C-PINS Inertial Metrology Method Statement

1 INERTIAL METROLOGY METHOD STATEMENT

Introduction

The purpose of this document is to provide technical details to CLIENT on the equipment and procedures required to complete an inertial metrology. CONTRACTOR has a proven track record over the last 10 years completing metrologies with a purely inertial sensor called C-PINS. The methods used have been refined to provide redundancy in quality control and be efficient as possible.

To date C-PINS has commercially delivered over 250 inertial metrologies worldwide;

West Africa - Angola, Congo, Nigeria, Ghana – on both rigs and survey vessels (currently have equipment in Angola and Ghana for current work scopes)

U.S. Gulf of Mexico - rigs and survey vessels (completed 12 remote metrologies)

North Sea from rig

Bahamas (42” dia. spool) shallow water barge with divers

Mexico divers in deep water (130m)

Sample Clients:

Total, Shell, Tullow, BHP Billiton, Statoil (Equinor), LLOG, Anadarko, Petrobras, Hess, Marubeni, PEMEX, Noble, TAQA, Oxy, Oceaneering, Subsea 7, Fugro, DOF Subsea, Ocean Installer, Harkand, Acergy, Jan de Nul, etc

Inertial Metrology Equipment

Two complete C-PINS systems (one system plus 100% spares), two complete sets of absolute depth equipment (one system plus 100% spares), and three sets of surface laptops equipment are proposed for the provision of these services:

IMU, TTU, internal Digiquartz, battery backup and all connections for external sensors.
External Paroscientific Digiquartz pressure transducer (Model 8CB XXXX-1)
Blanking plugs, interconnecting cable assemblies,
Various ROV lifting handles and adaptor plates

AML Minos.X Titanium (PDC-MNX-P1S2-10/60) or
SeaBird Seacat CTD data logging sensor (Model SBE 19plus V2)
Vaisala Barometer pressure transmitter (Model PTB210)
CONTRACTOR Tide software including relevant port and updated tide coefficients and import for any client provided tide data.

SSTT application (C-PINS surface software)
Aquanav navigation software, Geomatics Solution WX Geocalc with EPSG compliance, MS Office professional tools, Communications test applications, CONTRACTOR Tide software, Anti-virus software. DraftSight CAD license

Additional tools, consumables, PPE and support equipment

Tools including:

> Extensive tool kit, soldering iron, all tools required to interface and make up cabling to ROV, all tools required to make up ROV tooling and lifting hardware, cable molds, Dremel, spare connectors, serial connectors, gender changers, uninterruptable power supplies, power converters (110/220), external hard drives, etc.

Consumables including:

> Scotchcast potting compound, duct tape, tie wraps, hose clamps, heat shrink various size, electrical tape multi-color, grease, solder, rope, DB9 Female solder, DB9 male soldier, serial cable, Ethernet cable, subsea cable, etc.

Personal Protection Equipment (PPE) including:

> Gloves, earplugs, safety glasses, glass cleaner, hard hats, coveralls. All individuals will carry their own coveralls, hard hats, boots, gloves and glasses.

Real Time Quality Control

During the data acquisition we will be monitoring the quality of the individual data sets as they are collected and comparing them with other data within the specific data acquisition loops.

Heading, Pitch and Roll Quality Control

Built into SSTT (C-PINS surface software) we have heading, pitch and roll loop data comparison that automatically updates as the loops are completed. This software shows the SD of the data and the average as the solution. As quadrants are collected the software automatically rotates, within the software, the solution to plant north to show the combined structure North heading (True and Grid) as well as the pitch and roll of reference surface of the tooling. We can also deliver automatically the magnitude and direction of the "tilt" of the structure. All quadrant data will be provided to the client representative upon completion of the HPR data acquisition.

Position Loop Data Quality Control

As with the Heading, Pitch and Roll data the data collected during the position loops is processed in real time within our SSTT software and we have several quality checks on the screen that provide for confidence in the horizontal and vertical distance data include:

> A – B time out of zupt – we want this to be consistent and less than 4 minutes
> B – A time out of zupt – we want this to be consistent and less than 4 minutes
> Loop miss-closure – this should be less than 0.4m
> Spread of horizontal loop data – this should be less than 0.040m
> Spread of vertical loop data – this should be less than 0.040m
> Separately logged internal Digiquartz data for all of the position loops to check against the vertical inertial height difference data – difference between Inertial and Digiquartz height difference should be less than 0.020mm

If any of the above fall outside of our limits then we collect an additional loop – we need 6 good loops for distance measurements. All 3D position loop data and internal Digiquartz data will be provided to the client representative upon completion of the position loop data acquisition.

Equipment Installation

We usually set up a laptop in the ROV control room just for the duration of the survey, providing a separate screen (laptop) to the ROV pilot to allow for the navigation along the bathymetry route survey, or supplying a position string to the onboard navigation system (if on a MSV vessel with a survey spread).

The laptop will be connected to normal AC power and we will connect to a single serial port provided by the ROV crew where the C-PINS data is available at the surface. Separate from this location we will need a single space for the data processor to set up a laptop and printer to allow for data processing and CAD drawing.

Communications on the ROV to the surface:

The C-PINS system is a self-contained subsea data acquisition system that provides the power and communications channels for all of the instruments that we require to complete all measurements for a metrology. The C-PINS system requires a single communications channel from the ROV to the surface, RS232 38,400Baud (or greater)

Power on the ROV

The C-PINS system requires 24Vdc – 75W (3A 24Vdc power supply or greater)

Interface connector
A single connector is used to interface the C-PINS system to the ROV. CONTRACTOR has standardized on 21 Burton connectors for all C-PINS systems. The connector interface to the ROV will be ROV contractor specific. We require one serial channel and power. This is provided on 5 pins of the ROV provided connector:

RS232 Tx
RS232 Rx
RS232 Signal ground
Power +24Vdc
Power 0Vdc

If we are advised prior to the equipment arriving, we will supply the required connector/tails to mate to the ROV's survey port. If not, we expect the ROV contractor to provide the mating connector to the ROV bulkhead. We will supply all that is necessary to make this connector to our C-PINS cabling.

Back deck requirements:
To optimize the mobilization, we will store all components, consumables and interface tooling for the C-PINS system in a standard (client provided) 6ft mini container.

Detailed Metrology Method Statement

All metrology measurements will be completed through the use of our C-PINS inertial metrology system. This system interfaces to additional internal and external sensors for the data acquisition for the bathymetry route survey. The distance will be based on multiple position loops between hubs. The differential depth between the hubs will be determined in the same way, based on multiple position loops. The absolute heading will be determined by C-PINS. A CONTRACTOR supplied external Digiquartz sensor will be used in conjunction with C-PINS system for the bathymetry jumper route surveys. The external CDT instrument will be used for density measurements, and along with barometer we will deliver absolute depth information.

Inertial metrology can be split into the following operational stages:

Structure GVI, frame grabs to prove we are on the correct hubs/flanges
Tooling installation
Hub/receptacle cleaning
Alignment
Heading Pitch and Roll data acquisition
Position data acquisition
Bathymetry route survey (if required)

Preliminary work

Prior to stabbing the C-PINS system into the structures and proceeding with the metrology a simple GVI survey is completed to make sure we have fully identified the correct structure and hub/flange locations. We ask that a client representative confirm the locations based on the frame grabs collected. In some instances, clients require specific frame grabs of cutting piles, or spud disturbance during this phase. Once we have confirmed that we are at the correct locations any tooling will be installed and the receptacles for the metrology will be cleaned, a jetting tool on the ROV will blast these clean such that the tooling correctly seats into the metrology receptacle.

Alignment

All inertial systems need to be aligned after power is applied. The alignment process is more technically referred to as leveling, coarse gyro-compassing and fine alignment. In this proposal we will discuss this process as “alignment”.

During the process of alignment an inertial system (all enabled within the system software) uses the 3 axes of accelerometers to level the device, then the 3 axes of rate sensors (gyros) are used to find a coarse (low resolution) heading. Once the coarse alignment is completed the software automatically moves onto the fine alignment process. In fine alignment the system is optimizing all error states of bias and scale factors within the navigation software to provide very precise position and attitude data. The system will be rotated during alignment. The alignment will usually take about 45minutes – allowing some time for the rotations.

Heading Pitch and Roll data acquisition

Prior to collecting positioning data we use the collection of the heading, pitch and roll data (HPR) to train the ROV pilot and manipulator operator to maneuver the C-PINS system between the hubs, to define where they will hold onto the structures and where to lay out tether etc.. When we move to the positioning loops we want the ROV crew to move between well and manifold in an efficient manner.

During the alignment we will have collected the first data set of HPR data at Hub A. We then move to Hub B and continue to collect HPR data at each 90° quadrant

Hub B HPR data acquisition
2 minutes at +y – rotate the unit
2 minutes at +x – rotate the unit

2 minutes at -y – rotate the unit
2 minutes at -x – rotate the unit
2 minutes at +y – rotate the unit – close out the heading loop

Update position – recover the tool from the stab – move back to Hub A and repeat the data collection sequence shown above. This process is repeated so that we have two complete sets of data at each hub that are quality controlled in real time and deliver the Hub attitude data within the required tolerance stated in the scope of work. The same data will be collected at the receptacle at the WFB in this instance.

At this point the HPR data has been collected. This process is practically achieved in about 60 minutes. This time allows for the “normal” issues like manipulator operator not being familiar with stabbing the device, etc. If multiple headings are to be collected on the same face of a manifold then the amount of rotations may be reduced from the listing above. This will reduce the amount of time taken.

Position data acquisition

At this time the ROV pilot and manipulator operator have become familiar with maneuvering the C-PINS tool between the two hubs (this is when we usually suffer a shift change). They know how to hold the unit, how to recover from the stab and how to attach the ROV to structure for best access. We start the positioning loops at the original alignment position – Hub A. The positioning loops procedure:

Loop1 Hub A Positioning data acquisition
4 minutes at +y in zupt (zero velocity update)
Update position – recover the tool from the stab – move to Hub B
Stab into Hub B – wait 3 minutes in zupt – rotate to +y orientation
Hub 2 Position data acquisition
3 minutes at +y in zupt
Recover the tool from the stab – move to Hub A
Stab into Hub A – wait 3 minutes in zupt – rotate to +y orientation
3 minutes at +y in zupt
Log position data

The above sequence is repeated at least 5 times with real time QC being monitored to ensure that the required accuracy is being delivered. At this point all of the Position data has been collected. This process will practically take about 90 minutes.

Bathymetry route survey

At this time the C-PINS tool is held in the ROV 5 function manipulator or stabbed into a ROV mounted receiver. All ROV based offsets from this receiver to the bathymetry bracket will have been measured and logged. For the bathymetry route survey we will have pre-loaded a DXF or similar of the proposed jumper route into our navigation software (Aquanav). We prefer to step the jumper route using the external Digiquartz as this gives the ROV crew much more control over where the bathymetry data is collected. During all of the previous data acquisition the surface barometer data is being logged in CONTRACTOR data logging (with precise time stamp) Barometers. The internal Digiquartz pressure transducer has been logged to give us very accurate delta depths used as a quality control of the inertial differential depth data for the hubs. The Seabird or AML CTD has been tripped to the seabed to allow us to derive the appropriate density through the water column. We will also use tide data to offset all depths to absolute depth (LAT or any Operator required reference). We can use client provided tide, or tide tables based on British Admiralty Simplified Harmonic Prediction Method.

We start the bathymetry route survey - At Hub A Update position, log data at Hub A, recover C-PINS, place into 5 function or ROV receiver.

We collect differential hub height data with the external Digiquartz (Hub A, Hub B, Hub A – close). This sequence is repeated three times.
We then collect the step heights – from our receptacle reference to the appropriate location on the seabed under the Hub. (Hub, Seabed, Hub – close) this is repeated 3 times at each hub.
We then collect the bathymetry along the seabed by stepping the Digiquartz at client specified distances along the proposed jumper/spool route. During this time barometer data is logged and time tagged to the bathymetry data.

At this point the bathymetry route survey is complete.

Recovery of equipment

When the metrology operations have been completed, any seabed installed tooling will be recovered from the seabed.

Deliverables

Survey Task Plan and Risk Assessment

Once a detailed scope of work has been provided we will complete a first draft of the Survey Procedures/Task Plan for client to review and comment.

A specific Remote Metrology Risk Assessment will also be prepared and provided for review and comment at this time.

Data processing – QC data deliverable

Real time and post processing of all positioning, heading, pitch and roll data will be carried out either onboard or within the control room for remote operations. Within 24 hours of the completion of data acquisition all positioning data will have been checked and processed, all heading pitch and roll data will have been checked and processed. QC data as discussed earlier in this proposal will be supplied to the client representative for separate processing and review.

The C-PINS system has three different data storage file formats:

Raw data (true raw rate and acceleration data as well as raw sensor data and pressure from the Digiquartz) is stored within the subsea unit on compact flash (CF). This data is recovered once the system is back on the surface. The complete job can be re-processed (including alignment etc.) with this raw data. The CF capability has enough memory for apx. 64 hours of continuous survey operations.

All subsea processed data is sent to the surface/onshore and stored in a *.DAT file – this is 5Hz position, heading, pitch and roll data. The “fix” data needed to process the metrology job is also stored at the surface and this file is referred to as the Oplog (operational log) file. This is a much smaller data file that contains only the data needed to process the metrology solution. All Oplog data, CTD data and bathymetry data will be provided within a spreadsheet format to the client representative during the QC of the survey.

Field Metrology Report (ODEL)

The primary deliverable on the job site at the completion of each metrology measurement sequence will be a separate offshore deliverable (ODEL) field metrology report with full records of all data collected. This will be delivered to the client representative for approval. The results will be provided within the CONTRACTOR's normal offshore deliverable format. If any specific ODEL format is required, this can be provided with a clear definition from CLIENT. The ODEL is delivered within 24hours of the end of data collection.

This report will include all data as defined in the scope of work. Any client required format can be delivered:

- The structure identification, the revision number and the date
- The summary of results as detailed below
- The seabed profile between the connection points
- The measured values, computations and the processed data.

The ODEL will also contain an AutoCAD (client to define the version required) file for the bathymetry survey, showing a plan and bathymetry view of the planned jumper route.

Final Report

A Final Report will be issued to CLIENT not more than 15 days after completion of the metrology survey. This report will include:

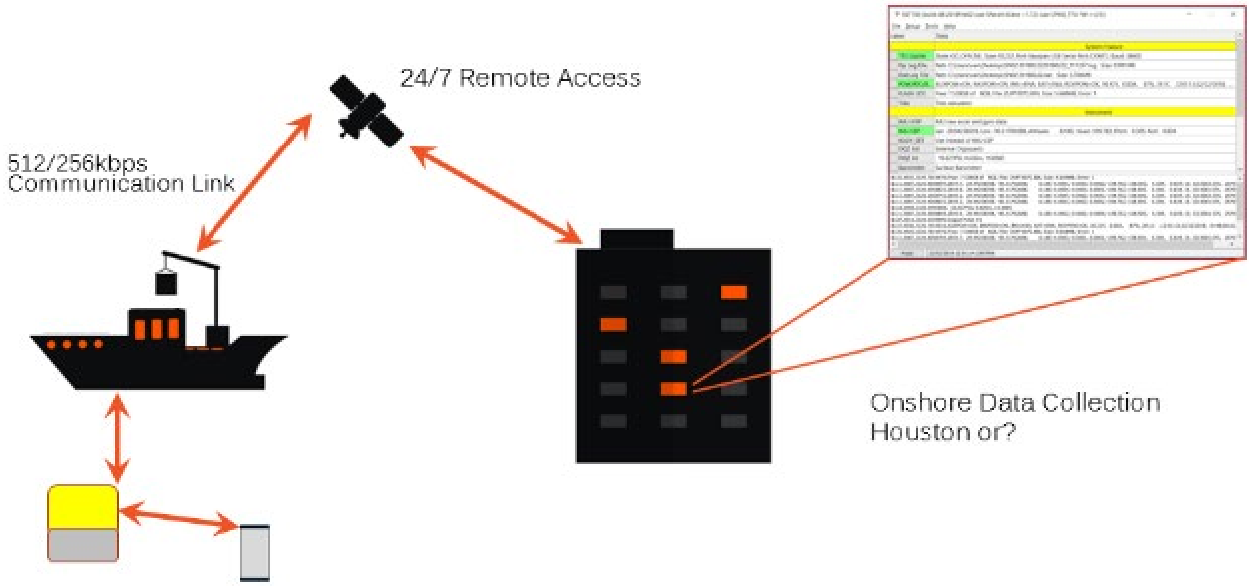
- Introduction/Scope of work
- List of personnel involved along with a list of equipment and software used.
- Reference to the Task Plan revision used – inclusion of this task plan containing the survey offsets and geodesy used.
- The structure identification, with revision number and date.
- Raw and Final Positioning data.
- Orientation of the structures (with reference mentioned).
- Operational summary, including brief discussion on timing of the project and specifically the metrology
- Metrology survey data
- Daily Operational Logs
- Calibration certificates
- The ODEL as an appendix
- All drawings including and tooling offset drawings etc.

2 REMOTE METROLOGY

CONTRACTOR has delivered a total of 12 remote metrologies to date.

In simple terms, all that we are doing to provide remote metrology services is to connect ROV video, serial data communications and voice (phone line) from offshore to onshore. The survey equipment is the same, the data acquisition software we use is the same, the survey team just sit at a conference table in Houston (or anywhere else globally) instead of sitting in the ROV control van offshore.

For fully "remote" operations we support the onshore data collection with a Party Chief and a single Inertial Surveyor at the control center for all operations. We would normally have no CONTRACTOR survey personnel offshore for fully remote services.



The equipment required is a small rack of equipment to provide the connection between offshore/onshore. This rack mount system contains all of the connectivity to allow the serial, video and voice to be connected to a single IP connection port (switch) in the ROV room or wherever the appropriate Ethernet connection port is made available on the vessel. The rack mount system contains:

Tunneling level 3 router to connect to the Satellite modem

Moxa NPort Serial to ethernet server (M5410 or M5210A) for C-PINS connection

H.265 Video encoding device for the video connection

IP Phone with headset

Uninterruptable Power Supply (UPS) with managed power distribution outlets (IP enabled)

The rack mount system is connected to vessel's power and the ethernet is connected to the appropriate switched port on the vessel. The serial connection from the C-PINS system on the ROV is connected to the Moxa N Port device (serial to Ethernet server), the video feed from the ROV will be connected to the video encoding device and the IP phone/headset will be placed next to the ROV pilot's work location. The remote rack is connected to a vessel-based IP system through the bandwidth providers managed switch.

What bandwidth do we need?

Note we specifically keep the conversation below to bits per second (bps) to try to not confuse megabytes per second MB/s (~10 times Mbps) with megabits per second Mbps.

As a minimum 512,000 bits per second (bps) is the short answer. This includes very decimated compressed video, the serial channel to our instrument and maybe a voice channel (VOIP).

Satellite communications are not that different than ROV mux communications. We need a specific amount of bandwidth up and down. Because of the cost of satellite bandwidth, the provision of satellite bandwidth services is very configurable (or confusing). If you need to just send information (perhaps video) from the vessel to onshore you need 512,000 bits per second (bps) "traffic coming from the vessel". If we are just sending simple commands like we send to C-PINS on the ROV from onshore to offshore we only perhaps need 128,000 bps "traffic going to the vessel". In the satellite business this connection is defined as a 512/128Kbps connection.

If we want to be sure that we have this bandwidth available to us (like quality of service in a network connection – QoS) we then define to the satellite bandwidth provider that this is a "Committed Information Rate" (CIR) 512/128Kbps connection.

Voice - IP Phone with headset (if needed)

In most cases we believe that we will be able to get a voice phone line into the ROV operational area and we may not need to deliver the voice channel through separate metrology specific bandwidth. It is our understanding that a single voice channel will need ~60,000 bps up and down using standard Codec's for encoding (G.726 56 Kbps Used in international trunk calls, G.728 32Kbps delivers toll voice quality for lower bandwidth). This is a bi-directional requirement.

C-PINS

38,400 bps serial comms via Moxa N Port Serial to ethernet server. This, with some overhead will need an additional 60,000 bps, but this is from offshore to onshore and from onshore to offshore we will need perhaps 20,000 bps capability for this serial comms capability.

Video - Compressed HD video – 1- or 2-seconds latency is not an issue

H.265 video encoding devices are readily available and deliver the best compression available for video. For a metrology survey we do not need high frame rate video with no latency, we need is to see what is happening subsea with C-PINS stabbed into the stab correctly and that the C-PINS system is located at the right heading and in the correct slot. We can work with lower frame rates of even 10fps. If we were watching a F1 race at 10fps we would be frustrated with the quality but watching C-PINS sitting in a receptacle does not need a high frame rate. Taking standard ROV HD video 1280×720 (HD) with 30fps encoded with H264 will require 3,000,000 bps. If encoded with H265 this should be cut by apx. 50% or 1,500,000 bps. When we drop the frame rate to 10fps this should be apx. 1,000,000 bps for H264 and 500,000 bps for H265. If we drop the frame rate by another third to a point where we start to see jitter between frames at 5fps this drops to 335,000 for H264 and 167,000 for H265.

This video bandwidth requirement is all from the vessel to the beach. We need nothing from the beach to the vessel – maybe just a very low IP config data rate (20,000bps).

Simple procedure for Remote Metrology

Equipment ships offshore. As soon as it arrives offshore ROV personnel check packing case count against manifest listing.

3 days prior to metrology:

ROV take all equipment to ROV deck and complete full system integration. When all is OK C-PINS is plugged in and tested. Then we have proven comms from the ROV to onshore. Equipment re-stowed

Day before metrology:

ROV personnel collect CTD profile, assemble C-PINS into lifting hardware and attach stab.

Metrology:

Bring system up – comms check to Houston – start collecting data

Post Metrology:

Equipment is demobilized and returned to CONTRACTOR in Houston at the convenience of the client. There is not a requirement to rush the metrology equipment off the vessel/rig to prevent additional equipment day rate fees

Inertial versus Acoustic Metrology

Between 2012-2017, CONTRACTOR was contracted to Total for the provisions of inertial metrologies in West Africa. Data from the five years of inertial metrologies were compiled and compared to five continuous years of acoustic metrologies in the same region to determine efficiency and repeatability of both metrology methodologies.

Total completed the comparison study independently and shared the results with CONTRACTOR. Results showed that CONTRACTOR's inertial metrologies, on average, were completed in under half of the vessel/spread time compared to acoustic metrology. Time comparison involved total vessel time taken for the metrology to be completed, including equipment deployment, calibration/alignment, data acquisition, etc. All times were taken from actual daily logs.