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INTRODUCTION TO SHIP DYNAMIC POSITIONING SYSTEMS

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ABSTRACT

The aim of this work deals with the general review of conventional dynamic positioning systems. A summary of the main elements of a DP vessel and a brief explanation of the most relevant tasks is presented, followed by an IMO and NMD classification of DP vessels, depending on the redundancy of the ship equipment.

Key Words: Dynamic positioning, position reference systems, IMA classification, NMD classification

INTRODUCTION

Ship's Dynamic Positioning (DP) is a procedure that automatically maintains a vessel's position and heading (station keeping) by using her own propellers and thrusters (Balchen(a) et all., 1976), (Balchen(b) et all., 1980), Balchen(c) et all., 1980) (Grimble(a) et all., 1980), (Sorensen et all., 1996). This allows operations at sea where mooring or anchoring is not feasible due to deep water, congestion on the sea bottom (pipelines, templates) or simply the place where DP operations are needed.

DP is defined by the (IMCA, 2003), (International Marine Contractors Association) as: *"A system which automatically controls a vessel's position and heading exclusively by means of active thrust"*.

This definition includes remaining at a fixed location, precision maneuvering,

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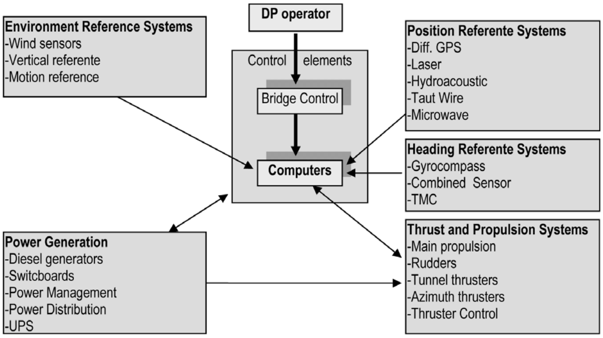

Fig. 1. Schematic diagram of a general DP system, showing the tasks and resources.

tracking and other specialist positioning abilities. To infer the mentioned positioning capabilities, a set of well defined tasks must be carried out. Furthermore, to carry out such tasks a set of resources or DP equipment is essential. Such tasks and resources are depicted in figure 1. In figure 2, the general arrangement of a DP system is shown. The necessary equipment to implement a DP system is also shown. With regard to this figure, a set of sensors acquires the necessary information, which is processed before entering the control algorithm (Grimble(b) et all.,1980), (Fossen et all., 1994), (Fossen et all., 1999), Strand et all., 1995), (Strand et all., 1999). The control algorithm computes the thruster setpoints as function of position, speed and environment conditions to operate the thrusters according power demand.

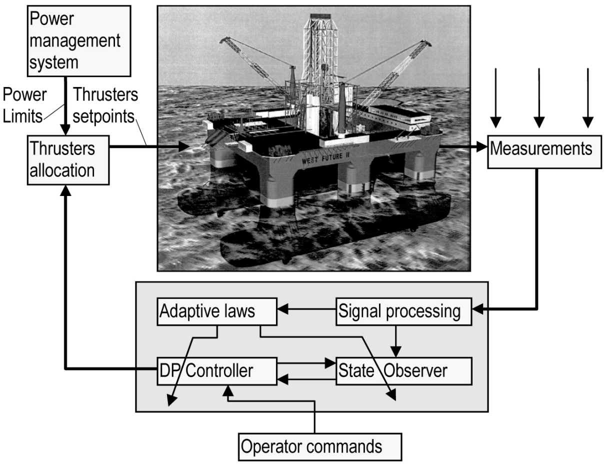

Fig. 2. The general arrangement of a DP system.

Any vessel can move in six degrees of freedom, three rotations (yaw, pitch and roll) and three translations (surge, sway and heave). Dynamic positioning conventionally is concerned with the automatic control of surge, sway and yaw. Surge and sway are related to the position of the vessel, while yaw is defined by the vessel heading.

Every vessel is subjected to forces from wind, waves and tidal movements (currents) as well as forces generated from the propulsion system and other external elements as fire monitors. The movement of the vessel with changes of position and heading is the result to these forces. Position is measured by position reference systems, while heading information is provided from gyrocompasses.

The vessel must be able to control position and heading within acceptable limits facing the external forces. If these forces are measured directly, the control computers can apply immediate compensation.

The DP control system calculates the offsets between the measured values of position and heading and the required values, and after that it calculates the forces that the thrusters must generate in order to reduce the errors to zero.

DP vessels duties would be:

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

Some advantages of dynamic positioning system are:

Vessel is fully self-propelled, setting-up on location is quick and easy, vessel is very maneuverable, rapid response to weather changes is possible, rapid response to changes in the requirements of the operation, versatility within system, 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 and can move to new location rapidly.

Te main disadvantages are:

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, 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) and requires more personnel to operate and maintain equipment.

The first DP control systems did not adapt to the actual sea conditions and vessel and thruster errors, that's the reason why it was necessary control improvements in station keeping accuracy (Loria et all., 2000) or optimal filtering based on the Kalman filter (Grimbre(b) et all., 1980), which provides an algorithmic procedure of recent implementation to improve maneuvering performance, and fast digital data transmission.

The elements of a DP system are computers, the control console, position reference systems, the heading reference, the environment reference, power systems and propulsion systems as shown in figures 1 and 2. (Bray, David 1997), (Kongsberg Maritime), (UKOOA).

Depending on the level of redundancy, DP computers and/or sensors and actuators are installed in single, dual or triple configurations.

The bridge console is the facility for the operator (DPO) to send and receive data located close to position reference system control panels, thruster panels and communications. Since 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.

In next section a brief description of the position reference system is described. In section 3,4,5,6 and 7, coordinate system, environment disturbances, power systems, propulsion system and class requirements are respectively briefly described.

POSITION REFERENCE SYSTEMS

All DP vessels have position reference systems (PRS), independent of the vessel's normal navigation suite. There are five types of PRS in common use in DP vessels:

– Hydroacoustic Position Reference (HPR).
– Taut Wire.
– Differential Global Positioning (DGPS).
– Laser-based systems (Fanbeam and CyScan).
– Artemis.

For any operations requiring DP redundancy it is necessary to utilize three position references. Two PRSs are not adequate, because if one has failed it would have contradictory reference data, whereas three systems provide two-out-of-three data.

If three PRSs are required, the DPO should choose systems that are different; because this reduces the probability of common-mode failure.

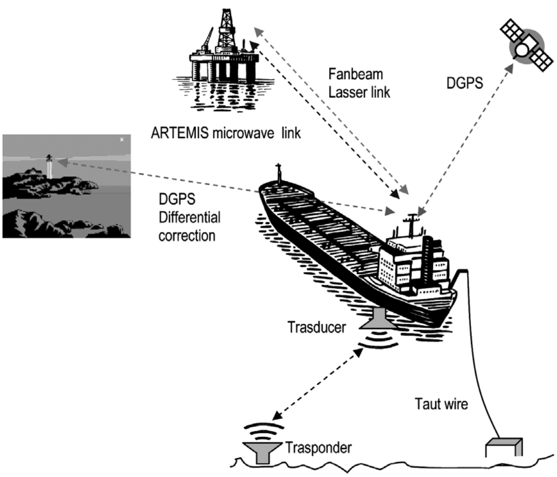

Fig. 3 Position reference systems.

Hydroacoustic Position Reference (HPR).

This system consists of one or more transponders placed on the seabed and a transducer placed in the ship's hull. The transducer sends an acoustic signal (by means of piezoelectric elements) to the transponder, which is triggered to reply. As the velocity of sound through water is known, the distance is known. Because there are many elements on the transducer, the direction of the signal from the transponder can be determined. Now the position of the ship relative to the transponder can be calculated. Disadvantages are the vulnerability to noise by thrusters or other acoustic systems. Furthermore, the use is limited in shallow waters because of ray bending that occurs when sound travels through water horizontally.

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).

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).

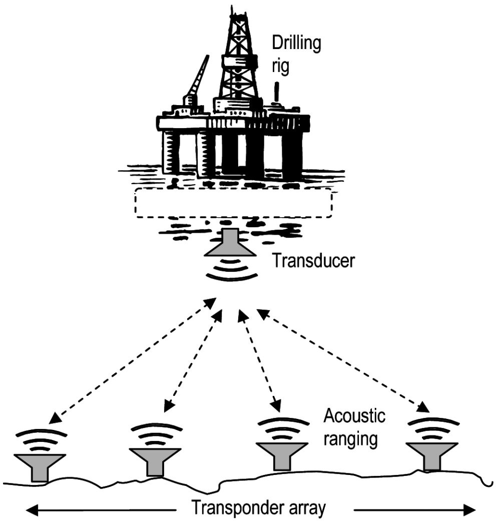

Fig. 4. LongBaseLine acoustic system.

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

The problem of this system is that the performance of an acoustic system is often limited by acoustic conditions in the water. And because of the nature of angle measurement, the accuracy deteriorates with increasing water depth.

Long Baseline System

It is the typical one in case of deepwater locations. It uses an array of three or more transponders laid on the seabed in the vicinity of the worksite. Usually the array forms a pentagon (5 transponders) on the seabed, with the drill ship at the centre above.

Once calibrated for position, individual interrogation of three or more of this array from a vessel's transducer will giver a series of ranges to the transponders, hence vessel position. The position should theoretically be located at the intersection of imaginary spheres, one around each transponder, with a radius equal to the time between transmission and reception multiplied by the speed of sound through water.

The angle measurements are not required at the transducer, thus a major source of error is eliminated and errors in range measurements caused by ray bending are less significant.

Short Baseline System.

It is like a long baseline system with an exception, there is an array of transducers (hydrophones), spread along the underside of the DP vessel and the baseline(s) are the distances between them. As the array is located on the ship, it needs to be corrected for roll and pitch.

They are typically installed in drilling rigs and semisubmersible barges.

Taut Wire Position Reference.

Taut wire is a useful short range position reference system, particularly where the vessel may spend long periods in a static location and where the water depth is limited. Also may be used on mobile equipment, where the vessel needs to maintain a location relative to a moving vehicle.

A normal configuration of a taut wire consists of a crane assembly on deck (usually at the side) and a depressor weight on a wire rope is handled by a constant tension winch. At the end of the boom of the crane are located angle sensors, which detect the angle of the wire. When the depressor weight is lowered to the seabed, the system switch to mooring mode (constant tension). The winch operates to maintain a constant tension on the wire and hence to detect the movements of the vessel.

The length of the wire deployed and the angle of the wire defines the position of the sensor head. This information is displayed on the DP system. Angles data are corrected from roll and pitch movements, and also the offset between the location of the sensor head and that the vessels centre of rotation.

The accuracy of the system will depend upon the depth of the water, the mooring tension, the wire angle to the vertical and the strength of tide.

Taut wire systems have limitations on wire angle because of the increasing risk of dragging the weight as angles increase. A typical maximum angle is 30 degrees (DP system will initiate a warning). At 35 degrees an alarm will occur and the DP system will reject this position reference system.

Advantages:

— High accuracy, especially in moderate depths of water.

— Good reliability (regular maintenance carried out).

— Quick and easy to set up.
— No need for assistance from external sources to set up or operate.
— System is mechanical, so on-board repair is possible.

Disadvantages:
— The system is of a short range only, especially in shallow water.
— Susceptible to strong tides (resulting in inaccuracies).
— Accuracy deteriorates in deep water.
— Maximum depth limitation.
— Adversely affected by debris or ice conditions.
— Possibility of weight dragging (positional errors).
— Wire may provide obstruction to underwater operations.
— System is not geographically referenced (relative positioning only).
— Wire may provide obstruction to underwater operations.
— Depressor weight may cause damage to seabed hardware when landing.
— If the vessel needs to move, taut wire must be continuously re-plumbed.
— Susceptible to mechanical damage.
— Limitations in range due bilge keel or other vessel structures.

The DGPS Position Reference System

The Global Positioning System (GPS) has typical accuracies available from the GPS Standard Positioning Service of 20m, but GPS accuracy is not adequate for DP purposes.

In order to improve GPS accuracy, differential corrections are applied to GPS data. This is done by establishing reference stations at known points on the WGS 84 spheroid. The pseudo ranges derived by the receiver are compared with those computed from the known locations of the satellites and reference stations, obtaining a correction.

Most DGPS services accept multiple differential inputs obtained from an array of reference stations widely separated. Network DGPS systems provide greater stability and accuracy, and remove more of the ionospheric error than obtainable from a single reference station.

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.

Some DP operations require the positioning of a vessel relative to a moving structure. For example, a shuttle tanker loading via a bow loading hose from the stern of an FPSO (Floating Production Storage and Offloading*)*. Since the FPSO can weathervane, the stern of the FPSO describes the arc of a circle, as well as it appears surge, sway and yaw motions, providing a complex positioning problem for the shuttle tanker.

An Artemis 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.

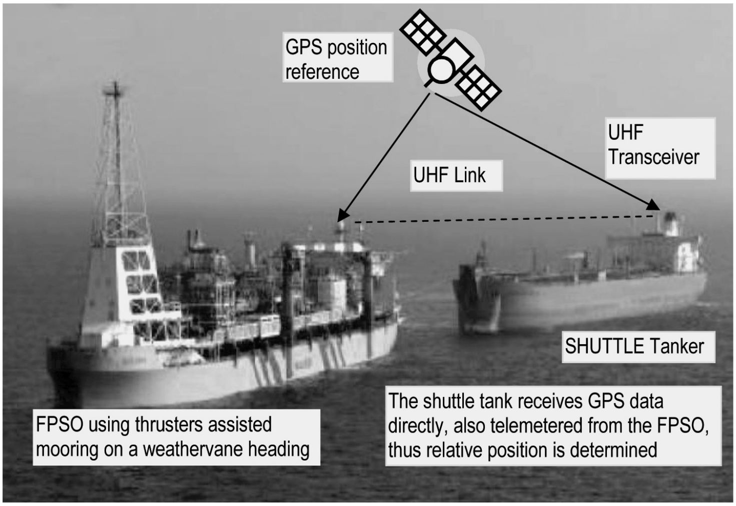

Fig. 5. Relative GPS.

There is another satellite system; the GLONASS (the Global Navigation Satellite System). It is similar in design and operation to the American GPS, but this is from Russia. The problem is that nowadays the number of available satellites is not good for positioning. So it is used as a position reference for DP and there are combined GPS/GLONASS receivers.

But the higher orbital inclination of GLONASS satellites (65°), compared to the GPS constellation (55°), results in better satellite availability in higher latitudes.

Laser-Based Position Reference

There are two laser DP position references in use: Fanbeam and CyScan.

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.

The Fanbeam system is manufactured by MDL of Aberdeen and it consists of two units, the laser scanner and the Universal Display Unit (UDU). The laser consists of an array of gallium arsenide semiconductor laser diodes. These produce a laser with a 20º vertical fan with a horizontal divergence of less than 4 miliradians, pulsed at 5.000 Hz. The pulses are emitted through a transmitter lens. Reflected received light is directed onto an array of photo sensitive diodes to produce an electrical signal. The range is determined from echo ranging; the accuracy is improved by averaging a number of returns from a target.

It is a very straightforward system, as only a small prism needs to be installed on a nearby structure. Some risks are that the Fanbeam could be locked on other reflecting objects and block the signal.

The scanner unit in a DP vessel should be placed in a location affording an unobstructed view of the horizon.

Ranges vary according to weather conditions, when the systems will be affected by reduced optical visibility. It is typically more than 500 meters.

The advantages of the Fanbeam systems are:

— Low cost in comparison with the other reference systems.
— Ease of installation.
— Passive target, no power supply required.
— Target does not require any support services.
— High accuracy.

But it has some disadvantages as:

— It will not operate with the sun shining directly into the lenses.
— The lenses can be affected by condensation, rain and salt spray.
— The system operation is impaired by fog, snow and heavy rain.
— The system may be confused by bright lights close to the target at night.
— The system may suffer interference from reflective items.

Artemis

Artemis is a trade name for a system produced by the Christian Huygenslaboritorium BV in Netherlands. The basis of position by Artemis is that of obtaining a range and bearing of a mobile station from some known fixed location. A low power microwave link is established between the two stations, using directional tracking antennae.

Specifications of the system:

Frequency:	9.2 – 9.3 GHz.
Range:	10m – 30,000m
Range accuracy:	0.1 – 1.0m
Bearing accuracy:	0.02 degrees.
Horizontal beamwidth:	2 degrees to the “half power “ points
Vertical beamwith:	22 degrees to the “half power” points
Antenna tracking:	maximum 15 degrees / second
Power supply:	24V DC, consumption approximately 40w

The signal delays are directly proportional to the distance between the fixed and the mobile stations. Normally, the fixed station is located on board a platform or other fixed location, while the mobile is located on a vessel. The mobile station acts as the Master; control and operator input is from the mobile. The mobile unit is interfaced to the DP system.

Corrections must be applied within DP algorithms to allow for the differences in location between the antenna and the vessel centre of rotation.

The system consists in two identical Artemis Basic Units, which are configured as a fixed and as a mobile unit. The operator interface is provided by means of an Extended Operator Panel (EOP) at the mobile station, and by a Basic Operator Panel (BOP) at the fixed Station. The EOP is the user interface aboard the vessel and is conveniently mounted adjacent the DP operator console, or integrated within it.

The antenna consists of a tracking slotted waveguide aerial, fitted in two halves. The tracking antenna has a horizontal beam width of 2º and a vertical beam width of about 22º. The radiated energy is about 100 mW, vertically polarized. It is arranged that the antennae at the fixed and mobile stations maintain a radio link by tracking the antennae in azimuth. Without considering the vessel movement, the two antennae track so as to face each other, with the antennae normal to the direction of the signal. Left and right halves of the antenna applies signals separately to four ports. The signal are applied equally but opposite in phase. This means that the output will be zero only if the antenna is perpendicular to the incoming signal direction. If this is not the case, drive motor will act to rotate the antenna to reduce the perpendicular error to zero. By this means the two antennas continually tracks each other.

To operate the system it is necessary to establish a microwave link between the mobile and fixed stations. The platform is contacted and a request is made to use the Artemis system. The platform personnel will switch the system on and connect their BOP. After selecting the required frequency channel and running a number of checks, they will aim the fixed antenna at the vessel. The vessel will do the same for the mobile. Then both units automatically "lock" and antennae will track. Range and bearing are displayed at the mobile end.

It is necessary to calibrate the fixed station in order to be properly referenced for azimuth. This is done by fitting a small telescope on the top of the antenna, to the same direction that the antenna is addressed. The objective is to determine the true grid bearing of a visual reference object (another platform for example) before use the system.

Advantages of the Artemis system:

— Long range.

— High accuracy.

— Possible to geographically reference the position data.

— Very convenient when inside the 500m zone.

Disadvantages:
— Requires a fixed station established on a nearby installation.
— Fixed units need to be correctly calibrated and configured.
— Specially designed units needed for hazardous areas.
— May require assistance from platform personnel to set up.
— May suffer interference from platform personnel.
— May suffer interference from heat or precipitation.
— May suffer line-of-sight interruption.
— Vulnerable to power supply problem at fixed end.
— Interference from 3cm radar.

CO-ORDINATE SYSTEMS

Position information from position-reference systems may be received by the DP system in several formats. Typically for DP applications the co-ordinate system used may be Cartesian (relative) or geodetic.

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 datum. Most offshore operations are conducted using UTM (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.

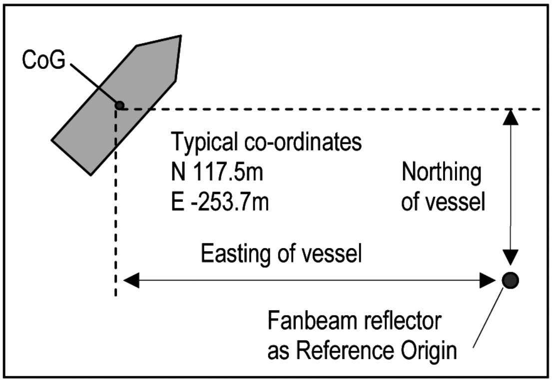

Fig. 6. Local or Cartesian reference co-ordinates.

UTM is a cylindrical projection with the axis of the cylinder coincident with the plane of the Equator; thus the line of contact between the cylinder and the sphere is a meridian. It cannot be used to chart the whole terrestrial surface. The useful scope of the projection consists of a zone 6°of longitude in width, with the centre upon the contact or "Central" meridian. Within this zone distortions are minimal.

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.

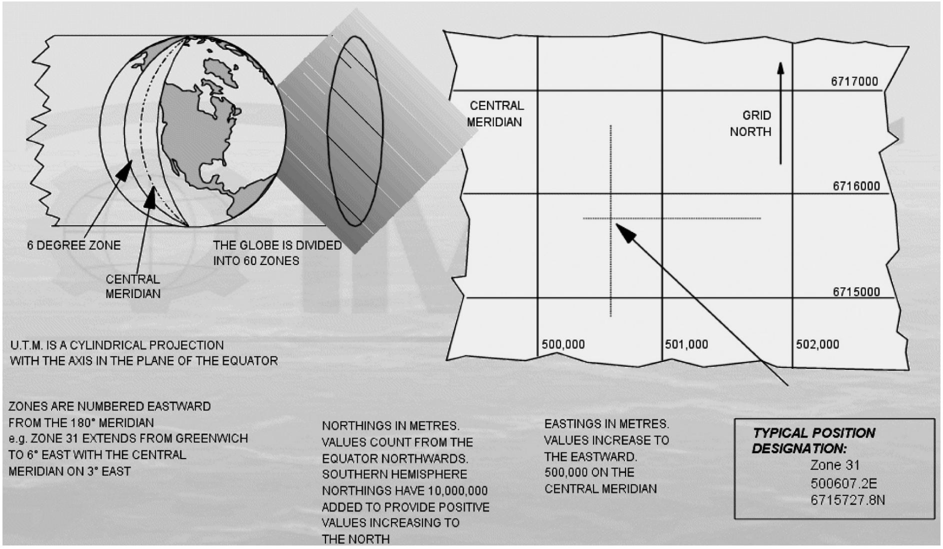

Fig. 7. Universal Transverse Mercator Co-Ordinate System.

In the case of current meters, they are not used in general, because they are expensive and generally the current forces change slowly.

For waves the DP control system does not provide direct compensation. In practice, the frequency of the waves is such that it is not feasible to provide compensation for individual waves. Wave drift forces build slowly and appear in the DP control system as current or sea force.

All DP systems have wind sensors (usually a rotating-cup anemometer). 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.

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).

A recent development is the provision of a system which utilizes 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.

POWER 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 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.

In the event of an interruption to the ship's main AC supply, batteries will supply power to computers, control consoles, displays, alarms and reference systems for a minimum of 30 minutes.

PROPULSION SYSTEMS

The DP capability 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.

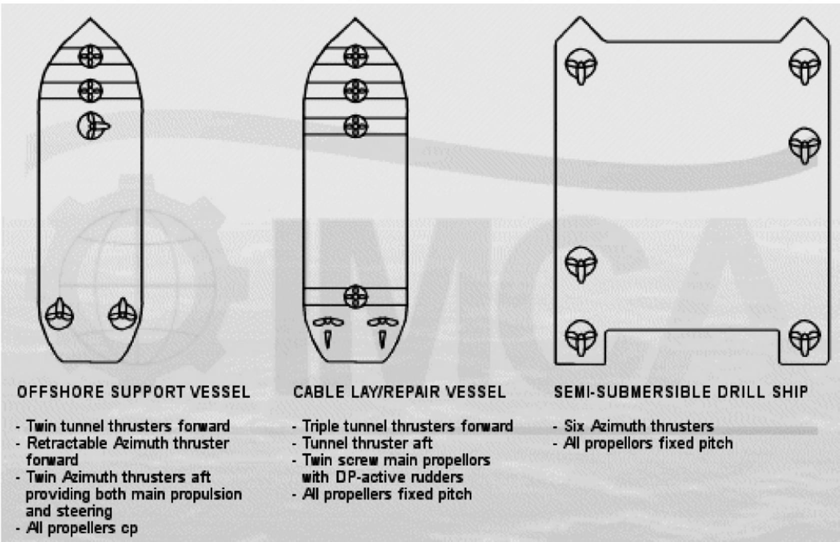

Fig. 8. Typical Propulsion System Layouts.

In DP vessels propellers may be controllable pitch (cp) running at constant rpm or variable speed.

DC motors or frequency-converter systems enable variable speed to be used with fixed-pitch propellers. Main propellers are usually accompanied by conventional rudders and steering gear.

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. 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.

CLASS REQUIREMENTS

Based on IMO (International Maritime Organization) publication 645 the Classification Societies have issued rules for Dynamic Positioned Ships described as Class 1, Class 2 and Class 3.

Equipment Class (EC) 1 has no redundancy. Loss of position may occur in the event of a single fault.

Equipment Class 2 has redundancy so that no single fault in an active system will cause the system to fail. 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, which also has to withstand fire or flood in any one compartment without the system failing. Loss of position should not occur from any single failure including a completely burnt fire sub division or flooded watertight compartment.

Classification Societies have their own Class notations:

Table 1. Class Classification

Description	IMO E.Class	LR E.Class	DnV E.Class	ABS E.Class
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-

Where IMO leaves the decision of which Class applies to what kind of operation to the operator of the DP ship and its client, the Norwegian Maritime Directorate (NMD) has specified what Class should be used in regard to the risk of an operation. In the NMD Guidelines and Notes No. 28, enclosure A four classes are defined:

- — Class 0 Operations; where loss of position keeping capability is not considered endangering human lives, or causing damage.
- — Class 1 Operations; where loss of position keeping capability may cause damage or pollution of small consequence.
- — Class 2 Operations; where loss of position keeping capability may cause personnel injury, pollution, or damage with large economic consequences.
- — Class 3 Operations; where loss of position keeping capability may cause fatal accidents, or severe pollution or damage with major economic consequences.

Based on this, the type of ship is specified for each operation according the following:

- — Class 1: DP units with equipment class 1 should be used during operations where loss of position is not considered to endanger human lives, cause significant damage or cause more than minimal pollution.
- — Class 2: DP units with equipment class 2 should be used during operations where loss of position could cause personnel injury, pollution or damage with great economic consequences.
- — Class 3: DP units with equipment class 3 should be used during operations where loss of position could cause fatal accidents, severe pollution or damage with major economic consequences.
- — Class 2 or 3 systems should include a "Consequence analysis" function that continuously verifies that the vessel will remain in position even if the worst single failure occurs.

The IMO Guidelines also specify the relationship between equipment class and type of operation. DP drilling operations and production of hydrocarbons, for instance, require equipment class 3, according to the IMO.

CONCLUSIONS

A general review of conventional dynamic positioning systems, including a summary of the main elements and tasks to be carried out on DP operations, has been presented. In the same way IMO and NMD classification of DP vessels, depending on the redundancy of the ship equipment has been defined. From this general review it is concluded the existence of a variety of DP missions which can be carried out under safety requirements that demand the application of the state of the art in marine engineering technology.

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