International Marine Contractors Association

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Guidance on

Position Reference Systems and Sensors for DP Operations

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Date	Reason	Revision
April 2020	Initial publication to summarise information on Position Reference Systems (PRS) and Sensors. Existing IMCA PRS guidance documents will be available for a period of at least 6 months following publication of this document.	

Guidance on Position Reference Systems and Sensors for DP Operations

IMCA M 252 – April 2020

1 Introduction

1.1 General

The purpose of this document is to summarise best practice for the selection and use of position reference systems (PRS) and sensors in dynamic positioning (DP) control systems. Some key recommendations and proposals are made for improved reliability in DP applications. The document is intended primarily for operators of reference systems and for owners or managers of DP vessels.

Many DP vessels regularly face the challenges of working in new environments and remote locations. For example, water depths of less than 20 m or greater than 1000 m present specific challenges to the reliable station-keeping of DP vessels. DP vessels continuously require position reference data in order to remain on the required position or track. The rate of position update and the reliability (stability and accuracy) of the update have a direct bearing on the performance of the DP control system and the footprint or excursion of the vessel from its required position or track.

Every measurement technology is bound by limitations (i.e. physics) and external factors (e.g. signal obstruction, solar activity, weather, sea conditions, range), which makes it difficult for one technology to cover all applications with uninterrupted service. Hence the growth in the use of DP has been accompanied by the development of internationally recognised rules, standards and guidelines against which DP vessels are designed, constructed and operated.

The selection of reference systems is therefore a vital element to a successful mission.

A DP vessel rarely uses only one position reference: two, three and sometimes four or more are often used simultaneously (reference the IMO requirements below). Thus, there is generally system redundancy and the design intent within the DP control system is that the failure of any one position reference should have little effect on the station-keeping performance. This is achieved firstly by the provision of other position references and secondly, by the DP control system's predicted mathematical model derived from recent performance. The model is a last resort if all position references are unavailable.

1.2 IMO Requirements

The guidelines for vessels with DP systems (MSC/Circ.645) were approved by IMO Marine Safety Committee (MSC) meeting 63 in May 1994 to provide the industry with an international standard for DP systems on all types of vessels. From these guidelines, classification societies create the rules which are fundamental to the way DP vessels are designed and built.

IMO MSC/Circ.645 was updated in 2017 by IMO MSC/Circ. 1580 for new vessels and units with DP systems. This new circular provides an amended standard reflecting the development in DP operation since 1994 and current DP technologies. For vessels and units constructed on or after 1 July 1994 but before 9 June 2017, the previous version of the guidelines (MSC/Circ.645) may continue to be applied; however, it is recommended that section 4 (operational requirements) of the present guidelines be applied to all new and existing vessels and units, as appropriate. The table below identifies the requirements of the two guidance documents with respect to position reference systems and external sensors.

			IMO MSC Circular 645 / IMO MSC Circular 1580 *MSC/Circ.645 6 June 1994 / MSC/Circ.1580 16 June 2017*		
Subsystem or Component			Minimum Requirements for Equipment Class		
Sensors	Position reference systems		**DP Class 1**	**DP Class 2**	**DP Class 3**
	External sensors	Wind	2[1+3]	3[1]	3[1] 1 in alternate control centre
		Heading reference sensor	1	3[2]	3[2] 1 in alternate control centre
		Motion reference sensor (VRS)	1	3[2]	3[2] 1 in alternate control centre

Comments:
(1) Based on at least two different principles and suitable for the operating conditions.
(2) Based on three systems serving the same purpose.
(3) Only within MSC/Circ.1580 16 June 2017 otherwise not specified.

Table 1 IMO requirements with respect to position reference systems and external sensors

There are some other specific functional requirements set out in the latest IMO guidance related to position reference systems and sensors as follows:

- The reference systems and sensors should be distributed on the UPSs in the same manner as the control systems they serve, so that any power failure will not cause loss of position keeping ability.
- New requirement for equipment class1 vessels:
  - for equipment class 1, at least two independent position reference systems should be installed and simultaneously available to the DP control system during operation.
- Further emphasis of the isolation required for equipment class 3 vessels
  - for equipment class 3, one of each type of sensor should be connected directly to the backup DP control system and should be separated by an A-60 class division from the other sensors. If the data from these sensors is passed to the main DP control system for their use, this system should be arranged so that a failure in the main DP control system cannot affect the integrity of the signals to the backup DP control system.

The IMO guidance document does not specifically address mission requirements. It is therefore the responsibility of owners and operators of vessels to ensure that their vessels are equipped with the appropriate PRSs for the missions they intend to undertake.

2 Glossary of Terms

A-60	The construction, insulation and subsequent ability of a bulkhead or deck to prevent gas, smoke and flames from passing and that the temperature of the non-exposed side of the construction will not increase beyond a set temperature limit over a 60-minute period.
Amplitude	The size or strength of the signal
Array	An alternative name for a network of seabed units
AUV	Autonomous underwater vehicle
Baseline	Either the distance between the receive elements of the USBL technique or the distance between the seabed transponders of an acoustic positioning system. In both cases, the reference points are considered fixed in their relationship at an ultra-short or short or relatively long distance
Beacon	Transponder or other seabed unit that transmits acoustic ranges or data
DGNSS	Differential global navigation satellite system
DP	Dynamic positioning
GNSS	Global navigation satellite system
GPS	Global Positioning System
Hydrophone	Underwater microphone – device designed to receive sound waves under water
IMO	International Maritime Organisation
IMU	Inertial measurement unit
INS	Inertial navigation system
LBL	Long baseline acoustic positioning system
MODU	Mobile offshore drilling unit
MRU	Motion reference unit
MSC	Marine Safety Committee
Pinger	An acoustic beacon set to transmit at a fixed and regular interval
PRC	Pseudo Range Correction
PRS	Position Reference System
ROV	Remotely operated vehicle
SBL	Short baseline
USBL	Ultra-short baseline acoustic positioning system

3 Reference System Basic Principles

3.1 Global Navigation Satellite System (GNSS)

3.1.1 Overview

GNSS refers to a group of satellite-based navigation systems, some of which have been available for many years and others which are still under development. Various systems are available, each having their own advantages and limitations. The number of satellites available from any of these systems may vary with consequent changes to availability of coverage. The satellites orbit the earth at a range of approximately 20,000km and transmit radio signals towards earth on multiple frequencies. The satellites act as reference points: in effect, their positions are always known even though their orbital speed is approximately 4km per second. By measuring signal travel times from at least three satellites, a GNSS receiver derives ranges for fixing the observer's position in a similar way to terrestrial navigation systems. Signals from three satellites are required for a 2-D (latitude and longitude) position. Four satellites offer a 3-D (latitude, longitude and height) position. Additional satellites improve the reliability of the position.

Reference Guidance on satellite-based positioning systems for offshore applications (IMCA M 242, IMCA S 024). This guidance contains detailed information on the selection and use of GNSS.

3.1.2 Modes of Operation

GNSS can be used in various modes to provide a position for the user. These modes are dependent on the way that the signals are interpreted and processed by the hardware generating the position.

The modes that are applicable to DP operations are:

3.1.2.1 Differential GNSS

DGNSS is by far the most common mode used in offshore vessel operations. It allows position to be corrected to between 2-5 m accuracy, with some service providers quoting 0.5-1 m achievable positioning accuracy (95% confidence regions).

Differential correction works to correct the effects of inherent signal errors such as satellite clock and orbit errors or inaccurate modelling of signal passage through the earth's ionosphere and troposphere. This is achieved by locating a GNSS receiver at a previously co-ordinated point and measuring a raw 'pseudo-range' for each of the satellites that are visible. The co-ordinates of the known point are used to calculate GNSS error corrections for each of the pseudo-ranges. The corrections are known as pseudo-range corrections (PRCs) and, having been obtained by 'differencing' theoretically correct ranges with erroneous pseudo-ranges, they are termed differential corrections (see note below).

The location at which the differential corrections are generated is known as the reference station. From here, the corrections are transmitted to the DGNSS user. There are several methods of transmission, but key factors are the speed and frequency with which the corrections can be received after they have been calculated at the reference station. The corrections for a particular satellite constellation are only valid for a short period of time (typically no more than 20 seconds).

The transmitted corrections are made available to the user via a specific differential correction receiver. Some services use integrated receivers for GNSS and differential correction reception. The GNSS receiver at the user's location also measures pseudo-ranges for each of the satellites in view. The corrections from the reference station are then applied to the common pseudo-ranges at the user's location and a differentially corrected position is calculated.

Note: not all differential services are based on the transmission of PRCs. Some compute corrections to position and transmit these to the DGNSS user instead. These services should be used with extreme caution in DP applications due to potential differences in satellites visible at each receiver location.

3.1.2.2 Combined GNSS/Inertial Navigation System

A non-differential GNSS combined with inertial navigation provides a solution that is both resilient to short term data outages and correction data. See section 3.6.

3.1.2.3 Relative GNSS

This mode of GNSS operation uses the differences between common pseudo-range observations from two spatially separated GNSS antennas to derive a relative vector, and hence the range and bearing between them. It is used where the relative position of a remote vessel from another vessel (or a fixed location) is required. Applications include shuttle tanker DP operations at offshore loading facilities, DP accommodation support vessels with gangway connected to a spread moored or turret moored FPSO and non-DP activities such as rig move anchor handling operations or the tracking of seismic tail buoys relative to the survey vessel.

Differential corrections are not necessary for computing a vector (offset) as the relative position of the remote antenna is determined independently of the positioning solution applied at the master antenna. Where coordinates are required, the position of the remote antenna can be derived by simultaneously applying the relative vector to the coordinates of the master antenna as derived by, for example, DGNSS. Many relative GNSS can operate several remote units from a single master unit.

Some early versions of relative GNSS operate in the position domain, however under certain conditions the satellite measurements observed by both receivers may not be common and inaccuracy may occur. Most systems are designed to operate in the range domain where only the pseudo-range measurements for common GNSS satellites are used to calculate the range and bearing. Users of Relative GNSS for DP applications are therefore advised to validate that the system provided meets the required specification.

3.1.2.4 Kinematic GPS

Kinematic GPS has been adopted primarily for land survey and positioning work. It has limited application offshore and is not considered within this guidance.

3.2 Microwave Radar Systems

3.2.1 Overview

Microwave radar systems accurately measure the range and bearing of a vessel relative to a position on a fixed or moving asset using equipment mounted on both the vessel and the asset.

The fixed and/or mobile station may have more than one sensor (transmitter/receiver) to improve the reference capability or accuracy.

Microwave sensors, are insensitive to the harsh environmental conditions often experienced in an offshore environment, being unaffected by heavy rain or fog in any significant way.

Because some of the sensors operate in the same frequency region as conventional X-band radars (9.3-9.5GHz), it is essential that manufacturer recommendations regarding separation between radar units are followed.

3.2.2 Modes of Operation

There are a number of different manufacturers of microwave radar equipment in the market, each solution having differing characteristics. Manufacturer specific operating and maintenance considerations should be referenced.

3.2.2.1 Artemis

The Artemis operates with very low power microwave transmissions (0.1W) in the band 9.2 – 9.3 GHz, using antennas on fixed and mobile stations which can track each other.

At the start of operations, one sensor is turned to face in the approximate direction of the other sensor. That sensor then rotates, searching for its counter station. Once a sensor detects the presence of another sensor, it measures the angle of arrival of the microwave signal from that sensor. It uses that measurement as feedback to control its own angular position so that the counter station is kept in the centre of its beam. In this way the two sensors lock on to each other, continuing to stare at each other as the vessel and asset move relative to one another.

The paired Artemis sensors use the microwave link between them to transfer data. Each sensor is then able to report the position and orientation of its counter station relative to it.

The standard system has a range of 10 to 10,000 metres, with an overall accuracy of one metre; and an azimuth range of 0 to 360 degrees, with an overall accuracy of 0.02 degrees.

3.2.2.2 RadaScan View and RadaScan

The RadaScan operates as a low power (1 Watt) frequency modulated continuous wave radar sensor operating over a 100MHz bandwidth in the 9.25GHz maritime radiolocation band. The sensor, on the vessel, picks up reflections from approved responders which are placed on the installation. The responders introduce a unique code into the reflection to allow unambiguous identification and robust tracking. At least two responders are required if the orientation of the asset relative to the vessel is required.

The sensor contains a 360° rotating antenna which scans continuously at 1Hz and so aids unrestricted vessel manoeuvrability. The standard system has a range of 10m to 600m. RadaScan is accurate to 0.25m and 0.2 degrees or better throughout its operating range. RadaScan view also provides a backscatter image of the surroundings. This can be helpful when interpreting feedback from multiple responders.

A larger version of RadaScan is available for long range applications (up to 1000m) and for extreme temperature (down to -50°).

3.2.2.3 RADius

RADius utilises radar principles in short range and direction monitoring and is designed to operate in close proximity to structures and other vessels.

The implementation is fully solid state and based on measurements of reflected radar signals from one or several passive transponders in the nearby area. Each reflected signal is mixed with a unique ID to separate different targets from each other.

RADius has a vertical and horizontal opening angle of 100°. This secures stabile manoeuvring in close-by operations where the difference in height for the mounted transponder and interrogator can be considerable. RADius is capable of detecting and measuring accurate range and bearing to any transponder within the range of up to 550 metres, depending on the target's transponders. Transponders are either battery operated or connected to a power source from the installation or vessel.

RADius can be deployed as an omni directional system utilising four sensor heads. These can be placed on suitable locations on the vessel, depending on the construction and operation. This provides full 360˚ signal acquisition as well as avoidance of blind angles.

3.2.2.4 XPR Long Range Relative Positioning System

XPR is a solid-state long-range microwave-based relative positioning system operating in the 9.2-9.3 GHz band, making it a highly resilient solution for dependable operation in any weather conditions. Each lightweight panel has an opening angle of 100°, with the option to integrate multiple panels for extended coverage (280°) depending on the operation. Features include automatic target selection, where target information is stored in the system. Continuous monitoring in all directions mitigates false target lock and secures fast target acquisition.

3.3 Acoustic Position References

3.3.1 Overview

Acoustic positioning systems measure ranges and directions to transponders fitted to underwater vehicles and objects or derive acoustic ranges from stations deployed onto the seabed. These latter units are held stationary by a clump weight with buoyed mooring (or some other form of fixed seabed framework). Several types of system such as ultra-short baseline and short baseline systems provide positioning relative to a host vessel or vehicle, whereas long baseline systems allow either a relative or absolute positioning framework to be developed. Many other scenarios exist including beacons being installed on remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and other types of towed vehicles. The systems have been developed specifically to meet the challenges of operating in deep water with sufficient accuracy and system reliability. The main elements of deep-water acoustic positioning systems will include:

- Transmission and reception of acoustic pulses to track or position a limited number of objects – both static and mobile;
- Processing and applying corrections to data to provide accurate and consistent performance parameters;
- Incorporation of peripheral data such as speed of sound in water, depth, heading and motion;
- Display of position relative to a certain reference system, e.g. vessel;
- Some form of noise and interference mitigation to enable continued working in harsh environments.

Reference Guidance on vessel USBL systems for use in offshore survey, positioning and DP operations (IMCA M 244, IMCA S 017) and Deep water acoustic positioning (IMCA M 200, IMCA S 013). A full explanation of underwater acoustics is beyond the scope of this document. However, some general descriptions are included.

3.3.2 Modes of Operation

Methods of deep-water acoustic positioning vary in terms of accuracy, precision, design and frequency. How accurate or precise a system will be is dependent on commercial requirements and the operational and environmental conditions in which they will be used. For the purposes of this document, the methods under consideration are the most commonly used techniques; long baseline (LBL), short baseline (SBL) and ultra-short baseline (USBL), which exhibit the key principles and considerations associated with acoustic positioning. For completeness, however, other methods are briefly covered in this section.

In all cases, it is only possible to monitor and assess the quality and reliability of the systems if there are sufficient observations and data redundancy supported by careful system calibration and monitoring during operation.

3.3.2.1 Long Baseline (LBL)

LBL systems take their name from the distance between seabed transponders or beacons which can be as much as several kilometres. The beacons are deployed onto the seabed in an array and are then, as transponders, set to transmit when interrogated by a user hydrophone.

LBL acoustic systems provide accurate fixing over a relatively small area. Three or more transponders located at known positions on the seabed are interrogated by a transducer fitted to the surface vessel, towed body or autonomous object. If at least three ranges are measured from a mobile hydrophone to transponders at fixed co-ordinated seabed locations, then the hydrophone position co-ordinates can be computed. The LBL method provides accurate local control and high repeatability. If there is a redundancy (e.g. four or more position lines), the quality of each position fix can also be estimated, and this is often a consideration when selecting a system for use.

3.3.2.2 Short Baseline (SBL)

In this type of system, the baseline referred to is that between the receive transducer (hydrophone) units on or below the hull of the host vessel. It requires a pinger, responder or transponder to operate the system. No fixed beacons on the seabed are required and the system positions relative to the surface vessel. The transducers for such a system are usually deployed through dedicated tubes in the hull and are generally separated by between 10 and 50m, dependent on the form of vessel on which they are fitted. The SBL system uses relative range and direction observations to transponders to determine position relative to the surface vessel.

3.3.2.3 Ultra-short Baseline (USBL)

This system is similar to that of the SBL system but adopts a very short and single combined transmitter and hydrophone unit, the transducer, for acoustic reception and any pulses or commands generated. Generally, the distance between elements in the transducer on USBL systems is of the order of 10cm.

The system computes the relative position of the transponder from the transducer in terms of a range and a bearing referenced to the system's heading unit. This is usually the ship's or the survey gyrocompass. System observations are corrected for transducer pitch and roll experienced during the measurement process using a dedicated motion reference unit (MRU) and the acoustic range is scaled correctly by application of the sound velocity profile (SVP) through the water column.

Although the physical size of the ship's equipment often makes it an attractive option for marine departments, the USBL transducer requires very careful installation, alignment, calibration and adjustment to ensure the measurements are accurate. This is critical for the USBL technique as, unlike the LBL and SBL techniques, the two observations of range and direction mean it is not possible to generate error statistics with redundant observations. As a consequence of these limitations, USBL is used in conjunction with attitude and heading sensors to maintain its positioning accuracy. At the start of a major project, the system needs to be thoroughly checked and tested to verify its settings and provide a means of quality control. This process varies but usually involves a period of time for the vessel to undertake a series of manoeuvres that describe an offshore calibration.

3.3.3 Hybrid Systems

Hybrid positioning solutions have been developed for use in deeper water. Acoustic positioning with depth aiding and heading sensors attached to an underwater vehicle have been available for some time. Inertial measurement units (IMUs), Doppler Velocity Logs and associated attitude sensors has enabled the development of solutions that integrate the sensor data to produce a single coherent position output. Hybrid solutions still often rely on acoustic signalling but in some cases, this is relegated to a secondary function, as the inertial navigation elements may be favoured and weighted in the position solution accordingly. The benefit of such integration lies in obtaining a reliable, accurate and efficient positioning solution where acoustics alone would be unable to deliver. Additionally, there is the possibility of better quality position solutions enhanced with redundant sensor data, which allow additional statistical error estimates to be generated.

A number of such solutions have been developed for autonomous underwater vehicle (AUV) positioning, very high accuracy short range metrology type work and for ROV activities requiring additional positioning support for existing ship based USBL equipment.

3.4 Laser

3.4.1 Overview (Targeted)

Laser systems use the principle of laser range finding by measuring the time taken for a pulse of laser light to travel from the laser source to a target (e.g., retro prism reflector) and back to the detector. In order to ensure that the laser beam can find targets which may have height diversity laser systems scan with a vertical fan of laser illumination. By scanning this fan horizontally in a controlled manner, a fixed target can be tracked from a moving vessel and its bearing, relative to the vessels heading, and range, can be determined.

Laser systems comprise of a laser/scanning unit mounted on a motorised yoke that can rotate 360°. The laser unit measures the range, and the scanner unit measures the bearing, to a target, relative to the vessels heading. All modern laser systems include auto-tilting mechanisms which allow greater variations in height between the vessel and target and also facilitate operation in greater sea states.

Retroreflective targets for laser position reference systems are all passive devices and thus do not need power. For best performance it is recommended that retroreflective prisms are used where possible.

3.4.2 Modes of operation

Laser systems can be used in single target or multi-target modes.

In single target mode a single reflector is tracked, and the sensor can report range and bearing to that single reflector. If two targets are tracked the sensor can report range, bearing and relative heading to the group. If more than two targets are tracked an additional level of redundancy is available that can cope with the temporary obscuration of a single target.

Non-equal spacing between targets strengthens this ability and can enhance the tracking capability of the system particularly in relation to false reflections. This is because the differences in spacing tend to make the configuration unique and easier for the system to identify.

3.4.2.1 CyScan AS

CyScan AS operates up to ranges in excess of 2000 meters against retroreflective prisms and to ranges of 450 meters against tape targets. It shows typical range and bearing noise of 0.05 meters and 0.2 milliradians.

The CyScan AS can utilise targets which can be identified as such by the sensor. This can assist the DPO in selection of target when initiating tracking.

3.4.2.2 Fanbeam

The system comprises a laser/scanning unit mounted on a motorised yoke that can rotate 360° at up to 50° per second. The system uses the principle of laser range finding by measuring the time taken for a pulse of laser light to travel from the laser source to a target and back to the detector. The scanner unit measures the bearing, to a target, relative to the vessels heading. The maximum range for use with DP is between 150 and 500 metres using retro prisms. Range accuracy is 0.2m.

3.4.2.3 SpotTrack

The SpotTrack sensor is a robust motion stabilised rotating laser sensor which measures range and bearing to one or several retro-reflective targets installed on the target platform or vessel. The system operates out to 1500 meters and has horizontal position accuracy of 1 meter and a bearing accuracy of 1 milliradian.

3.4.3 Overview (Targetless)

Traditional position reference sensors monitor the position of physical artefacts that have been introduced to the environment. A targetless system does away with these artefacts.

There are several means by which a targetless system may work.

The most general is to assume nothing about the surroundings. The sensor then builds up a map of the area. This map is compared to the current scan by the navigation algorithm, which is used to track a local position. The map can be updated as the sensor moves through the map, revealing previously unseen detail.

Alternatively, if the asset at which an operation is taking place has a specific known structure, for example, a wind turbine, then a targetless sensor can look for this structure.

3.4.4 Modes of Operation

3.4.4.1 SceneScan

The SceneScan is a targetless laser position reference sensor. It scans the environment at a rate of 1Hz. It has a detection range of about 300m, depending on the reflectivity of the surface.

The system uses a technique called Simultaneous Localisation and Mapping (SLAM) to create a 2D map of its surroundings which it then locates itself within. Before it starts tracking it will take a 3D scan of the area in order to choose the most reliable slice of environment to subsequently use to track.

In order to pass the position to the DP system a Scene Reference Point must be used. This is effectively a virtual target. The position of this target has no effect on the tracking performance of the system and no physical significance.

Typical ranges at which tracking can start vary between 100 meters and 250 meters, depending on the nature of the structure.

3.4.4.2 RangeGuard Monopile

The RangeGuard Monopole system is designed for DP approaches to monopole structures, typically wind turbines. It uses two microwave ranging sensors and knowledge of the expected geometry to track the position of the monopole. This removes the need for physical targets to be installed on a wind turbine monopole.

The system operates to a range of 100 meters. It has a range repeatability of 0.15 meters. It has a bearing repeatability of 0.15 degrees.

3.5 Taut Wire

The Taut Wire is a deck mounted position reference system. Its purpose is to provide data of a vessel's movements with respect to the position of a weight on the sea floor.

A wire is maintained at a constant tension by means of a depressor weight on the seabed and a pneumatic and electric servo-assisted 'mooring' system. Any movement of the vessel will cause the tensioned wire to deviate from its initial inclination. This movement activates potentiometers mounted in the gimbal (sensor) head and produces changes of analogue signals directly proportional to the deviation in inclination. These signals in conjunction with the wire length are used to calculate the position offset signal to the DP system.

For specific operations 'walking taut-wire-systems' are in use consisting of at least 2 Taut Wires which are reset in turn automatically when reaching their maximum limit.

3.6 Inertial Navigation System (INS)

A single accelerometer measures acceleration along a single axis. This output can be integrated once to obtain velocity and twice to obtain change of position. By arranging accelerometers in three axes and adding a heading reference the instant change of position can be derived. By introducing accelerometers in three axes, and a heading reference too, so that the direction of travel is known, the current position can be derived. This combination of accelerometers and heading reference sensors is referred to as the inertial measurement unit (IMU). An INS comprises an IMU accompanied by a computer processor to calculate and process the data to derive position.

Inertial navigation is a form of dead reckoning with the initial position known and the subsequent updates based upon data from additional sensors and their error models, used to reduce any unwanted biases. When used offshore, INS are typically 'aided' by frequent and regular updates of the position or other individual observations by additional sensors and systems, such that the INS-based solution maintains its overall accuracy. This blending or 'aiding' of the INS sensor with existing positioning systems provides a more robust and potentially more accurate overall positioning solution than could be obtained from any of the individual component parts.

Reference An introduction to inertial navigation systems (IMCA S 022).

3.7 Sensors

Vessel sensors should at least measure vessel heading, vessel motions and wind speed and direction. When an equipment class 2 or 3 DP control system is fully dependent on correct signals from vessel sensors, these signals should be based on three systems serving the same purpose (i.e. this will result in at least three heading reference sensors being installed). Detail of sensors related to specific mission requirements, for example, tension and/or stinger input for pipelay operations, tension input for ploughing, vertical lay system (VLS) input, tug assistance forces are not considered here. However, these sensors related to mission requirements may have a significant impact on the DP position holding capabilities of the vessel and may require careful consideration when in use. Vessel owners and operators must ensure that sensors related to mission requirements are interfaced in line with the redundancy principals of other sensors. Non redundant sensors, related to mission requirements, which indicate a rather static measurement, for example stinger angle or tower angle may be better interfaced manually in order to avoid a sudden impact on DP position holding capabilities in case of failure.

3.7.1 Heading Reference Sensors

Heading reference systems are often used by other vessel navigation systems but it is essential that independence for use by the DP system is well tried and tested. The most common heading reference sensor is a mechanical gyroscope unit with moving parts. However, fibre optic heading sensors without moving parts are becoming more popular. A fibre optic heading sensor is considered more reliable, more accurate and requires less maintenance.

3.7.2 Motion Reference Unit (MRU)

Typically installed at the centre of gravity of the vessel MRUs determine pitch, roll and heave for the purpose of feeding motion compensation data to the DP position reference sensors. Generally, the MRU sensors are to be calibrated regularly for maintaining accurate operation. A fibre optic heading sensor is generally capable of also providing pitch, roll and heave signals. Therefore, fibre optic heading sensors can fulfil two functions, providing heading and MRU information without the need for dedicated MRU sensors.

3.7.3 Combined Motion Reference Sensors

The introduction of laser and accelerometer-based sensors has resulted in the development of motion reference sensors which are a combination of a heading reference sensor and MRU. Most class societies approve the use of one such combined motion reference unit as a replacement for one gyro and one MRU.

To maintain diversity in both hardware and software, it is not recommended to replace all gyro and MRU units with the same combined motion reference sensors.

3.7.4 Anemometers

Installed to give minimum interference from vessel structures, all major classification societies now require three units to avoid shadowing. Anemometers are traditionally of the mechanical type with moving parts but more frequently now are of the ultrasonic type, without moving parts. For avoidance of common failures many vessels have units of both types.

4 Operational Considerations

Vessel operators are reminded that IMO and IMCA guidance require position reference systems used for DP equipment class 1, 2 and 3 operations to have at least two different principles and be suitable for the operating conditions.

4.1 Configuration of Individual Position Reference System (PRS) Units

In order to optimise the quality of PRS data being transmitted to the DP controller it is imperative to configure the individual PRS units. Most of the PRS units have a number of parameter settings which must be set before the PRS is enabled in the DP controller. This might be related to parameter settings, cut-off limits, quality indicators, fixed or mobile, UTM zone, speed of sound through water, satellite prediction, masking, etc. The operator manual of the various PRS also provide help functions, guidance for trouble shooting, data logging and data exporting. It is the responsibility of the vessel owner to ensure that the operator manual of the various PRS in use on their specific vessel are available and actively used by the DP operators.

PRS units which are not properly configurated have the potential for station keeping abnormalities and in the worst case a loss of position might occur.

In general, all DP controllers, regardless of make, perform a series of tests on the incoming data from the PRS in order to check that the measurements are accurate enough for use in the controller algorithms. The DP operator should fully understand the different tests carried out on each PRS and the actions to be taken when a test suggests that a position measurement is not accurate. The following tests are applied in most DP controller systems:

- A **Freeze test** rejects repeated measurements. If the variation in the measured position is less than a system set limit over a given period of time, the position-reference system is rejected.
- A **Variance test** monitors the measurement variance and compares the variance value with a calculated limit.
- A **Prediction test** detects sudden jumps or large systematic deviations in the measured position. The limit for the prediction test is a function of the estimated position in the vessel model and the actual measurement accuracy.
- A **Divergence test** gives a warning of systematic deviations and/or slow drift (before the system is rejected by the prediction test).
- A **Median test** detects position measurements that differ from the median position value with more than a predefined limit. The test is mainly designed to detect slowly drifting position-reference systems, therefore more than 2 PRS are required.

Reference should be made to the vessel specific DP operator manual.

Some PRS units are provided with a data logging and exporting function which often needs to be configured by the DP operator. The data logging storage capacity might be limited, therefore new sessions must be initiated at regular interval. If a manual action is required, to start a new session, it could be useful to provide a reminder as a task in the planned maintenance system.

4.2 Absolute Position Referencing

During DP operations requiring position to be maintained over the ground, it is possible to use a mix of absolute and relative position reference systems providing the relative position reference system fixed station or transponder are on stable non-moving assets.

4.3 Relative Position Referencing

During DP operations requiring position to be maintained relative to a moving asset, relative position reference systems are to be used with the fixed station or transponder on the asset.

Care shall be taken when using any relative positioning system as an active input together with an absolute position reference system while the vessel is operating at a structure that is not permanently fixed in place (drillship, turret FPSO, etc.). Motion and heading changes of the installation where the target is located will cause a divergence in the ship's position calculations, since the relative reference will be moving with the structure, while the absolute reference will feed a stationary position data. The conflict between absolute and relative PRS can be resolved by setting the relative PRS to a mobile target-follow mode. The DP system manual must be consulted to identify the most appropriate mode for working at floating installations. Setting the relative PRS to the mobile mode is a recommended practice.

The following table gives examples of combining relative and absolute PRS on mobile installations. Set-ups that allow an automatic adjustment of heading are identified as the safest. Multiple target functions can be offered by DP vendors as additional payable options and should be considered at the mobilisation stage. The characteristics of the DP system in use and the specific operations manual need to be considered.

Position Reference Systems Online		**DP2 Class redundant as per MSC Circ. 1580 (3 x PRS, at least two on a different principle)**	**Recommended by DP vendors**	**Move when Reaction Radius is exceeded**	**Move instantly with the relative target**	**Heading adjusted automatically**	**Not Recommended**
Set in Fixed mode	**Set in Mobile Follow-Target mode**						
2 x Abs	1 x Rel with 1 x Tgt	X		X			
2 x Abs	1 x Rel with 2 x Tgt	X		X		X	
1 or more x Abs	2 x Rel with 1 x Tgt	X	X	X			
1 or more x Abs	2 x Rel with 2 x Tgt	X	X	X		X	
1 x Abs	1 x Rel with 1 x Tgt			X			
1 x Abs	1 x Rel with 2 x Tgt			X		X	
N x Abs + N x Rel	-						X
1-2 x Rel	-				X		
3 or more x Rel	-	X			X		

Table 2 – Absolute (Abs) and relative (Rel) PRS combinations for station-keeping at floating units and targets (Tgt)

4.4 Operations in Deep Water

When operating in open water away from other floating assets the choice of position reference systems is limited. Operators are advised to follow the guidance contained in the following two documents:

- Deep water acoustic positioning (IMCA M 200, IMCA S 013)
- Guidance on satellite-based positioning systems for offshore applications (IMCA S 024)

4.5 Operations in Shallow Water

Most operators and suppliers regard a water depth of 20-30m as 'shallow water'. However, there are no clear overall limits on water depth for DP operations and each task should be considered individually on its merits. Thrusters and power generation systems may have to work harder, and the vessel's capability may itself be degraded in shallow water. It is recommended that the vessel owner take all necessary steps to anticipate these changes, including calculations of the environmental loading limits and DP capability in proposed shallow water conditions.

Shallow water DP operations can be affected by; degradation of thruster performance, mud or debris stirred up by thrusters, increased amount of floating debris, increased wave-frequency motions, strong tidal current or changes in current force coefficients, turbulence and reflections from the surface or structures on the seabed. All may lead to degraded performance and reduced operating limits but, provided they have been considered by the vessel operator for the particular location and operations in hand, they should not lead to an abrupt position loss. Sudden position loss could however be caused by large and rapid changes in current speed or direction.

When two subsurface position reference systems, such as taut wire and hydroacoustic position reference (HPR), are used for DP operations in shallow water, special consideration is required to ensure they are independent to the extent that a single mode of failure must not cause two of these systems to fail simultaneously. In shallow water DP operations, it is recommended that at least one surface or one DGNSS position reference be used, because of known difficulties with sub-surface systems.

Sub-surface taut wire and conventional HPR systems are a particular concern because they can quickly go out of range in shallow water.

Acoustic systems in general are sensitive to noise from engines, thrusters, thruster wash, air bubbles, reflections from the surface or structures on the seabed. These problems are likely to be exacerbated in shallow water. Conventional acoustic systems require a transducer to be mounted below the vessel and one or more transponders to be mounted on the seabed outside the regions likely to be affected by the thruster wake and turbulence. The dimensions of these units limit the minimum water depth in which the vessel can operate. The minimum distance between the keel and the seabed is the sum of:

a) the heights of the transducer and the transponder units; plus
b) the additional distance between these units required to keep the vessel within the ±30° cone angle during normal vessel excursions.

Conventional fixed HPR systems usually have a 60° angular cone (i.e. ±30°) of operation therefore the maximum horizontal movement is reduced as the water depth decreases. Such systems were reported to suffer from problems when the water depth is less than about 45m.

Taut Wire systems may be susceptible to fouling by large masses of kelp or other submerged objects. The main physical limitations in shallow water are that the devices must:

a) remain within a certain angle from the vertical, which is typically about ±20°;
b) not contact the vessel hull, when suspended over the side;
c) not allow the bottom weight to shift.

Taut Wire systems seem to be limited to water depths greater than about 20-25m; the limit depends on the angle the wire makes with the vertical. These systems typically have end-stop limits variously quoted at ±35-±40°. The permissible operating range is restricted by control software to about ±20°. The amount of the horizontal movement allowed thus decreases in proportion to wire length.

4.6 Operational Consideration Summary

Reference System	Subject	Operational Considerations
GNSS	The use of Dual GNSS	When using a dual DGNSS package, two receivers are essential; to avoid the possibility of a common mode of failure it is recommended that different models and software are used. Ideally the equipment would be from different manufacturers. Two fully independent differential links should be used and ideally should be based upon different transmission media e.g. Inmarsat and High Frequency (HF). Each receiver should be able to use more than one correction link so that operations can continue if there is a failure of a link and/or hardware or power supply. The connections between the receivers and the DP system should also be fully independent. If computers are used within the solution, then full computer hardware redundancy (i.e. a third PC) should also be considered to improve uptime. The DGNSS units in a dual set-up often use the same satellites; however, use of satellites from different systems can provide a degree of independence. DGNSS systems in dual configuration should not be selected on a primary and secondary system basis, but both should possess comparable performance.
GNSS	The use of Dual GNSS	If three position references are being used and comprise a dual DGNSS installation plus one other position reference, then simultaneous failure of both DGNSS has to be considered. Both DGNSS systems can be subject to common drift. This could make it appear that the third system is at fault as it would appear to drift away from both DGNSS positions. This is particularly valid if reliability is reduced e.g. due to poor satellite coverage.
GNSS	Satellite Antennas	Satellite antennas should always be sited in optimum locations on the vessel and, in dual DGNSS, also suitably separated. Therefore, if one is masked from satellites or damaged through local activity the other should still be operational. If an Inmarsat-based service is used, then a dedicated Inmarsat reception unit should be considered. If two Inmarsat links are used and more than one Inmarsat terminal is available, the DGNSS correction demodulators should be connected independently to both terminals.
GNSS	Satellite Antennas	If optimum satellite and differential antenna locations cannot be occupied, the DGNSS user should be aware of, and realistic about, the DGNSS performance limitations likely to result. The elevations and relative directions on which satellite or differential signals will be affected by obstructions or other transmitters should have been noted after installation. This will help to mitigate the effects of antenna locations which are less than ideal. Every effort must be made to make at least one DGNSS available at all times when two are installed.
GNSS	Differential Service Selection	Services and correction links which suit the vessel's known and potential work programme (e.g. DGNSS service coverage and performance) should be selected. Users should ensure that the correction data is not outdated.
GNSS	Reference Station Selection	With any single DGNSS service which has several reference stations, the optimum station(s) should be selected based on the following criteria: ♦ Distance from mobile to reference station (validity of corrections and range from transmitter should be considered); ♦ Direction to transmitter (potential obstructions should be considered as direct line of sight between vessel antenna and transmitter is required); ♦ Reliability of reference station (i.e. does it have a proven track record?); ♦ Intervention i.e. how easily and quickly can the service provider visit the station to remedy a fault? ♦ Availability of back-up reference station(s).

Reference System	Subject	Operational Considerations
GNSS	Satellite Visibility Software	In order to assess which satellites should be available to the user at a particular time, and their azimuths and elevations, satellite receiver manufacturers and software providers have produced satellite visibility programs. These may also allow GNSS users to predict the theoretical accuracy of satellite constellations and the effect of localised masking at specific satellite antenna locations. These packages are useful in planning an operation where reliable DGNSS is particularly important and for the investigation of satellite problems.
GNSS	Mask Angles	Increasing the satellite antenna mask angle can help to suppress GNSS signal instability (e.g. near platforms) by restricting use of signals until satellites are at higher elevation. Procedures should be in place for controlling and recording changes of such parameters in the GNSS receiver. Users should be wary when variable weighting is used to avoid jumps when using low elevation satellites; it cannot be assumed that three healthy position references are available when in fact one (or more) is less than ideal and perhaps useless for DP if another fails.
GNSS	Worksite Factors	If there is significant radio traffic in the proposed work area, such as offshore fields or port approaches, the main frequencies should be evaluated during planning. Differential transmitter elevations and azimuths at worksites should also be checked to avoid unexpected signal blockage.
GNSS	Jamming and Spoofing	Certain regions of the world are prone to jamming and spoofing of GNSS signals. Operators should be aware of the risk and ensure adequate resilience of position keeping capability.
GNSS	Shared use of DGNSS for DP and Survey	To maintain station, a DP system is designed to control a vessel's position by following commands entered into the DP system by its operator. In the majority of circumstances, a DP system is being provided with relative positional change, whereas in survey operations what is required is absolute, geo-referenced, positions. There are risks associated with sharing DP sensors for survey operations; these are highlighted in Guidelines on the shared use of sensors for survey and positioning purposes (IMCA S 023).
Microwave Radar	Equipment Selection	There are a number of different manufacturers of microwave radar equipment in the market, each solution having differing characteristics for specific mission applications; for example, operating range, accuracy or operating temperature. Depending on the manufacturer, the components that make up the microwave reference system can be passive or active in nature which can determine different operating and maintenance considerations. In addition to the vendor selection, other considerations might include: ♦ Desired number of sensors located on the fixed asset (e.g., a fixed platform may have two loading offloading zones); ♦ Desired arrangement of sensors located on the vessel (e.g., a pipelay vessel may require more than one sensor on the vessel to allow for specific operations); ♦ The environment in which the vessel will be operating (e.g., this technology is not susceptible to the weather related issues that cause laser based systems to suffer).

Reference System	Subject	Operational Considerations
Microwave Radar	Sensor placement (vessel)	Sensor placement varies with each application therefore it is important to consider the specific application in conjunction with the manufacturer of the sensor. For example, on a platform supply vessel (PSV), the typical mounting position for the sensor may be above the wheelhouse, with a clear view over the aft deck area or whichever operating area is required. This may be different for a tanker involved in tandem offloading. Some general considerations for sensor placement are as follows: ♦ With an unobstructed view, both vertically and horizontally, in the expected direction of the target; ♦ Above sea-level to prevent swamping or immersion; ♦ On a different vertical level to (or appropriately shielded from) any radar systems operating in the X-band; ♦ On a flat, rigid, horizontal surface able to support the sensor weight; ♦ Allowing for easy access to the connection panel and sensor information display; ♦ High enough to be level with the corresponding sensor placed on the fixed or receiving asset. ♦ Located such as not to cause potential interference with VSAT systems
Microwave Radar	Sensor placement (fixed/receiving asset)	To ensure highest performance of the system and quality of the relative position data sent to the DP system, the location, range and orientation of the fixed sensor must be optimised. Ideally fixed sensors should be mounted: ♦ Within the recommended height difference limits; ♦ Within the tilt limits; ♦ Facing the sensor directly; ♦ In a permanent location. Vertical separation between fixed and vessel sensors at close range can become critical therefore pre-site planning for positioning of the fixed sensor is essential.

Reference System	Subject	Operational Considerations
Microwave Radar	Sensor placement (fixed/receiving asset)	Other considerations are required when selecting equipment to be mounted on the fixed/receiving asset: ♦ Will the sensors be permanently installed or temporary for a given operation (if temporary then procedures and checklists may require development to ensure correct application)? ♦ How the unit is to be powered (mains/battery (rechargeable or non-rechargeable)) and the various technical and maintenance considerations that result; ♦ The local environment where the sensor will be mounted (e.g. hazardous area, within a crane lifting zone, exhaust outlet, etc); ♦ The sensor should be sited with consideration of the line of sight between the sensor and the vessel throughout the entire DP operation; ♦ In addition to direct line of sight considerations, also bear in mind the operation itself. For example, crane operations may pass through the area and interrupt the tracking lock.
Microwave Radar	Multipath reflection of the signal on the sea	'Multipath' is normally worse on a calm surface. Blanking, as it often is referred to, occurs when the directed signal is cancelled out by the reflected signal, causing the remaining signal to be too weak to be registered by the sensor. Operational experience has shown that the normal heave on a vessel eliminates this effect, as the blanking effect is strongly correlated with the height difference between the vessel mounted and fixed installation sensors. In microwave radar operations, the blanking effect is normally connected to the signal transmitted from the vessel mounted sensor, as the energy 'reflected' from the fixed sensor is much weaker than the transmitted signal. The effect of blanking is a result of the height of the vessel mounted and fixed installation sensors. As a general rule, the higher above the sea level the sensors are mounted, the lower the effects. The manufacturer should be engaged to determine the best course of action on a case by case basis depending on specific application. For example, the manufacturer may suggest the use of a higher gain sensor where, after the blanking effect, the signal is still strong enough to be used.
Microwave Radar	Operation of more than one system in a specific location	Systems can be set up on specific frequency 'pairs' so that mutual interference between two systems in the same area can be avoided. By giving the mobile and the fixed sensors an identical address code, they will only lock and respectively transmit when they receive the address code given. This avoids both a mobile station locking onto someone else's fixed station and a fixed station transmitting when it does not receive the correct address code. Further manufacturer specific precautions may also be necessary to avoid interference between two fixed stations for example during SIMOPS in field.

Reference System	Subject	Operational Considerations
Acoustic	General	Methods of deep-water acoustic positioning vary in terms of accuracy, precision, design and frequency. How accurate or precise a system will be is dependent on commercial requirements and the operational and environmental conditions in which they will be used. In all cases, it is only possible to monitor and assess the quality and reliability of the systems if there are sufficient observations and data redundancy supported by careful system calibration and monitoring during operation. In addition to the options of LBL, SBL and USBL, some manufacturers offer a combined package of two or more of the options to provide solutions for complex offshore positioning applications. Combined solutions have the potential to allow faster updates of positioning, better mitigation against errors or interference, less equipment requiring deployment and potentially more efficient support of multiple operations. Other factors which can affect acoustic position reference systems and therefore require to be carefully considered are: ♦ Array planning (mainly LBL systems) – the planning of the layout of acoustic array to ensure consistent and reliable results in the field; ♦ Distance restrictions on range; ♦ The local seabed terrain; ♦ Geometry planning & preparation. For all of these reasons, it is important to have an acoustic management plan in place to avoid undesired interference.
Acoustic	Deep-water Operations	Accurate heading input will enhance accuracy. Systems utilising GNSS and inertial measurement are used in preference to conventional gyros
Acoustic	LBL	LBL has the highest potential accuracy of all the commercial options; the accuracy is preserved over a wider operating area, only one hydrophone is needed through the hull of the vessel, and systems have redundant data for statistical testing/quality control. LBL systems require multiple seabed/subsea transponders, the update intervals are longer compared with SBL/USBL system, and there is a need to redeploy and recalibrate at each worksite.
Acoustics	SBL	SBL has good potential accuracy, requires only a subsea pinger, and has a 'one-time' calibration requirement. The accuracy is dependent on a shipboard motion and heading sensors. Unlike LBL, multiple hydrophones are required to be installed through the hull of the vessel.
Acoustics	USBL	USBL has good potential accuracy, requires only a subsea pinger or transponder, and has a 'one-time' calibration requirement. USBL systems have the highest noise susceptibility, and accuracy is dependent on the shipboard motion sensor.

Reference System	Subject	Operational Considerations
Acoustic	Hydrophone	The hydrophone should be installed in a relatively noise free location safe from obstructions and signal blanking, and ideally offering access for maintenance. In addition, the hydrophone needs to have its linear and rotational motion compensated for in order to remove biases due to these effects. The selection of a hydrophone location is usually based on the following criteria: ♦ Ease of access for maintenance and possible raising and lowering; ♦ Ability to clear the hull by a suitable amount (greater than 2m); ♦ Level of noise and freedom from obstructions; ♦ Relative motion of the unit with respect to the ship's centre of gravity and reference points. For multiple hydrophone installations each unit requires consideration of the above criteria, and, in addition, the relative distribution of the other hydrophones must be considered.
Acoustics	Transducer Pole	The basic criteria for a transducer pole are: ♦ It should withstand the rigours of the motion and forces acted on it by the water when the vessel is at sea; ♦ It should provide a stable point, with minimal vibration, to generate and receive acoustic signals; ♦ It should be free from local acoustic interference. Some operations may use vessels of opportunity and deploy an over-the-side pole for temporary use. Such a mounting is inherently prone to vibration, which can seriously affect the acoustic signalling at the transducer head. Having selected a suitable location point on the vessel, the physical size and length of the transducer pole should be considered. If it is too long, it could flex in the water when the vessel is underway. In general, a clearance from the hull of 1-2m is considered adequate, but it is recommended that the manufacturer is consulted to ensure that their recommendations and experience are taken into account. The diameter should be of sufficient size to provide a rigid mounting for the transducer, typically 25cm. Another aspect that should be addressed is the possibility of a round transducer pole rotating, either during installation or when operations are underway. The transducer heads of most USBL systems need to be aligned accurately and fixed so that a reliable direction can be derived for any received ranges.

Reference System	Subject	Operational Considerations
Acoustics	Seabed Units/ Transponders	The use of seabed units and various transponders in deep water requires that they are properly secured with appropriate fixings and that safe methods for deployment and recovery are adopted. The housings and pressure vessels required for use in deep-water are frequently large and heavy, requiring lifting equipment and special storage facilities to keep them secure whilst on-board. The deployment of systems starts with the testing and checking of units on deck prior to placing them on the seabed. For the units being taken to the seabed, there are several approaches used. The simplest is to attach a clump weight and a flotation collar to the transponder and release the unit over the side. The unit will then drop to the seabed where it will be monitored for correct operation and its co-ordinates determined by means of a box-in method. More sophisticated methods include using an ROV to place the unit directly into a frame or tripod at a pre-determined location on the seabed. This is, of course, a slower process and requires the ROV either to transport the units or for a work basket to be used to lower the units to the seabed for collection by the ROV. This method is used when the acoustic beacons need to be placed in specific holders on seabed assets. The above options apply to both USBL transponders/stations as well as LBL stations. A number of factors influence station deployment, including: ♦ Design of deep-water transponder frames; ♦ Suitability and use of acoustics as DP references; ♦ Depth rating of acoustic equipment; ♦ Power levels and battery technology.
Laser	Equipment Selection	There are a number of different manufacturers of laser position reference equipment in the market, each solution having slightly differing characteristics for specific mission applications, for example, operating range or accuracy. The components that make up the laser reference system are a mix of passive and active components and therefore different operating and maintenance considerations apply compared to those reference systems with only passive components. In addition to the vendor selection, other considerations might include: ♦ DP operating range – the range is typically shorter than other relative reference systems for example microwave radar; ♦ Desired number of and type of reflectors located on the fixed asset (different reflectors offer different range capabilities and increased numbers of reflectors can improve the reliability of the reference); ♦ The environment in which the vessel will be operating (as this technology is based on line of sight, the operating range is greatly reduced in fog, snow and heavy rain).

Reference System	Subject	Operational Considerations
Laser	Sensor Placement (vessel)	Sensor (scanner) placement varies with each application, therefore it is important to consider the specific application in conjunction with the manufacturer of the sensor. The scanner should be installed in an area that allows 360-degree rotation and has easy access to allow for routine maintenance and servicing. The mounting location should avoid areas where high vibrations are experienced and be away from sources of dust, smoke, water spray or radiant heat to avoid degrading reference performance. It has been found that the ideal place to install the scanner is on the vessel's centre line directly above the bridge. It is essential that the scanner be positioned to give a clear line of site in all directions where targets are to be installed. Some operators may require more than one mounting point on a vessel for task flexibility.
Laser	Target Placement	There are two main types of targets, reflective tape and retro prisms. Care should be taken to mount both types of target vertically. This is particularly important with vertically stacked prisms for longer range use. Poor targets are harder to track, and this increases the chance of picking up spurious targets. ♦ Reflective tape – only tape targets from laser PRS equipment manufacturers should be used. The condition of the tape target should be monitored, and should degradation occur the target should be replaced. Targets made from tape will generally give ranges up to 150 metres depending on conditions. It is recommended that targets be cylindrical, to allow viewing from all angles, 150mm in diameter, but not exceeding 250mm, and 1000mm in length. ♦ Retro prisms are required for longer ranges. A single prism will give reflections from +/- 30-degrees either side of the prism centre line. For 360-degrees working, a minimum of 8 prisms are recommended. For ranges over 1000 meters prisms may wish to be stacked for more robust tracking. ♦ The use of retroreflective prisms where possible should be encouraged. ♦ Targets should be sited with consideration of the line of sight between the sensor and the target throughout the entire DP operation. ♦ In addition to direct line of sight considerations, also bear in mind the operation itself. For example, crane operations may pass through the area and interrupt the tracking lock.
Laser	Target Less System	With no targets to deploy the system is ready for immediate use when entering the work area. The system relies on structures that provide a changing profile therefore reliance may not be possible given high straight sided assets. Ensure that the system has the correct size set for the vessel and correct offsets. Returns inside the envelope of the vessel are ignored by the tracking algorithm.

Reference System	Subject	Operational Considerations
Taut Wire	Equipment Selection	There are a number of different manufacturers of taut wire position reference equipment in the market, each solution having slightly differing characteristics. In addition to the vendor selection, other considerations might include: ♦ Water depth at operating location – the use of Taut Wire can be limited by the water depth (< 500m) and therefore more applicable to shallower water operations. Greater water depth solutions have been designed; however, they inherently suffer accuracy issues as any variation in wire tension directly causes an almost proportional variation in the estimated position of the weight. ♦ Mission of the vessel – the Taut Wire is only suitable for activities on a small footprint (heading and position) and therefore would not always be suitable. The shallower the operation, the smaller the permissible footprint. The Taut Wire system can also suffer long term drift as the current changes the catenary. ♦ The environment in which the vessel will be operating (e.g., heave, pitch and rolling). The inertia of the wire rope, plus any friction has to be overcome as does the inertia of the wire drum. Whenever the vessel heaves, the Taut Wire has to pay out or pay in wire, and so it has to overcome the inertia, dead bands, back lash and friction of all the mechanical moving parts. This means that the system must always have a finite response time; this therefore contributes to the degrading of accuracy of the tension control. ♦ A system incorporating 'walking Taut Wires' has been developed. With two Taut Wires in use, the system will automatically re-set one of the Taut Wires once a specified angle within operational limits has been reached. The system can be used for pipelaying operations, although has become less important due to availability of alternative PRS.
Taut Wire	Deployment	Consideration must be given during Taut Wire deployment due to: ♦ Ensuring no risk to vessel personnel (e.g., divers) or equipment (e.g., ROVs) in the water at the point of deployment. ♦ Subsea Infrastructure at location – the Taut Wire requires a weight to be placed on the seabed and therefore the location of subsea equipment (e.g., templates, risers, mooring lines, umbilical's, etc.) and seabed condition require consideration.
Heading Reference Sensor	Independence	Heading sensors used for DP systems need to be independent from other systems using the signal from the sensors
Heading Reference Sensor	Operation	It is recommended that gyro compass speed and latitude corrections are entered manually and not interfaced with GNSS. This recommendation is based on evidence gained from IMCA DP Station Keeping reports that have featured sudden unreliable readings being fed to the gyro compass.
Wind Sensor	Segregation	Wind sensors need to be suitably separated so that as far as possible at least one sensor is free from interference when the vessel is in operational mode

5 Operational Experience from IMCA DP Station Keeping Reporting Scheme

The IMCA DP Station Keeping Event Bulletins are an excellent method of sharing lessons with industry. Recent bulletins highlighting operational experiences involving position reference systems are reproduced here.

IMCA DP Bulletins are available for download on the IMCA website.

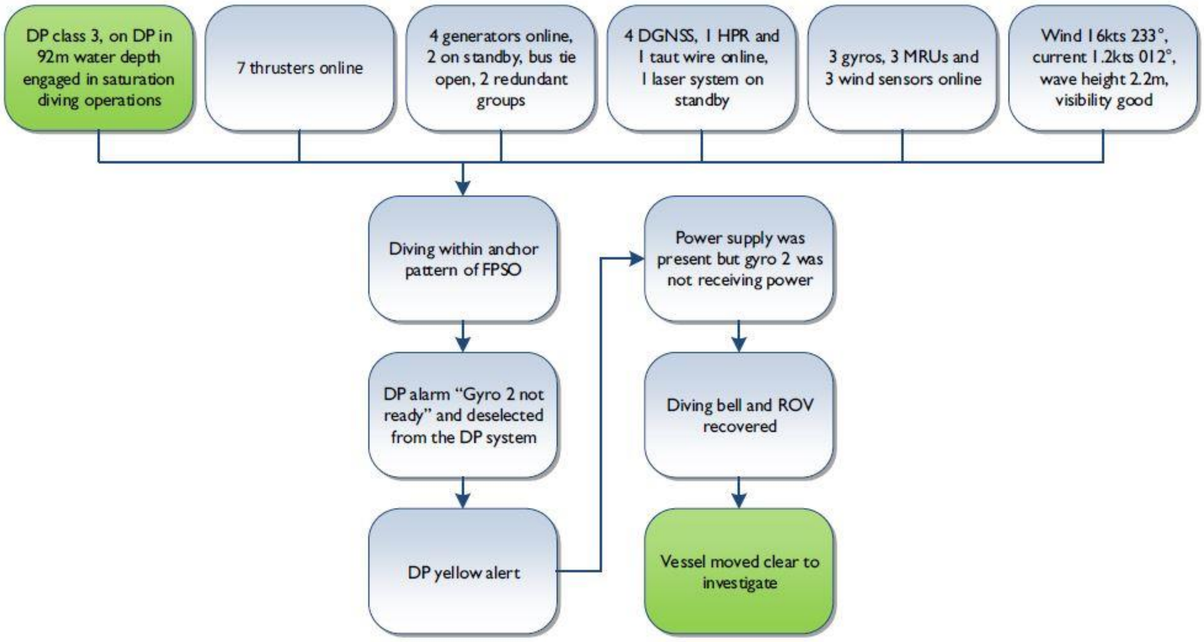
5.1 Position Reference Systems – A Timely Reminder

The IMCA Marine DP committee has identified a trend of DP station keeping events relating to the incorrect use or selection of PRSs. Events reported to IMCA include incidents where station keeping capability has been lost and undesired events where redundancy has been compromised.

Recent Events Reported to IMCA Include the Following Learnings:

- Incorrect selection of PRSs – the requirement for at least two different principles not being followed leading to position instability;
- Over reliance on one PRS, global navigation satellite system (GNSS), to the exclusion of others:
  - intermittent DGNSS signal outages in certain geographical locations
  - use of GNSS without differential correction
  - common mode failures of DGNSS caused by selection of hardware from single supplier and differential positioning services from one supplier
  - DGNSS signal reception becoming unsteady because of either shielding or shadowing;
- DP reference sensor UPS supplies not following the redundancy concept of the vessel – loss of UPS led to no references online;
- During cargo operations, removal of relative positioning system transponders/reflectors by installation crew prior to station keeping activities being completed;
- Laser based system locking onto a crew member standing close to the reflector (in a restricted area);
- Incorrect selection of PRSs for the mission requirements;
- Poor management of change (MoC) processes leading to loss of redundancy of position reference sensors – rewiring of sensors post worst-case failure to finish the mission;
- Incorrect PRS selection for use at a mobile installation leading to conflict between absolute and relative sensors causing drift off;
- Feed from the GNSS to the gyro leading to inaccurate latitude and speed correction signals;
- Poor MoC leading to the antenna of one GNSS being connected to two GNSS systems, creating a common mode failure;
- Select the most suitable reference origin considering the mission to be completed;
- In the case of instability, know the manufacturer's procedure for resetting the reference origin;
- Make sure to fully understand the different tests carried out on each PRS and the actions to be taken when a test suggests that a position measurement is not accurate.

5.2 An Un-Associated Failure of One Part of a Gyro System Affected the DP System



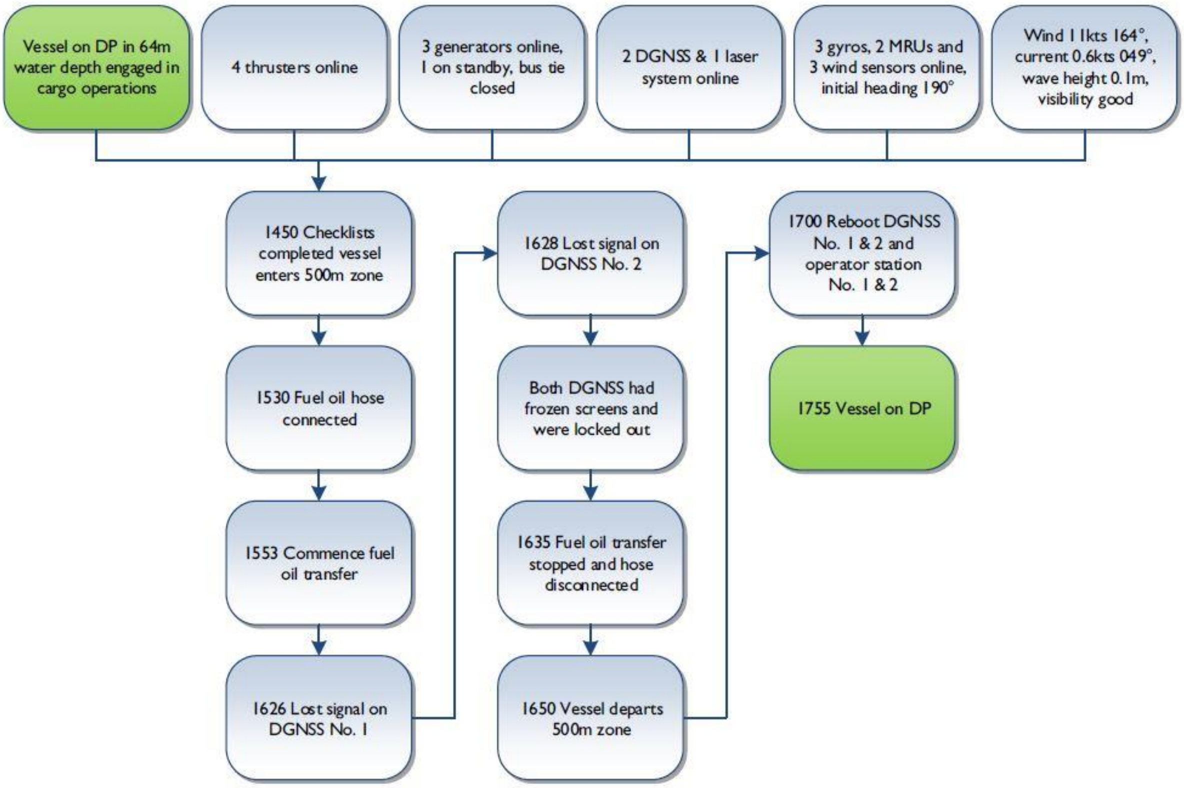
Comments from the report:

A new gyro was installed as a replacement but failed to start with first attempt. Further investigation revealed that the 'Gyro 2 remote control unit' located on the forward bridge had a fault, failure of it caused Gyro 2 to shut down. When the 'Gyro 2 remote control unit' was disconnected the new gyro was switched on with no further problems. After a stabilisation period the Gyro was tested, found operational and the signal to DP reinstated. DP operations were resumed. In conclusion, the original Gyro 2 was and remains healthy.

Considerations of the IMCA Marine DP Committee from the above event:

- It can be assumed that good operational activity planning took place and the ASOG indicated a yellow alert to be activated with the loss of one gyro.
- The logic of systems connected to the DP system need to be fully understood so that a failure in one part of a connected system does not affect the DP system.
- With the availability of so many position reference systems it may be better to use 2 DGNSS and keep the other 2 DGNSS as monitoring.
- It is unclear what the gyro 2 remote control unit is required for, but it appears to have introduced an additional failure mode of the gyro and should have been identified in the DP FMEA.

5.3 Common Mode Failure of DGNSS



Comments:

Both DGNSS systems had locked up, the touch screen was not responding and the NMEA signal was no longer being received, the DP system alarm displayed 'telegram timeout'. The GNSS manufacturer concluded that with both systems suffering issues at the exact same time it pointed towards a common factor, the likely root cause was signal interference.

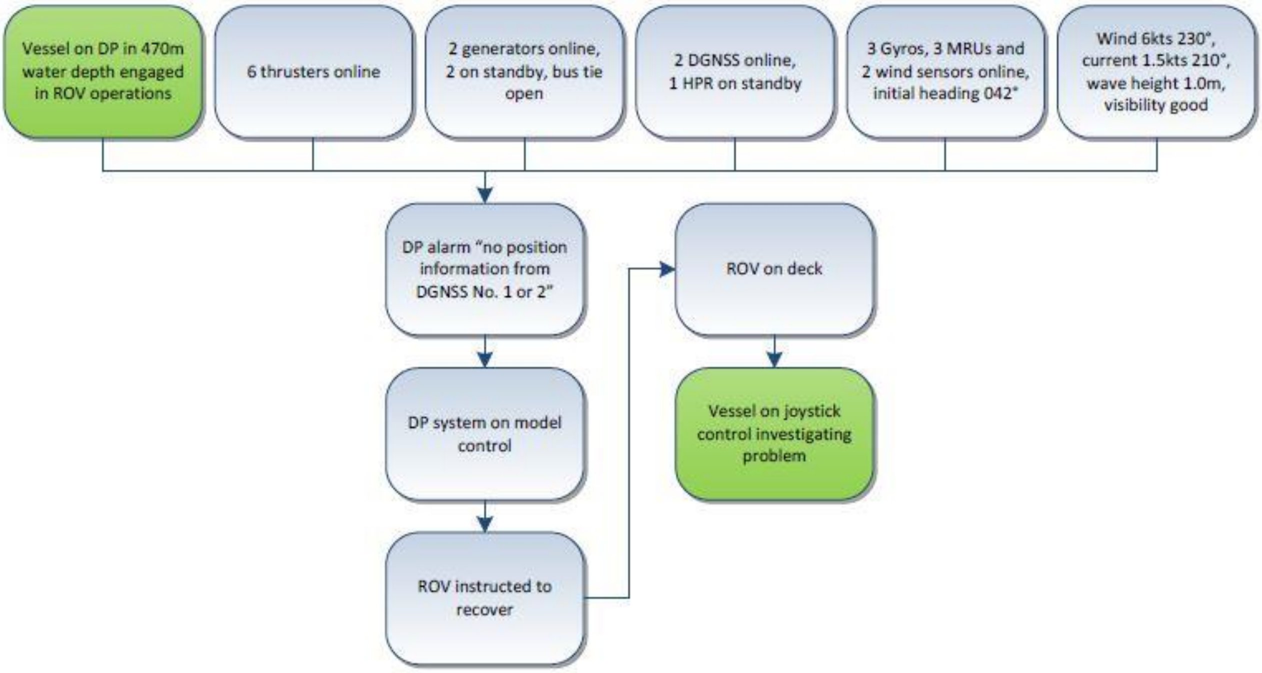
Recommendations included:

1) Ensure the antenna, cables and connectors are in a good condition and no damage to them.
2) Tune the MF module on each set to different MF stations.
3) Check if both systems are utilising the same 'precise point positioning' service; if so, consider changing one of them.
4) Copy the configuration files for reference.
5) If a further crash occurs take pictures of the system screens as there may be additional windows error messages.

Considerations from the above event:

- The DP system worked as designed, the vessel departed the 500m zone, for investigation, on DP using the laser system as reference.
- The root cause of the problem was not found, however, it was believed to be a common mode failure.
- Most DGNSS suppliers have a function available to check for shadow of satellites, users would be wise to make proper use of this tool.
- Improvement measure would be to use two different DGNSS suppliers and different differential position services.

5.4 Loss of DGNSS Resulted in ROV Being Recovered



Comments:

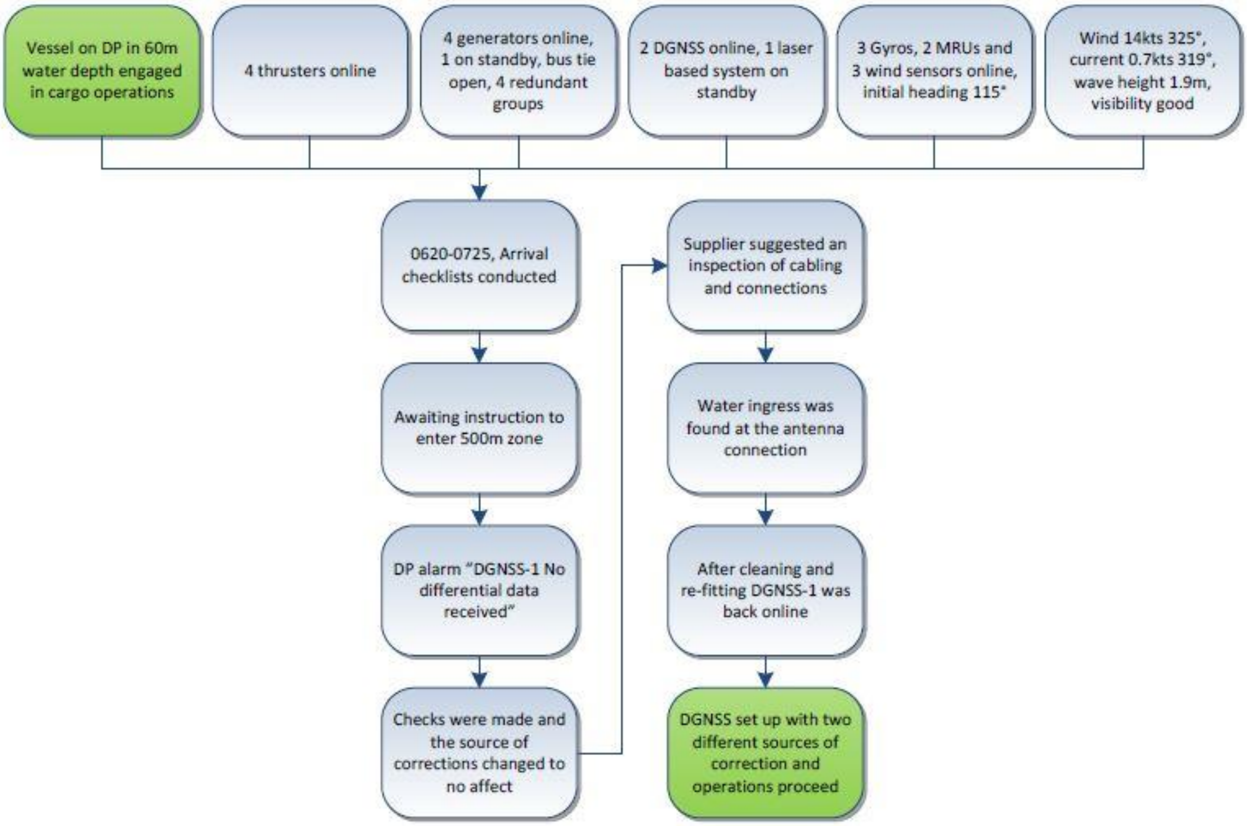
Both the satellite positioning systems in use were from the same provider.

The report recognised this and recommended that the systems were changed so that position information was provided by different service providers. The service provider informed the operator after the event that its services experienced periods of increased latencies for just over twenty minutes on the day and time of the incident.

Considerations from the above event:

- It would appear from the information available that the standby hydroacoustic position reference (HPR) system did not have an acoustic transponder on the seabed. In any event it was not utilised.
- Proper consideration should always be made of the required PRS based on the specific operation and the DP equipment class of the vessel.
- When considering redundancy of satellite systems, do not just consider equipment manufacturer and software versions; the correction type and transmission method should also be different.
- It is noted that two separate vendors could use correction details from the same source, therefore users should compare what correction type is being used.
- In similar situations users could consider switching to raw global navigation satellite system (GNSS) data, therefore staying on DP but with a larger footprint.

5.5 Bad Connection Causes Loss of DGNSS



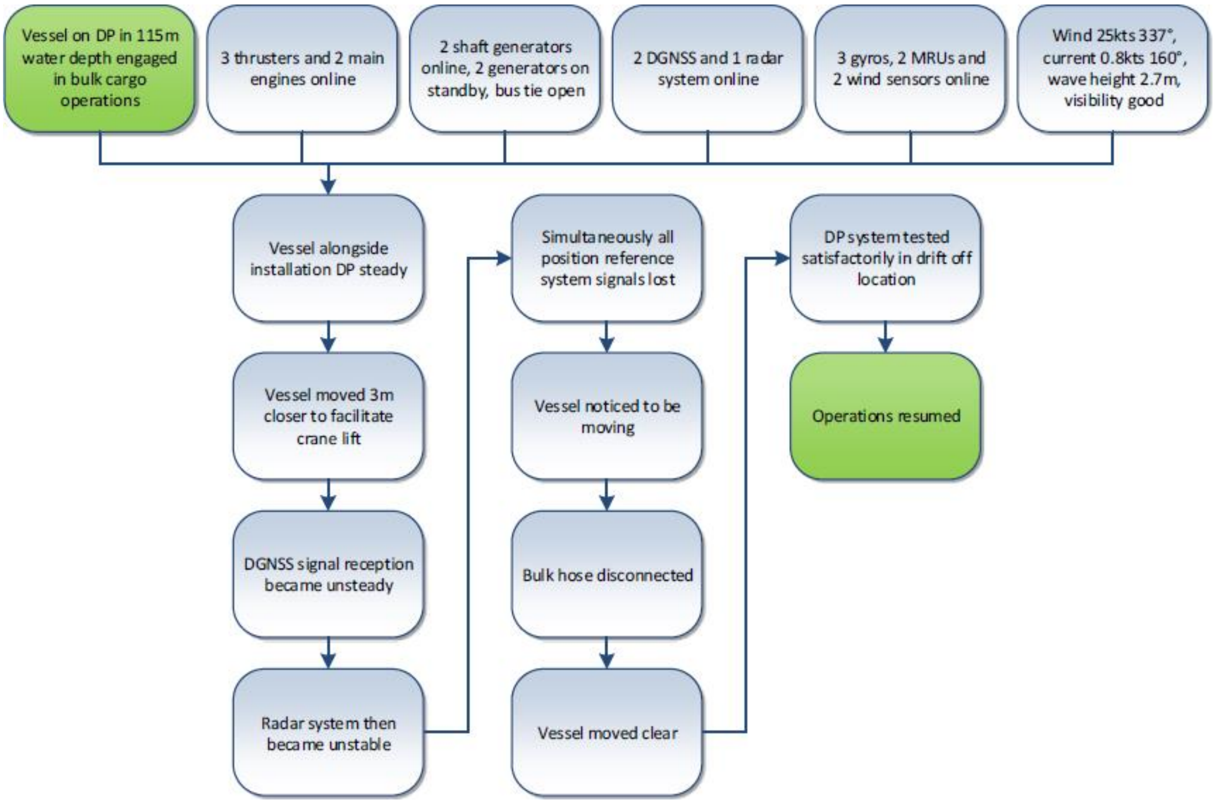
Comments:

After all the checking, it was found that there was water ingress at the L-Band connector to the antenna on the mast. This was dried and cleaned. The connectors were properly sealed with self-bonding electrical tape and cable ties.

Considerations from the above event:

- This observation reinforces the need for good practice conducting field entry/arrival DP checks making sure all DP systems are operational and healthy.
- It is unclear why the laser-based reference system was not in use, but it is assumed the system was not immediately available due to distance or shadowing.
- Several recent reports indicate the use of only two enabled position reference systems (PRS); these are often both DGNSS. It cannot be stressed enough that a mixture of PRS should be used.
- Regular checks of connections which are exposed to the environment need to be carried out and included in planned maintenance systems.

5.6 Instability of Position Reference Systems



Considerations from the above event:

- It is not clear from the report whether it was the differential correction signal or satellite constellation that was shielded; however, operators need to be aware of shielding and shadowing in similar situations.
- The GNSS constellation screen should be consulted and considered prior to moving closer to a possible obstruction.
- The reflector for the radar system might not have been sited for optimum performance; did the crane shield the radar from the reflector?

5.7 Loss of Three Gyros on a DP 3 Drill Ship

Three gyro compasses connected to DP system had a 'heading freeze' within 5 minutes of time.

What happened?

Three DP System connected gyros heading froze within 5 minutes of time. With all three gyros out of service, drill ship's DP model took over. 34 minutes later all gyros had been rebooted and were online in the DP System. Gyros were of modern fiber optic style.

The max excursion of vessel position was 20 meters over 34 minutes. Calm weather was benign enough to allow accurate model control of drilling vessel for duration of 34 minutes. Drill ship was connected to well head while tripping into hole when incident occurred, but emergency disconnect was not required.

What went wrong?

The investigation is ongoing which will require analysis of all three gyros in a laboratory by the original manufacturer. Nothing can be stated conclusively until root cause analysis and investigation is complete. Drill ship had been in service less than a year at the time of the incident.

What were the causes of the incident?

As of the writing of this safety flash, the proximate cause is unknown. Initial review reveals observations that may or may not have contributed to this incident, in whole or part, and is not intended to reflect negatively upon any vendor or operators' approach to construction/design:

- Commonality of three identical **make and model** gyros with common software, firmware, and hardware;
- Common backup 24volt power source among three gyros could have allowed voltage instability to affect all three gyros at the same moment in time;
- Out of date firmware existed on 3 gyros;
- Automatic feed of GNSSS inputs existed;
- Manufacturer's technical bulletins existed but it remains unclear if that is relevant;
- Simultaneous initial power-up start time of internal gyro clocks in shipyard possible;
- Unknown age of gyros installed in shipyard.

What lessons were learnt?

- An active, approved and well-rehearsed Well Specific Operating Guideline (WSOG) contributed to the safe reaction of on-board staff;
- Calm weather contributed to the effectiveness of the DP Model;
- Open and clear communications are crucial to successful response and resolution;
- Common mode faults should be interrupted through use of different brands, different power connections, and thoroughly tested during a Failure Mode Effect and Analysis (FMEA) conducted by an independent third-party;
- Concerns identified during FMEA testing should be followed up by management and risk assessed according to IMCA/industry.

What actions were taken?

- Deep root cause analysis is to be conducted and a step change to installed equipment is ongoing.

6 Failure Analysis

Reference System	Effect	Cause	Mitigation
GNSS	Interruption to satellite tracking	Multipath or obstructions to antenna such as when working close to platforms or other structures.	During installation ensure antennas have clear line of sight to the sky. At mission planning stage check whether obstructions will impact performance. Consider use of multiple GNSS systems to provide additional satellites (e.g. GPS and GLONASS).
GNSS	Radio-frequency interference	Transmitting devices such as data or video telemetry systems or satellite communication systems (e.g. VSAT, Sat-C) interfering with GNSS and satellite correction delivery system.	Antennas should be installed at the maximum distance from other radiating antennas (IMO recommendation 3m separation from other radiating sources). Ensure antenna cables are terminated correctly and outdoor connections are sealed with suitable waterproof tape. During installation and commissioning it is important to conduct comprehensive tests to identify any sources of RF interference. During maintenance visits, check cables and connectors for damage, cracking and water ingress – replace if necessary.
GNSS	Ionosphere – position bias in single frequency systems	Failure of iono-model to cancel out the effects of ionosphere delay in single frequency systems. Typically occurs during periods of increased ionosphere activity.	Use GNSS receivers to calculate true ionosphere delay error and an augmentation service that can remove ionosphere delay error to cancel this effect. The use of dual frequency receivers is recommended.
GNSS	Ionosphere – scintillation	Causes rapid fluctuations in the phase and amplitude of the L-Band satellite signal as it passes through small-scale irregularities in the ionosphere. This can cause the receiver to lose lock to the GNSS satellites and also the L-Band augmentation satellite link. The effects of scintillation appear in different localised regions of the sky and thus only affect certain satellites at a time.	If scintillation is detected it may be necessary to disable the particular satellite that is causing problem. Ensure redundancy in delivery of augmentation data (i.e. from different satellites and/or terrestrial broadcast). When possible, use multiple DGNSS reference stations and/or a precise point position (PPP) augmentation solution. Consider use of multiple GNSS systems to provide additional satellites (e.g. GPS and GLONASS).
GNSS	Loss of correction data	Failed correction data link. Failure of reference station(s).	Ensure redundant and diverse correction links. Ensure reference stations have redundant equipment and communications links. Use multiple reference stations, where possible, or use a PPP augmentation solution.
GNSS	Change of reference station or station combination used affecting position accuracy and redundancy	Incorrect/inappropriate selection of reference stations or vessel/vehicle has moved to new work location	Ensure selection of appropriate reference stations for work location (DGNSS) or use a PPP solution. Changes to system configuration should be formally recorded (preferably in a change management system).

Reference System	Effect	Cause	Mitigation
GNSS	Poor satellite geometry or insufficient number of satellites.	Elevation mask change.	Ensure elevation mask is set to a value such that stable tracked GNSS satellites are available for the position solution (typically between 5° and 12°). Changes to system configuration should be formally recorded (preferably in a change management system).
		Satellite masking caused by obstructions.	At mission planning stage check whether obstructions will impact positioning performance. Consider reducing (if possible and without further degradation) the elevation mask to include additional satellites. Consider use of multiple GNSS systems to provide additional satellites (e.g. GPS and GLONASS).
		Satellite de-selection – normally satellites are automatically flagged as unhealthy but occasionally the user may disable a particular satellite.	Ensure that only problem satellites are de-selected and when problem has cleared satellites should be re-introduced. Changes to system configuration should be formally recorded (preferably in a change management system).
		Changing constellation availability due to unhealthy satellites or satellite manoeuvres.	Monitor system performance and official warnings if available for any signs of degradation. Consider use of multiple GNSS systems to provide additional satellites (e.g. GPS and GLONASS).
GNSS	Loss of GNSS signal	Intentional signal jamming can occur when certain bodies (e.g. regulatory or military) conduct jamming trials. Intentional signal jamming can also occur if military forces are operating near to work location or if the user is operating close to military installations	Regulatory bodies will normally, but not always, issue notifications of where and when jamming trails are undertaken. Users should check notifications to see if work location is affected. User should monitor systems if military forces or installations are nearby for any signs of degradation in positioning.
		Un-intentional signal jamming is typically caused by RF interference from other transmitting devices – for example, re-radiating GNSS, microwave transmission links on offshore platforms, and military radar.	Conduct tests to discover source of interference by: ♦ Systematically switching off transmitting devices; ♦ Check antenna, cabling junction boxes for signs of damage, degradation or water ingress and repair if necessary. If working close to installations (e.g. offshore platforms) check for any transmitting communications devices such as microwave links which can cause interference.
GNSS	Equipment failure	Failure of hardware including GNSS receivers, correction receiver, PCs. Issues with software not operation or suffering corruption. Damage or degradation in condition of antennas and cables.	Ensure that there are a minimum of three position reference systems active within the DP system based on at least two different principles and suitable for the given operating conditions, as per IMO MSC/ Circ.645 6 June 1994 / MSC/ Circ.1580 16 June 2017. Have 100% spare equipment available including software installation files. Ensure all configurations, where possible, are backed up. Conduct regular inspection and maintenance to mitigate potential problems occurring.

Reference System	Effect	Cause	Mitigation
Microwave Radar	Equipment failure	Failure of hardware including transmitters and receivers, PCs. Issues with software not operation or suffering corruption. Damage or degradation in condition of transmitters and receivers, cleanliness of equipment, integrity of batteries and cables.	Ensure that there are a minimum of three position reference systems active within the DP system based on at least two different principles and suitable for the given operating conditions as per IMO MSC/ Circ.645 6 June 1994 / MSC/ Circ.1580 16 June 2017. During installation, commissioning, modification it is important to conduct comprehensive tests to ensure correct setup and calibration checks are adhered to. During maintenance visits, check cables and connectors for damage, cracking and water ingress, battery integrity, transmitter/receiver cleanliness/etc.
Microwave Radar	System unable to detect 'fixed' sensor.	Damage or degradation in condition of transmitters and receivers, cleanliness of equipment, integrity of batteries and cables, sensor obstruction.	During maintenance visits, check cables and connectors for damage, cracking and water ingress, battery integrity, transmitter/receiver cleanliness/etc. Check that there are no obstructions on the vessel or asset that could block or interfere with the signal, for example, a crane boom or scaffolding.
Microwave Radar	Degraded, False or no reference signals	Coding of transmitter/receiver incorrect. Unauthorised modification of sensor brackets. Multipath issues, interference from X band radar.	Incorrect setup/commissioning of system. Sensor bracket adjustment must be reflected in the system software setup. Correct installation location based on manufacturer recommendation.
Acoustic	Equipment failure	Failure of hardware including hydrophones, transducer poles, seabed transponders, MRU/gyro inputs, PCs. Issues with software not operation or suffering corruption. Damage or degradation in condition of equipment, cleanliness of equipment, integrity of system cables and batteries of seabed transponders (if applicable).	Ensure that there are a minimum of three position reference systems active within the DP system based on at least two different principles and suitable for the given operating conditions as per IMO MSC/ Circ.645 6 June 1994 / MSC/ Circ.1580 16 June 2017. During installation, commissioning, modification, it is important to conduct comprehensive tests to ensure correct setup and calibration checks are adhered to. During maintenance visits, check cables and connectors for damage, cracking and water ingress, battery integrity, equipment cleanliness/etc.
Acoustic	Degraded accuracy or no reference signals	Incorrect or lack of commissioning and calibration of equipment, signal interference, change in water temperature, thermoclines, pressure and density changes in the water, and changes in the salinity.	USBL – post accurate installation and alignment, rigorous calibration of the ships equipment and seabed units is required to ensure that the expected or specific quality of positioning reference is achieved. LBL by contrast, it is only when the network of stations is deployed to the seabed that time can be spent ensuring acceptable performance and accuracy are achieved by careful calibration of the seabed transponders (stations). Dependent on the co-ordination of the stations, the performance of an LBL array of stations is not generally related to the water depth. This is only partly true as the station co-ordinates are essentially derived from the vessel surface positioning by global navigation satellite system (GNSS). However, the mobile unit being tracked is positioned relative to the seabed stations, accuracy decreases as the vessel moves away from the centre of the LBL array.

Reference System	Effect	Cause	Mitigation
Laser	Interruption of laser beam	Signal blocked by obstructions or a dirty sensor lens.	Contingency planning of site and work requirements. Good communication with the asset hosting the targets to ensure they are not interfered with or obstructed. Ensure lens is kept clean.
Laser	Reduction in operating range	Operating range is greatly reduced in fog, snow and heavy rain.	Contingency planning through receipt of good weather forecasts.
Laser	Acquisition of a false target	Bright reflections in close proximity to system targets.	Optimum performance requires the use of the manufacturer's own targets.
Taut Wire	Inaccurate position reference	Thruster wash, creep over time due to current, fouling of clump wire including the Taut Wire touching the side of own vessel or, otherwise being restricted in its movement, or by a faulty gimbal sensor.	Operational and mission awareness is the best mitigation for most of the possible causes of taut wire reference inaccuracy.
Taut Wire	Wire break	Taut Wires are quite highly stressed for marine wire ropes and are liable to breakage, particularly at points of weakness, such as continuous 'spot' wear on the main sheave, continuous wear at any guide blocks and kinks or damage caused by poor spooling or where the wire is attached to the weight.	The potential for wire breakage is reduced by regular inspection and maintenance of the Taut Wire system and by cropping the Taut Wire on a regular basis.
Heading Reference Sensor	Inaccurate heading	Incorrect vessel speed and position data feed to gyro compass.	Operational awareness combined with suitable arrival and periodic DP checklist.
Wind Sensor	Inaccurate and variable wind reading	Shadowing caused by external structures or own vessel superstructure.	Operational and mission awareness deselection of affected wind sensor.
Wind sensor	Inaccurate and variable wind reading	Disturbance caused by helicopter operations.	Operational and mission awareness, deselection of wind sensors during helicopter operations.

7 Typical Use of Position Reference Systems (PRS)

7.1 Industrial Mission

The table below gives an indication of the position reference systems that are typically used by DP vessels engaged in different industrial missions. The operation examples are taken from Guidelines for the design and operation of dynamically positioned vessels (IMCA M 103). The requirements of the DP equipment class within IMO guidelines must be taken into account and the choice of PRS will also be dependent on water depth, geographical location, proximity of installations and whether those installations are fixed or moving. In general, a mix of different types and principles are preferable to ensure position reference systems and sensors do not have a common mode failure.

Position Reference System (PRS)	DGNSS	Relative GNSS	GNSS/Inertial navigation system (INS)	Microwave Systems	Acoustic LBL	Acoustic USBL/SBL	Acoustic Inertial Navigation System (INS)	Laser Systems	Tautwire
Industrial Mission									
Diving Support (DSV)	✓			✓*		✓		✓*	✓
Pipelay	✓		✓	✓	✓***	✓	✓	✓	✓**
ROV Support	✓		✓	✓*	✓	✓	✓	✓*	
Crane	✓	✓****	✓****	✓*	✓	✓	✓****	✓*	✓
Float Over	✓			✓*		✓		✓*	
Accommodation	✓	✓	✓	✓*	✓	✓		✓*	✓
Drilling (MODU)	✓		✓		✓	✓	✓		
FPSO	✓		✓		✓	✓	✓		
Shuttle Tanker		✓		✓*				✓*	
Trenching	✓			✓*		✓		✓*	✓**
Cable Lay/Repair	✓		✓	✓*	✓	✓	✓	✓*	✓**
Self-elevating (Jack-up)	✓			✓*				✓*	
Offshore Supply (OSV)	✓	✓	✓	✓*				✓*	
Anchor Handling	✓			✓*				✓*	
Well Stimulation	✓		✓	✓*		✓	✓	✓*	✓
Rock Placement	✓			✓*				✓*	
Dredging	✓			✓*				✓*	
Service Operations (SOV)	✓	✓		✓*				✓*	

* When within range of a platform
** Walking TW systems
*** Not used for DP positioning but for determination of laying within corridor
**** Position referencing during Crane Operations

7.2 Operating Conditions

The table below gives an indication of the position reference systems that are typically used by DP vessels given different operating circumstances. Static operations are taken to be operations where the vessel position is controlled relative to the ground. Therefore, operations such as pipelaying and cable laying to a predefined track are included. Relative DP operations are when the vessel position is maintained relative to an object and not ground stabilised. This would include, for example, cargo operations with a mobile offshore drilling unit. The requirements of the DP equipment class within IMO guidelines must be considered. In general, a mix of different types and principles are preferable to ensure position reference systems and sensors do not have a common mode failure.

Type of Operation	Position Reference System (PRS)	DGNSS	Relative GNSS	GNSS/Inertial navigation system (INS)	Microwave Systems	Acoustic LBL	Acoustic USBL/SBL	Acoustic Inertial Navigation System (INS)	Laser Systems	Tautwire
Static operations up to 200m depth		✓		✓	✓		✓	✓	✓	✓*
Static operations up to 200m depth – open water		✓		✓			✓	✓		✓*
Static operations up to 200m depth – within 500m zone		✓		✓	✓		✓*	✓	✓	✓*
Static operations up to 200m depth – subsea structures		✓		✓	✓		✓*	✓	✓	✓*
Deep water static operations – open water		✓		✓		✓	✓	✓		
Deep water static operations – within 500m zone		✓		✓	✓	✓	✓	✓	✓	
Surface referenced relative DP operations			✓		✓				✓	
Sub-surface referenced relative DP operations			✓				✓			

* Considerable care needs to be taken deploying clump weights and transponders in the vicinity of subsea structures, cables and pipelines