

Introduction to Dynamic Positioning

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1 – Introduction

Dynamic positioning (DP) is a rapidly maturing technology, having been born of necessity as a result of the increasing demands of the rapidly expanding oil and gas exploration industry in the 1960s and early 1970s. Even now, when there exist over 1,000 DP-capable vessels, the majority of them are operationally related to the exploration or exploitation of oil and gas reserves.

The demands of the offshore oil and gas industry have brought about a whole new set of requirements. Further to this, the more recent moves into deeper waters and harsh-environment locations, together with the requirement to consider more environmental-friendly methods, has brought about the great development in the area of Dynamic Positioning techniques and technology.

The first vessel to fulfil the accepted definition of DP was the "Eureka", of 1961, designed and engineered by Howard Shatto. This vessel was fitted with an analogue control system of very basic type, interfaced with a taut wire reference. Equipped with steerable thrusters fore and aft in addition to her main propulsion, this vessel was of about 450 tons displacement and length 130 feet.

By the late 1970s, DP had become a well established technique. In 1980 the number of DP capable vessels totalled about 65, while by 1985 the number had increased to about 150. Currently (2002) it stands at over 1,000 and is still expanding. It is interesting to note the diversity of vessel types and functions using DP, and the way that, during the past twenty years, this has encompassed many functions unrelated to the offshore oil and gas industries. A list of activities executed by DP vessels would include the following:

- coring
- exploration drilling (core sampling)
- production drilling
- diver support
- pipelay (rigid and flexible pipe)
- cable lay and repair
- multi-role
- accommodation or "flotel" services
- hydrographic survey
- pre- or post-operational survey
- wreck survey, salvage and removal
- dredging
- rockdumping (pipeline protection)

- subsea installation
- lifting (topsides and subsea)
- well stimulation and workover
- platform supply
- shuttle tanker offtake
- Floating production (with or without storage)
- heavy lift cargo transport
- passenger cruises
- mine countermeasures
- oceanographical research
- seabed mining

DP is also used in

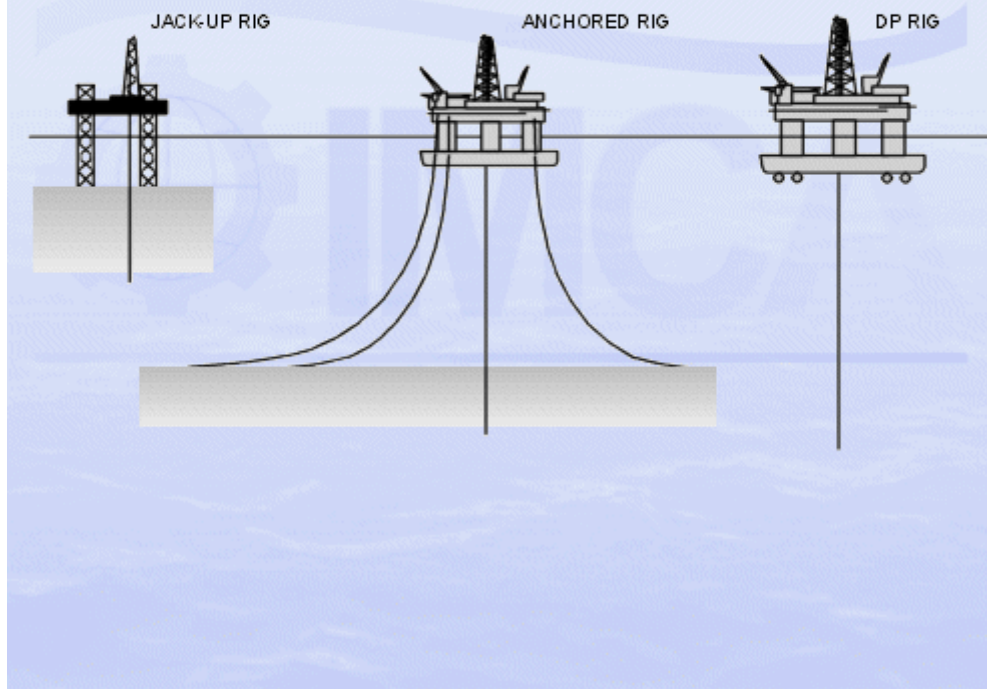
- rocket launch platform positioning
- repair/maintenance support to military vessels
- ship-to-ship transfer and
- manoeuvring conventional vessels

DP systems have become more sophisticated and complicated, as well as more reliable. Computer technology has developed rapidly and some vessels have been upgraded twice with new DP control systems. Position reference systems and other peripherals are also improving and redundancy is provided on all vessels designed to conduct higher-risk operations¹.

1.1 – Station Keeping

There are other methods for vessel station keeping. These include spread and fixed moorings or combinations of each. Jack-ups fix their position by lowering legs to penetrate the sea bed. Vessels using moorings or legs may also occasionally have DP control systems to assist the setting-up on position and, in the case of a moored unit, to reduce mooring line tension. Each system has advantages and disadvantages.

OFFSHORE DRILLING METHODS



Sketch 1.1 station keeping methods

DP Advantages:

- Vessel is fully self-propelled; no tugs are required at any stage of the operation
- Setting-up on location is quick and easy
- Vessel is very manoeuvrable
- Rapid response to weather changes is possible (weather vane)
- Rapid response to changes in the requirements of the operation
- Versatility within system (i.e. track-follow, **ROV**-follow and other specialist functions)
- Ability to work in any water depth
- Can complete short tasks more quickly, thus more economically
- Avoidance of risk of damaging seabed hardware from mooring lines and anchors
- Avoidance of cross-mooring with other vessels or fixed platforms
- Can move to new location rapidly (also avoid bad weather)

DP Disadvantages:

- High capex and opex
- Can fail to keep position due to equipment failure

- Higher day rates than comparable moored systems
- Higher fuel consumption
- Thrusters are hazards for divers and ROVs
- Can lose position in extreme weather or in shallow waters and strong tides
- Position control is active and relies on human operator (as well as equipment)
- Requires more personnel to operate and maintain equipment

From the above, it can be seen that DP will not always be the most economic solution. While vessels using moorings have a number of advantages, increasingly DP is the best option for many operations because the seabed is cluttered with pipelines and other hardware, so laying anchors has a high risk of damage to pipelines or wellheads. The option to moor to a platform rather than the seabed is also less frequent, because support vessels have become larger and platforms are not designed for the loads that can be placed in the mooring lines. Nevertheless, there is a risk that a DP vessel makes contact with a platform³.

During the 1990s there was a rapid increase in the number of vessels with dynamic positioning systems. Many of these vessels have been designed for DP and integrated control of engines and thrusters, but there are also a large number of conversions and upgrades. The situation is market-driven and relies on operational efficiency which, in turn, places a high reliability requirement on equipment, operators and vessel managers.

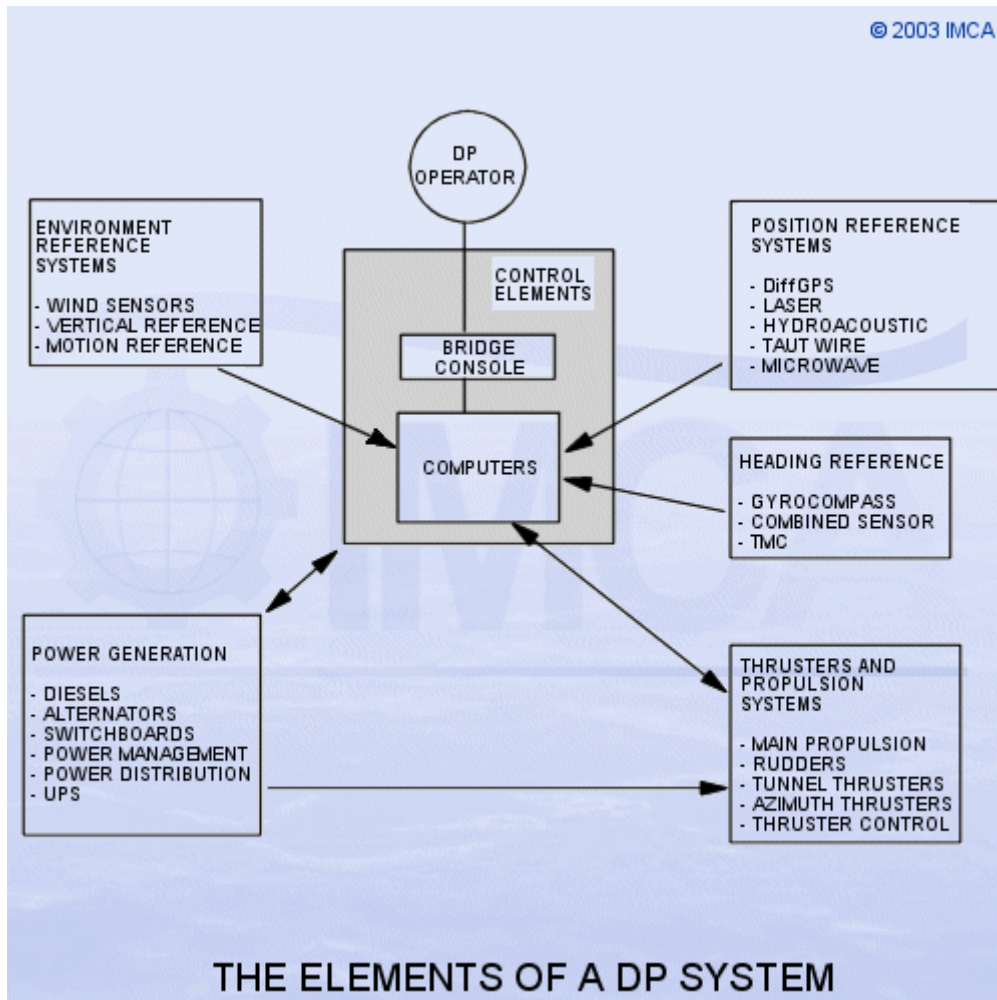
2 – Basic Principles of DP

Dynamic Positioning can be described as an integration of a number of shipboard systems to obtain the ability of accurate manoeuvrability. DP can be defined as:

A system which automatically controls a vessel's position and heading exclusively by means of active thrust.

The above definition includes remaining at a fixed location, but also precision manoeuvring, tracking and other specialist positioning abilities.

A convenient way of visualising the inter-relation of the various elements of a DP system is to divide the system into six parts, as the following sketch shows.

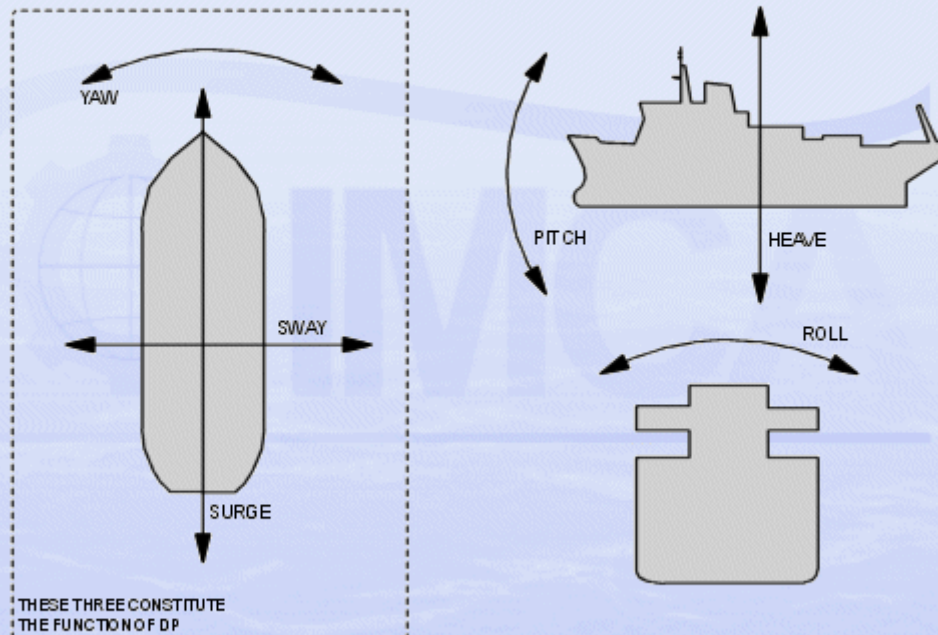


Sketch 2.1 – Schematic Diagram of a DP system

The prime function of a DP system is to allow a vessel to maintain position and heading. A variety of further sub-functions may be available, such as track-follow, or weathervane modes, but the control of position and heading is fundamental.

Any vessel (or other object) has six freedoms of movement; three rotations and three translations. In a vessel they can be illustrated as roll, pitch, yaw, surge, sway and heave.

THE SIX FREEDOMS OF VESSEL MOVEMENT



Sketch 2.2 – The Six Freedoms of Movement

Dynamic positioning is concerned with the automatic control of surge, sway and yaw. Surge and sway, of course, comprise the position of the vessel, while yaw is defined by the vessel heading. Both of these are controlled about desired or "setpoint" values input by the operator, i.e. position setpoint, and heading setpoint. Position and heading must be measured in order to obtain the error from the required value. Position is measured by one or more of a range of position references, while heading information is provided from one or more gyrocompasses. The difference between the setpoint and the feedback is the error or offset, and the DP system operates to minimise these errors.

The vessel must be able to control position and heading within acceptable limits in the face of a variety of external forces. If these forces are measured directly, the control computers can apply immediate compensation. A good example of this is compensation for wind forces, where a continuous measurement is available from windsensors. Other examples include plough cable tension in a vessel laying cable, and fire monitor forces in a vessel

engaged in firefighting. In these cases, forces are generated which, if unknown, would disturb the station keeping if unknown. Sensors connected to the cable tensioners, and the fire monitors allow direct feedback of these "external" forces to the DP control system and allow compensation to be ordered from the thruster before an excursion develops.

In addition to maintaining station and heading, DP may be used to achieve automatic change of position or heading, or both. The DP operator (DPO) may choose a new position using the control console facilities. The DPO may also choose the speed at which he wants the vessel to move. Similarly, the operator may input a new heading. The vessel will rotate to the new heading at the selected rate-of-turn, while maintaining station. Automatic changes of position and heading simultaneously are possible.

Some DP vessels, such as dredgers, pipelay barges and cable lay vessels have a need to follow a pre-determined track. Others need to be able to weathervane about a specified spot. This is the mode used by shuttle tankers loading from an offshore loading terminal. Other vessels follow a moving target, such as a submersible vehicle (ROV), or a seabed vehicle. In these cases the vessel's position reference is the vehicle rather than a designated fixed location.

2.1 – DP Model

Every vessel is subjected to forces from wind, waves and tidal movements as well as forces generated from the propulsion system and other external elements (fire monitors, pipelay tension, etc). The response to these forces is vessel movement, resulting in changes of position and heading. These are measured by the position reference systems and gyro compasses. The DP control system calculates the offsets between the measured values of position and heading, and the required (or setpoint) values, and calculates the forces that the thrusters must generate in order to reduce the errors to zero. In addition the DP control system calculates the wind force acting upon the vessel, and the thrust required to counteract it based on the model of the vessel held in the computer.

Modelling and filtering enable a 'dead reckoning' or 'DR' mode (often called 'memory') to operate if all position references are lost. The vessel will continue to maintain position automatically, although the position-keeping will deteriorate with the increasing length of time since the last position data received. In practical terms, this means that the DPO does not need to immediately select "manual" control upon the loss of all position reference.

The difference between the thrust calculated from the model and the wind speed and direction is the force taken as the current. The current force or ‘sea force’ is therefore a summation of all the unknown forces and errors in the DP model and displayed in the model as the speed and direction of the current.

The first DP control systems comprised simple analogue PDI controllers that did not adapt to the actual sea conditions and vessel and thruster errors. Control improvements, Kalman filtering and fast digital data transmission (“data highways”) have enabled significant improvements in station keeping accuracy.

3 – Elements of a DP System

3.1 – Computers

The processors operating the DP control software are generally known as the DP computers. The main distinction of concern to the DPO is the number of computers, their methods of operation, and the level of redundancy they provide.

The computers may be installed in single, dual or triple configurations, depending upon the level of redundancy required. Modern systems communicate via an ethernet, or local area network (LAN), which may incorporate many other vessel control functions in addition to the DP.

In all DP vessels, the DP control computers are dedicated specifically for the DP function, with no other tasks. A single-computer system, or ‘simplex’ DP control system provides no redundancy. A dual or two-computer system provides redundancy and auto-changeover if the online system fails. A triple or ‘triplex’ system provides an extra element of security and an opportunity for 2-out-of-3 voting. The level of redundancy depends on the equipment class selected by the vessel (see Section 7 on system redundancy).

3.2 – Control Console

The bridge console is the facility for the DPO to send and receive data. It is the location of all control input, buttons, switches, indicators, alarms and screens. In a well-designed vessel, position reference system control panels, thruster panels and communications are located close to the DP control consoles.



DP CONTROL SYSTEMS

Above: **Alstom**
 Right: **Kongsberg Simrad**

3.1 Photos – Kongsberg Simrad SDP console and Alstom ‘A’ Series console

The DP control console is not always located on the forward bridge – many vessels, including most offshore support vessels have the DP console located on the after bridge, facing aft. Shuttle tankers may have the DP system situated in the bow control station although most newbuild tankers incorporate the DP system on the bridge. Possibly the least satisfactory location for the DP console is in a compartment with no outside view. This is the case in a few older drilling rigs.

The facilities for the operator vary from push-buttons and/or touch-screens to pull-down menus activated by roller balls and ‘enable’ buttons.

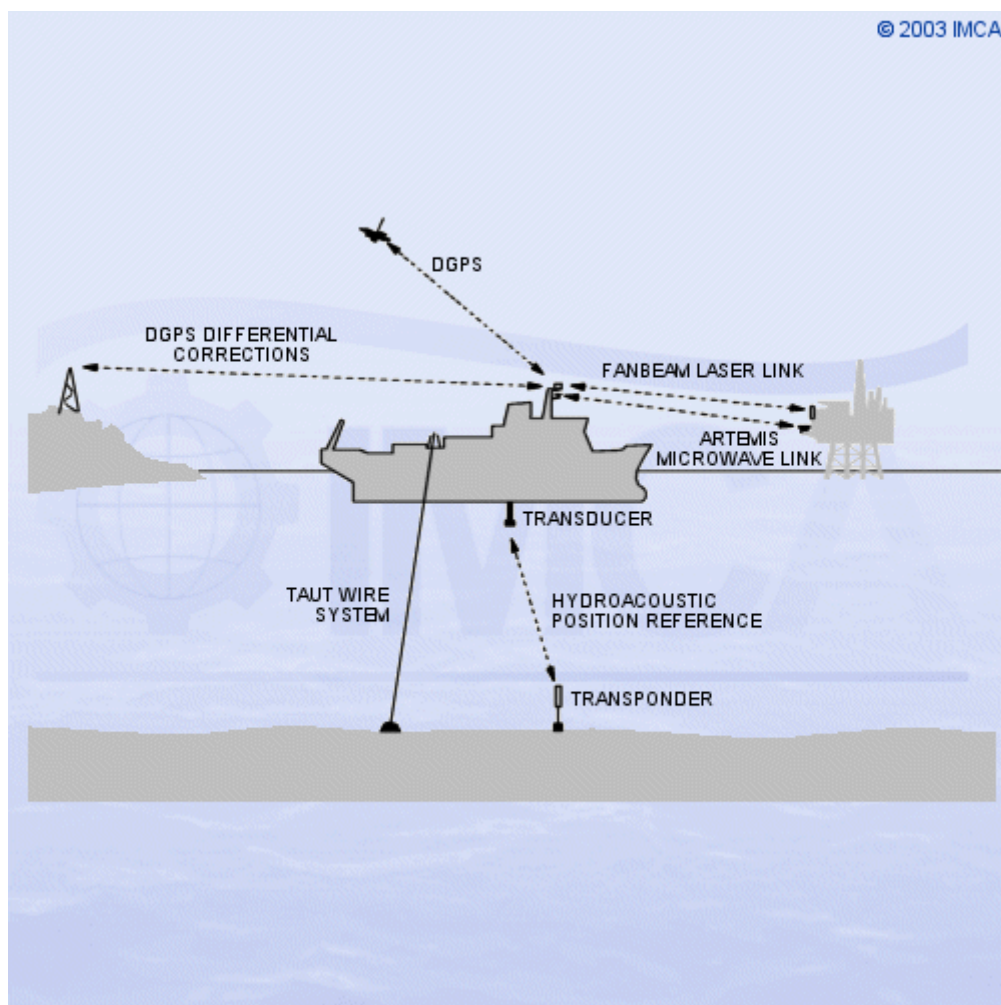
3.3 – Position Reference Systems

The number of position references enabled depends on a number of factors. In particular, the level of risk involved in the operation, the redundancy level that is sensible for the operation, the availability of references

of a suitable type, and the consequences of loss of one or more position references.

A variety of position reference systems is used by DP systems. The most common are: differential global positioning (DGPS – see Section 4.5), taut wires, hydroacoustics (HPR), and line-of-sight laser or microwave systems.

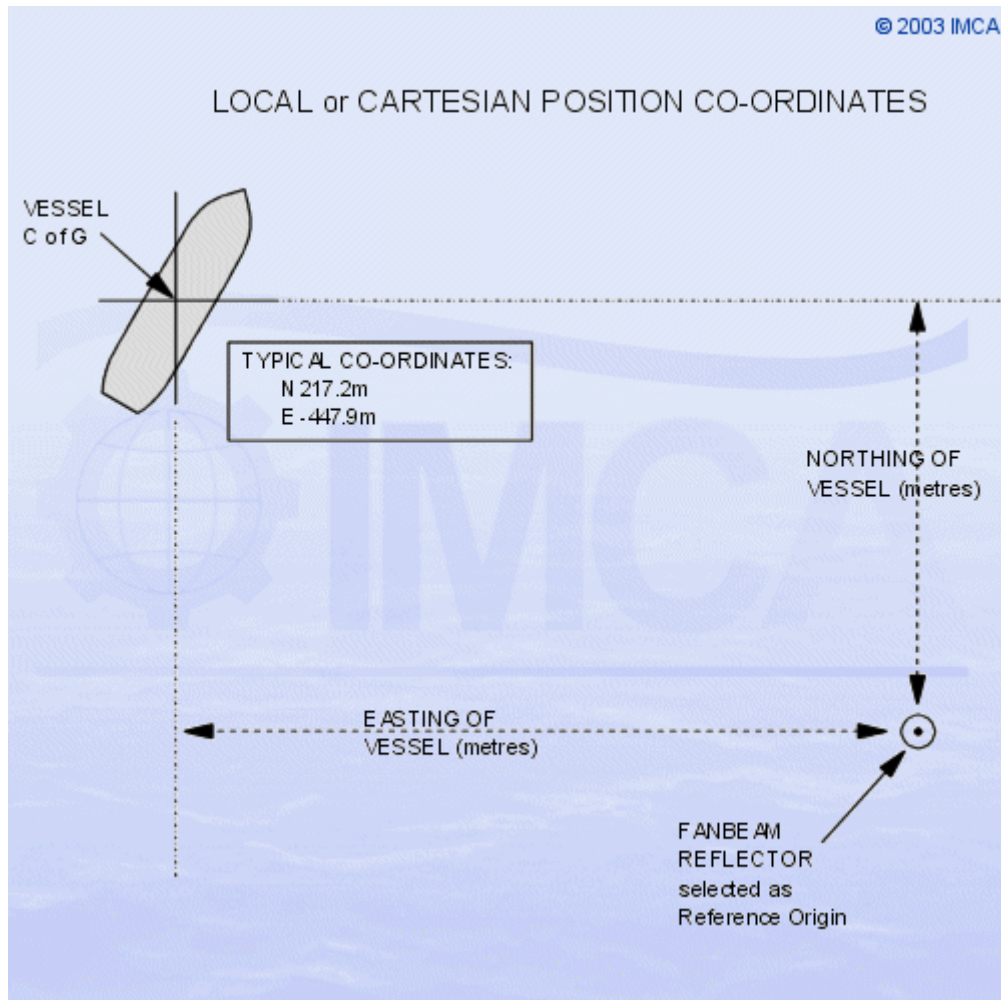
The reliability of position references is a major consideration. Each has advantages and disadvantages, so that a combination is essential for high reliability¹⁰. Individual position reference systems are described in Section 4.



Sketch 3.2 Position reference systems

Position information from position-reference systems may be received by the DP system in many forms. In addition, the type of co-ordinate system used may be cartesian or geodetic. The DP control system is able to handle information based on either co-ordinate system. A Cartesian, or local, co-ordinate system is based upon a flat-surface two-dimensional

measurement of the North/South (X) and East/West (Y) distances from a locally defined reference origin. This reference origin will be taken from one of the position reference systems (e.g. HPR transponder, fanbeam reflector, taut wire depressor weight location). This type of co-ordinate reference system is purely local, or relative, not absolute or earth-fixed.



Sketch 3.3 Local reference co-ordinates

For the DP system to handle earth-referenced type of data it is necessary to configure the DP system to accept geodetic data, or global references, such as GPS.

A DGPS system, provides co-ordinates in terms of latitude and longitude referenced to the WGS84 datum¹⁴. Most offshore operations are conducted using UTM (Universal Transverse Mercator) as the chart or worksite diagram projection. This reduces the positional co-ordinates into Northings and Eastings in metres. A fuller description of the UTM projection and co-ordinate system is given in Section 6.

Most modern DP control systems enable the DPO to select the type of presentation required, e.g. cartesian, geographic (lat/long or UTM). If the latter, the system will automatically calculate the UTM zone from received geodetic position measurements. The datum is usually selectable from a menu.

3.4 – Heading Reference

The DP vessel's heading is provided by one or more gyro compasses, which transmit data to the DP control system. In vessels where redundancy is necessary, then two or three gyros are fitted.

If three gyros are fitted, then the DP system may use two-out-of-three voting to detect a gyro failure, and give an appropriate warning to the DPO. Three gyros are typically fitted in vessels complying with equipment Class 2 or 3¹.

A heading reference may also be available from multiple GPS receivers – see 3.5 below.

3.5 – Environment Reference

There are three main environmental forces which cause the vessel to move away from her setpoint position and/or heading. They are the forces created by wind, waves and current. (A description has been given in Section 2 relating to the determination of current values.) Current meters to provide feed forward to the DP control system are hardly ever used by DP control systems, because they are expensive, especially if high reliability is required, and generally the current forces change slowly, so that integral term of the controller is adequate. However, a facility exists in some systems for 'quick current update', or 'fast learn'. This is a function which reduces the time constant of the integral term and allows the mathematical model build-period to be radically reduced. This is intended to allow the system to better react to rapidly changing tidal conditions or the new conditions after a large change of heading.

The DP control system provides no direct active compensation for waves. In practice, the frequency of the waves is such that it is not feasible to provide compensation for individual waves and the forces are too high. Wave drift forces build slowly and appear in the DP control system as current or sea force.

The roll, pitch and heave motions of the vessel are not compensated for by the DP control system, but it is necessary for the DP control system to be provided with accurate values of roll and pitch. This is to allow

compensation to be applied to all the various position reference sensor inputs for their offset from the centre of gravity of the vessel. Instrumentation to measure these values is provided in the form of a vertical reference sensor (VRS), vertical reference unit (VRU) or a motion reference unit (MRU). The MRU measures accelerations by the use of linear accelerometers and calculates inclination angles.

A recent development is the provision of a system which utilises two or more DGPS receivers with antennae mounted some distance apart. The GPS fixes and motion-sensors provide data on vessel position, heading, roll, pitch and heave values. This is able to provide a reference for position and heading as well as motion in and about each axis.

All DP systems have wind sensors. This data is used to calculate wind-induced forces acting upon the vessel's hull and structure, allowing these forces to be compensated before they cause a position or heading change. Typically, a wind sensor consists of a simple transmitting anemometer, usually of the rotating-cup type.

The direction of the wind is important for vessels needing to wind or weathervane, or find the minimum power heading. A correct assessment of this heading is vitally important to some vessels, e. g. the shuttle tanker and floating production vessels, which are reliant upon finding the best heading to maximise uptime.

The wind sensors are important because large changes in wind speed or direction can cause major disturbances in the positioning if they are not selected or shielded. The wind feed-forward allows an immediate compensatory thrust to be applied in direct proportion to the change detected in the wind speed and/or direction.

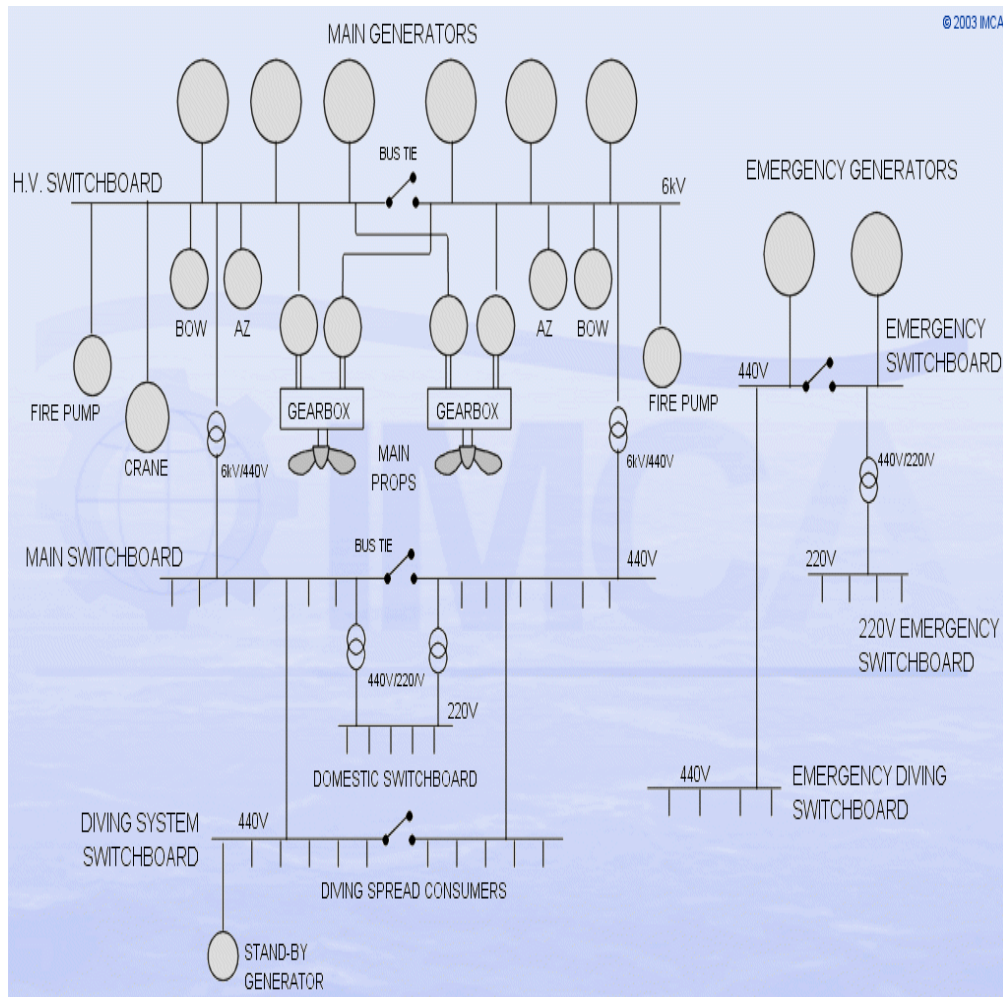
Many DP control systems also have a wind compensation facility within the manual (joystick) control function, providing the operator with an environmentally-compensated joystick control option.

3.6 – Power Systems

Central to the operation of any DP vessel are the power generation, supply and distribution systems. Power needs to be supplied to the thrusters and all auxiliary systems, as well as to the DP control elements and reference systems.

The thrusters on a DP vessel are often the highest power consumers on board. The DP control system may demand large changes of power due to rapid changes in the weather conditions. The power generation system must be

flexible in order provide power rapidly on demand while avoiding unnecessary fuel consumption. Many DP vessels are fitted with a diesel-electric power plant with all thrusters and consumers electrically powered from diesel engines driving alternators. A diesel engine and alternator is known as a diesel generator set.



Sketch 3.4 - Power Distribution on a Typical OSV

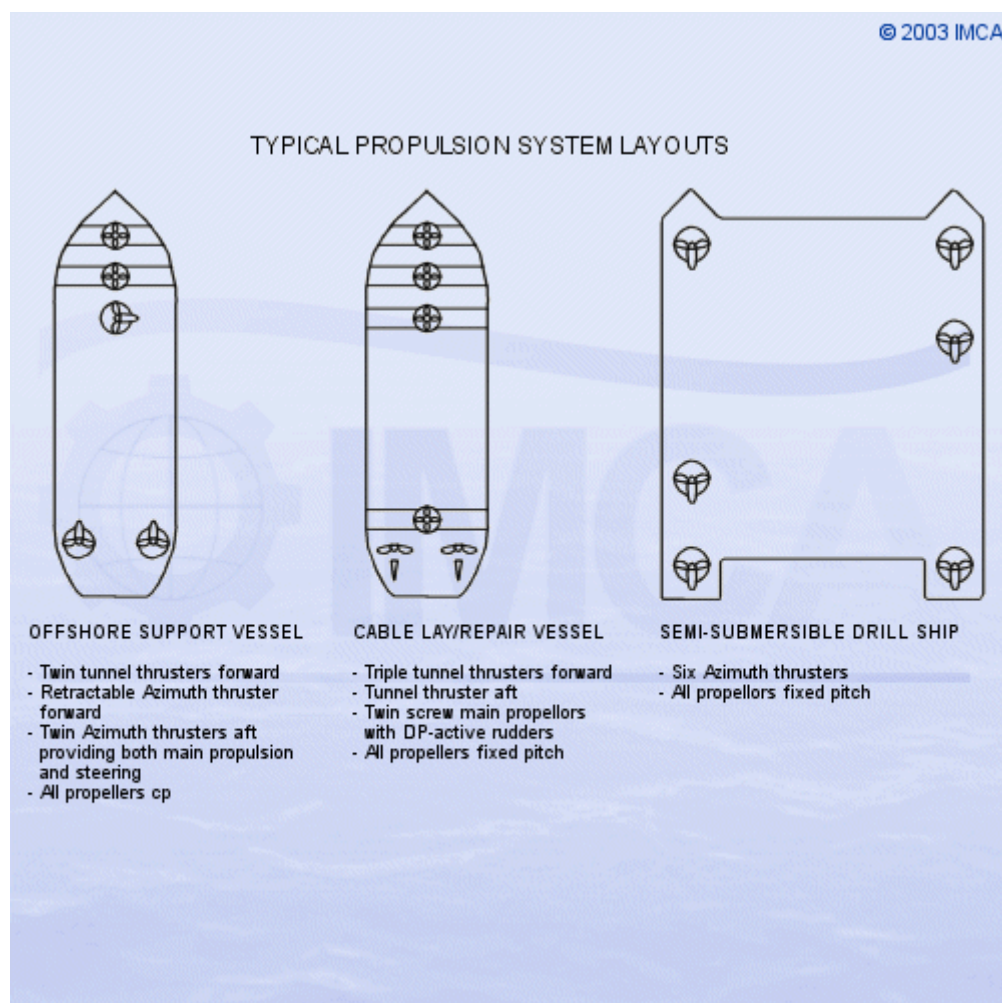
Some DP vessels comprise part diesel direct-drive thrusters and part diesel electric plant and motor-driven thrusters. A vessel may have twin screws as main propulsion driven direct by diesel engines and bow and stern thrusters electrically driven, taking power from shaft alternators coupled to the main diesels or from separate diesel generator sets⁶.

The DP control system is protected against a mains power failure by the inclusion of an uninterruptible power supply (UPS). This system provides a stabilised power supply that is not affected by short-term interruptions or fluctuations of the ship's AC power supply. It supplies the computers, control consoles, displays, alarms and reference systems. In the event

of an interruption to the ship's main AC supply, batteries will supply power to all of these systems for a minimum of 30 minutes.

3.7 – Propulsion Systems

The DP capability⁹ of the vessel is provided by her thrusters. In general, three main types of thruster are fitted in DP vessels; main propellers, tunnel thrusters and azimuth thrusters. Main propellers, either single or twin screw are provided in a similar fashion to conventional vessels. In DP vessels where such main propulsion forms part of the DP system, propellers may be controllable pitch (cp) running at constant rpm⁸ or variable speed² to be used with fixed-pitch propellers. Main propellers are usually accompanied by conventional rudders and steering gear. Normally, the DP installation will include control and feedback of the rudder(s). Some DP vessels are fitted with modern hi-lift high efficiency rudders which enhance the vessel's transverse thrust aft.



Sketch 3.5 – Typical Propulsion System Layouts

In addition to main propellers, a DP must have well-positioned thrusters to control position. Typically, a conventional monohull-type DP vessel will have six thrusters; three at the bow and three aft. Forward thrusters tend to be tunnel thrusters, operating athwartships. Two or three tunnel thrusters are usually fitted in the bow.

Stern tunnel thrusters are common, operating together but controlled individually, as are azimuth or compass thrusters aft. Azimuth thrusters project beneath the bottom of the vessel and can be rotated to provide thrust in any direction. Propeller drive is usually by bevel gearing from above. The whole unit may in some cases be retractable into the hull. Azimuth thrusters have the advantage that they can provide thrust in any direction and are often used as main propulsion in lieu of conventional propellers.

A podded thruster is also a type of azimuth thruster, but in this case the motor and shaft are enclosed and rotate with the thrusters below the hull. Ship rings provide the power from the vessel to the rotating pod containing the drive motor or motors.

4 – Position Reference Systems and Equipment

4.1 – General

Accurate, reliable and continuous position information is essential for dynamic positioning. Some DP operations require better than 3m relative accuracy. A DP control system requires data at a rate of once per second to achieve high accuracy. Reliability is, of course, of vital importance, to operations where life and property may be put at extreme risk through incorrect position data¹⁰.

All DP vessels have position reference systems (PRS), (sometimes referred to as position monitoring equipment or PME), independent of the vessel's normal navigation suite. Five types of PRS are in common use in DP vessels; Hydroacoustic Position Reference (HPR), Taut Wire, DGPS, Laser-based systems (Fanbeam and CyScan) and Artemis. A brief description will be given of each.

DP control systems 'pool', or combine, position reference data from two or more position reference systems. If only one position reference system is enabled into the DP then it is simply checked, filtered and used. If two or more are available, then the system needs to use both equally or according to their individual performance.

In all modern DP systems the weighted average option can be selected, whereby individual position references are weighted in inverse proportion to the variance or ‘spread’ of position data; the higher the weighting for an individual position reference system, the greater the influence of that system in the position calculation.

Early DP control systems did not have the capability to learn from the past performance other than by the integral terms of the controller. Modern systems are able to improve station keeping performance by using a Karman filter, which provides a model of recent performance to improve present performance.

For any operations requiring DP redundancy (equipment Class 2 or 3 operations) it is necessary to utilise three position references. Two PRSs are not adequate, because if one has failed, contradictory reference data provides an impasse, whereas three systems provide two-out-of-three voting to identify a rogue sensor.

Where three PRSs are required, the DPO should choose systems that are different. This reduces the probability of common-mode failure, where one event may result in a loss of position.

A brief description will be given of the five commonly used position reference systems.

4.2 – Hydroacoustic Position Reference (HPR)

Underwater acoustics have many applications, one of which is the provision of position reference for DP purposes¹³.

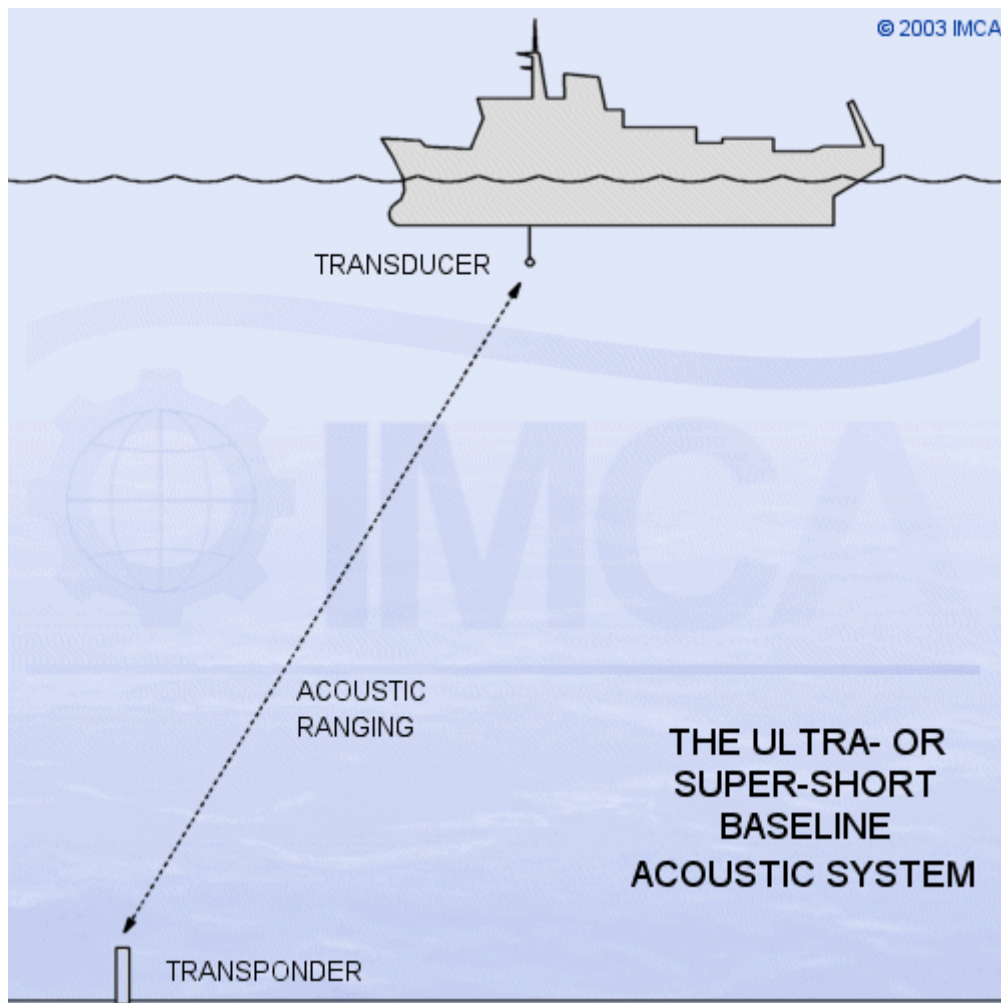
Acoustic positioning is also used for tracking of underwater vehicles or equipment, the marking of underwater features or hardware and the control of subsea equipment by means of acoustic telemetry.

There are three types of acoustic position reference systems in common use – ultra- or super-short baseline systems (USBL or SSBL), short baseline systems (SBL) and long baseline systems (LBL). Each has advantages and disadvantages which determine when and how each is used.

4.2.1 - Ultra- or Super-Short Baseline Acoustic System

The principle of position measurement involves communication at hydroacoustic frequencies between a hull-mounted transducer and one or more seabed-located transponders. The ultra- or super-short baseline

(SSBL) principle means that the measurement of the solid angle at the transducer is over a very short baseline (the transducer head).



Sketch 4.1 SSBL principles

An interrogating pulse is transmitted from the transducer. This pulse is received by the transponder on the seabed, which is triggered to reply. The transmitted reply is received at the transducer. The transmit/receive time delay is proportional to the slant and range. So range and direction are determined. The angles and range define the position of the ship relative to that of the transponder. The measured angles must be compensated for values of roll and pitch.

The vessel must deploy at least one battery-powered transponder. They can be deployed by downline from the vessel, by an ROV or simply dropped overboard.

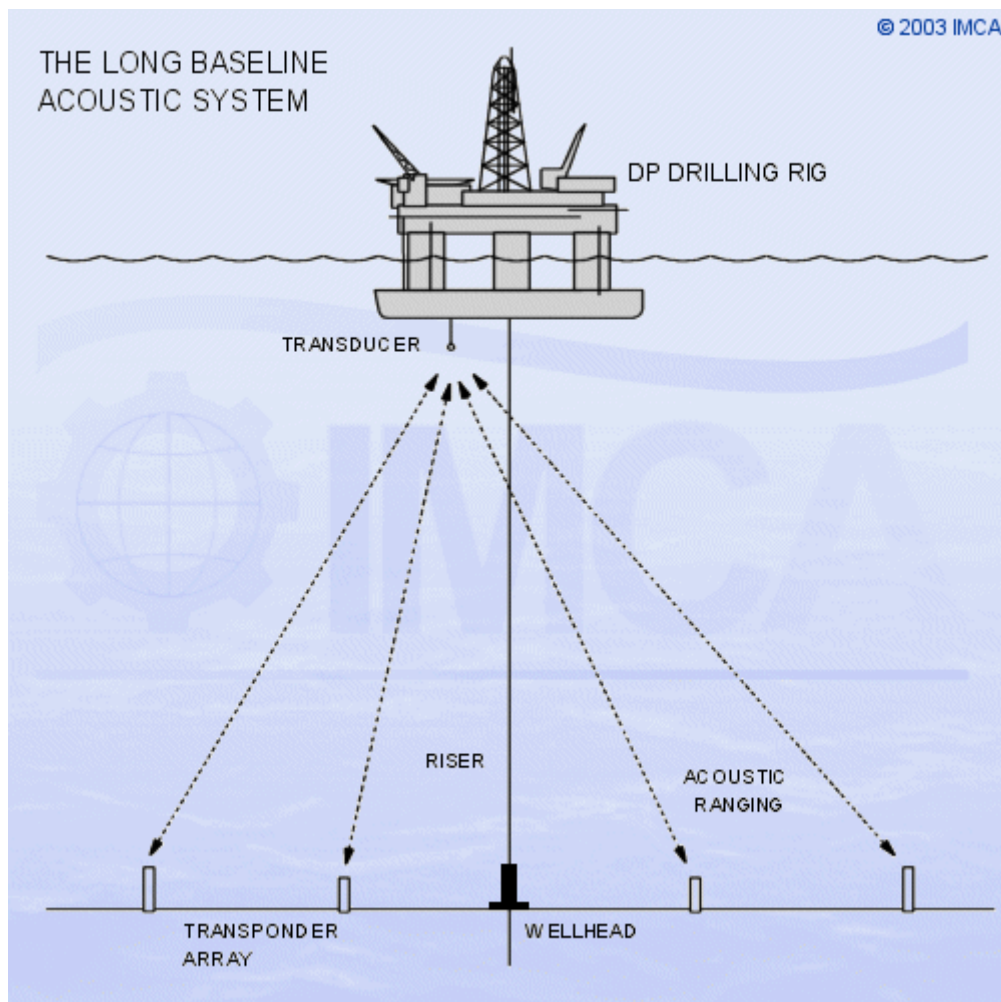
The performance of an acoustic system is often limited by acoustic conditions in the water. Noise from vessel thrusters and other sources, aeration and turbulence^{12, 13} will all be detrimental to efficient acoustic

positioning. Thus the limits of the system are ill-defined. In addition, layering can cause errors, especially when the horizontal displacement from the vessel is large.

Acoustic systems are supplied by a number of manufacturers, notably Kongsberg Simrad, Sonardyne and Nautronix. All use frequencies in the 20–30 kHz band. Some transponders are compatible with more than one supplier's equipment.

4.2.2 - Long Baseline System

In deepwater locations, where the accuracy of the other types degrades, the long baseline (LBL) becomes more appropriate. LBL systems are in extensive use in drilling operations in deep water areas (>1,000m).



Sketch 4.2 LBL system

The long baseline system uses an array of three or more transponders laid on the seabed in the vicinity of the worksite. Typically the array will

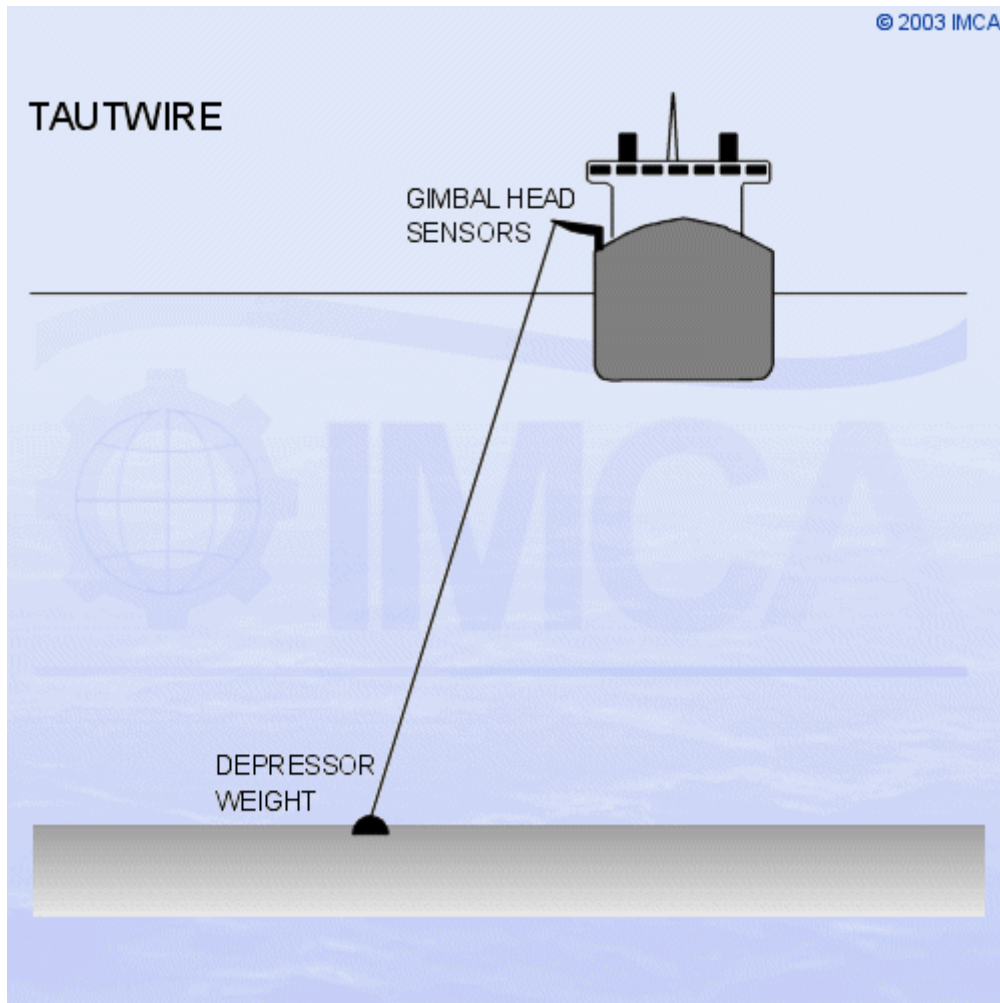
form a pentagon (5 transponders) on the seabed, with the drillship at the centre above. One transducer upon the vessel interrogates the transponder array, but instead of measuring range and angular information, ranges only are measured, because the baseline distances have already been calibrated (distances between transponders). Position reference is obtained from range-range geometry from the transponder locations. Calibration is done by allowing each transponder to interrogate all the others in the array, in turn. If, at the same time, the vessel has a DGPS or other geographically-referenced system, then the transponder array may also be geographically calibrated. Accuracy is of the order of a few metres, but the update rate can be slow in deep water because the speed of sound in sea water is about 1,500 m/sec.

4.2.3 - Short Baseline System

A short baseline is like a long baseline system, except that there is an array of transducers (hydrophones), spread along the underside of the DP vessel and the baseline(s) are the distances between them. Thus the accuracy can be better than the ultra- or super-short baseline type of system and work with one transponder or beacon, but it still relies on vessel motion corrections. Some vessels have as many as eight hull penetrations for tubes or poles on which the hydrophones are deployed.

4.3 - Taut Wire Position Reference

A taut wire is a useful position reference, particularly when the vessel may spend long periods in a static location and the water depth is limited. The commonest consists of a crane assembly on deck, usually mounted at the side of the vessel and a depressor weight on a wire lowered by a constant-tension winch. At the end of the crane boom angle sensors detect the angle of the wire. The weight is lowered to the seabed and the winch switched to constant tension, or 'mooring' mode. From then on, the winch operates to maintain a constant tension on the wire and hence to detect the movements of the vessel. The length of wire deployed, together with the angle of the wire, defines the position of the sensor head with reference to the depressor weight once the vertical distance from the sheave of the crane boom to the seabed is known. This is measured on deployment.



Sketch 4.3 – Taut Wire Principles

These angles are corrected at the taut wire or by the DP control system for vessel inclinations (roll and pitch angles and motion).

Vertical taut wire systems have limitations on wire angle because of the increasing risk of dragging the weight as angles increase. A typical maximum wire angle is 20 degrees, at which point the DP system will initiate a warning. Some vessels also have horizontal or surface taut wires that can be used when close to a fixed structure or vessel from which a position must be maintained. The principle of operation is the same, but a secure fixing point is required rather than a weight.

4.4 – The DGPS Position Reference System

DGPS has become the most commonly-used position reference for DP operations^{14, 15}. The US Department of Defense (DoD) Global Positioning System (GPS) is in widespread general use, with typical accuracies available from the GPS Standard Positioning Service (SPS – civilian access) of 20m (68% RMS or 1 sigma). Prior to May 2000 the DoD applied a further

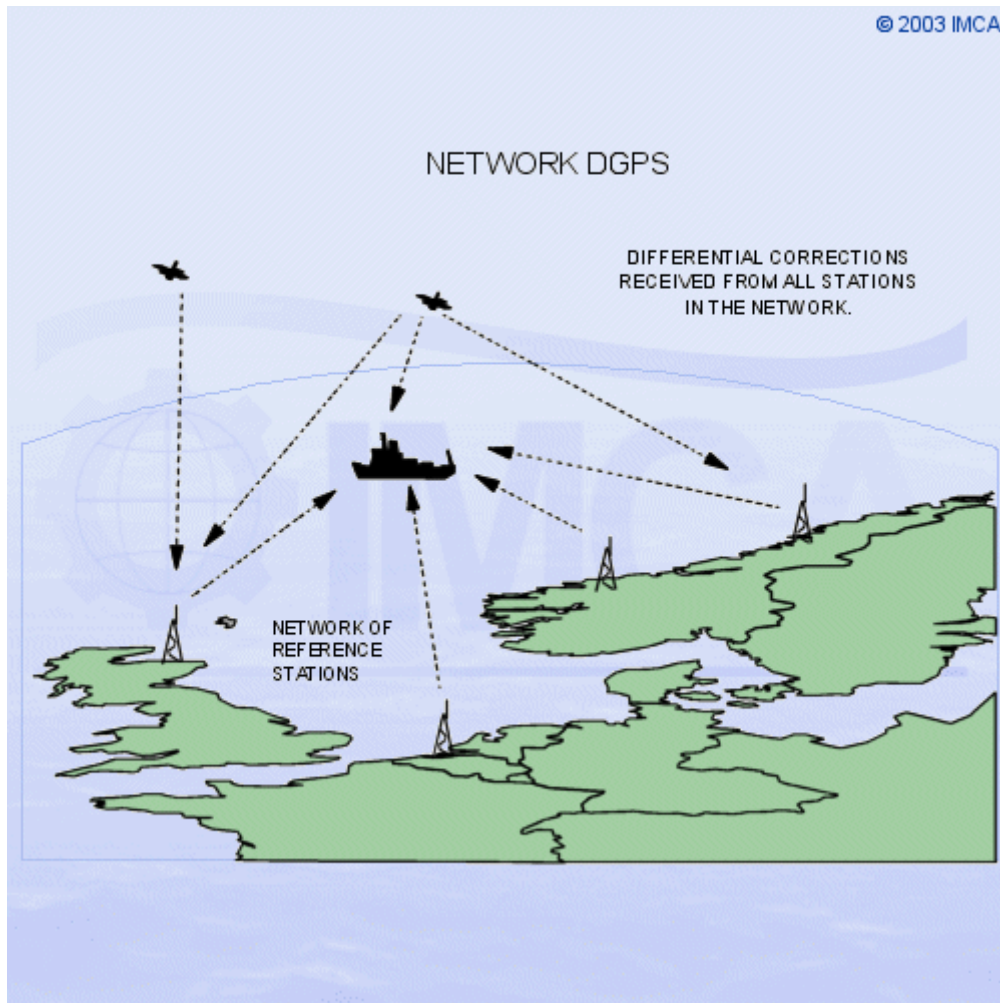
downgrading known as ‘selective availability’ (SA), which reduced SPS accuracy to values around 100m. SA has been switched off, but the DoD reserves the right to re-apply it. Even without SA, GPS accuracy is not adequate for DP purposes.

In order to improve GPS accuracy to levels useful for DP, differential corrections are applied to GPS data. This is done by establishing reference stations at known points on the WGS 84 spheroid (the working spheroid of the GPS system). The pseudo ranges derived by the receiver are compared with those computed from the known locations of the satellites and reference station, and a Pseudo-Range Correction (PRC) derived for each satellite. These corrections are then included in a telemetry message sent to the ship’s receiver by a data link. The receiver then applies the PRCs to the observed pseudo ranges to compute a differentially corrected position.

Differential GPS systems are provided on-board by a service provider. The provider maintains and operates a network of reference stations worldwide and will install receiving equipment on-board to access the services.

4.4.1 - Network DGPS

Most DGPS services accept multiple differential inputs obtained from an array of reference stations widely separated. Generally, network DGPS systems provide greater stability and accuracy, and remove more of the ionospheric error than obtainable from a single reference station. Network systems are more comprehensively monitored at the Hub, or control stations, where user information or warning data may be generated and sent out.



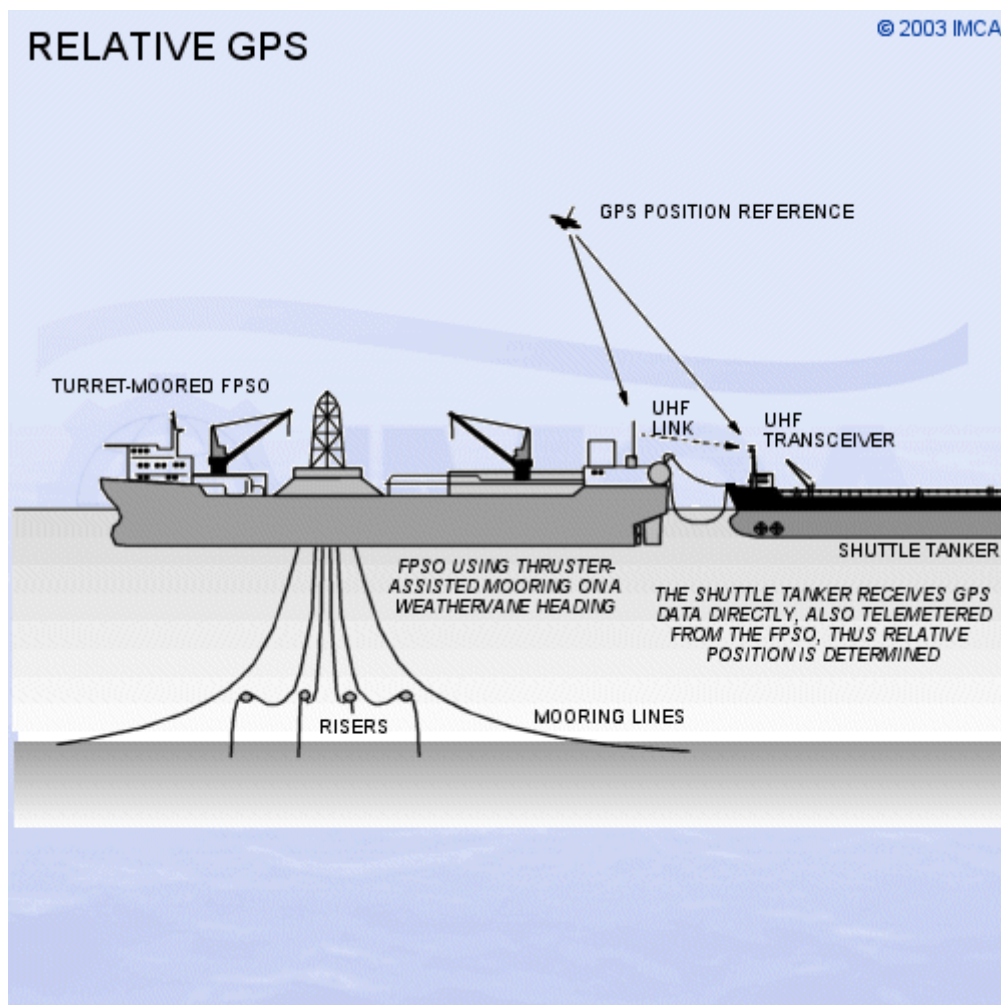
Sketch 4.4 – Network DGPS configuration

The choice of which link to hire or purchase must be made based on the vessel's expected work areas. If a vessel is expected to be working near fixed platforms, a local HF connection can be best. For floating production, storage and offloading (FPSO) vessels, a local UHF link and relative GPS solution can be the best arrangement.

The accuracy obtainable from DGPS systems is in the area of 1–3m dependent upon the distances to the reference stations, ionospheric conditions, and the constellation of satellites available. DGPS tends to be less reliable in close proximity to large structures (ie. platforms) due to interference to satellite and differential signals. DGPS performance near the magnetic equator has suffered due to scintillation (sun spot activity causing ionospheric disturbances). This reached a peak in 2001 with the maximum of the 11-year sunspot cycle.

4.4.2 - Relative GPS

Some DP operations require the positioning of a vessel relative to a moving structure. An example of this is the operation of a DP shuttle tanker loading via a bow loading hose from the stern of an FPSO. The FPSO may be turret-moored, so it can weathervane. The stern of the FPSO describes the arc of a circle, as well as surge sway and yaw motions, providing a complex positioning problem for the shuttle tanker.



Sketch 4.5 - Relative GPS

An Artemis²⁰ and a DARPS system (Differential, Absolute and Relative Positioning System) are configured to handle this problem. For the measurement of relative position by GPS, differential corrections are not needed, as the errors induced are the same for the shuttle tanker as they are for the FPSO. A DARPS transmitter on the FPSO sends the received GPS data to the UHF receiver aboard the shuttle tanker. A computer aboard the shuttle tanker then calculates a range/bearing from the FPSO's stern,

which is put in to the DP control system as position reference in the same way as Artemis.

4.4.3 - The GLONASS system

GLONASS (the Global Navigation Satellite System¹¹) is the Russian counterpart to the American GPS, being similar in design and operation. The system was initiated with the first satellite launches in 1982, and by 1996, 24 operational satellites were in orbit. However, this number has not been maintained and the number available has, at times, been inadequate for good positioning.

The principles and practice of position determination with GLONASS are identical to that of GPS, using pseudo-range measurement from time and ephemeris data transmitted from the satellites.

The higher orbital inclination of GLONASS satellites (65°), compared to the GPS constellation (55°), results in better satellite availability in higher latitudes. The limited satellite availability precludes the use of GLONASS as a continuous position reference for DP. A number of combined GPS/GLONASS receivers are available. These have the effect of increasing the number of usable satellites within view of the observer.

4.5 - Laser-Based Position Reference

Two laser DP position references are in use -Fanbeam and CyScan²¹.

Both systems lock onto a single target and/or a number of targets on the structure, from which position must be maintained. Light pulses are sent and received so that range and bearing can be measured.

Ranges vary according to weather conditions, when the systems will be affected by reduced optical visibility.

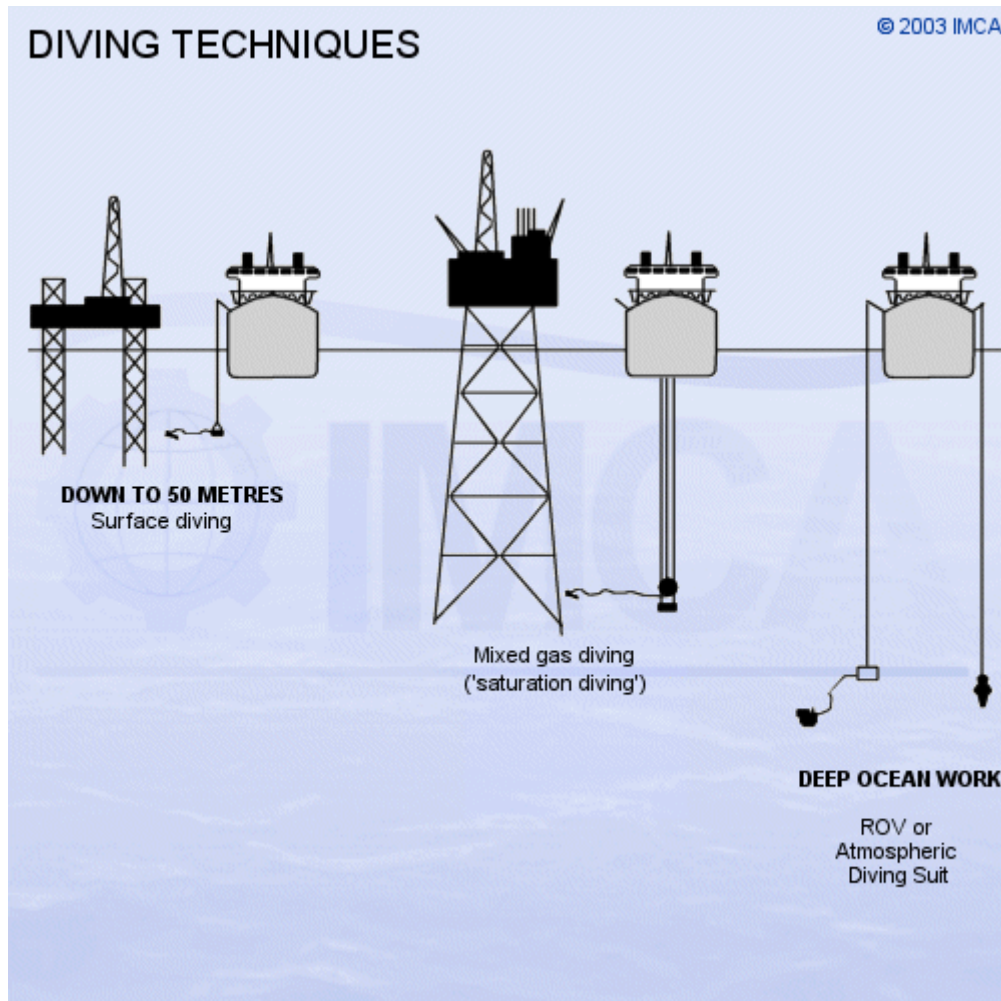
5 - DP Operations

5.1 - Diving and ROV Support Operations

Many DP vessels are designed specifically for supporting divers (DP DSVs). Other vessels have a multi-role function, including diver support. The variety of work that may be conducted by a diver is almost endless: carrying out inspection or survey work, installation and configuration of equipment, monitoring of an operation, or recovery of lost or abandoned

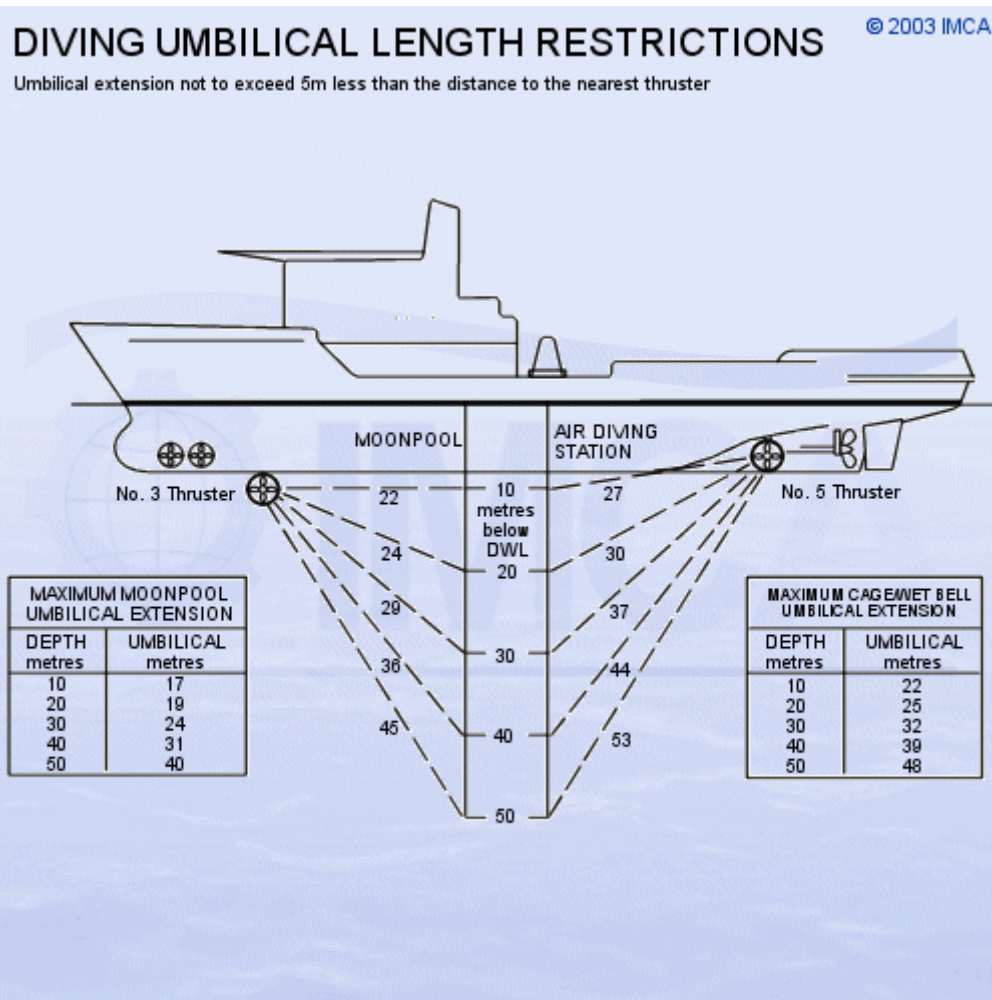
equipment. Much of the work hitherto conducted by diver is increasingly carried out by **ROVs** (remotely operated vehicles – unmanned submersible vehicles) but there are still tasks which cannot be completed remotely, and which require human intervention.

There are different types of underwater operations. 'Air range' diving is limited to a depth of 50m. The technique is so called because the diver's breathing gas is compressed air.



Sketch 5.1 – Diving techniques

The hazards of diving from vessels with rotating thrusters and propellers are obvious. One vital requirement of any diving set-up, from a **DP** vessel, is that the amount of umbilical the diver may be given, measured from the tending point (basket or bell) must be at least 5m less than the distance to the nearest thruster. This is to ensure that the diver cannot be drawn into a thruster or propeller. This can be broadly illustrated by the sketch below.



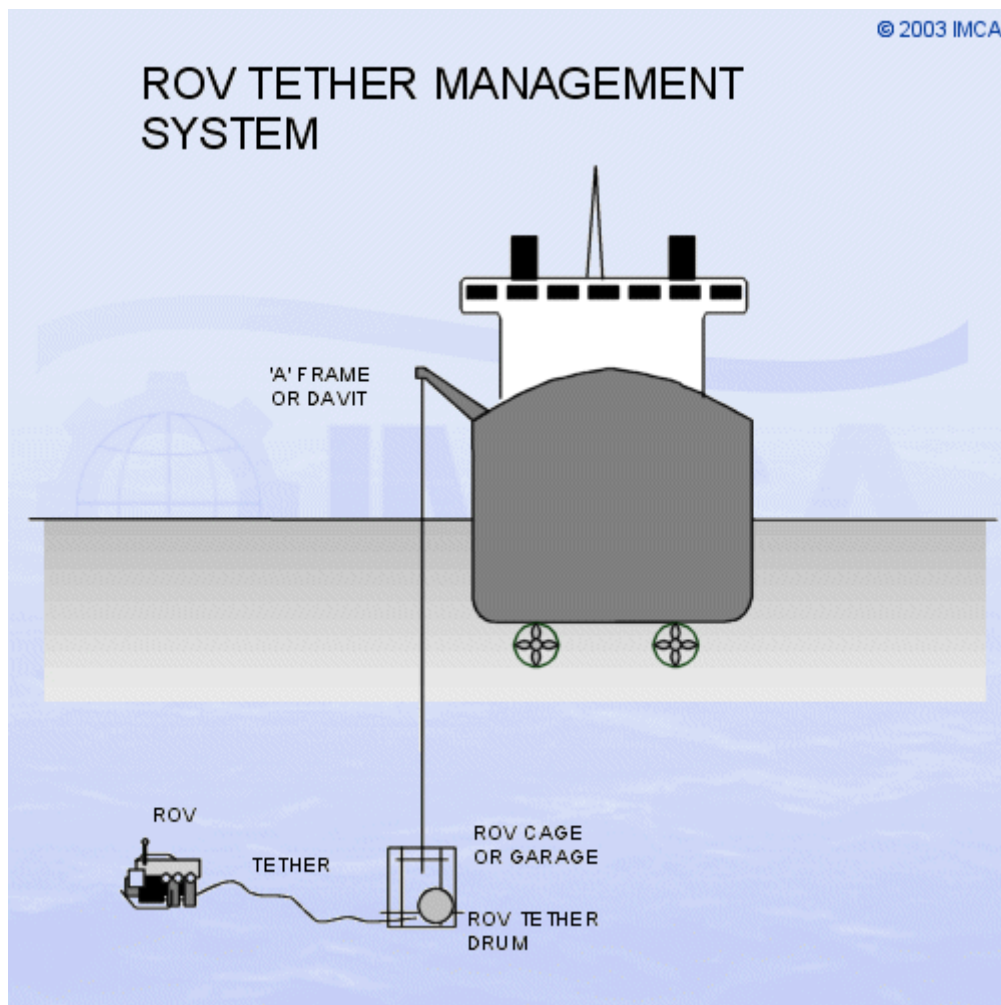
Sketch 5.2 – Umbilical length restrictions

Below 50m the diver must be deployed from a diving bell and his breathing gas is a helium/oxygen mix (Heliox). The diving bell maintains the diver at the pressure of the working depth, and mates with a hyperbaric complex on board the vessel. The divers live in this hyperbaric chamber, also maintained at pressure, for up to 28 days, travelling "to work" in the diving bell. This technique is known as "saturation diving". The bell is usually deployed through the moonpool, an open well in the centre of the vessel. A typical "bell run" would consist of three divers (two swimmers and a bell-man) operating for an eight hour shift. The swimmers are provided with all gas, hot water for heating, and communications through umbilicals connected to the bell and ultimately to the vessel.

At present the practical limit for bell diving is about 300m. At greater depths than this, the work must be done by deep-water ROV or a diver in an atmospheric diving suit (ADS) must do the work. ROVs or unmanned submersibles are increasingly sophisticated units able to operate a wide variety of tooling, sensors and other instrumentation.

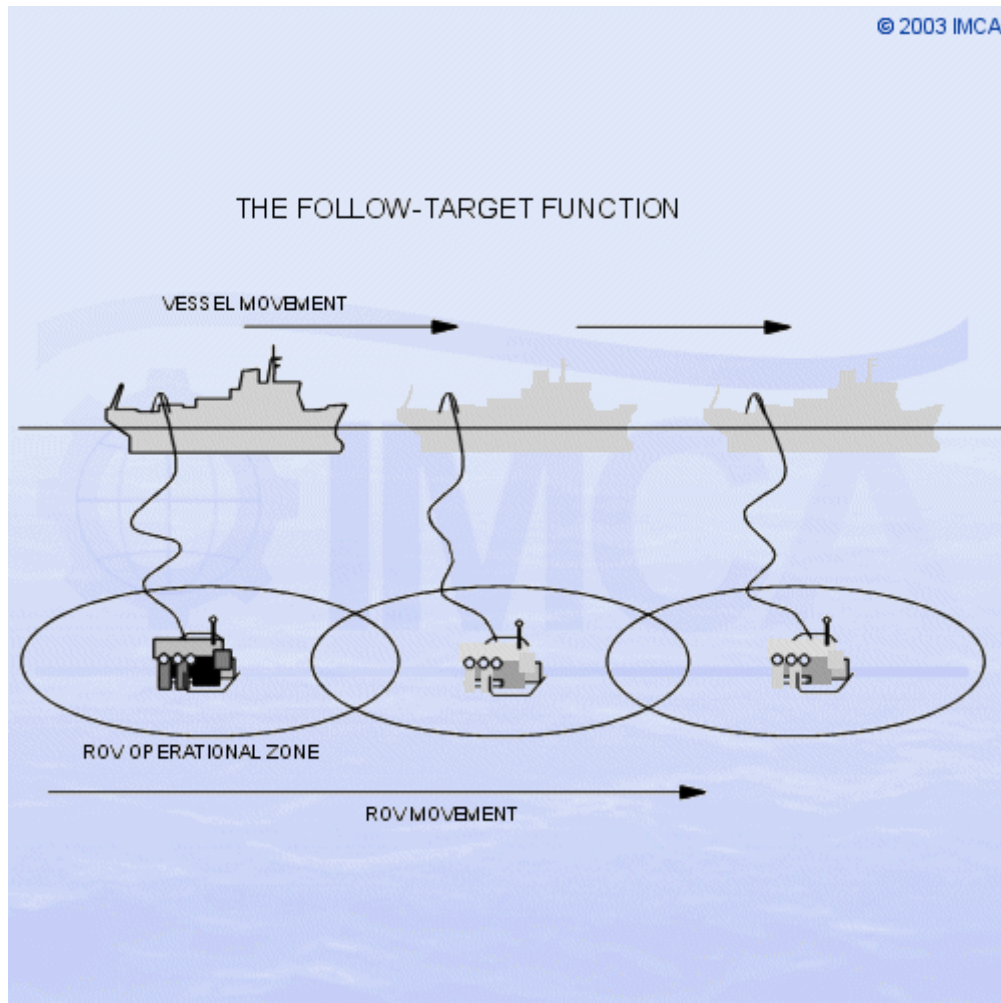
5.2 – Survey and ROV Support

Support vessels of this type may perform a multitude of tasks from hydrographic survey, wreck investigation, underwater recovery, site survey, installation inspection and maintenance. Although the task itself may be relatively non-hazardous, the location itself may have hazards, especially if in close proximity to a platform structure.



Sketch 5.3 – ROV Tether Management System (TMS)

An ROV may be deployed direct from a gantry or 'A' frame at the side or stern of the vessel, or from a tether management system (TMS) incorporating a cage or garage. If deployment is directly overside then great care must be taken to ensure that the umbilical does not foul the thrusters or propellers. The DP control system of the support vessel can be put into a 'follow sub' or 'follow target' mode for this work, where the acoustic transponder on the vehicle becomes the position reference.



Sketch 5.4 – Follow Target

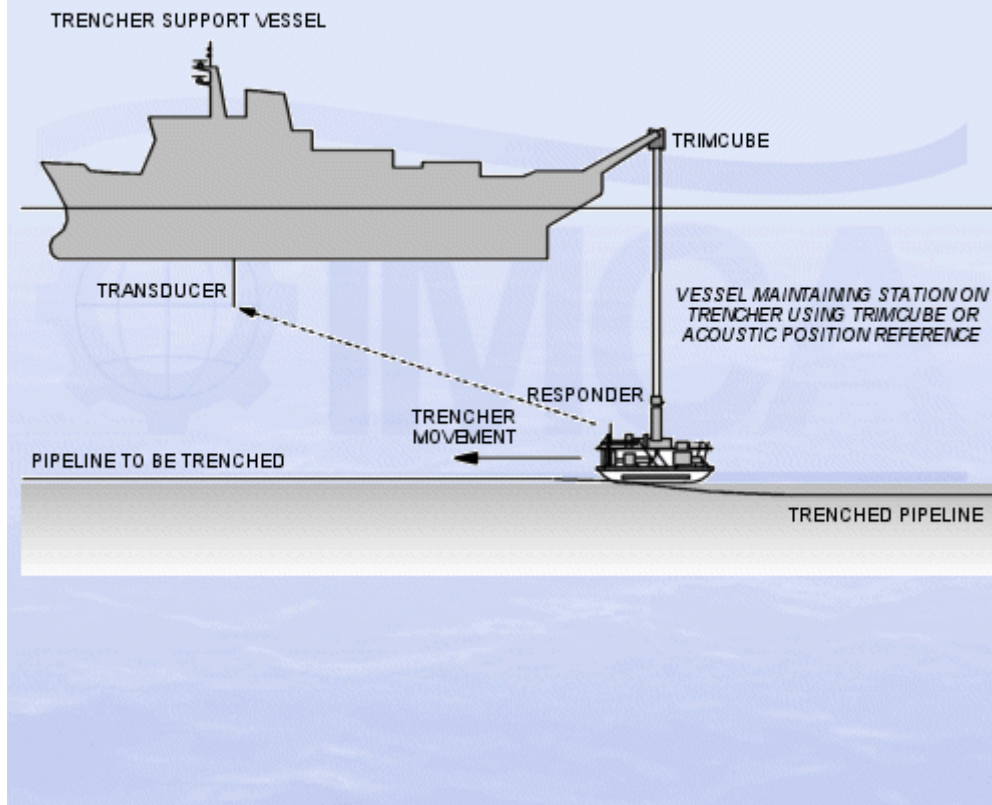
5.3 – Seabed Tractors and Trenchers

A seabed tractor or trencher may be configured to lay and bury a cable. These vehicles are tracked crawlers, built to be controlled from the vessel, with operators ‘driving’ the unit as if they were on board. These units usually move slowly, depending on soil conditions. In some cases an ROV is deployed independently, to record progress and performance.

Trenchers for pipeline burial are much larger and heavier. The trencher is lowered onto the seabed over the pipeline and the DP control system can set the centre-of-rotation of the trencher.

TRENCHING OPERATION

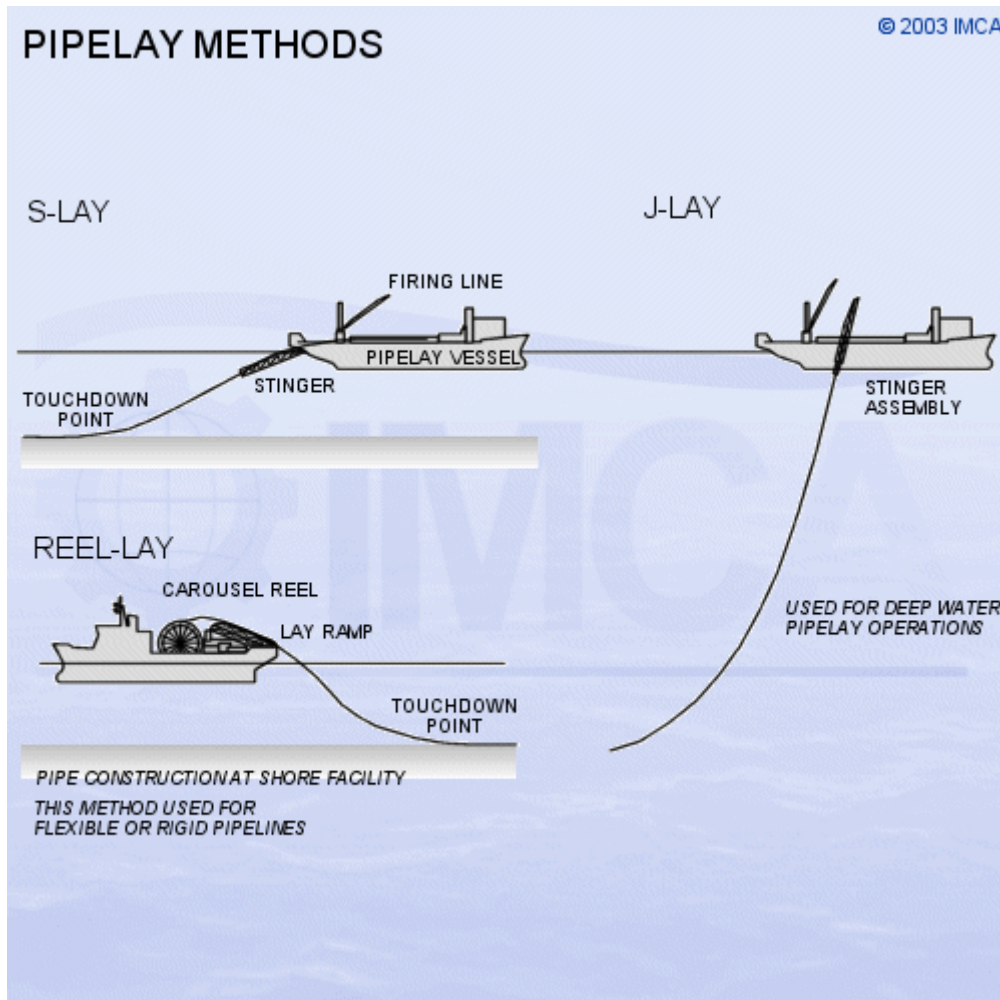
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Sketch 5.5 – trenching operation

5.4 – Pipelay Operations

Many pipelay operations are conducted by DP lay barges.



Sketch 5.6 – Pipelay methods

In a typical S-lay barge, the pipe is constructed in a linear pipe fabrication facility called the "Firing Line" in which a number of stages of welding take place. Each operation is conducted at a "station". Further stations conduct X-ray and NDT testing on the welded joints, anti-corrosion coating, and weight-coating if necessary. At intervals, the DPO initiates a move ahead a distance equivalent to the joint-length. Once the move ahead has been completed, the firing-line operations continue.

It is essential that tension is maintained on the pipeline. At the back end of the firing line, the pipe is held by a number of pipe tensioners, or caterpillar tracks clamping the pipe. The tensioners control the movement of the pipe, maintaining a set tension on the pipe string. The pipe is supported aft of the firing line by the "stinger", which is an open lattice gantry extending beyond the stern of the vessel, sloping downwards. Tension on the pipe is needed to prevent pipe damage from buckling. The set tension is to ensure a smooth catenary to the touchdown

point on the seabed. If tension is lost, then damage will occur at the touchdown area.

Pipe tension values are communicated to the DP system which is continually providing thrust commands to maintain tension, position and heading.

Pipelay operations are particularly dependent upon environmental conditions. The vessel must be able to cope effectively with the tides, sea state and wind conditions from most directions, because it is not possible to allow the vessel to weathervane.

5.4.1 - J-Lay Operations

In deeper water, S-lay is not feasible and J-lay is common. In J-lay operations, the stinger is configured as a tower, angled between the vertical, and up to 20 degrees from the vertical. Pipe lengths are pre-jointed into triple or quadruple joints before being raised to the vertical for welding onto the pipestring.

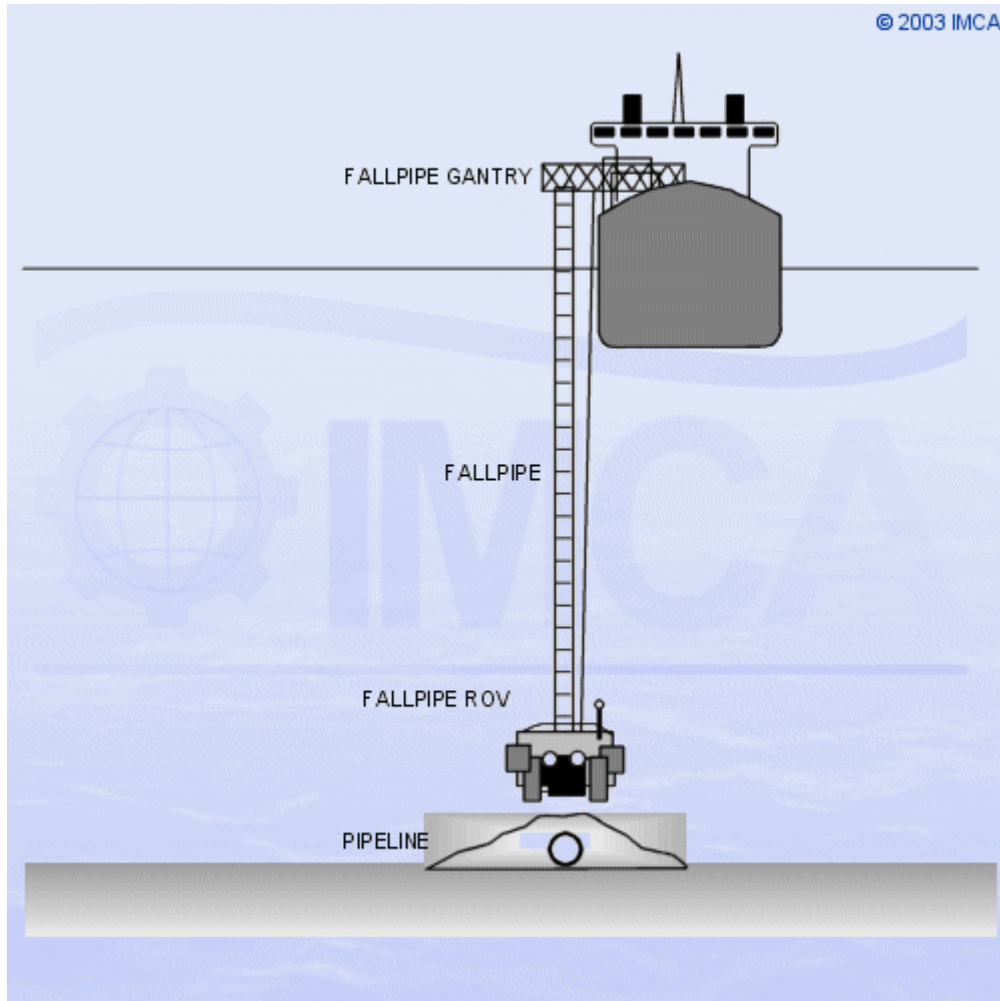
5.4.2 - Reel-Lay Operations

This type of operation varies from those described in that the pipestring is prefabricated in one length at a shore-based factory. The vessel loads the pipeline straight from the factory, spooling it onto a reel or into a carousel. The vessel can transit to site with the pipe to lay it by feeding it off the reel/carousel via straighteners and tensioners, either singly or as a bundle.

5.5 – Rock Dumping Operations

Rock dumping vessels have DP systems for accurately dumping rock on the seabed for a variety of reasons. They range from mini-bulk carriers, able to carry out burial operations using fallpipes, to smaller deck-loading vessels mainly used for erosion rectification projects. All of these vessels that work in the offshore industry are fitted with DP systems, because good track speed control, and hence uniform, economic rock distribution, is possible.

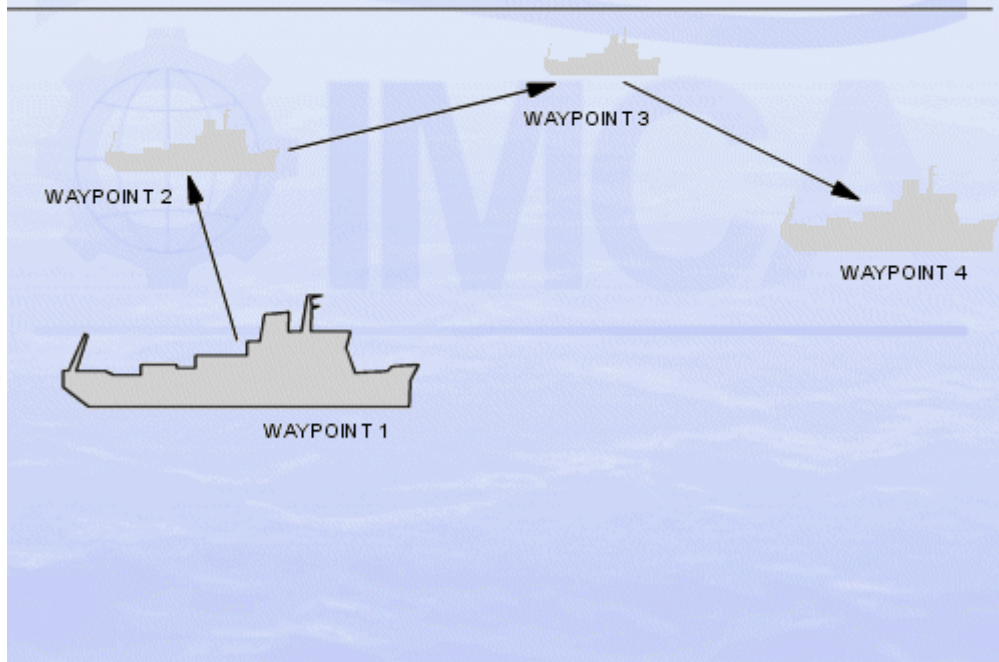
The commonest need for rock dumping is to provide protection to untrenched pipelines.



Sketch 5.7 – rockdumping

A commonly used feature is the ‘auto-track’ function of the DP control system, which enables the vessel to track accurately along a line defined from the preset waypoints of an earlier pipeline survey.

THE AUTOTRACK or TRACK- FOLLOW FUNCTION



Sketch 5.8 – Autotrack or Track Follow

This type of vessel is also used to provide protection against tidal scour or erosion, which occurs in high tidal stream areas. The sediment around the legs of a Jack-up drilling rig, for example, can become eroded to the point where the rig becomes unstable.

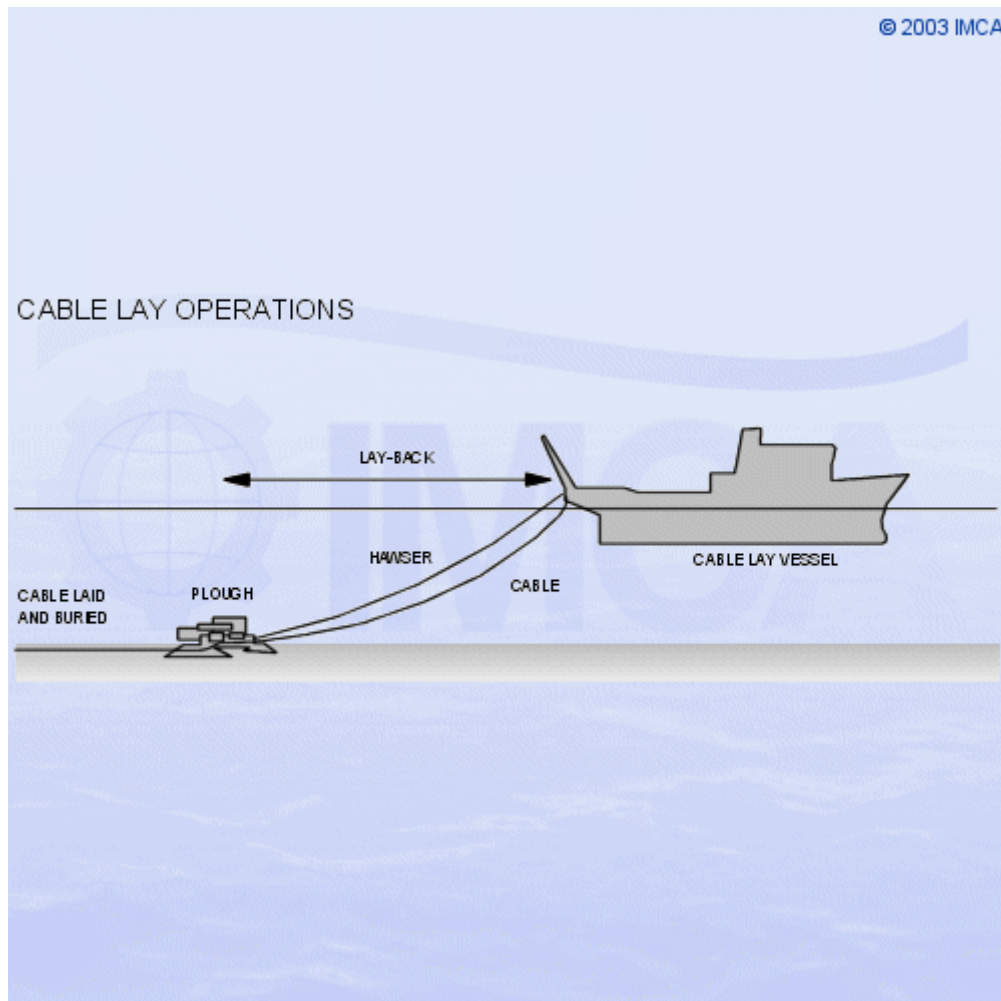
5.6 – Dredging Operations

Most new dredgers now have a DP capability, because they wish to move along parallel tracks. For the trailing suction dredger, for example, the tracks must be close together with minimum overlap. This is ideal for ‘track follow’ abilities of the DP control system.

Vessels dredging for aggregates can require precise positioning to ensure they are dredging in licensed areas and to assist with locating particular types of material.

5.7 – Cable Lay and Repair Operations

Modern fibre-optic cables are more fragile than traditional cables, so they have more limitations on loadings and bend radii. Thus it is now common to use DP vessels for cable lay and repair.



Sketch 5.9 – Cable lay methods

For cable lay operations within coastal waters or other shallow-water areas, it is often necessary to bury the cable in order to prevent damage from fishing gear. When a plough is used, it is towed by the ship, in a similar manner to a tractor towing an agricultural plough across a field. This reduces the power available for station keeping.

The phase of the operation where the DP capability proves most useful is the shore-end tie-in. This is where the vessel comes to the end of the lay, a short distance from "the beach", to complete the connection. This involves the vessel keeping a fixed location, close to the shore, in shallow water, where strong tides may also stream.

5.8 – Crane Barge Operations

Crane barges are employed all over the world in construction and de-commissioning operations relating to the oil and gas industries, and also in civil construction projects. They are also used in salvage and wreck removal operations.

Many crane barge and construction vessels are DP-capable – the larger ones generally to IMO equipment Class 3. The major advantage of DP to these vessels is the ability to complete a task in a very short time span, because the time needed to lay and recover moorings is saved, as is the risk of the moorings damaging nearby pipelines and structures.

5.9 – Mobile Offshore Drilling Units (MODUs)

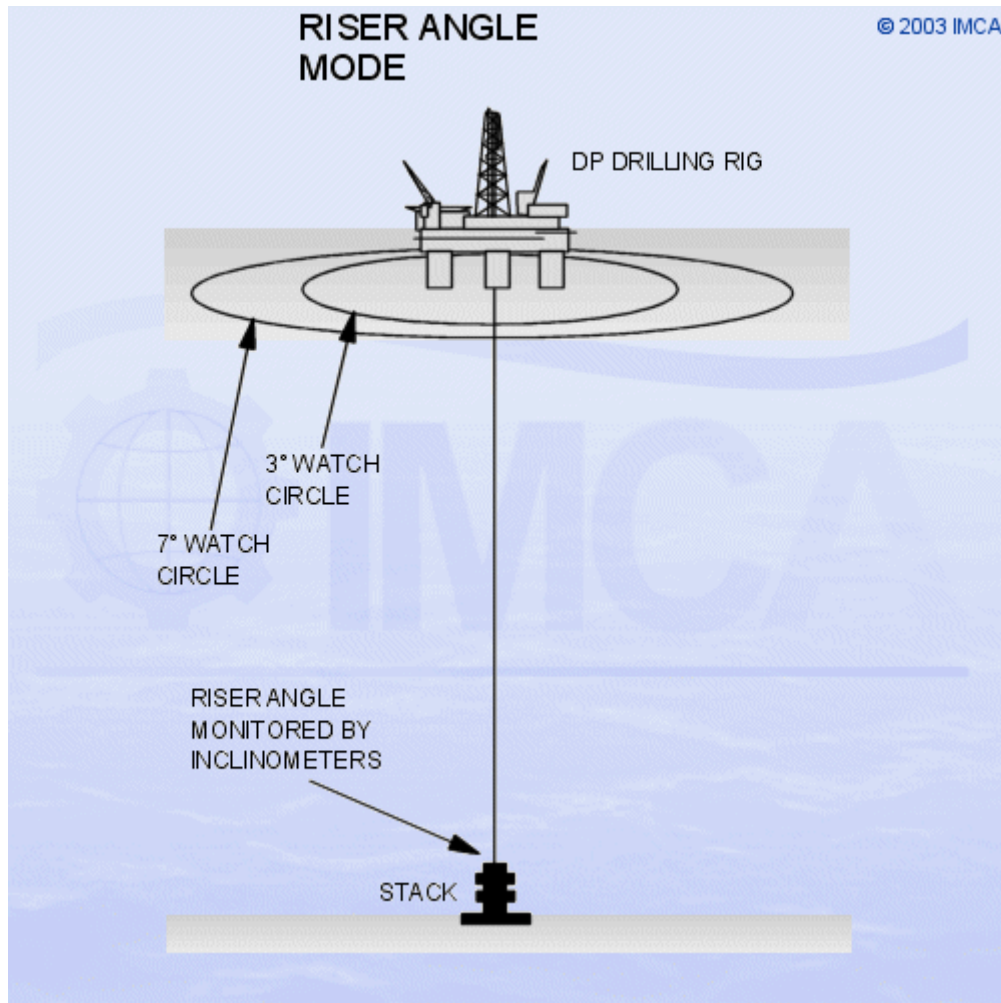
Deepwater developments offshore in the Gulf of Mexico, offshore Brazil, West Africa and the UK West of Shetland have made DP the only real option, as moorings are depth-limited. Even in shallower waters, DP is increasingly used for the positioning of drilling rigs while anchors are run. A DP rig or drillship may locate onto the worksite and commence drilling earlier than a similar rig using anchors. This is an advantage, particularly when only one or two wells are being drilled.

5.9.1 - DP Drilling Operations

The centre of rotation used by the DP control system is the centre of the drill floor rotary table, which for both monohulls or semi-submersible rigs is usually in the centre of the vessel.

For drilling operations, it is important for the vessel to keep over the well, such that the riser connecting the vessel to the well is practically vertical. The profile of the riser is, however, determined by current forces and tension, as well as by vessel position. The parameter that is continuously monitored is the lower main riser angle. If this exceeds 3° , action needs to be taken so that it does not get worse and force an unwanted disconnection.

For each well or location, the rig will have well-specific operational guidelines (WSOG), which determine when alerts are to be given and what action is appropriate. Watch circles might be used and set which are distances that represent angles at the lower end of the riser.



Sketch 5.10 – Deepwater drilling – the Riser Angle Mode

Some DP control systems have a function known as ‘riser angle mode’. When selected, the DP continues with a geographical position reference, but moves to reduce the riser angle. The reference for positioning is the angle of the riser at the stack, using sensors attached to the riser and the lower marine riser package (LMRP). These sensors may be electrical inclinometers, hard-wired to the rig up the riser or a Differential Inclinometer Transponder assembly, sending angular and positional information acoustically via the HPR system interfaced to the DP.

The DP system aboard the rig will have special display pages showing Riser angle offsets as part of a Position Plot display page.

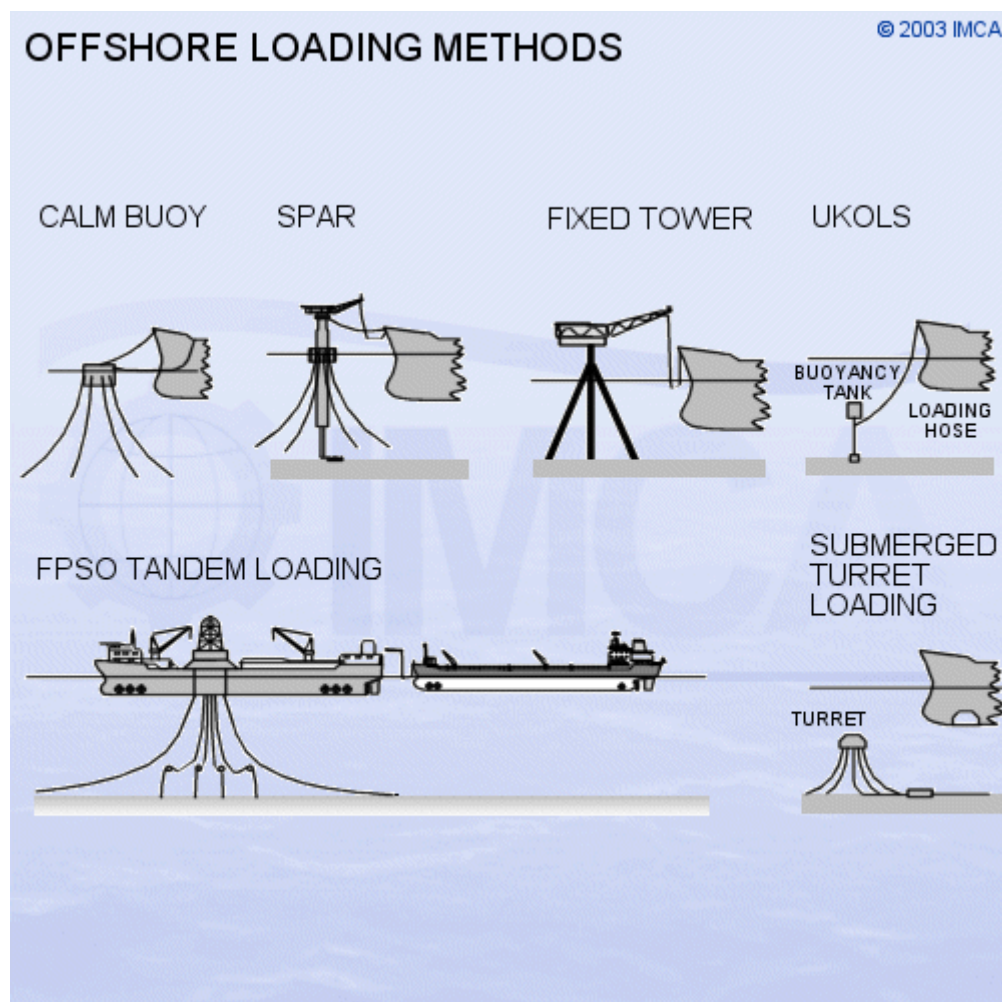
DP rigs are currently configured to operate in water depths of up to 3000m. In these water depths the most reliable form of position reference is DGPS. Two or three separate and distinct DGPS systems provide redundancy, provided that different differential correction links are used. Further

position-reference is obtained via deep water Long Baseline acoustic systems.

5.10 – Offtake Tanker and FPSO Operations

Tankers intended to load at Offshore Loading Terminals (OLTs) will be fitted with systems very similar to those in any other DP-capable vessel, but configured specifically for the offshore loading function.

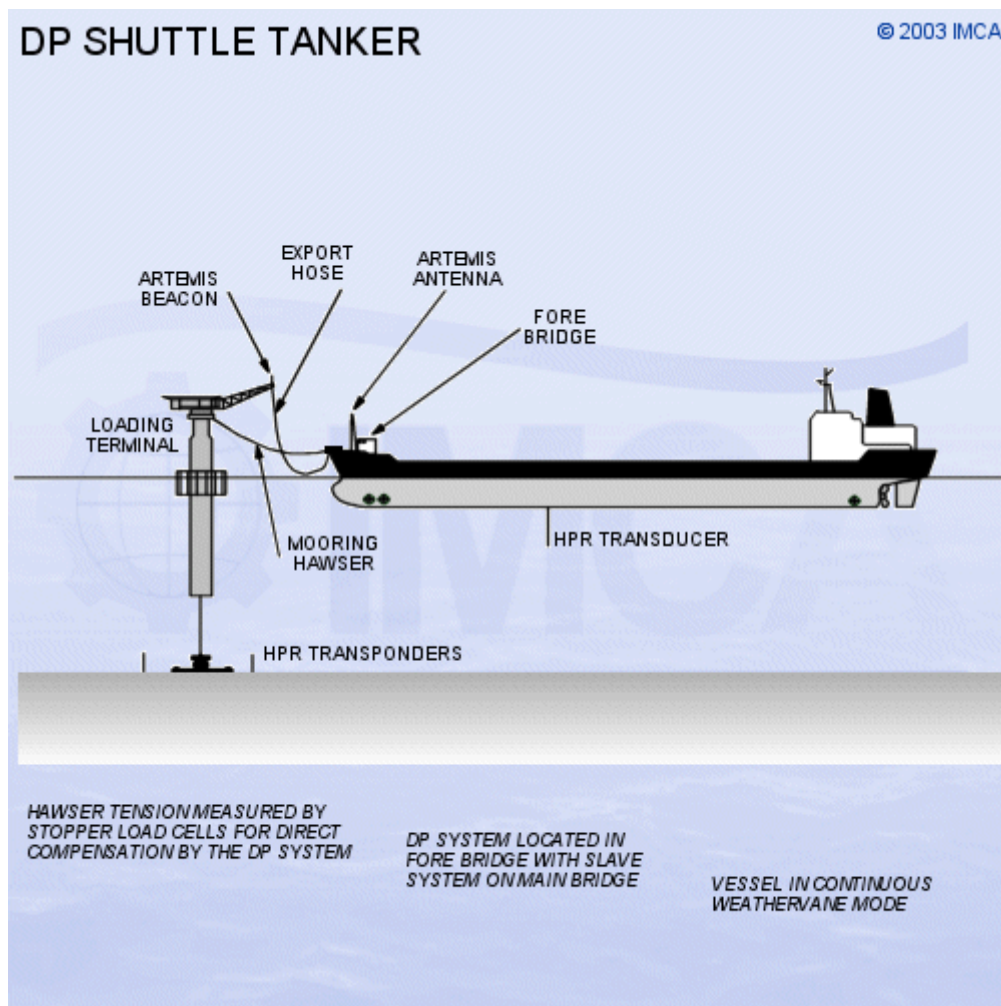
The installations which support offtake tanker operations vary from field to field. Typical installations are Spar buoys, which are large floating tower structures moored by a spread of mooring lines. Spar buoys usually carry a rotating turntable at the top to handle vessel moorings and hose handling equipment.



Sketch 5.11 – OLT configurations

A UKOLS facility has a loading hose connected to a mid-water buoy. The buoy is positively buoyant and is moored at a fixed depth, above a gravity-based housing or pipeline end manifold (PLEM). Vessels using this

facility have no need for a mooring hawser; the only connection to the buoy is the hose. A more recent development is the submerged turret loading (STL) system, where the loading connections are located in a subsea buoy. The buoy is moored above the PLEM at a depth greater than the draught of the offtake vessel. The STL is mated into a docking port built into the forebody of the vessel, and carries the flowline connections to the vessel. Once locked into position, the vessel is able to weathervane using the swivel through the centre of the STL. A development of the STL is used for production.



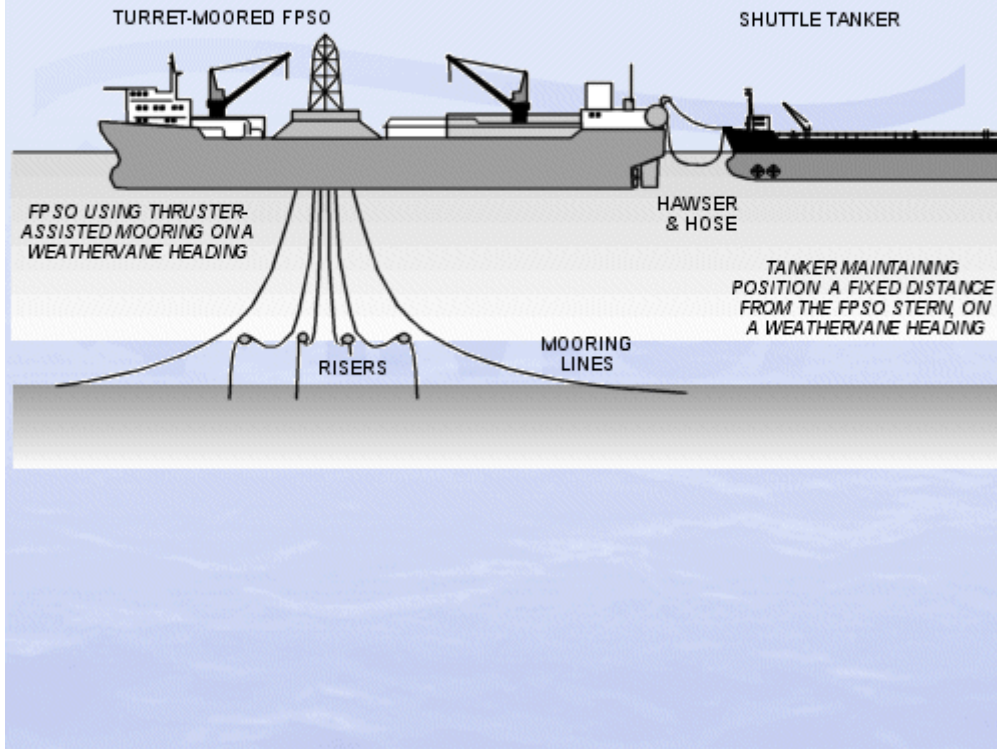
Sketch 5.12 - Shuttle tanker

5.11 – FPSO Unit Operation

Floating Production, Storage and Offtake units are becoming common in many parts of the world. Many FPSOs are able to weathervane around the turret and maintain heading into the weather.

FPSO SHUTTLE TANKER OFFTAKE

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Sketch 5.13 – FPSO/shuttle tanker offtake arrangement

Most FPSOs utilise offtake tankers for export of oil, and these tankers are usually DP-capable. With any FPSO/offtake tanker operation, the tanker will experience more positioning problems than when loading from an ALP. The offtake vessel keeps position within a circle defined by the length of the loading hose. The reference position is the hose terminal point on the stern of the FPSO. The mooring and positioning system in the FPSO allows a degree of movement, especially in deep water, so the FPSO may be continually weathervaning, so that the shuttle tanker reference point will be moving. The shuttle tanker can try to follow this movement or position absolutely to pre-set limits.

In FPSO offtake operations, a relative position reference is essential. One such position reference is the relative GPS (DARPS) system, yielding position information reduced to range/bearing data from the FPSO terminal location. Another position reference is Artemis, with the fixed station located on the FPSO and the mobile station located on the tanker. The prime

consideration is the clearance distance from the FPSO so that the collision risk is minimised⁷

5.12 – Other Functions and Operations Utilising DP

The various operations described above are the commonest. However, DP is rapidly expanding and new applications are being found.

5.12.1 - Passenger Vessels

Modern cruise vessels have shallow draughts to allow access to a greater range of cruise destinations, and ever larger freeboards. This shallow-draught, high-freeboard configuration leads to shiphandling problems in tight berthing locations. The addition of DP to the suite of facilities available to these vessels improves their flexibility and avoids anchoring in sensitive seabed areas.

5.12.2 - Specialist Semi-Submersible Heavy-Lift Vessels

Vessels intended to carry huge modules of heavy equipment to remote locations will often experience difficulty in both loading and off-loading their cargoes. Some of these vessels are of monohull, semi-submersible form, able to submerge to a loading draught, allowing the cargo to be floated aboard. A typical cargo may be a jack-up drilling rig for transport halfway around the world. DP facilities may be used during the loading operation.

5.12.3 - Military Operations and Vessels

A number of nations are making use of DP facilities in their naval and auxiliary fleets. Vessels for mine countermeasures, amphibious landing and forward repair are all good examples.

6 – DP Vessel Operations

With any DP vessel operation, comprehensive planning is essential. The operational requirements of the task in hand must be thoroughly discussed with the client, and a detailed plan of the preferred sequence of events compiled. The plan must include the approach to the worksite and set-up, together with the positional requirements of the task itself. At all stages there must be adequate contingency plans made.

6.1 – Operational Planning

DP operators (DPOs) must be familiar with the details of the worksite and of the tasks planned. In many operations the vessel is simply providing a working platform for a project team, but it is essential that the key DP personnel are familiar with the detail of the operation and the possible hazards.

6.1.1 - Contingency Planning

It is important that the planning of the worksite approach includes assessment of the various options for reaching a safe situation in foreseeable situations and hazards. One contingency will be for a power or thrust capability shortage caused by partial blackout or thruster failure. Other possibilities include failure of computer systems or position-reference systems, causing a drive-off²². The vessel should be able to reach a safe situation, which might require exit from the worksite, often the worst-case single-point failure.

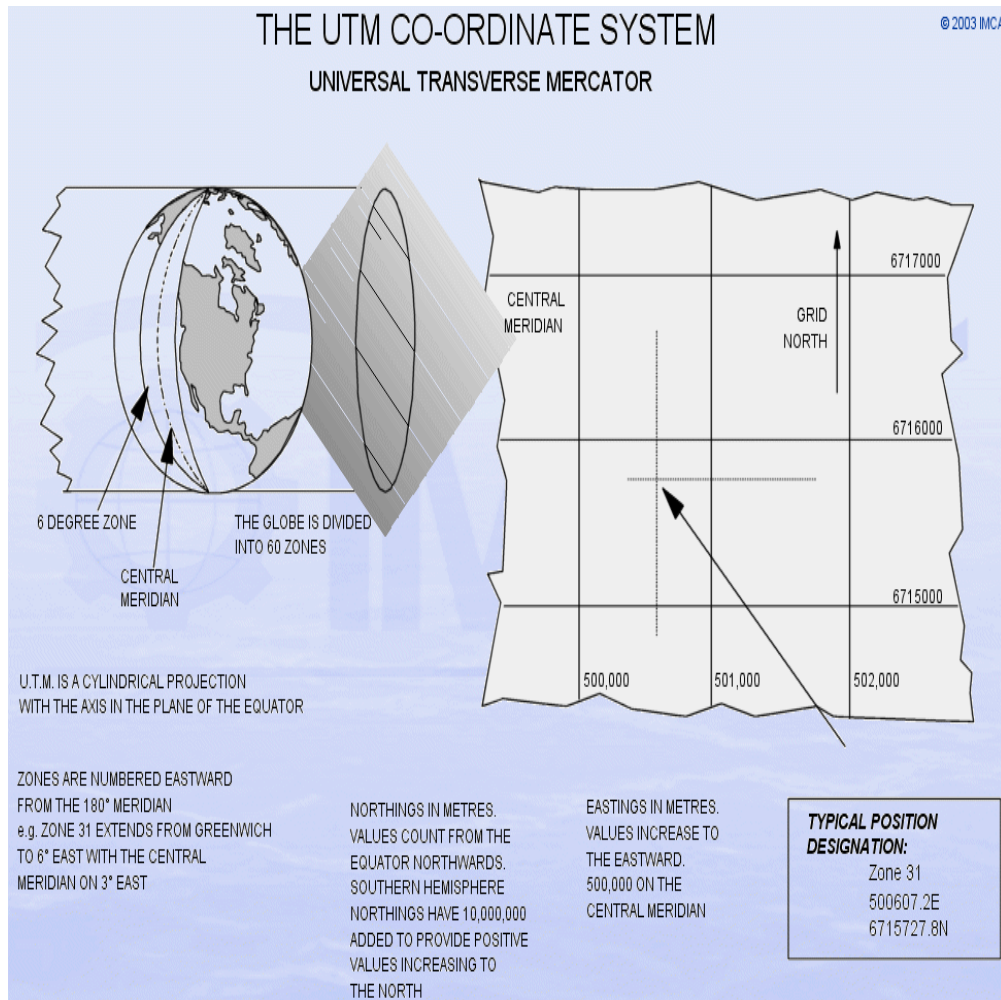
The DPO will make good use of plans and worksite diagrams provided by the client, either in paper or in electronic form. These drawings are likely to be prepared in UTM projection and co-ordinates. A description of this follows.

6.2 – The UTM Co-Ordinate System

A Geodetic co-ordinate system in widespread use is UTM, or Universal Transverse Mercator. This is a flat-surface, square-grid projection defined by a UTM zone number, and a Northing and Easting distance from the zero point of the zone. Some position reference systems, such as DGPS, may put out positions in UTM co-ordinates.

The Universal Transverse Mercator (UTM) projection is used extensively for survey and other offshore work.

UTM is a cylindrical projection with the axis of the cylinder coincident with the plane of the equator; the line of contact between the cylinder and the sphere is thus a meridian.



Sketch 6.1 – UTM

Obviously a single cylindrical projection of this type cannot be used to chart the whole terrestrial surface. The useful scope of the projection consists of a zone 6° of longitude in width, centred upon the contact or "Central" meridian. Within this zone distortions are minimal. Zones are identified by a number. The numbering scheme is based upon Zone 1 being the area between the 180° meridian and Longitude 174° West, with the central meridian at 177°W. Successive zones are numbered in an easterly direction, with the North Sea generally being covered by Zone 31 ranging from the Greenwich Meridian to 6°E, with the Central Meridian at 3°E. There are sixty zones in total.

Within a particular zone, the Northings and Eastings (in metres) are arranged to increase in a Northward and an Eastward direction, respectively, irrespective of position upon the globe. For Northings the datum is the equator, with Northern hemisphere Northings having a value of zero on the equator, and increasing northwards. For the Southern hemisphere, a false Northing of 10,000,000 is added to the (negative)

values. This resolves the problem of requiring positive values increasing Northwards throughout.

A false Easting of 500,000 is established on the central meridian, with Easting values increasing in an easterly direction. This allows the whole zone to be covered by positive Easting values.

6.3 – Worksite Approach

For some vessels, transfer of control must be made from the navigation bridge to the DP console in another location. The vessel will change over well clear of any obstructions, usually outside the 500m zone, and complete a DP checklist. Items to be checked or tested include main engine/thruster control functions, communications (external VHF/internal) radar and navigation aids, gyrocompasses and steering systems. In addition, checks are made on specialist operational items associated with the work. These checks involve the key DP personnel on the bridge and in the engine control room. Thrusters and main propellers must be “proved” by taking manual control and trying each thruster each way, checking response and feedback. Once transfer is complete the watchkeeper may turn his attention to the DP control system⁵.

6.4 – Final Setting-Up

For some DP operations, further checks are executed in the final working position. A settling period of about thirty minutes is allowed, ensuring that the DP control system has time to build the mathematical model. During this time the bridge watchkeepers should complete the pre-operational checklist, and verify that pre-operational checklists are complete at other locations, such as the engine control room.

The bridge team must be aware of the significant change in status that may occur once the go-ahead (green light) is given for the operation to commence. Once the ‘green light’ is given, the contingency plan may change, because it must allow for the vessel to maintain position and heading adequately to reach a safe situation¹.

7 – Information for Key DP Personnel

7.1 – Failure Mode and Effects Analysis

For all DP vessels, all failure modes and their effects should be considered in a formal FMEA (failure modes and effects analysis) study¹⁶. The presence of an FMEA document is often a requirement of the pre-charter

auditing and inspection process, as well as being a requirement of the classification society for DP class notation. The modes that should be considered are the sudden loss of major items of equipment, the sudden or sequential loss of several items of equipment with a common link, and various control instability failures. Faults that can be hidden until another fault occurs should also be considered. Also to be considered are the methods of detection and isolation of the fault mentioned. Operator responses to the types of failure considered should be reflected in the vessel's operations manual. The FMEA should consider likely operational scenarios of the vessel, such as shallow water, high tidal stream rates and limited provision of position reference. See Ref. 16 for further information on FMEAs.

Redundancy levels are defined by the IMO document MSC/Circ.645 – *"Guidelines for Vessels with Dynamic Positioning Systems"*¹⁷ and the IMCA document *"Guidelines for the Design & Operation of Dynamically Positioned Vessels"*¹⁸. Three 'equipment classes' are defined, summarised in the IMCA guidelines as follows:

Equipment Class 1

Loss of position may occur in the event of a single fault

Equipment Class 2

Loss of position should not occur from a single fault of an active component or system such as generators, thruster, switchboards remote controlled valves etc. But may occur after failure of a static component such as cables, pipes, manual valves etc.

Equipment Class 3

Loss of position should not occur from any single failure including a completely burnt fire sub division or flooded watertight compartment.

A single fault includes a single inadvertent act by any person on board the DP Vessel.

In basic terms, equipment Class 1 refers to non-redundant vessels, Class 2 relates to vessels with full redundancy of systems and equipment, while vessels built or fitted to equipment Class 3 are able to withstand the loss of all systems in any one compartment from the effects of fire or flooding.

7.2 – Classification Societies

A number of classification societies issue class notations for DP-capable vessels. The notations from each of the societies vary, but refer to the compliance with the equipment classes. The following table lists the class

notations and corresponding equipment classes for Lloyd' s Register, DnV and ABS:

<i>Description</i>	<i>IMO Equipment Class</i>	<i>Corresponding Class Notations</i>		
		<i>LR</i>	<i>DnV</i>	<i>ABS</i>
Manual position control and automatic heading control under specified maximum environmental conditions		DP(CM)	DNV-T	DPS-0
Automatic and manual position and heading control under specified maximum environmental conditions	Class 1	DP(AM)	DNV-AUT DNV-AUTS	DPS-1
Automatic and manual position and heading control under specified maximum environmental conditions, during and following any single fault excluding loss of a compartment. (Two independent computer systems).	Class 2	DP(AA)	DNV-AUTR	DPS-2
Automatic and manual position and heading control under specified maximum environmental conditions, during and following any single fault including loss of a compartment due to fire or flood. (At least two independent computer systems with a separate backup system separated by A60 class division).	Class 3	DP(AAA)	DNV-AUTRO	DPS-3

7.3 – Consequence Analysis

One of the requirements of the IMO Class 2 and 3 guidelines, is a system of Online Consequence Analysis to be incorporated in the DP system. This function continually performs an analysis of the vessel's ability to maintain its position and heading after a predefined, worst case failure during operation. Possible consequences are based on the actual weather conditions, enabled thrusters and power plant status. Typical worst-case single failures are:

- failure in the most critical thruster
- failure in one thruster group
- failure in one power bus section

If the consequence of the predefined failure is a loss of position, it is reported to the operator via the DP alarm system. The consequence analysis can operate for different configurations and give Class 2 or Class 3 alarms and warnings. A typical alarm message is "Consequence Analysis Drift-Off Alarm". The associated description reads: "Single worst case failure will cause drift-off". The analysis function typically runs every minute and averages over the last minute.

7.4 – Watchkeeping

There are many different DP vessels and DP operations. Some tasks require the vessel to maintain a static or relatively static position for days or even months on end (drillships, flotels). Other vessels will be continually manoeuvring in order to execute their work. Irrespective of the work the Watchkeeping principles are similar and some general watchkeeping procedures are included here¹⁸.

Some Class 1 vessels operate with one DPO on watch, but the majority of DP operations are carried out with two operators manning the bridge. On some vessels, one DPO mans the DP desk exclusively, while the other watchkeeper carries out all other bridge functions. These two individuals then swap roles every hour. The watch relief arrangement should allow staggered watch change-over such that there are never two fresh DPOs taking over at the same time. When taking over the watch, DPOs must familiarise themselves with certain aspects of the management of the vessel at that time. The list of information that the bridge team must acquire at this time includes (but is not limited to) the following:

- Position and heading of the vessel
- Status and recent performance of the DP system and its peripherals
- Details of Position Reference Systems in use and their performance
- Availability of further PRS on failure of the above
- Level of redundancy
- Status of the operation in hand. Planned changes/progress for the coming watch.
- Details and status of any operational elements (e.g. if the vessel is a DSV and diving operations are underway, then the status, position, depth of the diving bell or basket, the number of divers in the water, their umbilical lengths and expected return times, also details of their operational task)
- Weather conditions and forecasts
- Communications, on-board and external
- Traffic in the area. Any planned traffic movements that may affect the vessel and her operation or positioning
- Any planned helicopter operations

7.5 – Checklists

Checklists are an essential and accepted feature of most DP operations. It is essential that checklists are treated as an aid to memory and not as a complete substitute for 'thinking'. It is very easy for one person in a hurry to fill out a checklist without checking many of the items contained therein. Checklists need updating from time to time, as new important points are found and equipment is modified or updated. Checklists are usually controlled documents within the shipowner's quality assurance system, where alterations may be seen as a 'non-conformance' and change takes too long.

Typical checklists to be maintained by the watchkeeping DPO include:

- Pre-DP checklist
- Pre-operational checklist
- Watch hand-over checklist
- Periodic DP checklist
- MCR checklist