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SENSORS

The Application of Improved Dynamic Positioning Control Techniques and Advanced Acoustic Waveforms to Improve Performance in Deepwater And Ultra Deepwater

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INTRODUCTION

Deep water (1000m to 3000m) and ultra-deep water (greater than 3000m) presents many new challenges for dynamic positioning. Increased water depth allows the positioning accuracy to be relaxed compared to that required in shallower water. In addition, the dynamic positioning system must be able to continue operation on acoustics only in the event of loss of the DGPS system since in deep water and ultra-deep water, three separate positioning sensors are not available.

Dynamic Positioning

The control system can be modified to meet these conditions allowing smooth, stable operation on acoustics in deep water, while optimizing the blend of acoustic data with that from the other position sensors that are reliant on different technology. At this time only DGPS is available to provide redundancy of position measurement. This paper will discuss some of Nautronix's developments in their ASK 5000 series DP control systems to meet these requirements.

Acoustics

The traditional method of increasing the output source level of acoustic beacons for successful operation in deepwater has pretty much reached its limit given the need for extended battery life. Fortunately, advanced acoustic waveforms can increase the operational ranges of such systems without requiring an increase in the output source level. Nautronix has developed a new acoustic positioning system, the RS 925. This uses new waveforms to provide the range required for the present operating depths. This paper will cover the latest technology behind the development of these waveforms and show results from actual trials of the system at sea.

Experience

This paper will also present information from practical experience and actual measurements using these techniques for core drilling in 5560m of water (by the Joides Resolution) and record riser-based drilling in Brazil in 2777m (by the Deepwater Expedition). The DP techniques and acoustic systems described have both been or are being implemented on the Ocean Clipper, Deepwater Navigator and the Deepwater Discovery.

THE APPLICATION OF IMPROVED DYNAMIC POSITIONING CONTROL TECHNIQUES TO IMPROVE PERFORMANCE

The ASK 5000's DP Control System has been specifically developed to enhance performance and better meet the requirements of deepwater dynamic positioning operations particularly for applications with Short Base Line (SBL) Acoustics.

Several considerations combine to make the challenge of deep water positioning on SBL acoustics difficult in deep water:

- Fundamental position fixing noise level is directly proportional to water depth. In the deepest water depths, the fraction of a percent of water depth error inherent in the acoustic fixing process translates into large amounts of jitter in horizontal distance at the sea surface. If the control system responded to these noise levels directly, large thrust modulation would result.

- As the SBL solution relies on detection of acoustic pulse arrival time at separate hydrophones, position fixing requires very accurate independent vessel roll and pitch measurement. This allows the discrimination of actual vessel motion and from apparent vessel motion caused by changes in attitude (roll and pitch) of the vessel. On ship shape hulls, with a high center of roll due to derrick effects, it is important that the control system not issue excessive thrust commands that will heel the vessel and introduce additional errors due to vertical reference sensor dynamics, that in turn causes more heel and more errors, and so on. That is effect is commonly known as thruster induced roll.

This control system upgrade is comprised of a complement of revisions designed specifically to obviates the effects described above and allow smooth, stable operation on acoustics in deep water, this requires optimizing the blend of acoustic data with that from other position sensors relying on different technology. The following specific revisions are provided:

- The effects of wave and other sensor noise sources have been greatly minimized by converting to third-order elliptical filters.

- In companion with this increased noise filtering, a rate error compensation filter has been added to overcome the increased phase lag introduced with the increased noise filtering.

- Kalman filter gains are based on assumed process noise and the calculated instantaneous composite noise from all online sensors. This allows better adaptation as sensors are added and subtracted from the pool and ensures an increase in Kalman filtering for operations on SBL in deep water since overall position-fixing noise may increase.

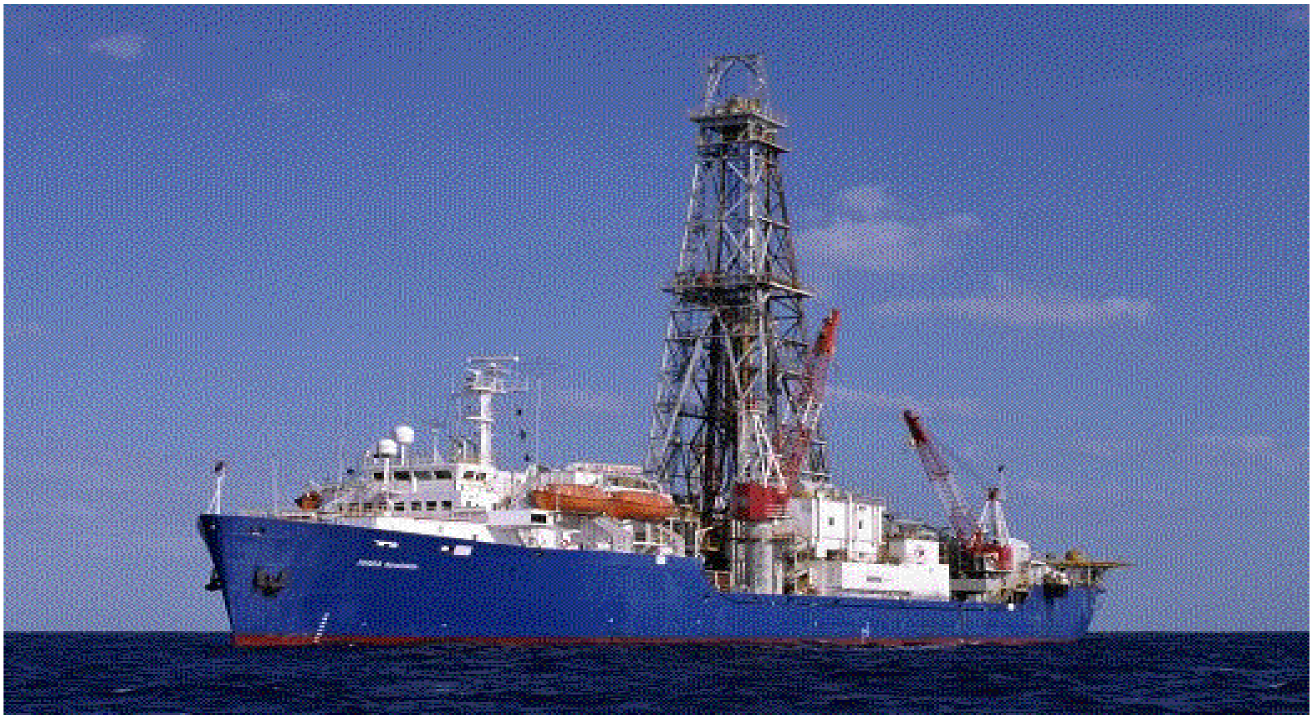
- The dynamic positioning control loop bandwidth is reduced as a function of water depth

This enhancement has been implemented on a number of vessels – see table 1. The enhancements have been verified during deepwater trials and operations on several of these vessels for example; the Joides Resolution and the Deepwater Expedition.

Return to Session Directory ►

Joides Resolution

The Joides Resolution is a core drilling vessel that has operational in 5370 meters of water using SBL acoustics in 20 knot winds and 3 meter seas.



Deepwater Expedition

Resultant watch circle was 0.1 percent of water depth. operating on LBL acoustics in 2777 meters of water with moderate weather conditions. Watch circle ranges a mere 1-2 meters.

Vessel	Type	Status	Deepwater DP Enhanced
Deepwater Navigator	RS925 Dual LBL/SBL	Waiting Installation	No
Deepwater Expedition	RS925 Dual LBL/SBL	Operational – Brazil	Yes
Glomar CR Luigs	RS925Dual LBL/SBL	Completing Trials	Yes
Glomar Jack Ryan	RS925 Dual LBL/SBL	Operational – GOM	Yes
Ocean Clipper	RS 925 Dual LBL/SBL	Operational – Brazil	Yes
Deepwater Discovery	RS925Dual LBL/SBL	Completing Trials	Yes
Joides Resolution	RS925 Dual SBL	Operational Worldwide	Yes

Table – Vessels with RS925 and or DP Enhancement

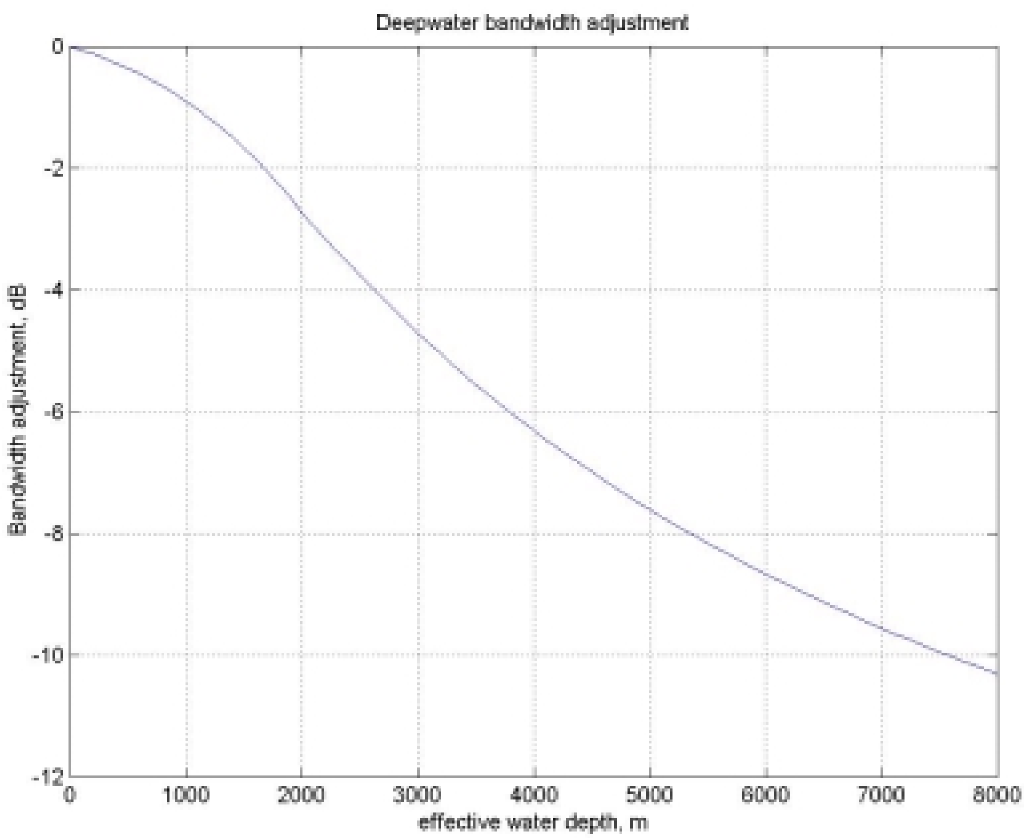


Figure – Bandwidth reduction with Water Depth

The graph shows the change in band width with water depth.

THE APPLICATION OF ADVANCED ACOUSTIC WAVEFORMS TO IMPROVE DP PERFORMANCE

Dynamically positioned drilling vessels operate in high acoustic noise environments; this environment is hostile to the performance of underwater acoustic positioning systems. In the past, in order to overcome this acoustic noise and to operate at extremes of depth, the output power of the acoustic positioning system beacons has been increased. There is however a practical limitation on the maximum power that can be transmitted from a transducer. Most existing systems utilizing conventional signaling technology are already operating close to this limit, at around 205 to 214dB depending on the design of the transducer.

The RS925 represents the next generation in acoustic tracking and positioning technology. The RS925, with its advanced Digital Spread Spectrum Acoustic Signaling Technology, accurately measures the position of the surface vessel from sub-sea acoustic beacons. The RS925 is designed specifically to meet the requirements of deep and ultra deepwater-drilling vessels that have to operate under the most difficult offshore conditions.

The RS925 utilizes advanced Digital Spread Spectrum signaling technology or ***"DSS***". This technology enables the system to accurately track up to eight sub sea acoustic beacons in water depths to 3500 meters (11,500 feet – 2.175 miles) to within 2.5 meters (8.2ft) accuracy, even under some of the noisiest acoustic conditions.

DIGITAL SPREAD SPECTRUM (DSS) SIGNAL TECHNOLOGY

The theory behind this technology is described in detail in The Use of Advanced Acoustic Waveform to Improve Positioning Systems – William R Garner – MTS DP Conference 1999. The basic principles used are:

- Instead of sending a single short 0.8ms high powered (198 dB plus) pulse through the sea water
- Send a longer (10ms), lower energy (196 dB plus), coded pulse.
- Spread the energy of the signal over a much wider spectrum by including up to 15 phase reversals in the signal.
- Code that signal with a series of phase flips according to a Pseudo Random Binary Sequence (PRBS), sometimes also known as an M series.

The principle is that the output of the beacon is modulated with a pseudo random sequence with 15 chips.

The major advantage of this technique is to increase the signal to noise ratio of the received signal. During reception, the spread signal is 'de spread'. In this process the signal energy across the bandwidth is re-combined coherently while the noise energy in the band sums non-coherently. This results in a processing gain of 12 dB in the ability to measure the time of arrival of the signal..

This technique has been developed for long distance underwater communication, where a message is sent at below the noise level of the surroundings. This technique has parallels in

Control Theory, where the impulse response of system can be obtained by correlating the output response with the PRBS coded signal injected at its input.

A simpler analogy is that it is akin to, one to hearing ones own name mentioned quietly across a noisy room of people talking. Your ears and brain manage to coherently pick out your name from all the noise.

The main advantages of this technique are as follows

- Improved Signal to noise ration (SNR) of the received signal without increasing the transmission level
- Improved Time of Arrival (TOA) estimation accuracy, and therefore more accurate vessel position estimation.
- By using these long coded pulses they can be easily differentiated from other similar waveforms at a similar frequency. This means that in areas were available frequencies for DP is sparse e.g. offshore Brazil.

In Long Base Line (LBL), because of the improvement in TOA estimate, the beacons need a baseline grid of 1000m in 3500m-water depth, rather than the more usual 3500m in this water depth for conventional LBL. This significantly reduces problems caused by ray bending of the signal due to the profile of sound velocity in deepwater.

SEA TRIALS RESULTS OF THE RS925

The system has been subjected to a number of sea trials – the results of which are presented in the remainder of this paper.

RS925 - First Sea Trial - Installation Onboard Offshore Supply Vessel

This was an in-house 'development' test and trial program to exercise the system and verify its capabilities to the greatest extent possible, prior to a first-of-class installation.

Trials Objectives

The objectives of the sea trials were:

- To test the reliability of the transmission from a sub sea beacon in deep water to the surface.
- To test the reliability of interrogation signals from surface hydrophones to sub sea beacons.
- To test the reliability of data telemetry from the beacon to the surface, and surface to the beacon.
- To confirm the integrity of the implementation of the tracking algorithms.

Installation and Deployment

The system was deployed onboard a chartered 72m offshore supply vessel (OSV) with dual DP capability. Four hydrophones were deployed on temporary over-the-side poles mounted on swivels from the deck. Three hydrophones were receive-only and one was an interrogator/receiver. 16m in a forward/aft axis and 17m-port/starboard axes separated the hydrophones.

The installation (on an OSV) is not considered representative of a typical RS925 system installation. The hydrophone mounts, although adequate for the test purposes, did allow some movement, and therefore some positioning discrepancy would be encountered especially in rough weather conditions.

External interfacing included surface positioning that was provided by a contracted DGPS service, a gyrocompass, a high accuracy commercial pitch and roll sensor, and a dual DP system.

Location and Conditions

Over a three-day period in June 1999, trials were conducted approximately 70 nautical miles west of Freemantle, Western Australia in 3,200 meters (10,500 feet). The location is in an area of practically unlimited fetch to the west and is subject to heavy seas and swell.

During the trial period, conditions ranged from Beaufort Force 4 on day one, to Force 6 and 7 on the subsequent days, with one three-hourly period having an average wind speed of over 40 knots with correspondingly high seas and swells.

Poor conditions prevailed throughout the trials (averaging Force 7 by day three). These conditions ensured both high levels of thruster activity (and resulting noise) to maintain station, together with extreme ranges of pitch (-4.4 to +3.6 degrees) and roll (-12.2 to +11.7 degrees).

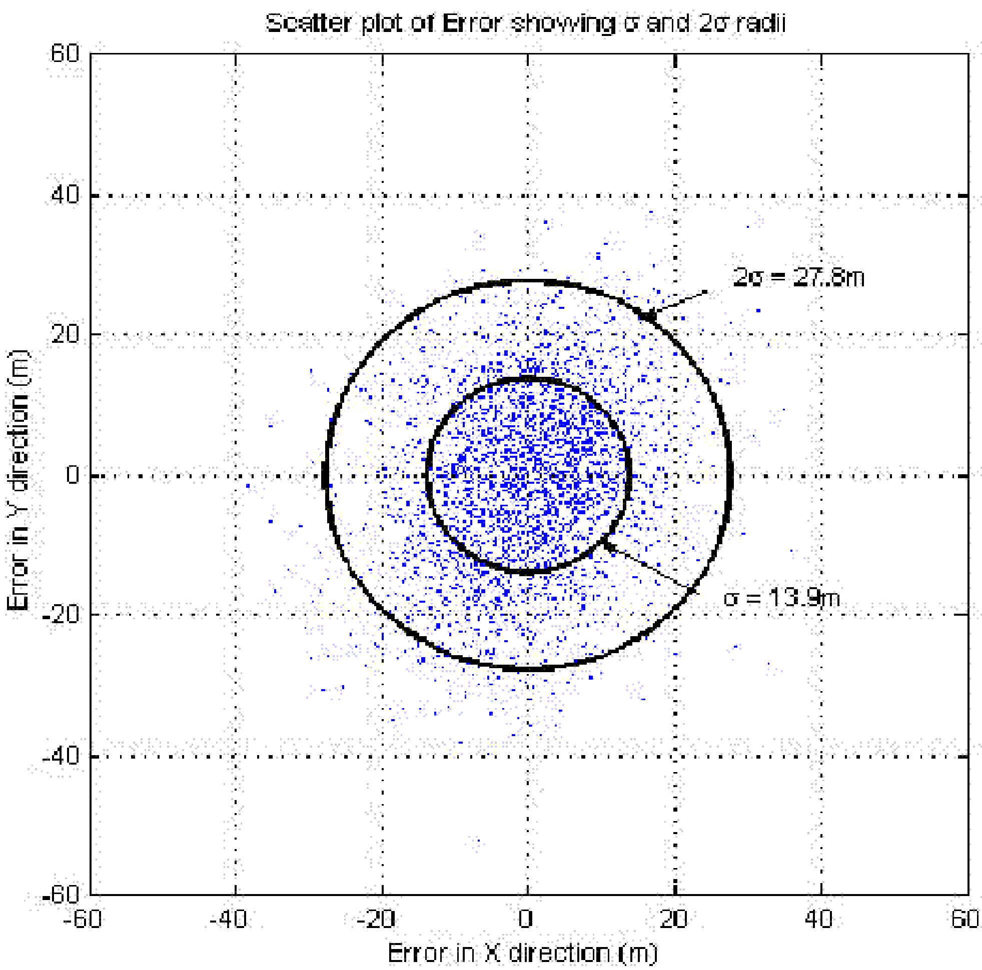
Results

As this vessel had no ROV capabilities and also due to the conditions, only one standard positioning Maxi Beacon (fitted with clump weight and a buoyancy collar to maintain vertical orientation) was deployed from the vessel. Consequently only the Short Baseline mode of operation was tested. Typically the accuracy for position measurement systems for DP needs to be within a radius of 1% of water depth. In this trial situation, this would equate to 32 meters. In the extreme conditions of this trial, the RS925 system accurately and consistently tracked the

Return to Session Directory ➤

beacon and maintained vessel position to within a radius of 13.9 meters (1 sigma) and 27.8 m (2 sigma).

Figure , Sea Trial 1 - Position Scatter Plot in 3200 m



The beacon was also interrogated from the surface and responded with parameters including beacon power output levels, battery voltage levels and acoustic release mechanism status, thereby successfully demonstrating the ability to telemeter data from the beacon to the hydrophones utilising the spread spectrum signaling technique.

Conclusions

- The transmission of signals from the sub sea beacon in 3200m of water was reliable and without interruption.
- The reliability of interrogation signals from the surface to the subsea beacon was proved to be robust as a reply was received for every interrogation.
- The reliability of the telemetry data was proved without any corruption.
- The integrity of the tracking algorithms proved to be consistent and reliable.

Return to Session Directory ►

RS925 - Second Sea Trial - Installation Onboard

A trial for the RS925 system was performed onboard the Drill ship "Deepwater Expedition" owned and operated by RB Falcon Corp. This trial was conducted prior to Customer acceptance.

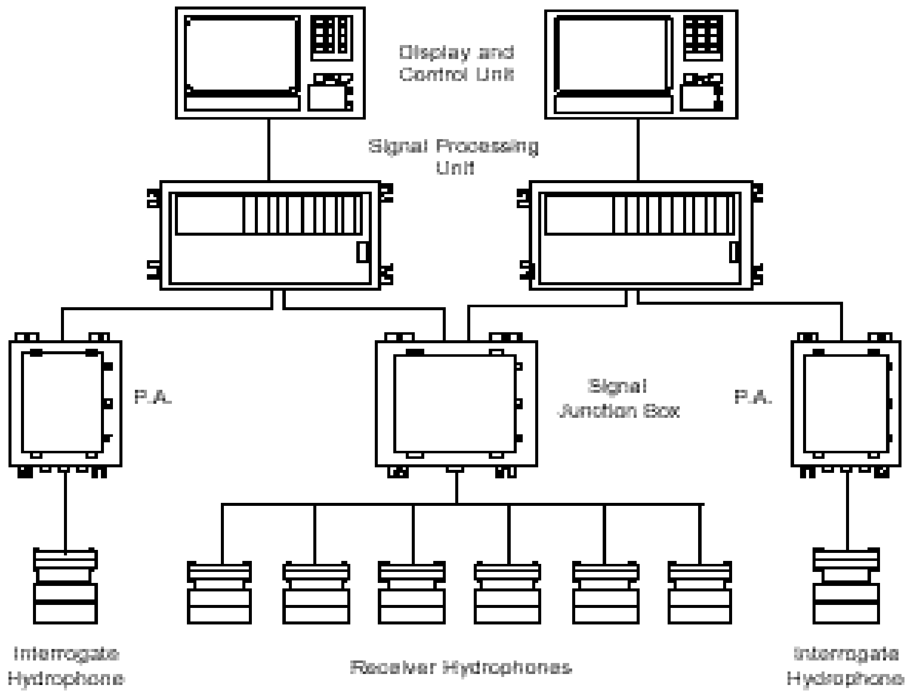


Figure 9. System Architecture

Trials Objectives

- To obtain customer acceptance of the RS925 system
- To prove the accuracy of the system in Short Base Line mode.
- To prove the system in shallower water operations.
- To prove the noise immunity of the spread spectrum signaling technology.

Installation

In July 1999, a dual redundant RS925 was installed on board the 170-meter drill ship "Deepwater Expedition". The vessel has six azimuthing thrusters to hold position during drilling operations. The Acoustic Positioning Reference System configuration included four receiver hydrophones and two transmit/receiver hydrophones. This installation was representative of typical RS925 operation for deepwater operations as envisaged by Nautronix. External interfacing included Differential GPS, a Gyrocompass, a high specification three-axis motion sensor, and a triple redundant Dynamic Positioning System.

Return to Session Directory ➤

Location and Conditions

These commissioning trials were carried out in benign conditions in the South China Sea, in a water depth of 580 metres.

Results

One Maxi Beacon with floatation collar and clump weight was deployed for the commissioning trials. Time constraints, beyond Nautronix's control, precluded laying an LBL grid to enable testing of the Long Base Line operation. A box-in calibration was completed utilising Short Base Line only. The stability of the acoustics is shown in the following figure.

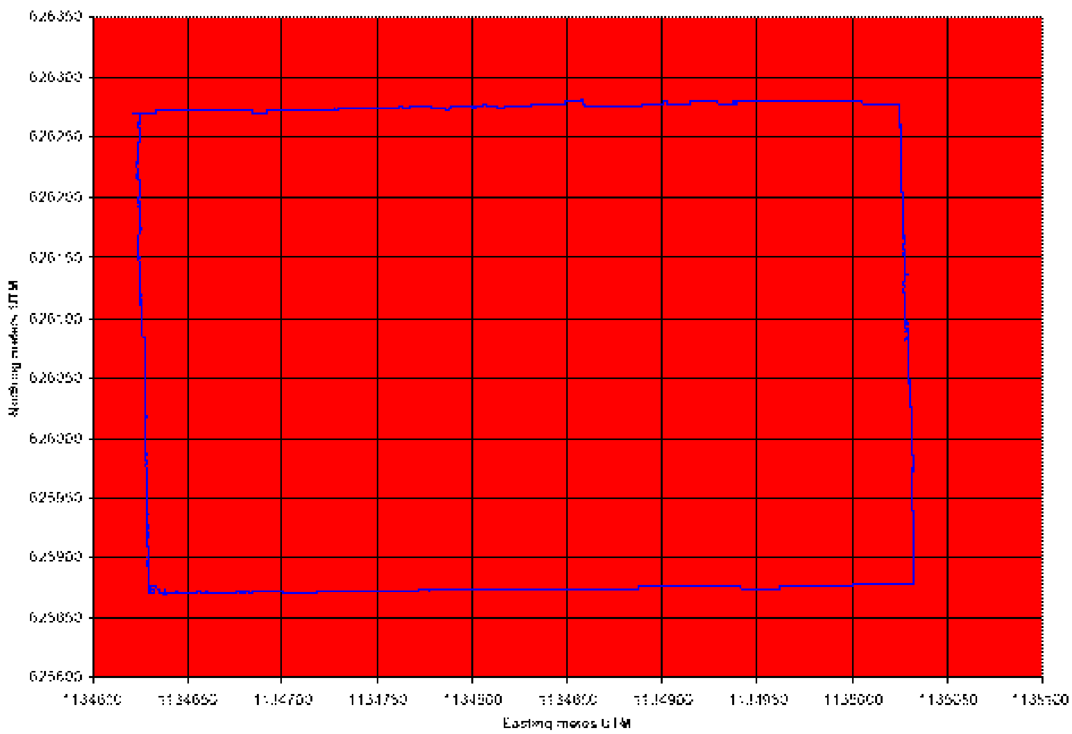


Figure , Sea Trial 2 – Acoustic Beacon Position during Box-In-Calibration

Position data was logged following the box-in calibration and the results are shown in the following scatter plot, which indicates an accuracy of 0.6m or 0.1% of water depth (1 sigma level). This is within the specification quoted of 0.15% of slant range for SBL mode (which equates to 0.87 meters in this example).

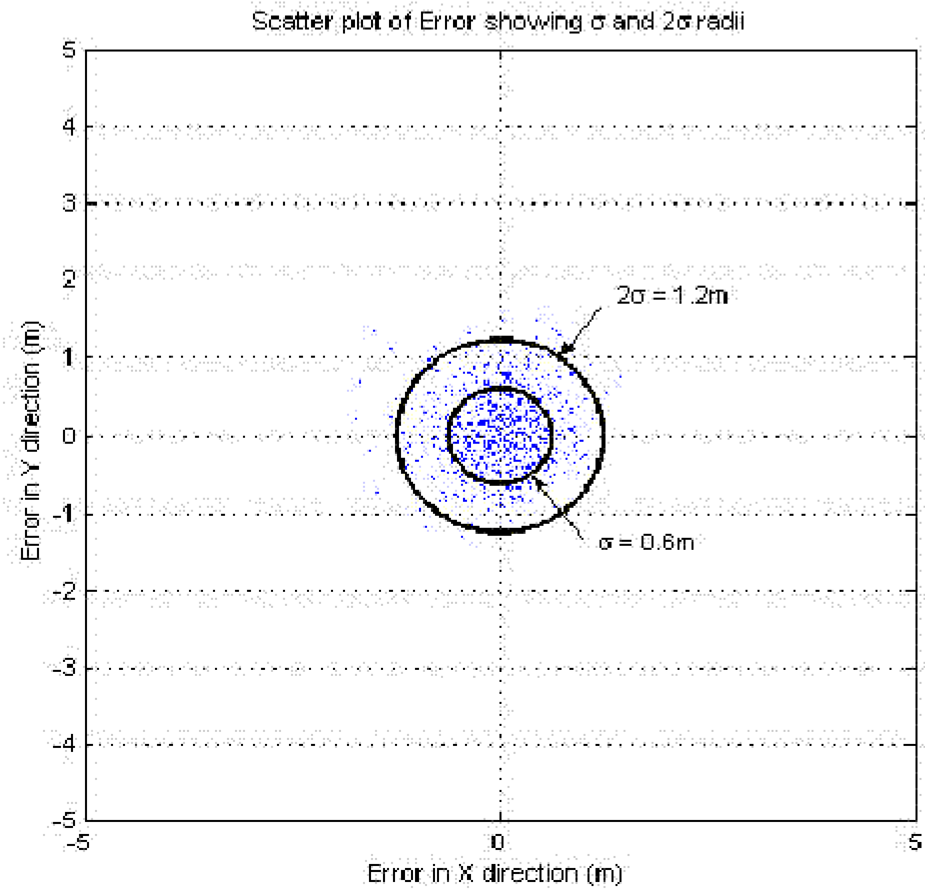


Figure Sea Trial 2 – Position Error in 580 m

Additional Trials

Following positioning trials, a thruster noise interference trial was conducted where different thrusters were vectored towards the hydrophones receiving the positioning signals from the sub sea beacon. No drop out of signals was experienced during this test and no alarms occurred from the either the acoustic system or dynamic positioning system. At the end of the allotted trials period, the acoustic release was commanded and the Maxi Beacon was recovered without problems.

Conclusions

- The customer accepted the system based on **outstanding** performance.
- The system met positioning specification and proved to be an excellent reference sensor for the Dynamic Positioning system.
- The system performed perfectly in the shallower water depth of 580m.
- When thrusters were directed on the hydrophones, and while the vessel was being moved utilising maximum thrust, no drop out of the signals was experienced.

RS925 - Third Sea Trial – "DEEPWATER EXPEDITION"

A trial for the RS925 system was performed to prove the abilities of the system in Long Base Line (LBL) mode, Short Base Line mode, combined Short and Long Base Line (LSBL) mode, and all other system features.

Trials Objectives

- To obtain customer acceptance of the RS925 system in Long Base Line mode.
- To prove again the accuracy of the system in Short Base Line mode in a different water depth.
- To verify all other telemetry functions.
- To prove the noise immunity of the spread spectrum signaling technology in different environmental conditions.

Installation

This trial took place during the month of September 1999. It consisted of a full set of trials exercising the entire system capability of Short Base Line and Long Base Line as well as telemetry functions. The configuration of the system was exactly the same as during the second sea trials, utilizing DGPS, a Gyrocompass, a high specification three-axis motion reference sensor and a triple redundant Nautronix ASK5003 Dynamic Positioning system.

Location and Conditions

The location was offshore Brazil with the following conditions - 35 knot wind on the beam with about one and a half meter wave height. The water depth was 2860 (9380ft) meters.

Results

Four Maxi Beacons with flotation collars and clump weights were deployed in a rectangular grid, approximately 500m apart for the LBL trials. A box-in calibration was completed utilizing SBL and LBL modes of operation. The stability, reliability, and repeatability of the acoustic system are shown in the following figure.

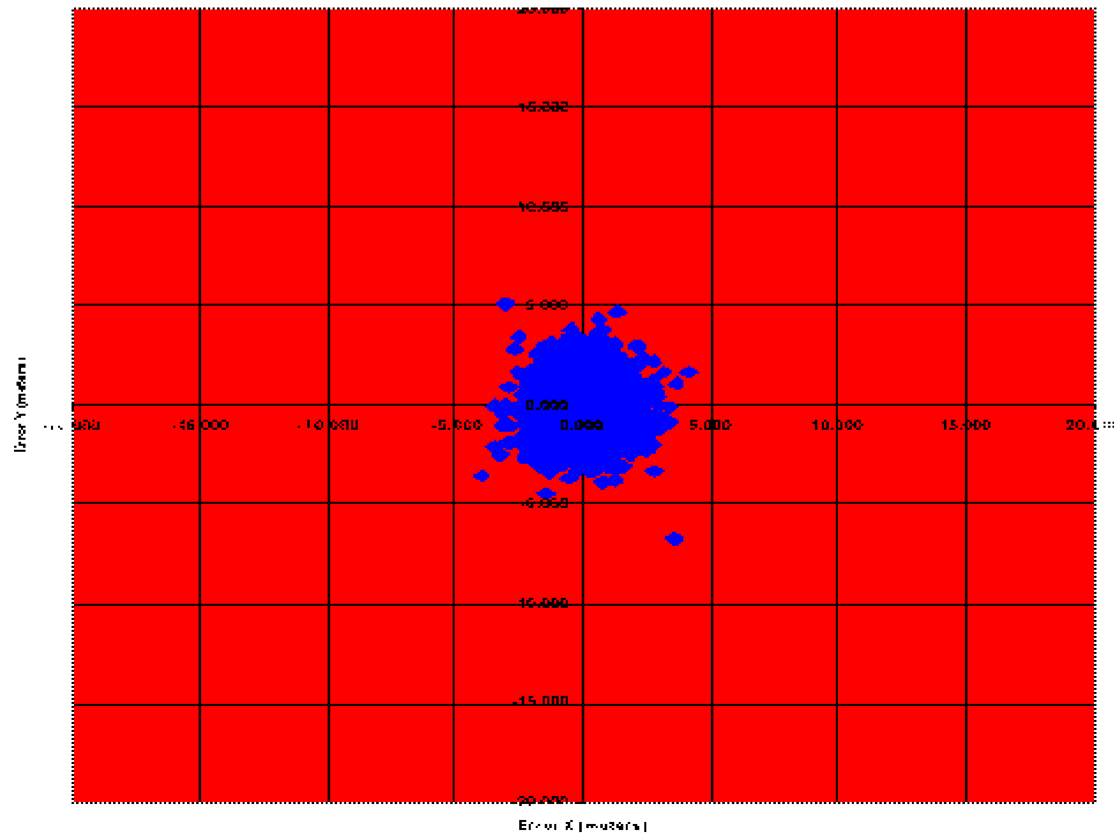


Figure Sea Trial 3 – Acoustic Beacon Position during Box-In-Calibration

Position data was logged following the box-in calibration and the results, shown in the scatter plot, indicate an accuracy of 1.7M RMS or 0.059% of water depth (1 sigma level), which is within the quoted system accuracy for SBL/LBL mode.

Petrobras and R & B The system passed all tests conducted over the of two day period. Falcon accepted the RS925 system after completion of the SBL and LBL testing offshore Brazil. In LBL mode the system was utilized in the minimum configuration of one interrogate hydrophone and three transponders and in SBL mode one beacon and three hydrophones. The vessel held in a **5m radius in SBL mode and within 2m in LBL mode.** Further testing was completed during a period of sunspot activity causing interference to the DGPS where the RS925 was the only position reference sensor available. No signal dropouts were experienced. A high-speed spin (30 degrees per minute) was completed using a single LBL solution as the DP reference. Again the system performed without signal dropouts or loss of position accuracy.

RS925 Additional Sea Trials

Riser Profiling

The riser profiling functions were tested as follows:

- One riser-profiling beacon was positioned half way down the riser with the capability of transmitting XZ and YZ Tilt, and current speed and direction.
- One riser angle beacon was positioned above the flex joint to measure XZ and YZ tilt from the vertical.
- Both beacons when interrogated provided realistic information both on tilt and current speed and direction.
- Petrobras and R&B Falcon both accepted the features of tilt, and current speed and direction.

Drillship "Joides Resolution"

The *"Joides Resolution"* recently had an RS925 SBL system installed. This is a scientific research vessel primarily used for core sampling. Most of the work is of relatively short duration. During the last two weeks of 1999 and the first two weeks of 2000 the vessel drilled 23 holes at 13 sites ranging in water depths between 4300m (14100ft) and 5700m (18,700ft) in the Antarctic. As the only position sensor used for the DP system is a single beacon in SBL mode, with no DGPS was available, no comparison is available to prove the accuracy of the RS925 system. However the very experienced DP operators were most impressed with the position keeping using the new RS925 system. At 5700M water depth they claimed the position holding was better than the their previous system at 1600M. Before the "Joides Resolution" departed for the Antarctic to perform the above work, the following data was obtained from the sea trials offshore Australia.

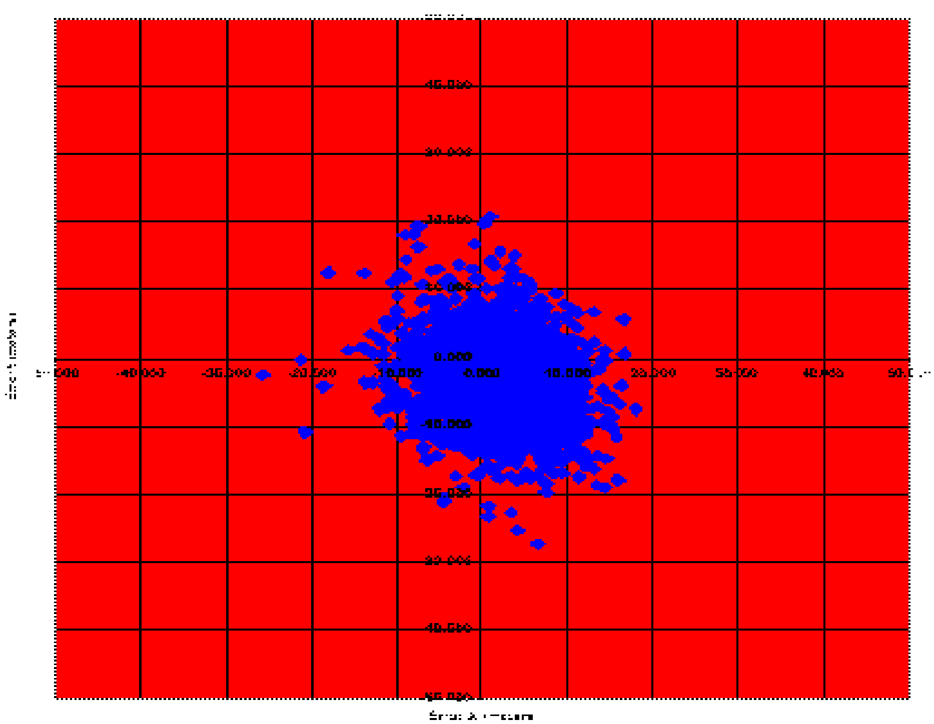


Figure , Sea Trial 2 –Position Error at 5300 m

The above scatter plot was taken in 5300M water depth and shows an average of 8.5M RMS. This represents an accuracy of 0.16% of the water depth.

CONCLUSIONS FROM ALL TRIALS

- Petrobras and R & B Falcon accepted the RS925 system in Short Baseline mode, Long baseline mode, and combined SBL/LBL mode.
- The system met the specified accuracy in 3500m water-depth in SBL mode. In 5830m the system accuracy was 0.01% of the water depth - better than the specified accuracy for 3500m.
- All telemetry functions were verified to be accurate.
- The spread spectrum technology did not appear to be affected in any way in the different environment conditions or by the different water depths. No dropout of signals was experienced throughout the trials.

REFERENCES:

1) The Use of Advanced Acoustic Waveforms to improve Positioning System – William R Garner – MTS DP Conference Houston 1999

2) RS925 – Acoustic Positioning System Sea Trials Report

ABOUT THE AUTHOR

Doug Phillips has an honours degree in Computer and Control Engineering and has worked with Dynamic Positioning for 26 years. The first 20 years with what is now Alstom designing, building and commissioning DP and anchor assist control systems. Initially as a project engineer, later as the manager of a team of project engineers and project managers. Then for 3 years in consultancy with Global Maritime performing FMEAs, trials etc on total DP systems on vessels with DP control systems from all suppliers including those from Simrad and ABB. During this time he also worked on DP Incidents and research for IMCA. For 3 years he was been the Vessel Controls Product Manager for Nautronix mainly involved with the development of the ASK5000 range. He has recently rejoined Global Maritime heading their DP effort in Houston.