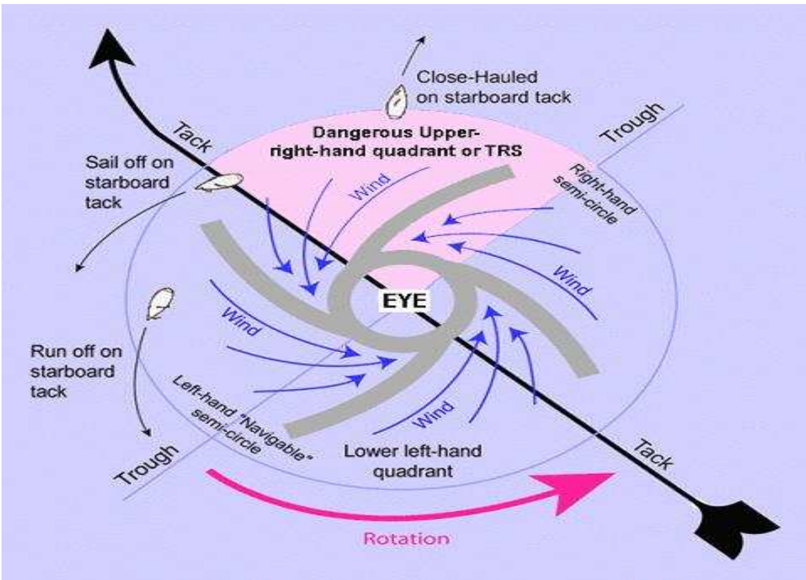


Figure6-7 Relationship of the wind and the typhoon eye
(http://www.mypowerboat.com/avoiding-tropical-storm.html)

In the northern hemisphere, the left semicircle is defined as the navigable semicircle; the right semicircle is defined as the dangerous semicircle. As the wind is relative large in the navigable semicircle, the wind will push the rig move to follow the typhoon tack or even trapped in the typhoon eye (Zoethout and Brugts, 2006).
Once the rig is situated in the dangerous semicircle and forward of the typhoon eye (the pink area on above figure), much attention should be paid as this is the most dangerous area. For a rig at this circle circumstance in South China Sea, it should

keep the wind 30-40 degrees on the bow starboard side of the rig and navigate until out of the dangerous semicircle.

Shielding area selection:
According to the predicted moving path of the typhoon, Ocean oil 981 will navigate to the area where the position and heading could be kept safely. The area could shield the rig from the direct expose to the large wind, seas and waves, and further protect the equipment and personnel being damaged and hurt. Sometimes, the Hainan Island could provide an ideal shielding area for the rig. However, attention should be paid to the suddenly direction change of the typhoon.

6.5 Severe weather response procedures for Ocean oil 981

DP operation status

DP operation status is normally divided into three status, they are green status, yellow status and red status, that we have been mentioned in the above chapter. Green status means that the system is performing safely; yellow status means that the system functionality is degraded due to component failure; red status means that the system loses the position keeping ability.

Response procedure

Due to potential severe weather conditions in the South China Sea, Ocean oil 981 has establish an emergency response procedure for dynamic positioning operation when coming the bad weather, such as the solitons, typhoons, tropical low pressures, monsoons, cold fronts and so on. Figure 6-8 shows the frame diagram of severe weather response procedure for Ocean oil 981.

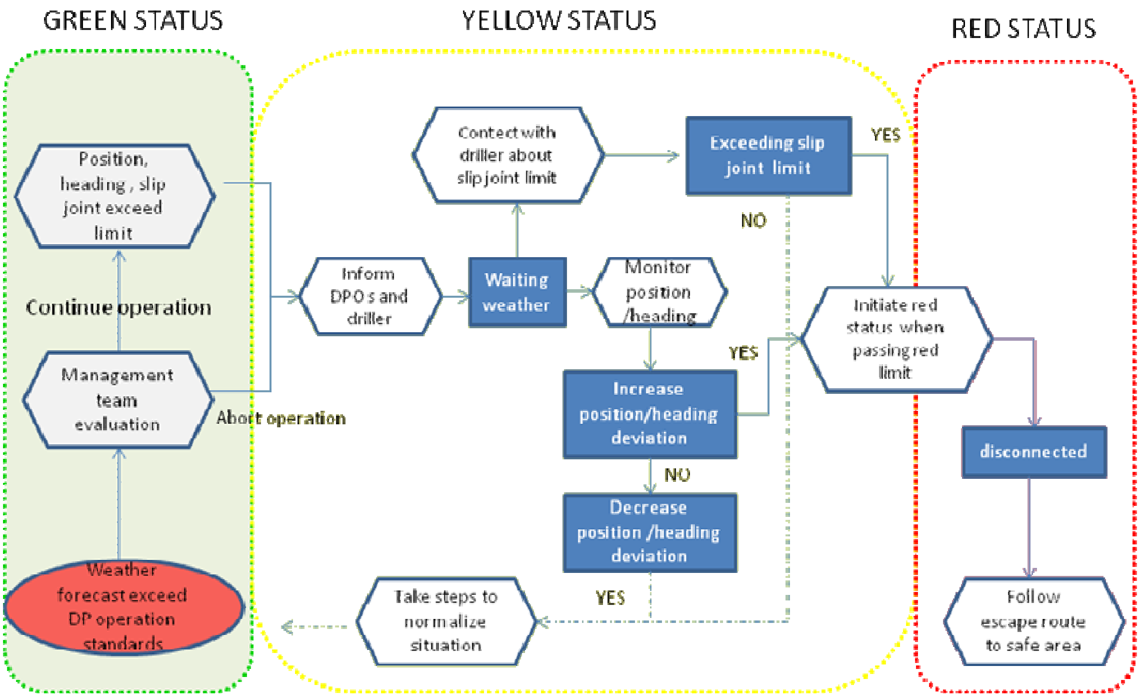


Figure 6-8 Ocean oil 981 severe weather response procedures

Step1: When Ocean oil 981 receives a weather forecast exceeding the DP operation standards shown in table 6-1, the management team will evaluate the system, and justify if the position, heading or the slip joint exceed the defined limitation. And then they will decide whether the drilling operation continued or not.
Stept2: If the weather condition exceeds the DP operation standards, or the position, heading or slip joint exceed the defined limitations, the drilling operation will abort. And the DP operation status will degrade from green status to yellow status. Then, the second DP operator and the driller will be informed, and the position, heading and slip joint will continue to be monitored, while waiting on the changes of the weather. If the deviation of the position, heading or the slip joint decrease, steps are taken to normalize the situation to green status. On the contrary, if the deviation increase due the weather force and the rig drifts off into the red limitation, then the DP operation status will degrade from yellow status to red status.
Stept3: For the red status, the emergency disconnects procedure will be carried out by Ocean oil 981, and then the rig will follow the escape route predefined to the safe area. When the severe weather is coming, all steps should be taken according to the response procedure.

DP operations in South China Sea have higher risk than in the other sea areas because of the severe weather conditions. Solitons, typhoons or the cold front all may push the DP vessels or the installations off position. Severe weather response procedure should be established and correctly carried out during the emergency situation or other situations needed.

6.6 Conclusions

The DP offshore support vessels or the DP mobile offshore drilling units that are planned to be operated in South China Sea, must be outfitted with the ability to resist severe weather conditions, as well as ability to establish severe weather emergency response procedures to cope with unexpected coming of bad weather. Successful operational experience of other DP installations in the South China Sea could be used for reference. There are abundant oil and gas resources in South China Sea, on the contrary, there are also challenges we need to cope with in the future.

Chapter 7 Recommendations

As the development of the offshore oil industry continues, all kinds of new advanced technologies are invented continuously. And also some technologies which were not reliability enough in the past are becoming mature and robust, just like the DP system. A drilling rig equipped with dynamic positioning system could be self propelled, and no anchor handling vessels are needed when changing well position; and this is much quickly for position changing which could save OPEX dramatically. And also it helps to increase the response to the weather changes, changing the direction or disconnecting the riser and move to a safety place by using the DP system.

For an offshore vessel equipped with a DP system, the vessel could automatically be controlled, increasing the safety, reliability and availability. And it helps to avoid damage to pipes or other subsea structures on the seabed as could be the case if dropping anchors.

As the offshore oil industry exploration and production activities are moving into deeper water further from shore, the DP system is the fundamental system needed to be used for the supporting activities by OSV.

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Appendix 1

Dynamic Positioning System Manufactures

Kongsberg

Information from the website of Kongsberg (http://www.km.kongsberg.com/)

Kongsberg maritime offers a full range of dynamic positioning systems, keep the vessel's position and heading in the required limitation. The K-pos operator station can be configured into single, duel or triple. DP product provide by Kongsberg includes: Compact dynamic positioning-DP system; Dynamic positioning-DP system, K-Pos DP11/12; Duel redundant dynamic positioning-DP system, K-Pos DP21/22; Dynamic positioning –DP system, Triple modular redundant K-Pos DP31/32.

Kongsberg also provides a unique dynamic positioning control system, the Green DP control system, which can reduce the fuel consumption and also the CO2 emission, by as much as 20%. The Green DP is base on forecasting the motion of the vessel, rather then acting on present condition, which can optimize the using of the thrusters. (Ref: http://www.km.kongsberg.com/)

Figure1 Control station of Kongsberg DP system

(http://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/14E17775E088ADC2C1256A4700319B04?OpenDocument/)

Address of the Kongsberg maritime: Kirkegardsveien 45 NO-3616 Kongsberg Norway.
Tel: +47 32 28 5000
Website: www.km.kongsberg.com

Rolls Royce

Information from the website of Rolls Royce (http://www.rolls-royce.com/marine/products/automation_control/positioning_systems/)

Rolls Royce is also one of the famous dynamic positioning system manufactures world widely. Icon DP is a dynamic positioning system from Rolls Royce. This system comply with the requirement of the IMO concerning DP class 1, 2 and 3. Poscon Joystick is another positioning system product from Rolls Royce.

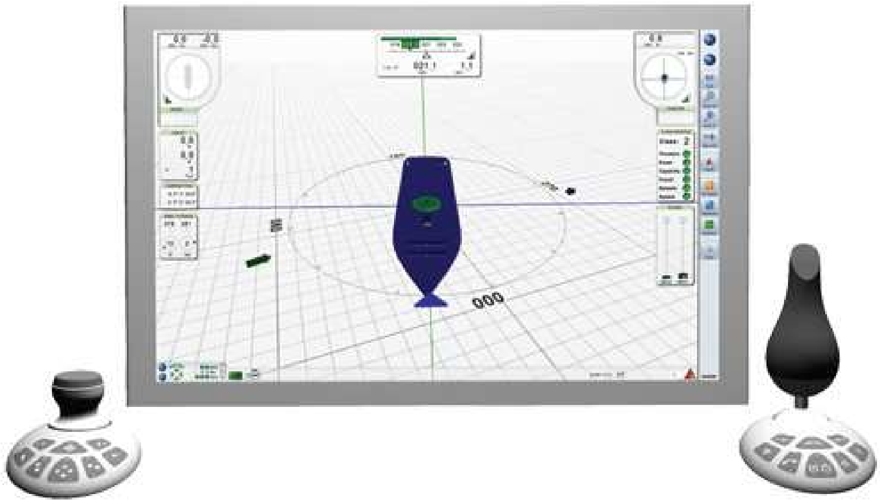

Figure2 Icon DP operator station
(http://www.rolls-royce.com/marine/products/automation_control/positioning_systems/)

Address of Rolls-Royce marine: 65 Buckingham Gate London, SW1E 6AT England
Tel: +47 20 7222 9020
Website: http://www.rolls-royce.com/marine/

MT-Marine technologies

Information from the website of MT-marine technologies (http://www.mtllc.us/dynamicpositioning.html/)

The aim of MT is providing the customers a cost effective product. The Bridge Mate concept DP system is the main dynamic positioning product of MT. It is designed to meet the IMO guideline for vessel with dynamic positioning system. User friendly is the main feature of the Bridge Mate concept DP system. It can greatly reduce the risk of human errors during operation as its special buttons design, as well as the user friendly software design.

Figure 3 Bridge Mate concept DP operator station
(http://www.mtllc.us/dynamicpositioning/dpconcept.html/)

The address of MT: Hovlandsveien 44 4370 Egersund Norway
Tel: +47 51 46 18 66
Website: http://www.mtllc.us/dynamicpositioning.html/

Beier Radio

Information from the website of Beier Radio (http://www.beierradio.com/products/Dynamic-Positioning)
IVCS 2000 is the most advanced dynamic positioning system provided by Beier Radio. It is ABS product design assessed. It allows the computer to perform operation command fast, safely and more efficiently. It is also called as the easiest to learn and operate DP system of the marine industry.

Figure 4 Beier Radio Beier IVCS2000 operator station
(http://www.beierradio.com/products/Dynamic-Positioning)

The address of Beier Radio: 2605 N. Concord Road Belle Chasse, LA70037,New Orleans, USA.
Tel: +1 504 341 0123
Website: http://www.beierradio.com/products/Dynamic-Positioning