| PETROBRAS | TECHNICAL SPECIFICATION | Nº I-ET-3000.00-5529-850-PEK-006 | |
|---|---|---|---|
| | CLIENT | PETROBRAS | SHEET 1 of 28 |
| | JOB | RIGID RISER SYSTEMS | |
| | AREA | – | |
| SUB | TITLE | **RIGID RISER MONITORING SYSTEM (RRMS) – STAND-ALONE SOLUTION** | PUBLIC |
| | | | SUB/ES/EECE/ECE |

## REVISION INDEX

| REV. | DESCRIPTION AND/OR REVISED SHEETS |
|---|---|
| 0 | Original . |

| | REV. 0 | REV. A | REV. B | REV. C | REV. D | REV. E | REV. F | REV. G | REV. H |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 14/06/2021 | | | | | | | | |
| DESIGN | ECE | | | | | | | | |
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| CHECK | Y5UJ | | | | | | | | |
| APPROVAL | UR6A | | | | | | | | |

# TABLE OF CONTENTS

# 1 INTRODUCTION

This document presents the Technical Specification of the RISER CONTRACTOR scope of an integrity monitoring system applicable for rigid steel risers.

## 1.1 RISER SYSTEMS

This informative section presents an overview of the riser configurations covered by this monitoring system specification.

### 1.1.1 Steel Lazy Wave Riser (SLWR)

A Steel Lazy Wave Riser (SLWR) consists of a steel riser with an intermediary section lifted by buoyancy modules. An illustration is presented in Figure 1

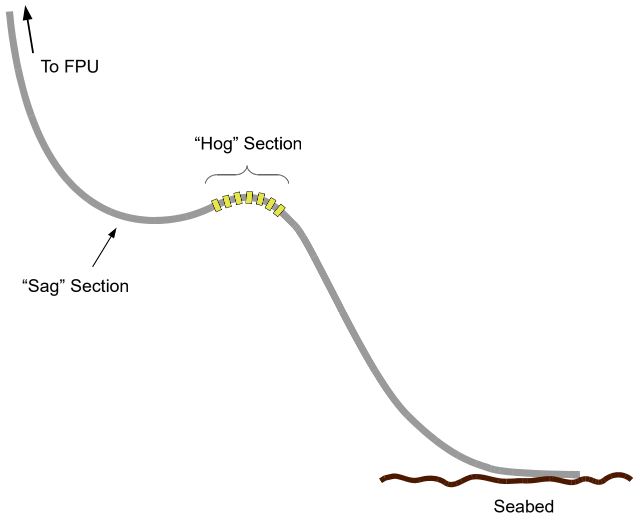


Figure 1 — SLWR illustration

### 1.1.2 Steel Catenary Riser (SCR)

A Steel Catenary Riser (SCR) is a steel riser that hangs from the FPU in a free single-catenary configuration. This concept is illustrated in Figure 2.

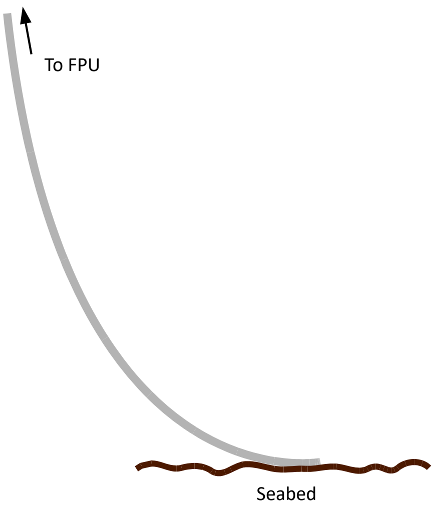


Figure 2 — SCR illustration

## 2 ABBREVIATION

| | |
|---|---|
| AC | Alternating Current |
| DC | Direct Current |
| EFL | Electrical Flying Lead |
| FAT | Factory Acceptance Test |
| FO | Fiber Optic |
| FPSO | Floating Production, Storage and Offloading |
| FPU | Floating Production Unit |
| GPS | Global Positioning System |
| IMU | Inertial Measurement Unit |
| I/O | Input/Output |
| IP | Ingress Protection |
| JB | Junction Box |
| PSU | Power Supply Unit |
| RDCT | ROV Data Communication Tool |
| RRMS | Rigid Riser Monitoring System |
| ROV | Remotely-Operated Vehicle |
| SCR | Steel Catenary Riser |
| SCU | Signal Conditioning Unit |
| SIT | System Integration Test |
| SDU | Subsea Data Unit |
| SLWR | Steel Lazy Wave Riser |
| TSP | Twisted Shielded Pair |
| USB | Universal Serial Bus |

## 3 REFERENCE DOCUMMENTS, CODES AND STANDARDS

This section lists standards and external documents applicable to the design of the monitoring system.

| | |
|---|---|
| API 17F | Standard for Subsea Production Control Systems |
| API 17Q | Recommended Practice on Subsea Equipment Qualification |
| API RP 17H | Remotely Operated Tools and Interfaces on Subsea Production Systems |
| ASME B16.5:2013 | Pipe Flanges and Flanged Fittings |
| ASTM A320:2015 | Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service |
| DNVGL-RP-B401:2017 | Cathodic Protection Design |
| IEC 60079 (latest revision) | Series Explosive Atmosphere Standards |
| IEC 60092 (latest revision) | Electrical installations in ships - ALL PARTS |
| IEC 60502-1 (latest revision) | Power cables with extruded insulation and their accessories for rated voltages from 1 kV ($U_m$ = 1,2 kV) up to 30 kV ($U_m$ = 36 kV) – Part 1: Cables for rated voltages of 1 kV ($U_m$ = 1,2 kV) and 3 kV ($U_m$ = 3,6 kV); |
| IEC 60529 (latest revision) | Degrees of Protection Provided by Enclosures (IP Code) |
| | |

| | |
|---|---|
| ISO 13628-6:2006 | Design and Operation of Subsea Production Systems – Subsea Production Systems |
| NMEA 0183 V 4.10 | Standard for Interfacing Marine Electronics Devices |

# 4 DEFINITIONS

| | |
|---|---|
| RISER CONTRACTOR | The company contracted by PETROBRAS to design, supply and install the risers, including the monitoring system (focus of this technical specification) |
| FPU CONTRACTOR | The company contracted by PETROBRAS to operate the Floating Production Unit |
| RSV TEAM | The party responsible for execution of ROV-related tasks, to be defined during the bidding phase. |
| OPERATIONAL CONTRACTOR | The company contracted by PETROBRAS to supply and process long time batch monitoring data (using data-loggers with batteries) |
| MAY | Is used when alternatives are equally acceptable |
| SHOULD | Is used when a provision is not mandatory, but is recommended as a good practice |
| SHALL | Is used when a provision is mandatory |
| WET-MATE [CONNECTOR] | Connector designed for plugging/mating in underwater environments |
| COVERAGE INTERVAL | Interval containing the set of true values of a measured quantity with a stated probability, based on the information available |
| COVERAGE PROBABILITY | Probability that the set of true values of a measured quantity is contained within a specified COVERAGE INTERVAL |

# 5 TECHNICAL CARACTERISTICS

## 5.1 DESIGN AND FABRICATION

**5.1.1** All subsea equipment shall be designed in accordance with API 17F and API 17H.

**5.1.2** Selection of materials for all subsea structures shall be in accordance with DNVGL-RP-B401:2017 item 5.5, and be designed for the same design life as the riser.

**5.1.3** All enclosures and equipment to be placed in hazardous areas shall comply and be certificated according IEC 60079 (latest revision).

**5.1.4** All enclosures with a required degree of ingress protection shall comply with IEC 60529 (latest revision).

**5.1.5** Electrical and communication analyses shall be performed, including simulations considering the parameters of specified cable types (for deck, hull and subsea cables).

## 5.2 QUALIFICATION

**5.2.1** All subsea equipment shall be qualified in accordance with API 17Q or ISO 13628-6:2006.

# 6 TECHNICAL REQUIREMENTS

## 6.1 GENERAL REQUIREMENTS

**6.1.1** Design life of the subsea components shall be the same of the riser, unless otherwise specified.

**6.1.2** The purpose of rigid riser monitoring is to assess fatigue life consumption due to cyclic loading. The main operational case of the system will be using data-loggers in order to acquire long period of data for onshore data analysis.

**6.1.3** The data-loggers shall be a scope of supply and work from OPERATIONAL CONTRACTOR. However, RISER CONTRACTOR shall supply/install the basic infrastructure from subsea instrumentation of the risers.

**6.1.4** The Figure 3 presents an overview of riser topology scopes.

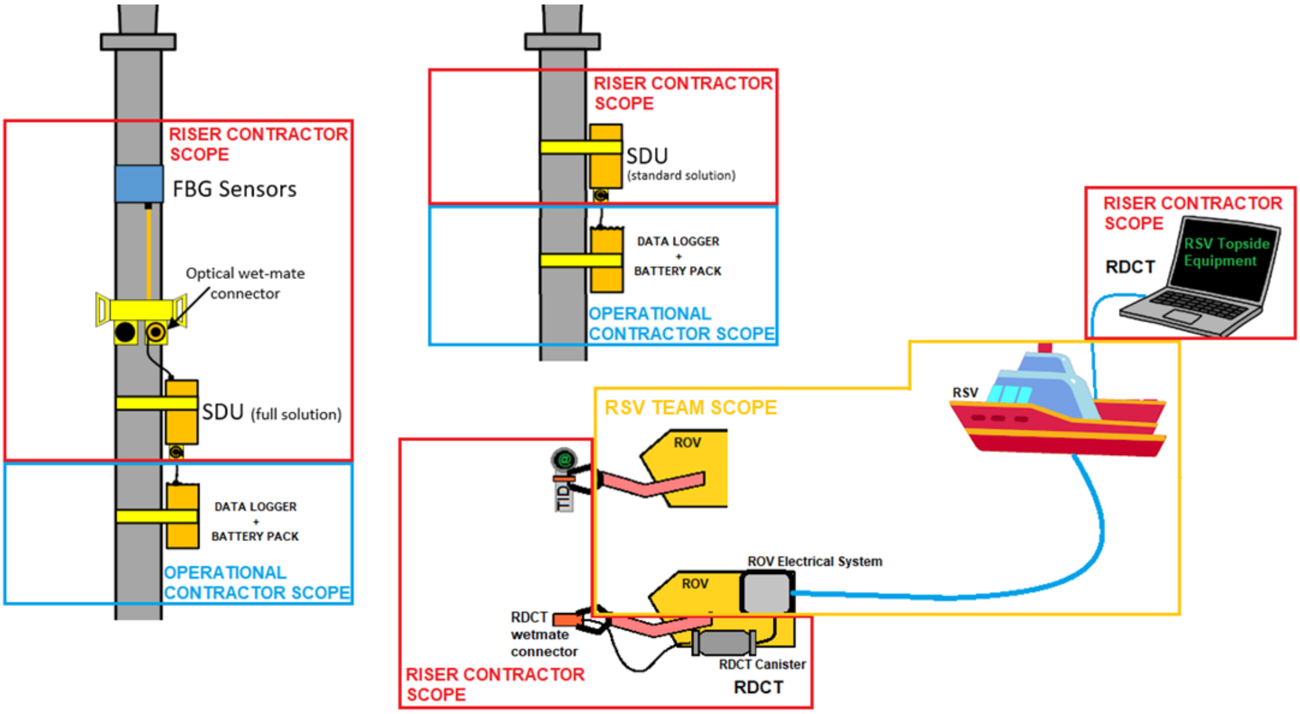


Figure 3 — Rigid riser connection scheme and scopes

**6.1.5** RISER CONTRACTOR shall provide ROV accessibility facilities (like resident grab bars and ROV retrievable docking clamp tool) for supporting ROV operation tasks in accordance with API RP 17H.

**6.1.6** Figure 4 presents RRMS general block diagram scope of RISER CONTRACTOR.

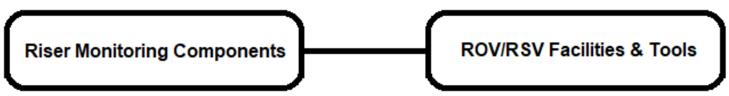


Figure 4 — General system block diagram

**6.1.7** The system is composed of two main blocks:

- Riser monitoring components;
- ROV/RSV facilities & tools.

## 6.2 RISER MONITORING COMPONENTS

**6.2.1** Riser monitoring components comprises all the riser monitoring subsea instrumentation and data interface. The technical details and requirements are specified at:

- SUBSEA DATA UNIT (section 6.3);
- TOP INCLINATION MEASUREMENT (section 6.4);
- TOP STRAIN MEASUREMENT (section 6.5).

## 6.3 SUBSEA DATA UNIT

**6.3.1** Subsea Data Unit (SDU) is the subsea module for acquiring rigid riser monitoring data. Subsea Data Unit (SDU) shall be designed for two solutions: standard SDU and full SDU.

**6.3.2** The standard SDU shall have the top inclination sensors (IMU and gyroscope and ROV interface connector.

**6.3.3** The full SDU shall have the top inclination sensors (IMU and gyroscope), strain measurement conditioning unit (SCU) and ROV interface connector.

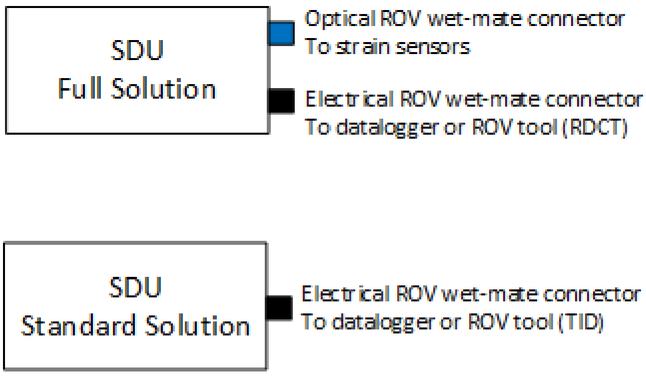


Figure 4 — SDU solutions

**6.3.4** Both SDU shall be designed in a subsea-proof enclosure rated for a minimum water depth of 100 meters or a higher depth if it goes through depths higher than 100m during pull-in installation. RISER CONTRACTOR shall evaluate the possibility for the SDU modules to be installed before the pull-in activities.

**6.3.5** Both SDU shall be designed with ROV clamp solution (complete set weight shall not exceed 70 kg in water) in order to be compatible with installation by ROV manipulator without the need of buoyancy modules.

**6.3.6** The ROV clamp solution shall be designed/supplied to firmly attach each SDU to the top part of the riser.

**6.3.7** For the full SDU solution, RISER CONTRACTOR shall design the SDU solution with a minimum 4-way APC ROV optical wet mate connector to collect the FBG sensors signals (main and redundant) from top strain measurement unit.

**6.3.8** For the full SDU solution, the optical wet-mate connector shall conform to the following requirements: be ROV-operated; be suitable for operation in the foreseen environment; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years. At the SDU ROV clamp solution, it shall be supplied a parking place for the optical wet mate connector.

**6.3.9** The full SDU solution optical connector pinout solution shall be designed according to Table 1.

| Connector pin | Name | Intended Function |
|---|---|---|
| #01 | MAIN LOOP A | Main FBG sensors array (strain/temperature) – branch A |
| #02 | MAIN LOOP A | Main FBG sensors array (strain/temperature) – branch B |
| #03 | REDT LOOP A | Redundant FBG sensors array (strain/temperature) – branch A |
| #04 | REDT LOOP B | Redundant FBG sensors array (strain/temperature) – branch B |

Table 1 — Optical connector pinout table

**6.3.10** RISER CONTRACTOR shall design both SDU solution with a 12-way ROV wet mate electrical connector interface.

**6.3.11** The electric wet-mate connector shall conform to the following requirements: be ROV-operated; be suitable for operation in the foreseen environment; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years. At the SDU ROV clamp solution, it shall be supplied a parking place for the electric wet mate connector and a protective dummy connector.

**6.3.12** The full SDU solution electrical connector pinout solution shall be designed according to Table 2.

| Connector pin | Name | Intended Function |
|---|---|---|
| #01 | GND | Common ground for power supplies |
| #02 | IMU PS | 24 VDC for IMU |
| #03 | GYRO PS | 24 VDC for gyro |
| #04 | STR PS | 24 VDC for top stain measurement internal modules (FBG Interrogator/ DSL Modem / OSC) |
| #05 | IMU D+ | IMU RS485 Data (+) |
| #06 | IMU D- | IMU RS485 Data (-) |
| #07 | GYRO D+ | Gyro RS485 Data (+) |
| #08 | GYRO D- | Gyro RS485 Data (-) |
| #09 | DSL D+ | DSL modem Data (+) |
| #10 | DSL D- | DSL modem Data (-) |
| #11 | OPT D+ | OSC RS485 Data (+) |
| #12 | OPT D- | OSC RS485 Data (-) |

Table 2 — Full SDU ROV interface connector pinout table

**6.3.13** The standard SDU solution electrical connector pinout solution shall be designed according to Table 3.

| Connector pin | Name | Intended Function |
|---|---|---|
| #01 | GND | Common ground for power supplies |
| #02 | IMU PS | 24 VDC for IMU |
| #03 | GYRO PS | 24 VDC for gyro |
| #04 | NC | --- |
| #05 | IMU D+ | IMU RS485 Data (+) |
| #06 | IMU D- | IMU RS485 Data (-) |
| #07 | GYRO D+ | Gyro RS485 Data (+) |
| #08 | GYRO D- | Gyro RS485 Data (-) |
| #09 | NC | --- |
| #10 | NC | --- |
| #11 | NC | --- |
| #12 | NC | --- |

Table 3 — Standard SDU ROV interface connector pinout table

**6.3.14** RISER CONTRACTOR shall not provide customized internal hardware in all SDU solutions. All components chosen (IMU, gyroscope, DSL and FBG interrogator) shall be equipment available off-the-shelf by three manufacturer at least.

## 6.4 TOP INCLINATION MEASUREMENT

**6.4.1** Instantaneous roll and pitch at the top of each rigid riser shall be monitored by an inertial measurement unit (IMU)

**6.4.2** The inclination signals shall be filtered by the IMU to reject vibration-induced high-frequency variations. The filtering scheme implemented by the IMU shall be presented for PETROBRAS approval.

**Note:** the filtering shall be performed by the IMU itself, since it is not possible to perform it as a later processing step (e.g. in the remote acquisition system) due to the low data acquisition frequency.

**6.4.3** Since measured angles depend on the alignment of the inertial unit with respect to the riser, measurements shall be transformed to a known reference system according to Annex A: *Rigid Riser Top Angles Calculation.*

**6.4.4** IMU maximum permissible errors, for 95% coverage probability, shall be ± 0.05° for roll and pitch.

**6.4.5** The IMU shall reside inside the SDU.

**6.4.6** The IMU attached to each rigid riser shall communicate with the RDCT by means of RS-485 link.

**6.4.7** The SDU canister shall also provide a tri-axial Gyroscope in order to measure the heading (angle accuracy of 0.1°) and calculate the misalignment of IMU as described on Annex A: *Rigid Riser Top Angles Calculation*. The gyro communication shall also observe item 6.3.11.

**6.4.8** The IMU and Gyroscope shall be powered with 24 VDC.

**6.4.9** The IMU and Gyroscope communication to RDCT shall be:

- Serial RS-485 format;
- NMEA-0183 protocol;
- Using two of twisted pairs available by RDCT jumper (see table 1).

**6.4.10** RISER CONTRACTOR shall inform the data format (string) used in all kind of communication from IMU and Gyroscope modules.

## 6.5 TOP STRAIN MEASUREMENT

**6.5.1** Axial tension and bending moments acting at the top of rigid risers selected by PETROBRAS shall be monitored.

**6.5.2** In order to assess these variables, strain and temperature sensors shall be installed below the riser flexible joint (or stress joint), in a section of pipe devoid of coating.

**6.5.3** Strain and temperature sensors shall be optical fiber Bragg grating (FBG) type. Each set of sensors (see item 6.5.4) shall be connected in series in a fiber optical loop and all sensors sets shall be aligned according to the positions. Each strain-monitored riser shall have two sensor sets (main and redundant).

**6.5.4** Each sensor set shall have:

- Sixteen (16) FBG sensors, installed around the riser section in two layers (hoop and longitudinal), equally spaced at 45° from each other, to measure hoop and longitudinal stresses at each point around the riser pipe.
- Four (4) body FBG temperature sensors at the strain monitoring location, equally spaced at 90° from each other, to be used for correction of thermal expansion effects.

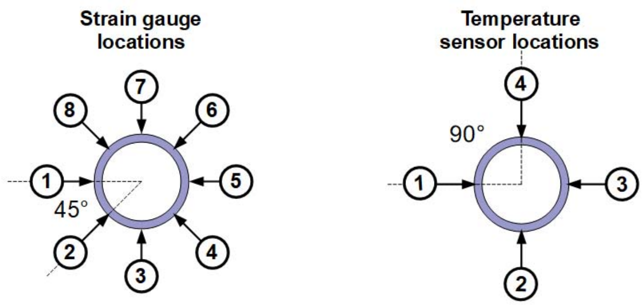


Figure 4 — Illustration of sensor positioning around rigid riser (cross-section view from top)

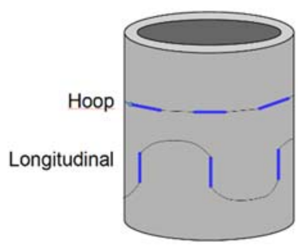


Figure 5 — Schematic view of strain sensing around riser pipe (only active sensors shown)

**6.5.5** All sensors shall be positioned on the external surface of the pipe, i.e. they shall not be intrusive to the riser. Moreover, sensors shall not be installed externally to the thermal insulation layer/coating.

**6.5.6** The FBG strain sensor attachment method and the coating strategy at pup piece shall be subjected to PETROBRAS approval.

**6.5.7** The selected attachment method, including all its components, shall be resistant to the temperature range foreseen in steady state conditions.

**6.5.8** The riser pipe surface shall undergo preparation in an adequate environment to receive the sensors (e. g. surface cleaning and removal of any contaminants).

**6.5.9** The temperature and strain sensors in each set shall be numbered starting from index #1 and increasing in the counter-clockwise direction, looking from above, as depicted in Figure 7.

**6.5.10** The maximum permissible error in temperature measurement, for 95% coverage probability, shall be of ± 0.2 °C.

**6.5.11** Temperature compensation in strain sensors readings shall be implemented for all sensors, in order to eliminate the effects of the thermal expansion of the pipe itself.

**6.5.12** The sensors attached to the riser shall be covered by a protective layer that prevent contact with water and other environmental conditions, and protect pipe section structure (i.e. corrosion) for the riser’s design life. Additionally, mechanical protection shall be provided in order to avoid FBG sensors damage during installation and pipe handling.

**6.5.13** The steel pup piece coating shall observe requirements at technical specifications:

- I-ET-0000.00-0000-210-P9U-001 - PIPELINE FIELD JOINT COATING AND FIELD REPAIR OF LINEPIPE COATING
- I-ET-0000.00-0000-431-P9U-001 - WET THERMAL INSULATION FOR FLOWLINES AND RISERS
- I-ET-0000.00-0000-250-P9U-002 - MINIMUM REQUIREMENTS FOR BUOYANCY MODULES FOR FLOWLINES AND SLWRS.

**6.5.14** The FBG sensors shall be connected to a signal conditioning unit using a subsea optical jumper, which shall collect FBG data (strain and temperature) by a FBG Interrogator and communicate to RDCT.

**6.5.15** The signal conditioning unit shall reside inside the SDU full solution. At the subsea optical jumper, it shall be supplied a ROV interface panel with an optical wet mate connector.

**6.5.16** Strain and temperature sensors shall not be designed for recoverability.

**6.5.17** The FBG interrogator, installed at SDU shall have the following minimum requirements:

- Swept wavelength laser scan frequency: 10 Hz or better (per channel simultaneously);
- Wavelength range: from 1460 to 1620 nm or wider including this range;
- Optical channels: 4 channels (for main loop branches A/B and redundant loop branches A/B);
- Wavelength accuracy: 2 pm or better;
- Wavelength repeatability: 1 pm or better;
- Dynamic range (peak): 21 dB or better;
- Full spectrum measurement;
- Peak detection functionality (at hardware firmware);

- SC/APC or LC/APC Optical Connectors;
- Ethernet Port;
- Sensing Analysis Software;

**6.5.18** The connection between FBG sensors and full SDU shall be made by optical jumper. In these jumpers, on both sides, shall be used optical wet-mate connectors (see figure 8)

**6.5.19** The full SDU shall have an Optical Switches Controller (OSC) to control (physically open the input) the optical channels inputs in order to make guarantee double redundancies for the FBG sensors arrays (in terms of main/redundant loops and branches A/B).

**6.5.20** The OSC communication to RDCT shall be RS-485 half-duplex (2-wire).

**6.5.21** The SCU shall communicate with the ROV over Ethernet protocol, supported by DSL modems (in both sides – full SDU/RDCT).

**6.5.22** If FBG Interrogator may have the internal functionality to remote control the optical channels over Ethernet protocol (equivalent to OSC functions), OSC shall be removed and the pins #11/ #12 shall be replaced as DSL modem redundant communication channel (Data +/-).

**6.5.23** The signal condition unit, OSC and DSL modem shall be powered with 24VDC.

## 6.6 ROV/RSV FACILITIES & TOOLS

**6.6.1** ROV/RSV facilities & tools comprises all the offshore hardware to gather and process riser monitoring data. The technical details and requirements are specified at:

- SUBSEA ROV FACILITIES (section 6.7);
- TOP INCLINATION DISPLAY - TID (section 6.8);
- ROV DATA COMMUNICATION TOOL - RDCT (section 6.9).

**6.6.2** TID and RDCT shall be supplied with two main functions:

- To commission the subsea sensors from SDU;
- To collect instantaneous data with ROV while data-loggers will not be installed.

## 6.7 SUBSEA ROV FACILITIES

**6.7.1** Subsea ROV facilities comprises all subsea infrastructure that supports ROV maneuvers at riser installation/commissioning/operation of RRMS. The main components are:

- ROV interface panels;
- ROV docking clamp tool;
- Flying-lead deployment frame.

**6.7.2** All ROV interface panels from RRMS shall have at least one resident grab bar. All wet-mate connector bulkheads from panels shall have a visual ID tag and a corresponding parking places. It shall also be supplied dummy connectors for ROV flying lead operations.

**6.7.3** RISER CONTRACTOR shall design/supply a ROV docking clamp tool. This retrievable tool shall be used in any part of the riser body in order to create a docking position (i.e. retrievable grab position) supporting any ROV operations offshore from RRMS.

**6.7.4** RISER CONTRACTOR shall design/supply a flying-lead deployment frame for support any flying lead operations (installation and/or uninstallation) applicable to the RRMS project. This tool shall be supplied with parking-places and all handling infrastructure for offshore installation (i.e. shackles, master links, slings etc) with the required tests/certifications.

## 6.8 TOP INCLINATION DISPLAY

**6.8.1** Top inclination display (TID) is a module for quick verification of the RAW inclination data (IMU and gyroscope) with a ROV camera visualization.

**6.8.2** TID shall be designed in a subsea-proof enclosure rated for a minimum water depth of 100 meters. TID shall be contained in a lightweight subsea enclosure, weighting up to 10 kg in water (without the addition of any buoyancy module). TID’s design shall not require a clamp module.

**6.8.3** TID shall be powered by internal rechargeable batteries allowing up to 4 hours of autonomous operation and supplying 24 VDC for top inclination sensors from SDU; no power or data connections to surface shall be necessary during ROV operations.

**6.8.4** TID shall have a ROV-mate connector matching the one at ROV interface clamp from SDU (section 6.3) in order to power and acquire top inclination sensors from SDU.

**6.8.5** TID shall have a dry-mate electrical connectors as needed for the following functions when brought back to surface:

- Unit configuration;
- Download of acquired data;
- Battery charging.

It shall not be necessary to disassemble the unit in order to perform these functions. The dry mate connectors shall be properly covered with protective caps during underwater deployment.

**6.8.6** TID’s weight, size and format shall be designed to be suitable and safe for ROV operation.

**6.8.7** TID shall be equipped with hoisting points (such as eye bolts) to allow it to be safely deployed and recovered from underwater work locations.

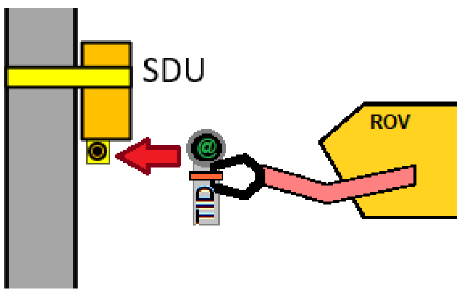


Figure 6 — TID general schematic

## 6.9 ROV DATA COMMUNICATION TOOL

**6.9.1** The ROV Data Communication Tool (RDCT) shall be responsible for commissioning for the monitoring system installed at the rigid riser and also be used to gather data during operational life of the riser.

**6.9.2** The ROV Data Communication Tool (RDCT) shall power supply and collect data from monitoring units by means of an appropriate subsea electrical jumper with the ROV system.

**6.9.3** The ROV Data Communication Tool (RDCT) shall comply the following items:

6.9.3.1 Subsea electrical jumper to connect a ROV interface connector;

6.9.3.2 RDCT canister;

6.9.3.3 Subsea electrical jumpers to connect RDCT canister and ROV electrical system;

6.9.3.4 RSV topside equipment.

**6.9.4** The ROV interface connector jumper (6.9.3.1) shall be terminated in a ROV-mate connector matching the one at ROV interface clamp. The other termination shall be designed with a dry mate connector compatible with the connector at the RDCT canister. The ROV interface connector jumper shall be 10 meters long.

**6.9.5** The RDCT canister (6.9.3.2) shall be in a subsea-proof enclosure rated for a minimum water depth of 300 meters and shall comply internally with the following items:

- One 24VDC (75W) power supply for monitoring system from the 127VAC supply from ROV system, beyond the possibility to use the ROV 24VDC (2.5A) power supply (including fuse protections);
- Internal serial communication channel for the RS485 (half-duplex) and also one serial converter RS485/RS232 in order to communicate with a ROV system that only has RS232 communication channel;
- One DSL modem for Ethernet protocol communication with the FBG interrogator and RSV topside equipment using the ROV Ethernet communication channel;
- Two visual indicators (i.e. LED indicators) for ROV camera to show the SDU powering status and working status related to data gathering;
- Local RAW data storage in order to collect data at the RSV topside in case of a failure at the ROV communication channels.

**6.9.6** The RDCT canister/ROV system jumpers (6.9.3.3) shall be supplied in two electrical cabling:

- Cable-A: ROV (24VDC/127VAC) power supplies and serial channels (RS232 / RS485);
- Cable-B: ROV redundant (24VDC/127VAC) power supplies and Ethernet communication channel.

**6.9.7** The RDCT canister/ROV system jumpers (6.9.3.3) shall be terminated in a dry-mate connectors compatible with the connectors at the RDCT canister and in the other ends shall be supplied in pigtails for the RSV team to terminate at the ROV electrical system. Both jumpers shall have 10 meters long each.

**6.9.8** RISER CONTRACTOR shall not provide customized hardware in RDCT canister. All components chosen shall be equipment available off-the-shelf by three manufacturer at least.

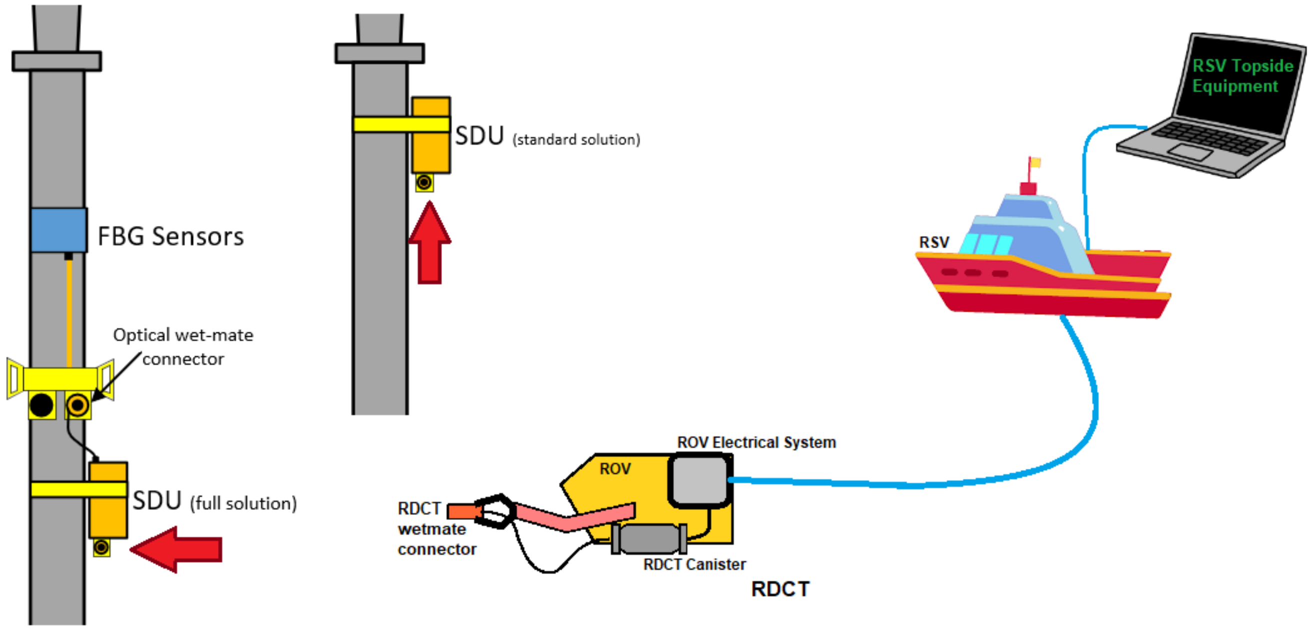


Figure 7 — RDCT general schematic

**6.9.9** The RSV topside equipment (6.9.3.4) shall communicate with the RDCT canister and act as an interface to human operators and external systems of the monitoring system (RSV positioning system).

**6.9.10** The RSV topside equipment (6.9.3.4) shall be responsible configuring and recharging battery from TID hardware and downloading and processing top inclination data acquired in TID internal memory.

**6.9.11** The RSV topside equipment (6.9.3.4) shall comply with an industrial notebook with Windows OS and all software for data acquisition, processing, visualization and exportation (CSV files). The data acquisition software shall be able to edit the mask of datagram received from each NMEA sensors (IMU and Gyroscope). This functionality allow communication with different models of IMU/Gyroscope in case of replacement after delivery of the system. All hardware accessories like cabling, power supplies and data protocol converters (RS232/RS485/USB) for the notebook shall be scope of supply.

## 6.10 SOFTWARE

**6.10.1** RISER CONTRACTOR shall provide a software in order to get and process all monitoring data from subsea sensors, applying calibration data.

**6.10.2** The use of a well-established integrated automation software solution able to provide all required functionalities is strongly advised. The software shall be designed to operate in three modes:

- ON-LINE MODE: real-time data gathering using RDCT link to RSV;
- BATCH MODE: get data downloading from TID or RDCT internal memories;
- MANUAL MODE: get data from standard tables (CSV or XLS files);

**6.10.3** Software shall be previously installed in laptop of RSV tool. RISER CONTRACTOR shall also provide 10 additional licenses to PETROBRAS to be installed at integrity subsea management office.

**6.10.4** The software installation shall not depend of RISER CONTRACTOR actuation.

**6.10.5** RISER CONTRACTOR shall provide with software the calibration data needed to process data from subsea sensors.

**6.10.6** Dedicated software dashboard screens shall report the value of every monitored variable as they are acquired, along with the status of communication channels and each monitoring unit, including the subsea power supplies status.

**6.10.7** The GPS UTC time provided by the RSV Positioning System shall be used as reference for the timestamps of all acquired data.

**6.10.8** Data shall be continuously retrieved from the instrumentation installed on risers. The sampling period shall be 1 second and a timeout event shall be understood as the unsuccessful retrieval of 3 consecutive samples.

**6.10.9** Angles measured by top inclination measurements unit (IMU) with gyroscope data shall be converted in accordance to Annex A: *Rigid Riser Top Angles Calculation*.

**6.10.10** Load and stress calculations for rigid risers should be implemented as described in Annex B: *Rigid Riser Stress Calculation Algorithm*. Other algorithms may be proposed and subjected to PETROBRAS approval.

**6.10.11** RISER CONTRACTOR shall design a software to receive monitoring data from all rigid risers that shall be connected to the RDCT or TID, and the user can set corresponding configuration data. The system shall be able to receive data from future rigid risers. The system shall permit to set at least the following parameters of each riser:

- Riser data (name, position, function, etc);
- Datagram map from IMU (NMEA);
- Datagram map from Gyroscope sensor (NMEA);
- Calibration parameters of FBG sensors;
- Source of FBG sensor data (FBG interrogator IP and port).

**6.10.12** A local database system for storage of generated data points shall be included. The database shall operate on a circular buffer pattern, whereby older records shall gradually be overwritten by newer samples once the database reaches its capacity

**6.10.13** The software shall allow for the querying and plotting of historical data for user-selectable intervals. Users shall be able to export data sets to files compatible with Microsoft Excel 2003 or newer.

**6.10.14** Two categories of password protected user accounts shall be implemented, common and privileged. Access to all functionalities of the supervisory shall be restricted exclusively to authenticated users belonging to one of these categories.

**6.10.15** Configuration duties, including the management of the various monitoring units and also of the user accounts themselves, shall be restricted to privileged users. All view-only functionalities shall be available to all authenticated users.

**6.10.16** It shall be possible to selectively disable, in the software screens, the acquisition of each individual strain pair (axial and hoop strain) of the riser top strain measurement.

**6.10.17** The software shall generate, display and log operation limits for monitored variables.

**6.10.18** Each limit shall be issued with a descriptive message that allows an operator to clearly identify the condition and its source (i.e. the structure, data tag and/or components involved).

**6.10.19** The software shall provide the infrastructure to manage and configure safe limits and to enable/disable each limit individually. A limit shall remain active until it is explicitly acknowledged by an operator.

**6.10.20** "Range"-type safe limits shall be implemented with configurable LL/L/H/HH limits for the monitored variable value.

**6.10.21** All safe limits should include some form of hysteresis mechanism in order to avoid excessive interruption event generation when the monitored value is near limit thresholds.

**6.10.22** Limits shall also be issued for monitoring system failure conditions (housekeeping), including loss of communications to any component and detection of faulty sensors.

**6.10.23** Limits shall be classified in the following severity levels:

- **High:**
  - LL/HH (low-low/high-high) range.
  - Loss or degradation of monitoring system functionality, or conditions which may imminently lead to that. Example: loss of communications with a component/sensor (timeout).
- **Medium:**
  - L/H (low/high) range.
  - Conditions which do not cause degradation of monitoring system functionality but may lead to that if unchecked.
- **Low:**
  - Notifications of changes in system operating modes.
  - Any other implementer-defined conditions which do not present an immediate thread to integrity.

**6.10.24** Detailed design of the limit system shall be submitted for PETROBRAS approval prior to implementation.

**6.10.25** All data (RAW and processed) shall be provided to external systems and users via CSV files.

**6.10.26** RISER CONTRACTOR shall inform, during the commissioning, all administrator passwords needed to operate and manage all equipment.

**6.10.27** All software shall be provided by RISER CONTRACTOR with its respective license without need of activation after the delivery. It means that Petrobras shall not depend on RISER CONTRACTOR (or its SUBSUPPLIER) to reinstall the software in future maintenances. All software license shall allow for future installation in at least 10 future different computers.

# 7 TESTS, COMMISSIONING REQUIREMENTS AND ASSISTED OPERATION

## 7.1 QUALIFICATION TESTING

**7.1.1** All subsea equipment shall be qualified in accordance with API 17F and API 17Q.

**7.1.2** Previously qualified equipment may be accepted by PETROBRAS if the provided qualification program has been witnessed/certified by an accredited independent party or by a PETROBRAS representative.

## 7.2 FACTORY ACCEPTANCE TESTING

**7.2.1** All subsea equipment (including deliverable spares) shall undergo factory acceptance testing in accordance with API 17F

**7.2.2** All sensors shall be calibrated. Calibration reports shall be presented to demonstrate performance requirements are met.

**7.2.3** All units shall undergo a full functional test. These tests shall demonstrate correct and stable long-term operation in all possible modes.

**7.2.4** Dimensional and electrical checks shall be performed on all units.

**7.2.5** Specific requirements are detailed in the next sections.

**7.2.6** For Strain Measurement Sensors (included redundancy), the load sensing system shall be calibrated for the specified performance in accordance with ASTM E74 (latest revision). Other standards or methodologies may be proposed and subjected to PETROBRAS approval.

## 7.3 SYSTEM INTEGRATION TESTING

**7.3.1** Integration tests shall be performed with the purpose of verifying interfaces between components and proper operation of the system as a whole.

**7.3.2** All mechanical, electrical, instrumentation and automation interfaces shall be functionally tested.

**7.3.3** All system operation modes (and combinations thereof, when multiple components are involved) shall be tested with the aim of ensuring proper long-term, stable operation.

**7.3.4** The system integration test shall be performed with the actual components of the system.

**7.3.5** Simulators may be used in place of the RSV GPS system and ROV umbilical lines. Simulators for cables and umbilical shall be RLC circuits.

**7.3.6** The proper operation of external data interfaces shall be attested with a connection to a test computer running client data acquisition software.

## 7.4 INSTALLATION AND COMMISSIONING REQUIREMENTS

**7.4.1** The requirements presented in this section shall be met regarding commissioning activities. Planning of installation and commissioning activities shall be developed and submitted for PETROBRAS approval.

**7.4.2** Commissioning is understood, in this context, as the process of placing the system (or parts thereof related to a particular monitored structure) in a fully functional state, without any pending issues.

**7.4.3** All equipment shall be tested onshore before deployment at sea. Testing and interventions on equipment shall not be planned or performed during offshore deployment (on deck), save for emergency occasions, in which case approval shall be explicitly given by PETROBRAS.

**7.4.4** The system shall be delivered with all configurable parameters (such as safe limits and calibration coefficients) preset to correspond to all the risers design data.

**7.4.5** RSV topside components shall be installed and commissioned prior to installation of any riser, in order to be ready to receive monitoring data as soon as it becomes available.

**7.4.6** The commissioning schedule of monitoring system shall be agreed with PETROBRAS. The base case to be considered is to perform commissioning of monitoring units for each riser shortly after its respective pull-in operation.

## 7.5 ROV INSTALATION

**7.5.1** The party responsible (RSV TEAM) for the ROV activities described herein shall be defined at project’s RRMS material requisition document.

**7.5.2** RSV TEAM shall execute ROV operations to install monitoring components (i.e. SDUs, clamps, interconnecting subsea cabling etc, supplied by the RISER CONTRACTOR), if needed, onto rigid risers supported directly to the FPU.

**7.5.3** RISER CONTRACTOR shall provide technical assistance offshore, with a technician with thorough knowledge of the ROV activities, for ROV operations for installation/commission of monitoring units onto rigid risers.

## 7.6 ASSISTED OPERATION

**7.6.1** Assisted operation offshore, with maximum duration of 15 days, shall occur after the last riser will be full commissioned (end of the installation campaign). The technician with thorough knowledge of the system shall be assigned to board one RSV from PETROBRAS fleet and support system operations and configurations for one monitored riser selected by PETROBRAS.

**7.6.2** Onshore, the technician in a maximum duration of 5 days, shall support PETROBRAS operation team to integrate the acquired data from offshore campaign with PETROBRAS database.

# 8 DOCUMENTATION REQUIREMENTS

**8.1.1** Documentation shall be issued in compliance with agreed standards and formal processes.

**8.1.2** All documentation delivered to PETROBRAS shall conform to the following standards:

- N-0381 – format and execution
- N-1710 – identification/coding

**8.1.3** Safe operation limits of monitored structures shall also be delivered to PETROBRAS in the form of a document.

**8.1.4** The RRMS documentation shall include at least the following:

- Design basis;
- Detailed design documentation covering, among others, equipment, software, cabling and general accessories;
- Mechanical drawings for all individually delivered assemblies;
- Datasheets, manuals and certificates for every equipment/instrument when applicable, covering operation, maintenance and installation guidelines;
- Calibration procedures, reports and certificates for every sensor;
- Equations and calibration curves used for converting raw sensor data (e.g. ADACs) into engineering values, along with all coefficients used in conversion, for all sensors;
- Detailed system arrangement, including but not limited to, electrical diagrams, cable layout and equipment interconnection diagrams;
- LAN diagram and Complete descriptions of all communication protocols used between equipment;
- Detailed definition and specification of the safe limits and alarm systems designed for the OPERATIONAL CONTRACTOR future integrity analysis;
- Complete OPC I/O list with all implemented tags;
- As-built drawings, when applicable;
- Detailed installation procedures;
- Detailed procedures for all installation/deployment operations to be performed by third parties, including ROV operations to be executed by the RSV TEAM;
- Detailed test and commissioning procedures and reports;
- System operation and maintenance manuals;
- Assisted operation reports;
- Training plan.

## 9 TRAINING REQUIREMENTS

**9.1.1** Training shall be provided to qualify personnel appointed by PETROBRAS to operate and maintain (install, dismantle, replace parts and make adjustments) each system component.

**9.1.2** Training shall be performed at PETROBRAS facilities in Rio de Janeiro, Brazil (on-shore). Training courses shall be given for two classes of 10 students (total of 20 students). The two classes shall be scheduled at least 1 month apart, to accommodate for PETROBRAS offshore labor regime. Training course shall be sized for 3 days as a minimum. Lessons shall be taught in Portuguese.

**9.1.3** The training program shall cover basic system operation and maintenance aspects. A detailed training program shall be submitted for PETROBRAS approval.

**9.1.4** The training program shall cover, at least, the following items:

- Complete description of equipment and system;
- Technical and operational characteristics;
- Operating principles;
- Operational cautions and warnings;
- Operational procedures and routines;
- Preventive maintenance routines;
- ROV operations (subsea equipment retrieval and installation);
- RSV Topside Software operation;
- Storage and conservation of spare equipment.

# 10 SCOPE OF SUPPLY & WORK

## 10.1 RISER CONTRACTOR

**10.1.1** Design, supply and install the RSV topside processing system as described in section 6.

**10.1.2** Execute fabrication, qualification, testing and calibration tasks in accordance with the requirements presented in section 7. Any required simulators shall also be provided by RISER CONTRACTOR.

**10.1.3** Execute installation and commissioning as described under section 7. RISER CONTRACTOR shall provide all tools, accessories and consumables required for these activities.

**10.1.4** Provide assisted operation as described under section 7.6.

**10.1.5** Provide documentation as described under section 8.

**10.1.6** Provide training as described under section 9.

**10.1.7** For each rigid riser: execute design, supply and installation scope of all components described in section 6 and associated components (clamps, interconnection jumpers) onto rigid risers.

**10.1.8** Design, supply and install the Subsea Cabling, as described in section 6.

**10.1.9** Provide assistance, with an offshore technician, for ROV operations for installation of monitoring units onto rigid risers as described in section 7.5.

**10.1.10** Supply the following spare units related to rigid risers:

- 2× SDU standard solution with clamps and dummy connectors;
- 1 x SDU full solution with clamp and dummy connectors;
- 1 x set of jumpers (optical and electrical) with dummy connectors at both terminations;
- 1 x optical dummy connector for FBG sensors (from ROV panel);
- 1 × RDCT spare kit;
- 1 x ROV docking clamp tool spare;
- 1 × TID spare;
- 1 x optical FBG array in a rugged enclosure for onshore testing SDU full solution;
- 1 x electrical test box for onshore testing SDU standard/full solution with RDCT kit.

**10.1.11** Spare units shall be identical to the items they replace and undergo the same fabrication, calibration and testing. Spares shall be supplied in packaging proper for long-term storage.

## 10.2 FPU CONTRACTOR

**10.2.1** Provide permission for RSV TEAM operations at rigid riser top part.

## 10.3 RSV TEAM

**10.3.1** RSV TEAM shall provide activities as described in section 7.5

## 10.4 OPERATIONAL CONTRACTOR

**10.4.1** Design, supply and process long-time batch monitoring data (using data-loggers with batteries).

# ANNEX A: RIGID RISER TOP ANGLES CALCULATION

A.1 Top inclination angles shall be reported in the order yaw-pitch-roll, that is, extrinsic rotations around axes $\boldsymbol{z}$, $\boldsymbol{y}$ and $\boldsymbol{x}$ in that order. For each riser, the reference frame shall be defined as follows (see Figure B1).

- The $z$ axis shall be normal to the horizontal plane, pointing upwards.
- The $y$ axis shall be normal to the plane of the riser catenary, parallel to the horizontal plane.
- The $x$ axis shall be contained in the plane of the riser catenary, parallel to the horizontal plane.
- The directions of axes $x$, $y$ and $z$, shall be chosen to satisfy *the right-hand rule*.

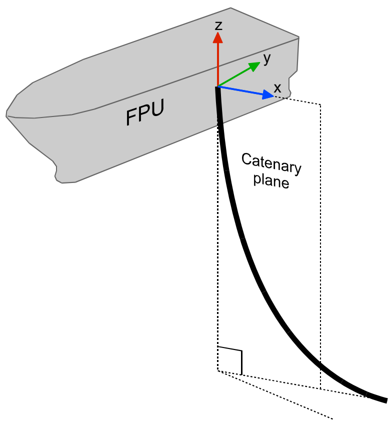


Figure B1 — Illustration of coordinate system for rigid riser top angle calculation

A.2 Corrections shall be carried out to compensate for the misalignment of the IMU around the riser (see Figure B2) so that pitch and roll angles are measured in the reference frame defined in A.1.

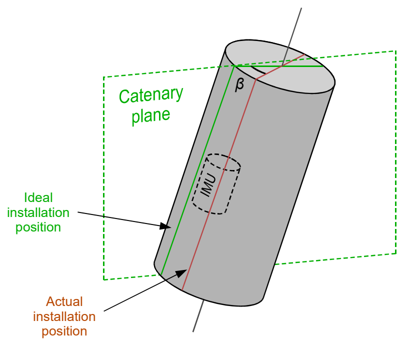


Figure B2 — Illustration of IMU misalignment with respect to rigid riser catenary plane

A.3 In order to measure the angle of misalignment ($\boldsymbol{\beta}$) for each IMU, the triaxial gyroscope heading data (item 6.3.9) shall be used to measure the clamp misalignment in relation to the riser catenary final azimuth.

A.4 All necessary calculations for angle corrections of inclination measurements from IMU, given the determined misalignment angle for each riser, shall be implemented in the RRMS topside software. RISER CONTRACTOR shall present the calculations used for angle corrections for PETROBRAS approval.

# ANNEX B: RIGID RISER STRESS CALCULATION ALGORITHM

This annex presents the desired algorithm and procedure for calculating strains, stresses and tensions on rigid risers.

## B.1 Requirements

B.1.1 All computations shall be performed with sufficient precision as needed to obtain the specified accuracy.

B.1.2 Output quantities shall be presented through the standardized OPC interface in the prescribed engineering units.

## B.2 Inputs

B.2.1 The algorithm takes the following input variables, which will generally be different for each riser:

- $\mathrm{N_{sens}}$: number of longitudinal and hoop strain sensors around riser pipe
- $\varepsilon_{\ell \mathrm{i}}$: longitudinal strain sensor $\mathrm{i}$ reading; $\mathrm{i} = 1{,}2, \ldots \mathrm{N_{sens}}$
- $\varepsilon_{\mathrm{hi}}$: hoop strain sensor $\mathrm{i}$ reading; $\mathrm{i} = 1{,}2, \ldots \mathrm{N_{sens}}$
- $\mathrm{D}$: pipe outer diameter
- $\mathrm{t}$: pipe wall thickness
- $\mathrm{T}$: pipe temperature
- $\mathrm{T_0}$: reference temperature at which pipe dimensions $(\mathrm{D}, \mathrm{t})$ are taken
- $\mathrm{E}$: material bulk modulus (material property)
- $\nu$: Poisson coefficient (material property)
- $\alpha$: thermal dilation coefficient (material property)

## B.3 Algorithm Steps

B.3.1 The algorithm steps are summarized next. The description given is for calculations to be performed for a single riser (whose index is denoted by *n*). Figures are merely illustrative.

1. Raw longitudinal strain readings ($\varepsilon_{\ell i,\mathrm{raw}}$) from each sensor around the riser pipe shall be acquired and properly converted using stored calibration data.

   The individual raw strain readings $\varepsilon_{\ell i,\mathrm{raw}}$ shall be output as data tags `RIG_n_LONG_STRAIN_i`.

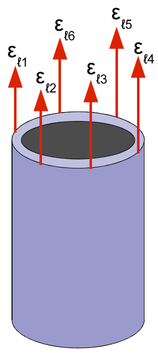


Figure B3 — Individual longitudinal strain measurements around riser pipe

2. Raw hoop strain readings ($\varepsilon_{hi,\mathrm{raw}}$) from each sensor (strain gauge) around the riser pipe shall be acquired and properly converted using stored calibration data.

   The individual raw strain readings $\varepsilon_{hi,\mathrm{raw}}$ shall be output as data tags `RIG_n_HOOP_STRAIN_i`.

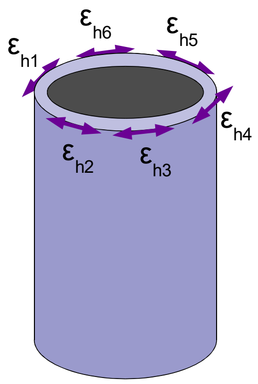


Figure B4 — Illustration of riser hoop strain measurements

3. The strain reading compensated for thermal dilation effects shall be computed for each sensor:

$$\varepsilon_{\ell i} = \varepsilon_{\ell i,\mathrm{raw}} - \alpha(T - T_0)$$
$$\varepsilon_{hi} = \varepsilon_{hi,\mathrm{raw}} - \alpha(T - T_0)$$

4. The radial strain shall be computed at each point:

$$\varepsilon_{ri} = \frac{\nu}{\nu - 1}(\varepsilon_{\ell i} + \varepsilon_{hi})$$

5. Longitudinal and hoop stresses shall be calculated as:

$$\sigma_{\ell i} = \frac{E}{(1+\nu)(1-2\nu)}[(1-\nu)\varepsilon_{\ell i} + \nu(\varepsilon_{hi} + \varepsilon_{ri})]$$
$$\sigma_{hi} = \frac{E}{(1+\nu)(1-2\nu)}[(1-\nu)\varepsilon_{hi} + \nu(\varepsilon_{\ell i} + \varepsilon_{ri})]$$

6. A plane-fit algorithm shall be applied to the longitudinal stress data.

   The goal is to obtain a least-squares plane fit, i.e. minimize

$$\sum_{i=1}^{N_\ell}\left(\sigma_{\ell i} - \sigma_{\mathrm{fit}}(x_i, y_i)\right)^2$$

   Where $\sigma_{\mathrm{fit}}(x, y) = a + bx + cy$ is the plane fit function at point $(x, y)$.

   Let matrix $\mathrm{M}$ be defined as

$$M = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots \\ 1 & x_{N_\ell} & y_{N_\ell} \end{bmatrix}$$

   Where $x_i$ and $y_i$ are the positions of the strain sensors installed around the riser:

$$\phi_{\ell i} = \frac{2\pi(i-1)}{N_\ell}$$

$$x_i = R\cos(\phi_{\ell i})$$

$$y_i = R\sin(\phi_{\ell i})$$

The coefficients of the plane fit function, $a$, $b$ and $c$, shall be computed as follows:

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = M^\dagger \begin{bmatrix} \sigma_{\ell 1} \\ \sigma_{\ell 2} \\ \vdots \\ \sigma_{\ell N_{\text{sens}}} \end{bmatrix}$$

Where the operator $[\ ]^\dagger$ denotes the Moore–Penrose pseudoinverse and is mathematically equivalent to $(M^T M)^{-1} M^T$, the operator $[\ ]^T$ denotes matrix transposition and the operator $[\ ]^{-1}$ denotes matrix inversion.

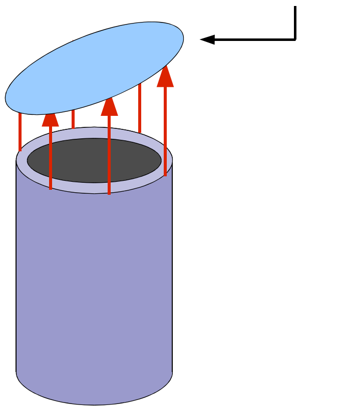


Figure B5 — Illustration of plane fit over longitudinal stress measurements

7. The estimated longitudinal stress distribution around the pipe $\sigma_{fit}(\phi)$ (where $\phi$ is the azimuth) resulting from application of the plane fit shall be decomposed into:
   - The overall axial stress, $\sigma_a$, which represents the strain induced by pure axial tensioning of the pipe, and shall be computed as:

     $$\sigma_a = a$$

     The quantity $\sigma_a$ shall be output as data tag `RIG_n_AXIAL_STRESS`.
   - A bending stress component, which represents the superimposed effect of pipe bending. The output maximum bending strain, $\sigma_b$, shall be reported as the maximum value of the bending strain around the pipe, and shall be computed as

     $$\sigma_b = R\sqrt{b^2 + c^2}$$

     The quantity $\sigma_b$ shall be output as data tag `RIG_n_MAX_BENDING_STRESS`.

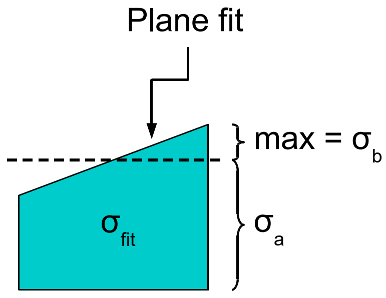


Figure B6 — Illustration of longitudinal stress profile (side view)

8. The overall hoop stress $\sigma_h$ shall be computed as the mean of the individual hoop stress readings:

$$\sigma_h = \frac{1}{N_{\text{sens}}} \sum_{i=1}^{N_{\text{sens}}} \sigma_{hi}$$

The quantity $\sigma_h$ shall be output as data tag `RIG_n_HOOP_STRESS`.

9. From the fit plane, the bending plane azimuth angle $\theta_b$ shall be computed as follows:

$$\theta_b = \text{atan2}(c, b) \qquad \text{(see note 1)}$$

The direction $\theta_b$ points away from the center of curvature of the pipe at the monitored section, and shall be measured in the counter-clockwise direction from the position of strain sensor pair #1, as illustrated in Figure B7.

The quantity $\theta_b$ shall be converted to degrees (in the range $-180° < \theta_b \leq 180°$) and output as data tag `RIG_n_BENDING_DIR`.

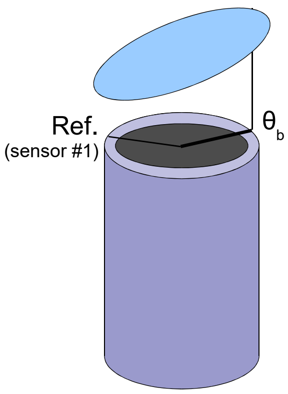


Figure B7 — Illustration of riser bending direction

[1] $\text{atan2}(x, y)$ is formally defined as:

$$\text{atan2}(y, x) = \begin{cases} arctan\left(\frac{y}{x}\right) & x > 0 \\ arctan\left(\frac{y}{x}\right) + \pi & y \geq 0, x < 0 \\ arctan\left(\frac{y}{x}\right) - \pi & y < 0, x < 0 \\ +\frac{\pi}{2} & y > 0, x = 0 \\ -\frac{\pi}{2} & y < 0, x = 0 \\ \text{undefined} & y = 0, x = 0 \end{cases}$$

10. From the calculated stresses, the overall axial tension $F_a$ and bending moment $M_b$ shall be computed:

$$F_a = \sigma_a \pi (Dt - t^2)$$

$$M_b = \frac{2I\sigma_b}{D}$$

where $I = \frac{\pi}{64}(D^4 - (D - 2t)^4)$ is the moment of inertia of the pipe around a perpendicular axis.

The quantities $F_a$ and $M_b$ shall be output as data tags `RIG_n_AXIAL_TENSION` and `RIG_n_BENDING_MOMENT` respectively.