Note 1: the following team worked in the development of this Technical Specification:

Bruno Dutra (U513) ENG-SUB/PROSUB/EIES/EES
Eugenio Simões (CJM5) ENG-SUB/PROSUB/EIES/EES
Guilherme Aires (BYE8) ENG-SUB/PROSUB/EIES/EES
Murilo Holtman (U5E5) ENG-SUB/PROSUB/EIES/EES
Rafael Góes (UT6L) ENG-SUB/PROSUB/EIES/EIS
Roberto Ferreira (CX4H) ENG-SUB/PROSUB/EIES/EES
# TABLE OF CONTENTS

## 1 Introduction

- References ........................................... 5

## 1.2 Abbreviations and Definitions

- Abbreviations ........................................ 6
- Definitions ........................................... 7

## 1.3 Riser Systems

- Free-Standing Hybrid Riser (FSHR) .................. 8
- Hybrid Riser Tower (HRT) ............................ 8
- Riser Support Buoy (BSR) ............................ 9
- Steel Lazy Wave Riser (SLWR) ....................... 9
- Steel Catenary Riser (SCR) .......................... 10

## 2 System Overview .................................. 11

## 3 Subsea Components ............................... 12

### 3.1 Rigid Riser Monitoring

- Top Inclination Measurement ....................... 12
- Top Strain Measurement ............................ 13
- Electrical Connection Jumper ...................... 16

### 3.2 Hybrid Riser Monitoring

- General Requirements ............................... 16
- Data Acquisition Unit (DAU) ....................... 17
- Position Measurement .............................. 18
- FSHR/HRT Buoyancy Tank Thrust Measurement .... 19
- BSR Buoyancy Tank Thrust Measurement ........... 19
- BSR Rigid Riser Monitoring ....................... 20
- Monitoring Umbilical ............................... 20
- Subsea Umbilical Termination (SUT) ............... 20
- Acoustic Communications ......................... 21
- Battery Module .................................... 21
- Interconnections .................................... 21

### 3.3 ROV Communication Tool (RCT)

- General Requirements .............................. 22
- RCT Bottle ........................................ 22
- RCT Laptop ....................................... 23
- RCT Case ......................................... 23
- Definitions ........................................ 24

## 4 FPU Components ................................. 24
4.1 Topside Processing System .......................................................... 24
4.1.1 General Requirements .......................................................... 24
4.1.2 Riser Data Collection System (RDCS) .................................... 24
4.1.3 Supervisory and Data Server .................................................. 26
4.1.4 RHMS Cabinet and Equipment .............................................. 30
4.1.5 Rigid Riser Cabling Cabinet .................................................. 30
4.1.6 Connection Architecture ...................................................... 31

4.2 FPU Provisions for Hybrid Risers ............................................... 32
4.2.1 Umbilical Junction Box ........................................................ 32
4.2.2 Acoustic Communications .................................................... 33
4.2.3 Acoustic Positioning ............................................................ 33
4.2.4 FPU Mechanical Interfaces ................................................. 33
4.2.5 Adaptor Structure ............................................................... 35
4.2.6 FPU Electrical Interfaces ..................................................... 37
4.2.7 Acoustic Systems Junction Boxes ......................................... 39
4.2.8 Electrical Connection Jumpers .............................................. 39

4.3 FPU Provisions for Rigid Risers ................................................. 40
4.3.1 FPU Hull Cables and Connectors .......................................... 40

4.4 FPU Deck Cabling ................................................................. 44
4.4.1 General Requirements ........................................................ 44
4.4.2 Common Deck Cabling ....................................................... 44
4.4.3 Rigid Riser Deck Cabling .................................................... 45
4.4.4 Hybrid Riser Deck Cabling ................................................. 46
4.4.5 Acoustic Systems Deck Cabling ........................................... 46

5 Fabrication, Qualification, Testing and Calibration Requirements .......... 47
5.1 Design and Fabrication ............................................................. 47
5.2 Qualification Testing ............................................................... 47
5.2.1 Subsea Equipment ............................................................. 47
5.2.2 FPU Equipment ............................................................... 47
5.3 Factory Acceptance Testing ...................................................... 47
5.3.1 General Requirements for Subsea Equipment ....................... 47
5.3.2 FSHR/HRT/BSR Thrust Measurement ................................... 48
5.3.3 SCR/SLWR Strain Measurement Sensors .............................. 48

5.4 System Integration Testing ....................................................... 48
6 Installation and Commissioning Requirements ................................... 49
7 Assisted Operation ....................................................................... 50
8 Documentation Requirements ....................................................... 51
9 Training Requirements ............................................................................................................. 52
10 Scope of Supply & Work ..................................................................................................... 53
  10.1 RISER CONTRACTOR .................................................................................................. 53
    10.1.1 General/Common Scope ....................................................................................... 53
    10.1.2 Hybrid Riser Scope ............................................................................................. 53
    10.1.3 Rigid Riser Scope ............................................................................................... 54
  10.2 FPU CONTRACTOR ....................................................................................................... 55
    10.2.1 General/Common Scope ....................................................................................... 55
    10.2.2 Hybrid Riser Scope ............................................................................................. 56
    10.2.3 Rigid Riser Scope ............................................................................................... 56
  10.3 PETROBRAS .................................................................................................................. 56
  10.4 DIVING TEAM ................................................................................................................ 57
Annex A: OPC Interface Requirements .................................................................................... 58
  A.1 Data Tags ....................................................................................................................... 58
Annex B: Rigid Riser Top Angles Calculation ......................................................................... 59
Annex C: Rigid Riser Stress Calculation Algorithm ................................................................ 61
  C.1 Requirements ............................................................................................................... 61
  C.2 Inputs ............................................................................................................................ 61
  C.3 Algorithm Steps ............................................................................................................ 61
Annex D: Scope of Work Drawings ....................................................................................... 66
  D.1 Design & Supply Scope ............................................................................................... 67
  D.2 Installation Scope ......................................................................................................... 68
1 INTRODUCTION

This document presents the Technical Specification of an integrity monitoring system applicable for steel risers and hybrid riser systems serving an offshore floating production unit (FPU).

This document is organized as follows:

- Chapters 1 and 2 respectively present informative overviews regarding riser systems and the overall system architecture.
- Chapters 3 to 9 present technical requirements applicable to the system.
- Chapter 10 presents the division of the scope of work among each involved party.

This specification is not applicable to turret-moored FPSOs (Floating Production, Storage and Offloading vessels).

1.1 References

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

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASME B16.5:2013</td>
<td>Pipe Flanges and Flanged Fittings</td>
</tr>
<tr>
<td>ASTM A320:2015</td>
<td>Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service</td>
</tr>
<tr>
<td>DNVGL-RP-B401:2017</td>
<td>Cathodic Protection Design</td>
</tr>
<tr>
<td>I-DE-3000.00-5529-850-P6B-001</td>
<td>FPU Support for Acoustic Devices</td>
</tr>
<tr>
<td>IEC 60079 (latest revision)</td>
<td>Electric Apparatus for Explosive Gas Atmospheres</td>
</tr>
<tr>
<td>IEC 60502-1 (latest revision)</td>
<td>Power cables with extruded insulation and their accessories for rated voltages from 1 kV ( (U_m = 1.2 \text{kV}) ) up to 30 kV ( (U_m = 36 \text{kV}) ) – Part 1: Cables for rated voltages of 1 kV ( (U_m = 1.2 \text{kV}) ) and 3 kV ( (U_m = 3.6 \text{kV}) );</td>
</tr>
<tr>
<td>IEC 60529 (latest revision)</td>
<td>Degrees of Protection Provided by Enclosures (IP Code)</td>
</tr>
<tr>
<td>NMEA 0183 V 4.10</td>
<td>Standard for Interfacing Marine Electronics Devices</td>
</tr>
<tr>
<td>PETROBRAS N-1710</td>
<td>Coding of Technical Engineering Documents</td>
</tr>
<tr>
<td>PETROBRAS N-0381</td>
<td>Execution of Drawings and Other General Technical Documents</td>
</tr>
</tbody>
</table>
1.2 Abbreviations and Definitions

The following tables define abbreviations and terms used in this Technical Specification.

### 1.2.1 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>AHRS</td>
<td>Attitude and Heading Reference System</td>
</tr>
<tr>
<td>BSR</td>
<td>Bóia de Sustentação de Riser (Riser Support Buoy)</td>
</tr>
<tr>
<td>BT</td>
<td>Buoyancy Tank</td>
</tr>
<tr>
<td>CCR</td>
<td>Command &amp; Control Room</td>
</tr>
<tr>
<td>DAU</td>
<td>Data Acquisition Unit</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DMZ</td>
<td>Demilitarized Zone</td>
</tr>
<tr>
<td>EFL</td>
<td>Electrical Flying Lead</td>
</tr>
<tr>
<td>FAT</td>
<td>Factory Acceptance Test</td>
</tr>
<tr>
<td>FO</td>
<td>Fiber Optic</td>
</tr>
<tr>
<td>FPSO</td>
<td>Floating Production, Storage and Offloading</td>
</tr>
<tr>
<td>FPU</td>
<td>Floating Production Unit</td>
</tr>
<tr>
<td>FSHR</td>
<td>Free-Standing Hybrid Riser</td>
</tr>
<tr>
<td>FXJ</td>
<td>Flexible Joint</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HRT</td>
<td>Hybrid Riser Tower</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/Output</td>
</tr>
<tr>
<td>IP</td>
<td>Ingress Protection</td>
</tr>
<tr>
<td>JB</td>
<td>Junction Box</td>
</tr>
<tr>
<td>LRTA</td>
<td>Lower Riser Termination Assembly</td>
</tr>
<tr>
<td>OPC</td>
<td>Open Platform Communications (from OPC Foundation)</td>
</tr>
<tr>
<td>OPC UA</td>
<td>OPC Unified Architecture</td>
</tr>
<tr>
<td>PBOF</td>
<td>Pressure Balanced Oil-Filled</td>
</tr>
<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
<tr>
<td>PSU</td>
<td>Power Supply Unit</td>
</tr>
<tr>
<td>RCT</td>
<td>ROV Communication Tool</td>
</tr>
<tr>
<td>RDCS</td>
<td>Riser Data Collection System</td>
</tr>
<tr>
<td>RHMS</td>
<td>Rigid &amp; Hybrid Riser Monitoring System</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely-Operated Vehicle</td>
</tr>
<tr>
<td>SCR</td>
<td>Steel Catenary Riser</td>
</tr>
<tr>
<td>SIT</td>
<td>System Integration Test</td>
</tr>
<tr>
<td>SLWR</td>
<td>Steel Lazy Wave Riser</td>
</tr>
<tr>
<td>SUT</td>
<td>Subsea Umbilical Termination</td>
</tr>
<tr>
<td>TSP</td>
<td>Twisted Shielded Pair</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptible Power Supply</td>
</tr>
<tr>
<td>URTA</td>
<td>Upper Riser Termination Assembly</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>USBL</td>
<td>Ultra-Short Baseline</td>
</tr>
</tbody>
</table>
### 1.2.2 Definitions

<table>
<thead>
<tr>
<th><strong>RISER CONTRACTOR</strong></th>
<th>The company contracted by PETROBRAS to design, supply and install the risers, including the monitoring system (object of this specification)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FPU CONTRACTOR</strong></td>
<td>The company contracted by PETROBRAS to construct the FPU</td>
</tr>
<tr>
<td><strong>DIVING TEAM</strong></td>
<td>The party responsible for execution of diving-related tasks, to be defined during the bidding phase.</td>
</tr>
<tr>
<td><strong>MAY</strong></td>
<td>Is used when alternatives are equally acceptable</td>
</tr>
<tr>
<td><strong>SHOULD</strong></td>
<td>Is used when a provision is not mandatory, but is recommended as a good practice</td>
</tr>
<tr>
<td><strong>SHALL</strong></td>
<td>Is used when a provision is mandatory</td>
</tr>
<tr>
<td><strong>WET-MATE CONNECTOR</strong></td>
<td>Connector designed for plugging/mating in underwater environments</td>
</tr>
<tr>
<td><strong>COVERAGE INTERVAL</strong></td>
<td>Interval containing the set of true values of a measured quantity with a stated probability, based on the information available</td>
</tr>
<tr>
<td><strong>COVERAGE PROBABILITY</strong></td>
<td>Probability that the set of true values of a measured quantity is contained within a specified COVERAGE INTERVAL</td>
</tr>
</tbody>
</table>
1.3 Riser Systems

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

1.3.1 Free-Standing Hybrid Riser (FSHR)

The Free-Standing Hybrid Riser (FSHR) solution consists of a single vertical steel riser supported by an underwater Buoyancy Tank (BT). The vertical risers terminated on its top end by the Upper Riser Termination Assembly (URTA), also referred to as the top assembly. The URTA is connected to the Buoyancy Tank by means of a tether, whilst the riser line itself is connected to the FPU through a flexible jumper. Figure 1 presents an illustration of this solution.

![FSHR Illustration](image)

**Figure 1 — FSHR illustration**

1.3.2 Hybrid Riser Tower (HRT)

A Hybrid Riser Tower (HRT) is a concept similar to the FSHR, except that it supports a bundle of pipes instead of a single pipe. This kind of riser has several jumpers from the URTA to the FPU, one for each riser line in the bundle.
1.3.3 Riser Support Buoy (BSR)

A Riser Support Buoy (BSR, Bóia de Sustentação de Riser) is yet another type of hybrid riser system consisting of a large buoy anchored to the sea floor by means of several tethers, which supports several steel catenary risers. Each riser is connected to a corresponding flexible jumper, which in turn is connected to the FPU. Figure 2 presents an illustration of this concept.

1.3.4 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 3.
1.3.5 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 4.

Figure 4 — SCR illustration
2 SYSTEM OVERVIEW

Figure 5 presents a general diagram of the riser monitoring system.

The system is composed of a topside processing system which communicates with sensors and equipment installed on subsea riser structures.

It shall be noted that while the topside processing system is common for all monitored risers attached to the FPU, each type of riser has its own particular monitoring requirements, presented in § 3 Subsea Components.
3 SUBSEA COMPONENTS

Different types of riser systems may be connected to the FPU, depending on contracted scope. The next subsections present the monitoring requirements for subsea units that shall apply for each particular riser type. Additional FPU units related to each particular riser type are specified in § 4 FPU Components.

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

3.1 Rigid Riser Monitoring

This section specifies monitoring requirements for SLWRs and SCRs, including those supported by BSRs. The purpose of rigid riser monitoring is to assess fatigue life consumption due to cyclic loading.

3.1.1 Top Inclination Measurement

3.1.1.1 Instantaneous roll and pitch at the top of each rigid riser shall be monitored by an inertial measurement unit (IMU). The requirements presented herein shall apply to rigid risers supported by the FPU or by a BSR.

3.1.1.2 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 topside acquisition system) due to the low data acquisition frequency.

3.1.1.3 Because 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 B: Rigid Riser Top Angles Calculation.

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

3.1.1.5 For risers supported directly by the FPU, the IMU shall reside in a subsea-proof enclosure rated for a minimum depth of 100 m. IMU weight shall not exceed 10 kg in water, in order to be compatible with installation by divers.

3.1.1.6 For rigid risers supported by BSRs, the IMU shall reside in a subsea-proof enclosure rated for at least 1.5 times the operational depth and designed for installation by a work-class ROV.

3.1.1.7 An appropriate clamp shall be supplied to firmly attach each IMU to the riser at an appropriate location just below the flexible joint.

3.1.1.8 For rigid risers supported by the FPU, the clamp shall be designed for installation by divers.
3.1.1.9 For rigid risers supported by a BSR, the clamp shall be designed for installation by a work-class ROV.

3.1.1.10 In all cases, the outer surface of the rigid riser shall include painted indications of the correct locations for IMU clamp installation, for use as cues during these operations.

3.1.1.11 For rigid risers supported by the FPU, the IMU attached to each rigid riser should communicate with the RDCS by means of TIA/EIA-485/422. Other options may be proposed and subjected to PETROBRAS approval and shall be compatible with the type and length of specified cabling (as described in § 4.4.3 and § 4.3.1).

3.1.1.12 For rigid risers supported by a BSR, the IMU attached to each rigid riser should communicate with the DAU by means of TIA/EIA-485/422. Other options may be proposed and subjected to PETROBRAS approval.

3.1.1.13 Installation procedures shall account for necessary methods to measure the misalignment of the IMU as described on Annex B: Rigid Riser Top Angles Calculation, with sufficient accuracy to guarantee maximum permissible errors.

3.1.1.14 A tool for measuring clamp misalignment (with respect to the riser catenary plane) shall be supplied according to Annex B: Rigid Riser Top Angles Calculation.

3.1.2 Top Strain Measurement

3.1.2.1 Axial tension and bending moments acting at the top of rigid risers selected by PETROBRAS shall be monitored. The requirements presented herein shall apply only to rigid risers supported directly by the FPU.

3.1.2.2 In order to assess these variables, strain and temperature sensors shall be installed below the riser flexible joint, in a section of pipe devoid of coating, as illustrated in Figure 6.

Figure 6 — Illustration of strain monitoring location in rigid risers
3.1.2.3 Each strain-monitored rigid riser shall be fitted with the following sensors (as illustrated in Figure 7):

- Eight (8) rosette-type strain gauges, installed around the riser, equally spaced at 45° from each other, to measure hoop and longitudinal stress at each point around the riser pipe, as illustrated in Figure 8.
- Four (4) riser body temperature sensors at the strain monitoring location, equally spaced at 90° from each other, to be used for correction of thermal dilation effects.

![Strain gauge locations](image)

![Temperature sensor locations](image)

Figure 7 — Illustration of sensor positioning around rigid riser (cross-section view from top)

![Schematic view of strain sensing around riser pipe](image)

Figure 8 — Schematic view of strain sensing around riser pipe (only active sensors shown)

3.1.2.4 The strain sensors shall be strain gauges. Other technologies may be proposed and subjected to PETROBRAS approval.

3.1.2.5 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.

3.1.2.6 The strain gauge attachment method shall be suggested and subjected to PETROBRAS approval.

3.1.2.7 The riser pipe surface shall undergo preparation in an adequate environment to receive the sensors.

3.1.2.8 The temperature and strain sensors in each set shall be numbered starting from 1 and increasing in the counter-clockwise direction, looking from above, as depicted in Figure 7.
3.1.2.9 The maximum permissible error in temperature measurement, for 95% coverage probability, shall be of ± 0.2 °C.

3.1.2.10 Temperature compensation to account for variations in sensor outputs with temperature, and not to be confused with the effect of thermal dilation of the pipe itself, shall be implemented for all sensors, e.g. Wheatstone bridges in full or half configurations.

3.1.2.11 Strain and temperature sensors, shall not be designed for recoverability, however the signal conditioning unit shall be retrievable by diver.

3.1.2.12 The design life of top strain sensors shall be of at least 5 years. This requirement shall apply only to the sensing elements (e.g. strain gauges), when they are directly attached to riser surfaces. For all other components and cases, the general requirements stated in § 5.1 shall apply.

3.1.2.13 The sensors attached to the riser shall be covered by a protective layer that impedes contact with water and other environmental conditions. Additionally, mechanical protection measures shall be provided in order to avoid sensor damage during installation.

3.1.2.14 The sensors shall be connected to a signal conditioning unit, which shall amplify and digitalize sensor signals. The signal conditioning unit shall be installed as close as possible to the sensors.

3.1.2.15 The signal conditioning unit should communicate with the RDCS using the TIA/EIA-485/422. Other options may be proposed and subjected to PETROBRAS approval and shall be compatible with the type and length of specified cabling (as described in § 4.4.3 and § 4.3.1).

3.1.2.16 A detailed description of the suggested algorithm to compute axial tensions and bending moments at the top of each rigid riser is given in Annex C: Rigid Riser Stress Calculation Algorithm. Other algorithms may be proposed and subjected to PETROBRAS approval.

3.1.2.17 It shall be possible to selectively enable/disable the acquisition of input from each rosette-type strain gauge.

3.1.2.18 The strain measurement system shall satisfy the following performance requirements:

- Maximum permissible error for axial tension, for 95% confidence level: ± 80 kN.
- Range: to be defined during execution phase. The range shall be selected as appropriate to properly assess fatigue damage in the riser.
3.1.3 Electrical Connection Jumper

3.1.3.1 The monitoring units (as per the previous sections) for each SCR and SLWR directly supported by the FPU shall be connected by means of an appropriate subsea jumper.

3.1.3.2 The subsea jumper shall be terminated in a diver-mate connector matching the one on the FPU side (see § 4.3.1 *FPU Hull Cables and Connectors*). The connector model shall be defined during project execution through formal consultation with PETROBRAS.

The connector model shall conform to the following requirements: be diver-operated; be suitable for operation in the foreseen environment, with a maximum operating depth of at least 3000 m; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years.

The models listed next are known to fulfill these requirements; other models that meet or exceed the required performance may be proposed and subjected to PETROBRAS approval:

- 12-way Tronic DigiTRON+ Diver Connector Receptacle
- 12-way ODI Nautilus Manual-Mate Plug
- 12-way Seacon CM 2000 Diver Mate Connector (exposed pins)

3.1.3.3 When strain measurement apparatus is required for a given riser, it may be connected either in a piggy-back configuration to the inclination measurement system or by means of a multi-termination connector/bifurcating jumper. Only one FPU-side wet-mate connector will be available.

3.1.3.4 The jumper shall be designed considering the connection scheme specified in § 4.3.1 *FPU Hull Cables and Connectors*, especially regarding cable run lengths. Information on FPU dimensions and infrastructure shall be obtained in consultation with PETROBRAS.

3.2 Hybrid Riser Monitoring

3.2.1 General Requirements

3.2.1.1 This section specifies monitoring requirements and units comprising the monitoring system for FSHRs, HRTs and BSRs. The diagram in Figure 9 illustrates the overall functions of the hybrid riser subsea monitoring system.

3.2.1.2 All monitoring system units shall be designed to be installed, retrieved and replaced by a work-class ROV of opportunity, except where specified otherwise. Accessibility studies shall be performed to demonstrate this requirement is met in accordance to applicable ROV technical specifications.

3.2.1.3 The monitoring system shall remain fully functional when the umbilical connection is unavailable, relying on the battery module for power and on the alternative channels for communication.
3.2.1.4 The monitoring system shall remain fully functional when the Acoustic Communication unit is unavailable, relying on the umbilical communication.

3.2.1.5 The monitoring system shall remain fully functional when the battery module is unavailable, relying on the umbilical power supply.

3.2.1.6 Cathodic protection, painting and coating shall be in accordance with technical specifications and standards applicable to the subsea structure considering the design life of the subsea structure.

![Diagram of subsea hybrid riser monitoring units](image)

Figure 9 — Diagram of subsea hybrid riser monitoring units

3.2.2 Data Acquisition Unit (DAU)

3.2.2.1 The Data Acquisition Unit (DAU) shall act as a single point connection between subsea and FPU units, distributing power and enabling data connections between subsea instrumentation and FPU systems. The DAU shall also house a few sensors, as described by the requirements to follow.

3.2.2.2 Appropriate sensors shall provide an indication of the DAU depth below sea level.

- Maximum permissible error, for 95% coverage probability: ± 1 m

3.2.2.3 For BSRs and HRTs only, an AHRS (Attitude and Heading Reference System) unit shall provide the roll, pitch and heading of the DAU. Maximum permissible errors, for 95% coverage probability, shall be:

- Roll and pitch: ± 0.05°
- Heading: ± 0.3° secant latitude
3.2.2.4 No data processing, such as engineering unit conversion or data filtering, shall be performed by the DAU. This processing shall be left to topside units.

3.2.2.5 It shall be possible to power the DAU, and hence the associated subsea units, by any of the following sources, based on a priority scheme. In order of precedence:

   i. FPU power (umbilical)
   ii. ROV power
   iii. Battery module power

3.2.2.6 The DAU shall include provisions for a hard reset functionality (power off/on), to be manually triggered by a signal from the topside cabinet. The hard reset shall temporarily disconnect the DAU from all power sources.

3.2.2.7 The system shall automatically switch between power supplies as they become available, without the need for operator intervention. The FPU power (umbilical) shall be the main power supply; that is, whenever the umbilical is available it shall supply power for all subsea units.

3.2.2.8 The following communication channels shall be supported:

   i. Umbilical
   ii. Acoustic link
   iii. ROV connection

3.2.2.9 At any time the DAU shall respond to requests incoming from any communication channel. All channels shall provide the same functionalities indistinguishably.

3.2.2.10 It shall be possible to update any and all configuration parameters for the DAU remotely, through all available communication channels.

3.2.2.11 An interface shall be available for the ROV Communication Tool (RCT). The interface shall be a wet-mate connector, allowing an ROV-handled EFL to be hot plugged in, i.e. upon connection the RCT communication channel shall become immediately available.

3.2.2.12 The DAU shall be interchangeable with a spare unit without the need to perform changes in the surface system.

3.2.3 Position Measurement

3.2.3.1 The absolute position of the buoyancy tank of every BSR and of the riser top assembly (URTA) of every FSHR/HRT shall be monitored by means of an USBL subsea acoustic positioning using the absolute position of the FPU provided by the POS system (Positioning and Navigation Systems for Floating Production Unit (FPU)).

3.2.3.2 Two (2) acoustic transponders shall be installed in separate receptacles at the buoyancy tank of every BSR and at the riser top assembly of every FSHR/HRT.
3.2.3.3 When the umbilical connection is not available, the transponders shall draw power from the local battery module. When umbilical power is available, it shall be used instead of the batteries.

3.2.3.4 For performance requirements, please refer to § 4.2.3 Acoustic Positioning.

### 3.2.4 FSHR/HRT Buoyancy Tank Thrust Measurement

3.2.4.1 BT thrust shall be monitored by measuring the mechanical load on the BT tether connected to the riser top assembly. Six (6) individual load sensors shall be installed evenly spaced at 60° around the tether.

3.2.4.2 The load sensors shall be designed to be individually replaced in case of failure/malfunction.

3.2.4.3 Acceptable load sensor technologies are Linear Variable Displacement Transducers (LVDT) or Vibrating Wires. Other technologies may be proposed and subjected to PETROBRAS approval.

3.2.4.4 Temperature compensation to account for variations of sensor outputs with temperature, not to be confused with the effect of thermal dilation of the tether itself, shall be implemented.

3.2.4.5 The load measurement system shall compensate for effects of tether thermal dilation and include sensors for local temperature measurement.

3.2.4.6 The sensors shall be connected to a signal conditioning unit, which shall amplify and digitalize load sensor signals as necessary. The signal conditioning unit shall be installed as close as possible to the load sensors and a single EFL shall connect it to the DAU.

3.2.4.7 The thrust measurement system shall be designed to accurately detect the flooding of a single BT compartment.

- Maximum permissible error, for 95% coverage probability: 30% of the thrust provided by a single tank compartment
- Sampling period: 1 second

### 3.2.5 BSR Buoyancy Tank Thrust Measurement

3.2.5.1 BSR thrust shall be monitored by measuring the mechanical load on every mooring tether. Two (2) individual load sensors shall be installed evenly spaced at 180° around each tendon.

3.2.5.2 The load sensors at each mooring tether shall be designed to be replaced in case of failure/malfunction.

3.2.5.3 Acceptable load sensor technologies are Linear Variable Displacement Transducers (LVDT) or Vibrating Wires. Other technologies may be proposed and subjected to PETROBRAS approval.
3.2.5.4 Temperature compensation, to account for variations of sensor outputs with temperature, not to be confused with the effect of thermal dilation of the tendon itself, shall be implemented.

3.2.5.5 The load measurement system shall compensate for effects of tendon thermal dilation and include sensors for local temperature measurement.

3.2.5.6 The sensors shall be connected to a signal conditioning unit, which shall amplify and digitalize load sensor signals as necessary. One signal conditioning unit shall be installed per mooring tendon group, as close as possible to the load sensors, and a single EFL shall connect each signal conditioning unit to the DAU.

3.2.5.7 A splitter box may be used to connect the conditioning units to the DAU, using a single EFL.

3.2.5.8 The thrust measurement system shall be designed to accurately detect the flooding of a single BSR compartment.

- Maximum permissible error, for 95% coverage probability: 30% of the thrust provided by a single tank compartment.
- Sampling period: 1 second

3.2.6 BSR Rigid Riser Monitoring

3.2.6.1 The monitoring requirements detailed in section § 3.1.1 shall be implemented for the rigid risers supported by the BSR. Strain measurement shall not be implemented on BSR rigid risers.

3.2.7 Monitoring Umbilical

3.2.7.1 A subsea umbilical shall provide power and communications to subsea monitoring equipment residing on each hybrid riser structure.

3.2.7.2 The umbilical shall be designed for the monitoring application, with redundancy for all electrical/optical cables.

3.2.7.3 The surface end of the umbilical shall have exposed cable pigtails of at least 2 m for connection inside the umbilical junction box (see § 4.2.1 Umbilical Junction Box). Individual cables within the umbilical shall be properly identified at their pigtails.

3.2.8 Subsea Umbilical Termination (SUT)

3.2.8.1 The subsea end of the umbilical shall be terminated in a structure that provides an electrical/optical interface to subsea components. The termination structure shall be integral to the umbilical and provide mechanical coupling/support to the hybrid riser structure.

3.2.8.2 The SUT shall provide wet-mate connectors as required.
3.2.9 Acoustic Communications

3.2.9.1 One (1) acoustic modem shall allow the DAU to acoustically communicate with the FPU.

3.2.9.2 Acoustic communications and positioning may be integrated in a single device, if such technology is available.

3.2.9.3 Communication by acoustic means shall employ data fragmentation and error detection/retransmission techniques, in order to enable transmission of large data sets under high-noise conditions. The data segment (fragment) size shall be chosen suitably.

3.2.10 Battery Module

3.2.10.1 A battery pack housed inside a single subsea enclosure shall provide backup power for subsea units when other external sources are not available. The battery module shall be retrievable and installable by a work-class ROV (with addition of buoys if necessary).

3.2.10.2 The battery module shall be sized to power the system for a minimum of 6 months, considering the prescribed data acquisition and acoustic positioning rates during operation in the absence of other external power supplies.

3.2.10.3 The battery module shall have an ROV-operated on/off switch to control power supply to subsea components.

3.2.10.4 The battery module shall include a state-of-charge sensor as needed for acquisition of charge measurement.

3.2.11 Interconnections

3.2.11.1 All connections between components in separate enclosures shall be made with wet-mate Electrical Flying Leads (EFLs) suitable for ROV handling.

3.2.11.2 All connecting flying leads or jumpers shall be properly fastened to subsea structures or be laid over proper cable trays to avoid damage due to sway or friction.

3.2.11.3 Parking places for all flying leads shall be available on nearby subsea structures.

3.2.11.4 Dummy connectors shall be supplied for all bulkhead connectors.

3.2.11.5 The choice of connectors on EFLs and equipment shall be made considering that live (powered) pins shall not be exposed to sea water. The design shall allow disconnections and connections to be made in any order.
3.3 ROV Communication Tool (RCT)

3.3.1 General Requirements

3.3.1.1 An ROV Communication Tool (RCT) shall provide means for intervention and configuration of the subsea units. The RCT shall connect to specific interfaces provided by the DAU for that purpose.

3.3.1.2 The RCT shall be designed to be used with a work-class ROV of opportunity.

3.3.1.3 The design of the RCT shall include surface and subsea components as illustrated in Figure 10.

- A subsea enclosure containing the electronic system to provide power and communications to the subsea DAU (specified in § 3.3.2).
- A laptop computer containing software to communicate and retrieve data from the DAU (specified in § 3.3.3).

![Figure 10 — RCT illustration](image)

3.3.2 RCT Bottle

3.3.2.1 The RCT bottle shall provide necessary power and communication interfaces between the ROV and the DAU. RCT connections are illustrated in Figure 11.

![Figure 11 — RCT bottle connection diagram](image)
3.3.2.2 The RCT bottle shall convert power supplied by the ROV to the levels used by the DAU. It shall be able to power all subsea components in the absence of the umbilical.

3.3.2.3 The RCT bottle shall be designed to accept 24 VDC @ 2 A and/or 120 VAC @ 5 A supplied by the ROV.

3.3.2.4 The RCT bottle shall be able to communicate both by TIA/EIA-232 or TIA/EIA-485 with the ROV MUX. Means to select between them shall be provided.

3.3.2.5 A set of jumpers shall be available for connection of the RCT bottle to ROV power/communications systems.

   ▪ Two (2) jumpers shall be supplied with pigtailed on the ROV end, for splicing with ROV MUX cables at the surface before deployment as required.
   ▪ One (1) jumper shall be supplied with a subsea connector on the ROV end; the type of connector is to be defined during the design phase.
   ▪ Each jumper shall be at least 5 meters long.

3.3.2.6 A wet-mate ROV-operated jumper (EFL) shall be supplied to make the connection between the RCT bottle and the ROV interface on the DAU. The EFL shall be sufficiently long to allow this connection.

3.3.3 RCT Laptop

3.3.3.1 The RCT laptop shall contain hardware interfaces for connection to surface ROV MUX (at the ROV vessel) and software to enable communication with the DAU.

3.3.3.2 The laptop shall be of a rugged design, appropriate for field operations.

3.3.3.3 The RCT laptop shall provide access to all functionalities of the subsea system, including data acquisition, configuration and maintenance where applicable.

3.3.3.4 The RCT laptop software shall convert the following real-time data items supplied by the DAU to engineering units:

   ▪ BT/BSR thrust measurements;
   ▪ Depth;
   ▪ Water temperature;
   ▪ Remaining battery module charge.

3.3.3.5 It shall be possible to export acquired data to a common USB mass storage medium, such as a flash drive, in a format supported by Microsoft Excel 2003 or newer.

3.3.4 RCT Case

3.3.4.1 A case for storage and transport of all equipment comprising the RCT shall be supplied.

3.3.4.2 The case shall provide protection against shocks during transport and adverse weather, including water ingress.
4 FPU COMPONENTS

This section describes components of the monitoring system aboard the FPU.

4.1 Topside Processing System

4.1.1 General Requirements

4.1.1.1 The FPU processing system shall have a two-layered architecture:

- The Riser Data Collection System (RDCS) shall be responsible for collecting data from the various sensors.
- The Supervisory and Data Server shall act as a supervisory system, serve data to external clients, process acquired data, issue alarms and log data in a historian data base.

4.1.1.2 RHMS shall not be part of the FPU cause and effect matrix (i.e. shall not be used to trigger emergency shutdowns).

4.1.1.3 In the case of power loss, the RHMS shall be able to restart automatically without the need for operator intervention.

4.1.2 Riser Data Collection System (RDCS)

4.1.2.1 The Riser Data Collection System (RDCS) shall collect data from all the various specified sources and therefore act as a hub for data distribution at the FPU. It shall operate autonomously without any need for operator intervention.

4.1.2.2 The FPU position provided by on-board GPS and AHRS (Attitude and Heading Reference System) shall be retrieved by the RDCS from the POS system (Positioning and Navigation Systems for Floating Production Unit (FPU)) as it is broadcast by means of three (3) TIA/EIA-485 connections:

- **GPS NMEA 0183 link**: GGA and ZDA messages.
- **AHRS TSS1 link**: FPU attitude in TSS1 protocol.
- **AHRS NMEA 0183 link**: HDT message.

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

4.1.2.4 Data shall be continuously retrieved from the instrumentation installed on SLWRs and SCRs (refer to § 3.1 Rigid Riser Monitoring). The sampling period shall be 1 second and a timeout event shall be understood as the unsuccessful retrieval of 3 consecutive samples.

4.1.2.5 Angles measured by top inclination measurements unit (IMU) shall be converted in accordance to Annex B: Rigid Riser Top Angles Calculation.
4.1.2.6 Load and stress calculations for rigid risers should be implemented as described in Annex C: *Rigid Riser Stress Calculation Algorithm*. Other algorithms may be proposed and subjected to PETROBRAS approval.

4.1.2.7 Data acquisition from sensors installed on FSHRs, HRTs and BSRs shall be accomplished continuously through the umbilical (refer to § 3.2 *Hybrid Riser Monitoring*). The sampling of all monitored variables shall be performed with a period of 1 second and a timeout event shall be understood as the unsuccessful acquisition of 3 consecutive samples.

4.1.2.8 FSHR/HRT/BSR thrust shall be calculated in a way similar to the SCR/SLWR overall axial tension, as described in Annex C: *Rigid Riser Stress Calculation Algorithm*.

4.1.2.9 In addition to the umbilical, data shall also be periodically acquired from all DAUs installed on FSHRs, HRTs and BSRs by means of acoustic communication (refer to § 3.2 *Hybrid Riser Monitoring* and § 4.2.2 *Acoustic Communications*).

- One sample shall be retrieved every 60 minutes for each variable.
- Exception shall be made for variables produced by the AHRS unit, which shall instead be retrieved with a periodicity of 180 minutes.

**Note:** acoustic data retrieval shall be continuously executed even with umbilical links in place, in order to continuously verify whether the acoustic links are operational.

4.1.2.10 In case a communication attempt through the acoustic link fails, new attempts shall be made every 2 minutes thereafter until it succeeds or a maximum of 5 attempts are performed. In case all attempts fail, a timeout event for the acoustic link shall be registered and the retrieval of data skipped once.

4.1.2.11 Both communication channels shall be continuously available and operate independently from each other.

4.1.2.12 The RDCS shall coordinate usage of the acoustic medium in order to avoid mutual interference between acoustic devices (e.g. positioning and communication).

4.1.2.13 Warm up/settling time requirements shall be observed for every subsea unit regardless of the active communication channels. Battery Module design restrictions may require units to be powered off between data retrievals through the acoustic link, therefore adequate mechanisms shall be implemented to power every unit on at an adequate time prior to acquisition as necessary, in order to honor all acquisition intervals and performance requirements.
4.1.2.14 The positions of subsea structures shall be continuously retrieved from all acoustic positioning systems on the FPU (specified in § 4.2.3 Acoustic Positioning). The following requirements shall apply:

- When the subsea system is powered by the umbilical, the sampling period shall be 15 seconds.
- When the subsea system is powered by the battery module, a sequence of 8 samples, with an interval of 15 seconds between successive samples, shall be taken every 60 minutes. This shall be employed to conserve power from subsea positioning responder batteries.
- Switching between modes shall take place automatically (i.e. without the need for operator intervention).
- Acoustic positioning data shall be filtered to avoid generation of spurious alarms due to interference phenomena, with particular consideration for the intermittent presence of dynamic positioning vessels near the FPU. The filtering scheme shall be designed and subjected to PETROBRAS approval.

4.1.2.15 Annex A: OPC Interface Requirements presents a summary of the variables to be monitored. Additional data shall be acquired as necessary in order for the monitoring system to keep track of the status of every unit and communication channels alike.

4.1.2.16 The RDCS shall communicate with the Supervisory and Data Server, relaying sensor data. It shall also provide the supervisory with access to all configuration and maintenance interfaces of the various sensors and equipment. Refer to § 4.1.3 Supervisory and Data Server.

4.1.2.17 The RDCS shall be implemented by robust hardware solutions with proven long-term reliability.

4.1.3 Supervisory and Data Server

4.1.3.1 A Supervisory and Data Server shall communicate with the Riser Data Collection System and act as the only interface to human operators and external systems of the monitoring system. The Supervisory and Data Server shall be based on Microsoft Windows.

4.1.3.2 The supervisory and data server shall be set up on a computer fit for industrial environments. It shall minimally meet the following requirements:

- 2 frontal USB 3.0 ports available for external devices.
- 2 Gigabit Ethernet ports, provided by independent boards.
- Internal storage of 1 TB – independent of the historian database storage (see item 4.1.3.6).

4.1.3.3 The use of a well-established integrated supervisory solution able to provide all required functionalities is strongly advised.
4.1.3.4 Dedicated supervisory 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 remaining charge of subsea battery modules. The minimum set of monitoring variables is specified in § A.1.

4.1.3.5 A historian database system for storage of generated data points shall be included. The data tags for which database storage is mandatory are indicated in § A.1. The design may include storage of additional variables.

4.1.3.6 The historian database shall operate on a circular buffer pattern, whereby older records shall gradually be overwritten by newer samples once the database reaches its capacity. Storage space shall be provided as a dedicated RAID 1 array, sized for at least 24 months of logging at the highest possible data sampling rate.

4.1.3.7 The supervisory 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.

4.1.3.8 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.

4.1.3.9 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.

4.1.3.10 The supervisory shall keep a log of all accesses, both local and remote, for a minimum of 12 months.

4.1.3.11 The supervisory system shall provide Web Interface (HTTP) access to all screens from within PETROBRAS corporate network. Authenticated users shall be given access to all functionalities just as they are available locally.

4.1.3.12 The Web Interface shall be fully compatible with the latest versions of the Internet Explorer, Mozilla Firefox and Google Chrome browsers, without the aid of any plugins.

4.1.3.13 At least 20 concurrent accesses to the supervisory shall be supported by the Web Interface.

4.1.3.14 The standard Microsoft Windows remote desktop solution shall also be provided to allow remote access to the system from onshore facilities.

4.1.3.15 It shall be possible to selectively disable, in the supervisory screens, the acquisition of each individual strain gauge pair (axial and hoop strain) of the SCR/SLWR top strain measurement (refer to § 3.1.2).

4.1.3.16 It shall be possible to selectively disable, in the supervisory screens, the acquisition of each individual load sensor of the FSHR/HRT/BSR buoyancy tank thrust measurement system (refer to § 3.2.4 and 3.2.5).
4.1.3.17 The supervisory system shall generate, display and log alarms for monitored variables. The type of alarm mechanism applicable to each variable is specified in § A.1.

4.1.3.18 Each alarm 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).

4.1.3.19 The supervisory shall provide the infrastructure to manage and configure alarm limits and to enable/disable each alarm individually. An alarm shall remain active until it is explicitly acknowledged by an operator.

4.1.3.20 “Range”-type alarms shall be implemented with configurable LL/L/H/HH limits for the monitored variable value.

4.1.3.21 Offset diagram alarms shall be computed for hybrid riser positions (obtained via subsea acoustic positioning) as illustrated in Figure 12. The following requirements shall apply.

- There shall be two configurable regions, “yellow” (unusual condition) and “red” (imminent threat to structure integrity).
- Each region shall be specified by its center point coordinates and radius (in meters).
- The respective offset diagram alarm shall be triggered when the measured position of a subsea structure is outside the limiting region.
- Offset diagram alarms shall be based on the position variables after filtering (see item 4.1.2.14).

![Figure 12 — Offset diagram illustration for an FSHR](image)

4.1.3.22 All alarms should include some form of hysteresis mechanism in order to avoid excessive alarm generation when the monitored value is near alarm thresholds.

4.1.3.23 Alarms shall also be issued for monitoring system failure conditions, including loss of communications to any component and detection of faulty sensors. Refer to § 4.1.2 for details on the definition of timeout regarding some of the monitored variables.
4.1.3.24 Alarms shall be classified in the following severity levels:

- **High:**
  - LL/HH (low-low/high-high) range alarms.
  - “Red” offset diagram alarms.
  - 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 alarms.
  - “Yellow” offset diagram alarms.
  - 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 threat to integrity.

4.1.3.25 Detailed design of the alarm system shall be submitted for PETROBRAS approval prior to implementation.

4.1.3.26 Data shall be provided to external systems and users via standardized OPC UA (Unified Architecture) interfaces as follows:

- OPC UA Data Access (DA) for real-time data.
- OPC UA Historical Access (HA) for historical data.
- OPC UA Alarms & Conditions (AC) for alarms.

Details are given in the next items.

4.1.3.27 Real-time data shall be made available for external access through a standardized OPC UA Data Access interface. The minimum set of tags to be implemented is specified in Annex A: *OPC Interface Requirements*.

4.1.3.28 Historical data stored on the local database (item 4.1.3.5) shall be accessible through an OPC UA Historical Access interface. The minimum set of tags to be implemented is specified in Annex A: *OPC Interface Requirements*.

4.1.3.29 Alarms shall be made available for external clients through an OPC UA Alarms & Conditions interface.

4.1.3.30 The provided interfaces shall be ready for use by external systems from the PETROBRAS corporate network which are allowed through FPU network firewalls.
4.1.4 RHMS Cabinet and Equipment

4.1.4.1 The complete topside processing system shall be supplied as a single stand-alone cabinet, the RHMS Cabinet.

4.1.4.2 The cabinet shall be installed in a non-classified, temperature-controlled room allowing frontal and rear access. As a general rule, the RHMS Cabinet shall be installed in the same electrical panel room as the subsea production control system cabinets (e.g. Master Control Stations). The chosen location shall make it feasible for the cabinet to be installed offshore, i.e. not in a shipyard.

4.1.4.3 The location of the cabinet shall be agreed with PETROBRAS during the execution phase.

4.1.4.4 The dimensions of the cabinet shall be 800 mm × 800 mm × 2000 mm (width × depth × height). The cabinet shall have a transparent front door.

4.1.4.5 Cables shall enter the RHMS Cabinet through the bottom.

4.1.4.6 Mechanical interfaces of the cabinet for floor mounting shall be agreed during execution phase.

4.1.4.7 The cabinet shall be powered by a nominal voltage of 220 V AC (+/- 10%), 50-60 Hz, to be supplied through a cable including a protective earth conductor. Maximum power demanded by the cabinet shall be limited to 4000 W. It shall be treated as a regular load, i.e. neither essential nor emergency.

4.1.4.8 The supplied cabinet shall conform to the applicable FPU cabinet technical specification.

4.1.4.9 The cabinet shall provide power to all other components of the monitoring system by means of redundant power supplies, each protected by dedicated circuit breakers.

4.1.4.10 User interface devices, including keyboard, mouse and monitor, shall be available for local access to the supervisory system. All user interface devices shall be installed at a comfortable height for human users and with proper consideration for ergonomics.

4.1.4.11 The RHMS Cabinet shall include a hardware switch/button to trigger the hard reset on each subsea DAU (as described in item 3.2.2.6).

4.1.5 Rigid Riser Cabling Cabinet

4.1.5.1 In case rigid risers are served by the system, an additional intermediate cabinet shall be supplied to receive all cabling associated with rigid risers. This is termed the Rigid Riser Cabling Cabinet.

4.1.5.2 The Rigid Riser Cabling Cabinet shall be installed side-by-side with the RHMS Cabinet (see previous section), in the same equipment room.
4.1.5.3 The Rigid Riser Cabling Cabinet shall be populated with any equipment deemed necessary to connect and operate monitoring units on rigid risers, such as terminals, converters, power supplies, etc.

4.1.5.4 Cabling between this cabinet and the main RHMS Cabinet shall be employed to make necessary connections for data acquisition.

4.1.5.5 The dimensions of the cabinet shall be 800 mm × 800 mm × 2000 mm (width × depth × height). The cabinet shall have a transparent front door.

4.1.5.6 Cables shall enter the Rigid Riser Cabling Cabinet through the bottom.

4.1.5.7 Mechanical interfaces of the cabinet for floor mounting shall be agreed during execution phase.

4.1.5.8 The cabinet shall be powered by a nominal voltage of 220 V AC (+/- 10%), 50-60 Hz, to be supplied through a cable including a protective earth conductor. Maximum power demanded by the cabinet shall be limited to 4000 W. It shall be treated as a regular load, i.e. neither essential nor emergency.

4.1.5.9 The supplied cabinet shall conform to the applicable FPU cabinet technical specification.

4.1.6 Connection Architecture

4.1.6.1 The interconnection layout of main processing components is illustrated in Figure 13. Communication protocols between the RDCS and the underlying monitoring components shall be defined by the designer, except when otherwise specified. The design shall rely exclusively on the cabling made available for this specific purpose, described in § 4.4 FPU Deck Cabling.

![Connection Architecture Diagram](image)

**Figure 13 — Processing system interconnection architecture**

4.1.6.2 Any protocol converters and network switches shall be off-the-shelf, industrial-grade components. All physical interfaces/cards shall have added redundancy.
4.1.6.3 The supervisory system shall be connected to an FPU network (such as the DMZ). A connection to PETROBRAS corporate network shall be available through firewalls, in accordance to applicable security policies. The RHMS shall be assigned a single fixed IP address, to be defined during execution phase in conjunction with PETROBRAS.

4.1.6.4 The firewalls shall be configured to allow access from the PETROBRAS corporate network to RHMS using the following protocols through any of their standard ports:

- OPC UA-related protocols;
- Windows Remote Desktop services;
- HTTP, HTTPS;
- FTP, FTPS;
- SQL;
- SSH and Telnet.

4.2 FPU Provisions for Hybrid Risers

This section describes FPU provisions which are specific for monitored hybrid riser structures.

4.2.1 Umbilical Junction Box

4.2.1.1 For each hybrid riser, a junction box shall make the connection between deck cables (see § 4.4.4 Hybrid Riser Deck Cabling) and monitoring umbilical cables. These junction boxes shall house any intermediate equipment that otherwise may not be installed in the RHMS Cabinet.

4.2.1.2 The junction box and all accessories shall be certified for explosive atmospheres as required by FPU hazardous area classifications, and with a minimum ingress protection degree of IP 56.

4.2.1.3 The junction boxes shall be supplied with:

- Appropriately-sized cable glands suitable for the hazardous environment and for cables exhibiting cold-flow characteristics;
- All fasteners needed for installation;
- Stopper plugs in sufficient quantity for all holes.

4.2.1.4 Design shall be constrained to a maximum size of 800 mm × 800 mm × 400 mm (width × height × depth) and a maximum weight of 100 kg.

4.2.1.5 A clearance of 1000 mm shall be foreseen in the area underneath the box. The box shall be installed in a location with frontal access.

4.2.1.6 The junction box shall be installed at the riser balcony in a location at most 1 m distant from the upper support reserved for the monitoring umbilical, so as to allow direct connection of umbilical pigtails into the box.
4.2.2 Acoustic Communications

4.2.2.1 One FPU-side (surface) acoustic modem shall be provided for each hybrid riser to provide an acoustic channel for communication with the DAU.

4.2.2.2 Acoustic communications and positioning (see next §) may be integrated in a single device, if such technology is available.

4.2.2.3 The communication protocols used between the acoustic modem and the topside acoustic junction box and then to the RHMS Cabinet shall be compatible with the type and length of specified cabling (as described in § 4.2.6 and § 4.4.5).

4.2.2.4 Specific deployment locations for acoustic communication devices shall be defined during detailed design depending on the subsea layout.

4.2.3 Acoustic Positioning

4.2.3.1 One FPU-side (surface) acoustic positioning transducer shall be provided for each hybrid riser, to work in conjunction with the subsea transponders attached to these structures.

4.2.3.2 The acoustic positioning system shall be based on Ultra-Short Baseline (USBL) technology and use FPU position provided by GPS to compute the absolute position of subsea transponders. There shall be compensation for vessel attitude in determining target positions.

4.2.3.3 Maximum permissible errors in northing and easting, for 1σ coverage probability, shall be of ± 0.3% of slant range.

4.2.3.4 If subsea transponders also have the ability to emit a positioning signal upon reception of an electrical signal (synchronization pulse) when the umbilical connection is available, this shall be the preferred positioning method, for greater accuracy.

4.2.3.5 The communication protocols used between the acoustic positioning transducer and the topside acoustic junction box and then to the RHMS Cabinet shall be compatible with the type and length of specified cabling (as described in § 4.2.6 and § 4.4.5).

4.2.3.6 Specific deployment locations for acoustic positioning devices shall be defined during detailed design depending on the subsea layout.

4.2.4 FPU Mechanical Interfaces

4.2.4.1 FPU-side acoustic modems and positioning transducers shall be deployed in pairs at deployment locations to be defined during the detailed design phase. The number of deployment locations shall be equal to the number of subsea hybrid structures (FSHRs/HRTs or BSRs).
4.2.4.2 At each deployment location, the acoustic devices shall be supported by two structures, as illustrated in Figure 14.

- A permanent structure, shown in teal Figure 14, shall be provided on the FPU hull to support the adaptor which accommodates each pair of acoustic devices. A separate illustration is given in Figure 15.
- Each pair of acoustic devices (positioning transducer and modem) shall be supplied with an adaptor structure, shown in gray in Figure 14, to be seated and fastened onto the FPU-side support.

4.2.4.3 The locations of FPU-side supports shall be defined in agreement with PETROBRAS, considering the need for unobstructed line of sight to subsea structures.

4.2.4.4 The choice of locations for FPU-side supports shall consider the need for at least 1 meter of clearance between the transponders and the FPU hull or any nearby structures.
4.2.4.5 The interface between the adaptor and the FPU-side support shall be based on the drilling pattern of ASME B16.5:2013 class 150 flange, 6-inch, socket welding type.

4.2.4.6 The FPU support interface shall be designed and manufactured in accordance with drawing I-DE-3000.00-5529-850-P6B-001 – FPU Support for Acoustic Devices.

4.2.4.7 Support structures shall be designed considering appropriate materials and techniques for the subsea environment.

4.2.5 Adaptor Structure

4.2.5.1 Each pair of surface acoustic devices (positioning transducer and modem) shall be supplied with an adaptor structure, shown in gray in Figure 14, to be seated and fastened onto the FPU support. An illustration of the coupling between these structures is presented in Figure 16.

![Figure 16 — Sample illustration of coupling between support structures for acoustic transducers](image)

4.2.5.2 The adaptor structure shall be designed for compatibility with the FPU-side support (§ 4.2.4 FPU Mechanical Interfaces).

4.2.5.3 Flange material shall be as specified by ASTM A105, or other mild steel with specified minimum yield stress (SMYS) limited to 280 MPa.

4.2.5.4 The adaptor structure shall accommodate both acoustic devices (positioning transducer and modem) and be designed for their appropriate orientation, tilting and clearance from nearby structures as needed.

4.2.5.5 The adaptor structure shall have two built-in pins instead of holes in the flange positions facing the FPU, as illustrated in Figure 17. The purpose of the pins shall be to provide alignment and to prevent loss of the entire assembly if the fasteners become loose during operation. Dimensions of the pins shall be as given in Figure 18.
Figure 17 — Illustration of adaptor interface

Figure 18 — Dimensions for adaptor structure pins

4.2.5.6 Fasteners shall be supplied along with the adaptor. Bolts shall conform to ASTM A320, grade L7 and nuts shall conform to ASTM A194, grade 4/S. Bolts shall be plated in conformance with ASTM B841, class I, grade 10, type B/E (or ASTM B841 with 8 to 12% nickel, balance in zinc, class I, grade 10, type B), followed by dehydrogenation. Polymeric coatings (e.g. Xylan) shall not be applied to the fasteners, due to prevention of efficient cathodic protection. Other types of fasteners may be proposed and subjected to PETROBRAS approval.

4.2.5.7 The adaptor structure shall be designed considering dynamic loading at the points of attachment to the FPU support.

4.2.5.8 The adaptor structure housing acoustic devices shall be designed and built for installation by divers.

4.2.5.9 A skid shall be designed and supplied for protection of each adaptor structure (complete with installed transducers) during deployment. The skid shall include proper eye bolts for lifting/lowering.

4.2.5.10 Adaptors shall be designed considering appropriate materials and techniques for the subsea environment.
4.2.6 FPU Electrical Interfaces

4.2.6.1 Subsea-grade cables and connectors shall be provided on the FPU hull to connect acoustic devices at each deployment location. The connection scheme is illustrated in Figure 19.

![Diagram of FPU side acoustic devices](image)

Figure 19 — Connection scheme for FPU-side acoustic devices

4.2.6.2 Two (2) hull-side subsea cables shall be run to each deployment location.

4.2.6.3 Each cable shall be run individually through an appropriate closed conduit. The conduit shall be designed to provide mechanical protection to the cable throughout the FPU design life.

4.2.6.4 Both cable ends shall be firmly held by centering elements at the exits of the conduit pipes, in order to avoid damage to the cables due to friction against pipe borders.

4.2.6.5 Each hull-side subsea cable shall meet the following minimum specifications:

- 2 × 4 mm² cross-section power conductors, 0.6/1 kV rating
- 5 × TSPs of 1.5 mm² cross-section for communications, 250 V rating
- Enclosed in PBOF-type hose; other solutions may be proposed and subjected to PETROBRAS approval
4.2.6.6 The subsea end of each cable shall be terminated in a wet-mate connector with protected (non-exposed) electrical contacts, of a type suitable for proper termination of the subsea cable. The connector model shall be chosen during the construction phase in formal consultation with PETROBRAS.

The connector model shall conform to the following requirements: be diver-operated; be suitable for operation in the foreseen environment, with a maximum operating depth of at least 3000 m; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years.

The models listed next are known to fulfill these requirements; other models that meet or exceed the required performance may be proposed and subjected to PETROBRAS approval:

- 12-way Tronic DigiTRON+ Diver Connector Plug
- 12-way ODI Nautilus Manual-Mate Receptacle
- 12-way Seacon CM 2000 Diver Mate Connector (non-exposed pins)

4.2.6.7 Each connector shall be fitted with a dummy connector for protection from the subsea environment until its corresponding jumper is connected. For cable integrity testing purposes, the dummy shall internally connect each pair of pins with a resistor as specified in Table 1.

4.2.6.8 The body of each subsea connector shall be electrically connected to the FPU cathodic protection system if necessary.

4.2.6.9 Each subsea connector shall be fastened to an appropriate supporting plate welded/bolted to the FPU hull at most 2 meters away from the corresponding deployment location.

4.2.6.10 Connections between subsea connector pins and hull cables, for all connector types, shall be as specified in Table 1.

<table>
<thead>
<tr>
<th>Connector Pin Number</th>
<th>Hull Cable Assignment</th>
<th>Dummy Resistance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power conductors</td>
<td>10 kΩ</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Signal TSP 1</td>
<td>15 kΩ</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Signal TSP 2</td>
<td>22 kΩ</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Signal TSP 3</td>
<td>33 kΩ</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Signal TSP 4</td>
<td>47 kΩ</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Signal TSP 5</td>
<td>56 kΩ</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 — Hull connector pin assignment for acoustic systems

4.2.6.11 On the topside, each hull-side subsea cable shall be terminated inside a junction box (see next §).
4.2.7 Acoustic Systems Junction Boxes

4.2.7.1 For each deployment location, a deck junction box shall make the connection between deck cables (see § 4.4.5 Acoustic Systems Deck Cabling) and cables to acoustic equipment. These junction boxes shall house any intermediate equipment that otherwise may not be installed in the RHMS Cabinet.

4.2.7.2 The location of each junction box (on the deck) shall be chosen to be as near as possible to the corresponding deployment location.

4.2.7.3 The junction box and all accessories shall be certified for explosive atmospheres as required by FPU hazardous area classifications and with a minimum ingress protection degree of IP 56.

4.2.7.4 The junction boxes shall be supplied with:

- Appropriately-sized cable glands suitable for the hazardous environment and for cables exhibiting cold-flow characteristics;
- All fasteners needed for installation;
- Stopper plugs in sufficient quantity for all holes.

4.2.7.5 Design shall be constrained to a maximum size of 800 mm × 800 mm × 400 mm (width × height × depth) and a maximum weight of 100 kg.

4.2.7.6 A clearance of 1000 mm shall be foreseen in the area underneath the box. The box shall be installed in a location with frontal access.

4.2.8 Electrical Connection Jumpers

4.2.8.1 Each acoustic device shall be supplied with an appropriate subsea jumper terminated in a diver-mate connector compatible with the ones provided on the FPU side. The connector model shall be defined during project execution in formal consultation with PETROBRAS.

The connector model shall conform to the following requirements: be diver-operated; be suitable for operation in the foreseen environment, with a maximum operating depth of at least 3000 m; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years.

The models listed next are known to fulfill these requirements; other models that meet or exceed the required performance may be proposed and subjected to PETROBRAS approval:

- 12-way Tronic DigiTRON+ Diver Connector Receptacle
- 12-way ODI Nautilus Manual-Mate Plug
- 12-way Seacon CM 2000 Diver Mate Connector (exposed pins)

4.2.8.2 The jumper shall be designed considering the connection scheme specified in § 4.2.6 FPU Electrical Interfaces.
4.2.8.3 Appropriate mechanisms to fasten the jumpers to the adaptor structure shall be provided, in order to avoid damage due to sway or abrasion.

4.3 FPU Provisions for Rigid Risers

This section describes FPU provisions which are specific for monitored rigid risers. In case PETROBRAS requests that provisions be made for future rigid risers at given locations, the scope presented in this section shall be executed accordingly.

4.3.1 FPU Hull Cables and Connectors

4.3.1.1 A subsea-grade cable and connector shall be provided on the FPU hull for connecting monitoring units attached to each rigid riser. The connection scheme is illustrated in Figure 20.

![Figure 20 — Rigid riser connection scheme](image)

4.3.1.2 One subsea cable shall be run to each rigid riser support location.

4.3.1.3 Each hull-side subsea cable shall be run individually through an appropriate closed conduit. The conduit shall be designed to provide mechanical protection to the cable throughout the FPU design life.

4.3.1.4 Conduit inner diameter and path shall be chosen to allow free passage of the cable during installation (without the risk of tearing or rupturing), respecting the minimum bending radius (MBR) and mechanical resistance of the cable.

4.3.1.5 Both ends of the cable shall be firmly held by centering elements at the exits of the conduit pipe, in order to avoid damage to the cables due to friction against pipe borders.
4.3.1.6 Each hull-side subsea cable shall meet the following minimum specifications:

- 2 × 4 mm² cross-section power conductors, 0.6/1 kV rating
- 5 × TSPs of 1.5 mm² cross-section for communications, 250 V rating
- Enclosed in PBOF-type hose; other solutions may be proposed and subjected to PETROBRAS approval

4.3.1.7 The subsea end of the cable shall be terminated in a wet-mate connector with protected (non-exposed) electrical contacts, of a type suitable for proper termination of the subsea cable. The connector model shall be chosen during the construction phase in formal consultation with PETROBRAS.

The connector model shall conform to the following requirements: be diver-operated; be suitable for operation in the foreseen environment, with a maximum operating depth of at least 3000 m; be able to withstand at least 100 connection/disconnection cycles; have a design life of at least 25 years.

The models listed next are known to fulfill these requirements; other models that meet or exceed the required performance may be proposed and subjected to PETROBRAS approval:

- 12-way Tronic DigiTRON+ Diver Connector Plug
- 12-way ODI Nautilus Manual-Mate Receptacle
- 12-way Seacon CM 2000 Diver Mate Connector (non-exposed pins)
4.3.1.8 Near each wet-mate connector (at the end of the hull-side cable) on the lower riser balcony, a tray shall be installed to guide and support the intermediate section of the jumper between riser sensors/components and the corresponding hull connector. Examples are given in Figure 21, Figure 22 and Figure 23. The final design shall be submitted for PETROBRAS approval.

Figure 21 – Sample side view of cable tray on lower riser balcony (shown in teal color)

Figure 22 – Sample close-up view of cable tray on lower riser balcony (shown in teal color)
4.3.1.9 Each connector shall be fitted with a dummy connector for protection from the subsea environment until its corresponding jumper is connected. For cable integrity testing purposes, the dummy shall internally connect each pair of pins with a resistor as specified in Table 2.

4.3.1.10 The body of each subsea connector shall be electrically connected to the FPU cathodic protection system if necessary.

4.3.1.11 Each subsea connector shall be fastened to an appropriate supporting plate welded/bolted to the FPU hull at most 2 meters away from the riser support (e.g. lower I-tube) location.

4.3.1.12 Connections between subsea connector pins and hull cable conductors, for all connector types, shall be as specified in Table 2.

<table>
<thead>
<tr>
<th>Connector Pin Number</th>
<th>Hull Cable Assignment</th>
<th>Dummy Resistance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power cable</td>
<td>10 kΩ</td>
</tr>
<tr>
<td>3</td>
<td>Signal cable TSP 1</td>
<td>15 kΩ</td>
</tr>
<tr>
<td>5</td>
<td>Signal cable TSP 2</td>
<td>22 kΩ</td>
</tr>
<tr>
<td>7</td>
<td>Signal cable TSP 3</td>
<td>33 kΩ</td>
</tr>
<tr>
<td>9</td>
<td>Signal cable TSP 4</td>
<td>47 kΩ</td>
</tr>
<tr>
<td>11</td>
<td>Signal cable TSP 5</td>
<td>56 kΩ</td>
</tr>
</tbody>
</table>

Table 2 — Hull connector pin assignment for rigid riser slots
4.3.1.13 On the topside, each hull-side subsea cable shall be connected to the corresponding deck cables. Refer to § 4.4.3 Rigid Riser Deck Cabling.

4.3.1.14 In case PETROBRAS requests that preparations be made for future rigid risers at given locations, the scope presented in this section shall be executed accordingly.

4.4 FPU Deck Cabling

4.4.1 General Requirements

4.4.1.1 Cabling shall be designed in accordance with international standards. In no occasion shall the design or installation of any item described herein infringe norms or standards in force at the FPU.

4.4.1.2 Connectors/terminations shall be properly protected from exposure before final assembly to junction boxes and other equipment.

4.4.1.3 Cables shall be properly identified with visible tags.

4.4.1.4 Individual cables within a bundle (multi-cable) shall be properly identified on both ends, through tags or color coding.

4.4.1.5 Cabling shall conform to the IEC 60502-1 standard.

4.4.2 Common Deck Cabling

4.4.2.1 The following minimum cabling interfaces shall be available for the topside monitoring system units common to all configurations.

<table>
<thead>
<tr>
<th>Cable Specification</th>
<th>No. of Runs</th>
<th>From/To</th>
<th>Termination</th>
<th>Intended Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shielded category 6 Ethernet cable</td>
<td>2 (1 spare)</td>
<td>RHMS Cabinet location to FPU network switch</td>
<td>Standard RJ-45 connector on RHMS Cabinet end</td>
<td>FPU network connection</td>
</tr>
<tr>
<td>Signal – 3 TSPs 1.5 mm²</td>
<td>2 (1 spare)</td>
<td>RHMS Cabinet location to FPU positioning system</td>
<td>–</td>
<td>Positioning data acquisition</td>
</tr>
</tbody>
</table>

Table 3 — Common topside cabling interfaces
4.4.3 Rigid Riser Deck Cabling

4.4.3.1 For each monitored rigid riser, the following minimum cabling interfaces shall be available.

<table>
<thead>
<tr>
<th>Cable Specification</th>
<th>No. of Runs</th>
<th>From/To</th>
<th>Termination</th>
<th>Intended Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power – 2 cores 4 mm² 0.6/1 kV rating</td>
<td>1</td>
<td>Rigid Riser Cabling Cabinet location to junction with each subsea cable</td>
<td>Connected to corresponding subsea cable, on area end</td>
<td>Power for rigid riser monitoring equipment</td>
</tr>
<tr>
<td>Signal – 5 TSPs 1.5 mm² 250 V rating</td>
<td>1</td>
<td>Rigid Riser Cabling Cabinet location to junction with each subsea cable</td>
<td>Connected to corresponding subsea cable, on area end</td>
<td>Communications to rigid riser monitoring equipment</td>
</tr>
</tbody>
</table>

Table 4 — Topside cabling interfaces for rigid risers

4.4.3.2 Each deck cable meant for a rigid riser shall be connected, in a conductor-by-conductor basis, to the corresponding hull cable at a convenient junction box, as shown in Figure 24. Refer to § 4.3.1 FPU Hull Cables and Connectors for details on hull cables.

4.4.3.3 All corresponding shields belonging to each cable (deck vs. subsea) shall also be interconnected at the junction point.

4.4.3.4 In case PETROBRAS requests that preparations be made for future rigid risers at given locations, the scope presented in this section shall be executed accordingly.
4.4.4 Hybrid Riser Deck Cabling

4.4.4.1 For each monitored hybrid riser, the following minimum cabling interfaces shall be available.

<table>
<thead>
<tr>
<th>Cable Specification</th>
<th>No. of Runs</th>
<th>From/To</th>
<th>Termination</th>
<th>Intended Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power – 4 cores 6 mm² 0.6/1kV rating</td>
<td>1</td>
<td>RHMS Cabinet location to each umbilical JB location</td>
<td>Protection against exposure</td>
<td>Power for subsea monitoring equipment</td>
</tr>
<tr>
<td>Signal – 8 TSPs 1.5 mm² 250 V rating</td>
<td>1</td>
<td>RHMS Cabinet location to each umbilical JB location</td>
<td>Protection against exposure</td>
<td>Communications for subsea monitoring equipment</td>
</tr>
<tr>
<td>Fiber optic – 4 cores 50/125 μm multimode, compatible with Ethernet 100BASE-FX</td>
<td>1</td>
<td>RHMS Cabinet location to each umbilical JB location</td>
<td>SC-type connectors on both ends, protection against exposure</td>
<td>Communications for subsea monitoring equipment</td>
</tr>
</tbody>
</table>

Table 5 — Topside cabling interfaces for hybrid risers

4.4.5 Acoustic Systems Deck Cabling

4.4.5.1 The following cabling interfaces shall be available for each acoustic junction box.

<table>
<thead>
<tr>
<th>Cable Specification</th>
<th>No. of Runs</th>
<th>From/To</th>
<th>Termination</th>
<th>Intended Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power – 6 cores 4 mm² 0.6/1 kV rating</td>
<td>1</td>
<td>RHMS Cabinet location to each acoustic JB location</td>
<td>Protection against exposure</td>
<td>Power for acoustic equipment</td>
</tr>
<tr>
<td>Signal – 10 TSPs 1.5 mm² 250 V rating</td>
<td>1</td>
<td>RHMS Cabinet location to each acoustic JB location</td>
<td>Protection against exposure</td>
<td>Communications for acoustic equipment</td>
</tr>
<tr>
<td>Fiber optic – 8 cores 50/125 μm, multimode, compatible with Ethernet 100BASE-FX</td>
<td>1</td>
<td>RHMS Cabinet location to each acoustic JB location</td>
<td>SC-type connectors on both ends, protection against exposure</td>
<td>Communications for acoustic equipment</td>
</tr>
</tbody>
</table>

Table 6 — Topside cabling interfaces for acoustic systems
5 FABRICATION, QUALIFICATION, TESTING AND CALIBRATION REQUIREMENTS

5.1 Design and Fabrication

5.1.1.1 All subsea equipment shall be designed in accordance with ISO 13628-6:2006.

5.1.1.2 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.

5.1.1.3 All enclosures and equipment to be placed in hazardous areas shall comply with IEC 60079 (latest revision).

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

5.1.1.5 A length of at least 500 m shall be considered for all FPU deck cables in electrical and communication analyses.

5.1.1.6 A length of at least 60 m shall be considered for all FPU hull cables in electrical and communication analyses.

5.1.1.7 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 Testing

5.2.1 Subsea Equipment

5.2.1.1 All subsea equipment shall be qualified in accordance with ISO 13628-6:2006, § 11.2.

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

5.2.2 FPU Equipment

5.2.2.1 All equipment installed in hazardous areas (explosive atmospheres) shall be certified according to IEC 60079 (latest revision).

5.3 Factory Acceptance Testing

5.3.1 General Requirements for Subsea Equipment

5.3.1.1 All subsea equipment (including deliverable spares) shall undergo factory acceptance testing in accordance with ISO 13628-6:2006, § 11.3.
5.3.1.2 All sensors shall be calibrated. Calibration reports shall be presented to demonstrate performance requirements are met.

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

5.3.1.4 Dimensional and electrical checks shall be performed on all units.

5.3.1.5 Specific requirements are detailed in the next sections.

5.3.2 FSHR/HRT/BSR Thrust Measurement

5.3.2.1 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.

5.3.3 SCR/SLWR Strain Measurement Sensors

5.3.3.1 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.

5.4 System Integration Testing

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

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

5.4.1.3 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.

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

5.4.1.5 Simulators may be used in place of the FPU positioning system, deck and hull cabling, and the umbilical. Simulators for cables and umbilical shall be RLC circuits.

5.4.1.6 The proper operation of external data interfaces (OPC UA) shall be attested with a connection to a test computer running client data acquisition software.
6 INSTALLATION AND COMMISSIONING REQUIREMENTS

6.1.1.1 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.

6.1.1.2 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.

6.1.1.3 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.

6.1.1.4 The system shall be delivered with all configurable parameters (such as alarms, safe limits and calibration coefficients) preset to correspond to the riser design data.

6.1.1.5 FPU components (refer to § 4 FPU 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.

6.1.1.6 For hybrid risers, commissioning of the monitoring system shall be performed in two steps: (1) for acoustic communications mode, immediately after riser/BSR installation; and (2) for umbilical mode, after umbilical installation.

6.1.1.7 For rigid risers, the commissioning schedule 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 ASSISTED OPERATION

7.1.1.1 Assisted operation shall be performed in two separate periods. For the length of each period, one technician with thorough knowledge of the system shall be assigned to board the FPU and assist PETROBRAS with initial system operation.

7.1.1.2 One assisted operation period, with duration of 4 days, shall occur immediately after the first riser is commissioned. If only one riser is in the contracted scope, then this clause does not apply and a single assisted operation period shall be executed in accordance with the next clause.

7.1.1.3 One assisted operation period, with duration of 7 days, shall occur after the last riser is commissioned (end of the installation campaign).
8 DOCUMENTATION REQUIREMENTS

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

8.1.1.2 All documentation delivered to PETROBRAS shall conform to the following standards:

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

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

8.1.1.4 The RHMS 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;
- Complete descriptions of all communication protocols used between equipment;
- Detailed definition and specification of the alarm system designed for the supervisory system;
- 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 diving operations to be executed by the DIVING TEAM;
- Detailed test and commissioning procedures and reports;
- System operation and maintenance manuals;
- Training plan.
9 TRAINING REQUIREMENTS

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

9.1.1.2 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.

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

9.1.1.4 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 (equipment retrieval and installation and RCT operation);
- Supervisory system operation;
- Storage and conservation of spare equipment.
10 SCOPE OF SUPPLY & WORK

The scope of supply & work to be executed by each involved party is described in this section. The PETROBRAS material requisition will inform the types and quantities of risers within the scope of supply & work.

Annex D: Scope of Work Drawings presents drawings intended to aid in comprehending the scope of work, but which in no way override or substitute any textual requirements.

10.1 RISER CONTRACTOR

10.1.1 General/Common Scope

This scope is applicable in all cases. General requirements applicable to all tasks described in the next sections are also included here.

10.1.1.1 For each FPU: design, supply and install the topside processing system as described in § 4.1.

10.1.1.2 Provide terminations to deck cables whenever needed.

10.1.1.3 Execute fabrication, qualification, testing and calibration tasks in accordance with the requirements presented in § 5. Any required simulators shall also be provided by RISER CONTRACTOR.

10.1.1.4 Execute installation and commissioning as described under § 6. RISER CONTRACTOR shall provide all tools, accessories and consumables required for these activities.

10.1.1.5 Provide assisted operation as described under § 7.

10.1.1.6 Provide documentation as described under § 8.

10.1.1.7 Provide training as described under § 9.

10.1.2 Hybrid Riser Scope

This section is applicable when the contracted scope includes one or more hybrid riser systems.

10.1.2.1 For each hybrid riser: execute design, supply and installation scope of all components described in § 3.2, except for the installation of umbilicals (described in § 3.2.7).

10.1.2.2 For each FPU: design and supply one complete set of RCT components as described in § 3.3.

10.1.2.3 Design, supply and install umbilical junction boxes as described in § 4.2.1.
10.1.2.4 Supply FPU-side acoustic systems and all associated components, as described in § 4.2.2, 4.2.3, 4.2.5, 4.2.7 and 4.2.8, including (but not limited to) design and supply of:

- Junction boxes;
- Adaptor structures, complete with all fastening components and deployment skids;
- Electrical jumpers.

10.1.2.5 Install junction boxes for FPU-side acoustic systems, which includes performing cable connections, as described in § 4.2.7.

10.1.2.6 Provide assistance, with an offshore technician, for diver operations for installation of FPU-side acoustic devices as described in § 6.

10.1.2.7 For each FPU, supply the following spare units related to hybrid risers (BSR or FSHR/HRT):

- One cable gland of each type for each supplied junction box
- 1 × DAU
- 1 × subsea acoustic positioning transponder
- 1 × subsea acoustic modem
- 1 × battery module
- 1 × signal conditioning unit for thrust measurement per hybrid riser
- 2 × EFLs of each type, per hybrid riser
- 1 × FPU-side acoustic positioning transducer
- 1 × FPU-side acoustic modem
- 1 × interconnection jumper of each type for FPU-side acoustic systems
- In the case of FSHR/HRT, 1 set of buoyancy tank thrust load sensors, comprising 6 individual load sensors.
- In the case of BSR, 4 sets of buoyancy tank thrust load sensors, each comprising 2 individual load sensors.

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.

10.1.3 Rigid Riser Scope

This section is applicable when the contracted scope includes one or more rigid risers.

10.1.3.1 For each rigid riser: execute design, supply and installation scope of all components described in § 3.1, except for the installation of IMUs (described in § 3.1.1) and associated components (clamps, interconnection jumpers) onto rigid risers supported directly from the FPU.
Note: installation of inclination measurement units onto rigid risers supported from BSRs is still RISER CONTRACTOR responsibility.

10.1.3.2 Design, supply and install the Rigid Riser Cabling Cabinet, as described in § 4.1.5.

10.1.3.3 Define, supply and install any necessary interconnecting cabling between the Rigid Riser Cabling Cabinet and the RHMS Cabinet.

10.1.3.4 For each FPU: supply one (1) tool for measuring clamp misalignment on rigid risers, as described in Annex B: Rigid Riser Top Angles Calculation.

10.1.3.5 Provide assistance, with an offshore technician, for diver operations for installation of monitoring units onto rigid risers as described in § 6.

10.1.3.6 For each FPU, supply the following spare units related to rigid risers:

- 2 × rigid riser IMUs; or, if different models are used, one spare unit of each model shall be supplied
- 1 × IMU clamp of each type
- 1 × top strain measurement signal conditioning unit
- 2 × connection jumpers/harnesses of each type

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 General/Common Scope

This scope is applicable in all cases. General requirements applicable to all tasks described in the next sections are also included here.

10.2.1.1 Supply all deck cabling required in this and subsequent sections in accordance with the requirements presented in § 4.4.1.

10.2.1.2 Supply and install all common deck cabling, including terminations, as described in § 4.4.2.

10.2.1.3 Provide continuous transmission of FPU positioning system data to the riser monitoring system as specified in item 4.1.2.2, including cable connections to the FPU POS cabinet (see § 4.4.2).

10.2.1.4 Provide space and facilities (infrastructure) for the RHMS Cabinet, considering the requirements described in § 4.1.4.

10.2.1.5 Provide a network connection to the RHMS Cabinet, considering the requirements in items 4.1.6.3 and 4.1.6.4. This shall include configuration of firewalls and allocation of network addresses.
10.2.1.6 Provide assistance to all activities to be performed by the RISER CONTRACTOR aboard the FPU, including crane operation, transportation of loads (cabinets, junction boxes, etc.), heavy mechanical installations (such as of junction boxes, cabinets, etc.) and issuance of work permits when needed.

10.2.1.7 Provide documentation from the FPU side with all information needed for the design of the monitoring system, including but not limited to: cabling information, wiring diagrams, area classification, mechanical and electrical interfaces.

10.2.2 Hybrid Riser Scope

This scope is applicable when the design of the FPU includes provisions for one or more hybrid risers.

10.2.2.1 Supply and install all deck cabling, including terminations, as described in § 4.4.4 and § 4.4.5.

10.2.2.2 Provide space and a mounting support for each umbilical JB considering the requirements described in § 4.2.1.

10.2.2.3 Design, build and install FPU-side interfaces for acoustic systems, as described in § 4.2.4 and 4.2.6.

10.2.2.4 Provide space and a mounting support for each acoustic JB considering the requirements described in § 4.2.7.

10.2.3 Rigid Riser Scope

This scope is applicable when the design of the FPU includes provisions for one or more rigid risers.

10.2.3.1 Supply and install all deck cabling, including terminations, as described in § 4.4.3.

10.2.3.2 Design, supply and install FPU provisions for each rigid riser as described in § 4.3.

10.2.3.3 Provide connections between deck cables and hull/subsea cables for rigid risers, as described in § 4.4.3.

10.2.3.4 Provide space and facilities (infrastructure) for the Rigid Riser Cabling Cabinet, considering the requirements described in § 4.1.5.

10.3 PETROBRAS

10.3.1.1 Install umbilicals supplied by the RISER CONTRACTOR, described in § 3.2.7, unless otherwise informed in the bid documentation.
10.4 DIVING TEAM

The party responsible for the activities described herein shall be defined elsewhere in contract documents.

10.4.1.1 Execute diving operations to install monitoring components (top inclination measurement units, clamps and interconnecting jumpers, supplied by the RISER CONTRACTOR) onto rigid risers supported directly by the FPU, as described in § 3.1.

10.4.1.2 Execute diving operations to measure misalignment of rigid riser IMUs as described in § 3.1.1 and Annex B: *Rigid Riser Top Angles Calculation*, following procedures provided by the RISER CONTRACTOR.

10.4.1.3 Execute diving operations to install the FPU-side acoustic transducers and related components/accessories, described in § 4.2.2, 4.2.3, 4.2.4, 4.2.5, 4.2.6 and 4.2.8, to their respective mechanical and electrical interfaces on the FPU.
### ANNEX A: OPC INTERFACE REQUIREMENTS

#### A.1 Data Tags

**A.1.1** Table 7 presents the minimum set of standard data tags that shall be logged by the historian data base (HDB) and published through the OPC UA Data Access (for real-time data) and Historical Access (for historical data) interfaces.

**A.1.2** Additional tags may be included as required.

**A.1.3** Placeholders for indices in variable tags (e.g. lower-case \( n \) and \( i \)) shall be substituted for the respective numbers, formatted in decimal base with no leading zeroes (e.g. 1, 2, 3, ...).

<table>
<thead>
<tr>
<th>Tag</th>
<th>Data Type</th>
<th>Description</th>
<th>Unit</th>
<th>Alarm Type</th>
<th>OPC Alarm Source Logged in HDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHMS_INTERF_REV</td>
<td>8-bit integer</td>
<td>RHMS interface revision (constant) Must be 2 for this version</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NHM_HVB</td>
<td>8-bit integer</td>
<td>Number of monitored hybrid risers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRM_RIG</td>
<td>8-bit integer</td>
<td>Number of monitored rigid risers</td>
<td>Valid indices ( m ) for hybrid riser data tags ( \text{HYB}_n _xxx ) shall be in the range 1..N_HVB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPU_EASTING</td>
<td>32-bit floating-point</td>
<td>PPU absolute easting, as supplied by POS system</td>
<td>m</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>FPU_NORTHING</td>
<td>32-bit floating-point</td>
<td>PPU absolute northing, as supplied by POS system</td>
<td>m</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>FPU_ROLL</td>
<td>32-bit floating-point</td>
<td>PPU roll angle, as supplied by POS system</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>FPU_PITCH</td>
<td>32-bit floating-point</td>
<td>PPU pitch angle, as supplied by POS system</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>FPU_HEADING</td>
<td>32-bit floating-point</td>
<td>PPU heading with respect to true north, as supplied by POS system</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>HYB_n_NAME</td>
<td>String</td>
<td>Hybrid riser descriptive name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYB_n_NUM_TETHER_STRAIN</td>
<td>8-bit integer</td>
<td>Hybrid riser n number of tether/bendon strain sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYB_n_TETHER_STRAIN_l</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n raw tether/bendon strain measurement ( \text{LL/L only} )</td>
<td>( \mu \text{strain} )</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>HYB_n_TETHER_TEMP</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n tether/bendon temperature</td>
<td>°C</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>HYB_n_THRUST</td>
<td>8-bit integer</td>
<td>Hybrid riser n horizontal thrust</td>
<td>kN</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>HYB_n_AIRS</td>
<td>Boolean</td>
<td>Whether hybrid riser n has an AHRS unit (BSR or HRT only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYB_n_DAU_ROLL (1)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS roll angle</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>HYB_n_DAU_PITCH (1)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS pitch angle</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>HYB_n_DAU_HEADING (2)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS heading with respect to true north</td>
<td>°</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>HYB_n_DAU_DEPTH</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU depth measured with depth meter</td>
<td>m</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_NAME</td>
<td>String</td>
<td>Hybrid riser n descriptive name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_NUM_TETHER_STRAIN</td>
<td>8-bit integer</td>
<td>Hybrid riser n number of tether/bendon strain sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_TETHER_STRAIN_l</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n raw tether/bendon strain measurement ( \text{LL/L only} )</td>
<td>( \mu \text{strain} )</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_TETHER_TEMP</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n tether/bendon temperature</td>
<td>°C</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>RIG_n_THRUST</td>
<td>8-bit integer</td>
<td>Hybrid riser n horizontal thrust</td>
<td>kN</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_AIRS</td>
<td>Boolean</td>
<td>Whether hybrid riser n has an AHRS unit (BSR or HRT only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_DAU_ROLL (1)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS roll angle</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_DAU_PITCH (1)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS pitch angle</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_DAU_HEADING (2)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU/ARPS heading with respect to true north</td>
<td>°</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_DAU_DEPTH</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n DAU depth measured with depth meter</td>
<td>m</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_STRAIN_MON</td>
<td>8-bit integer</td>
<td>Hybrid riser n number of position transponders</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>RIG_n_NUM_POS</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n Transponder/absolute northing (SIRGAS), before filtering</td>
<td>i = 1..RIG_n_NUM_POS</td>
<td>m</td>
<td>&quot;RIG_n&quot;</td>
</tr>
<tr>
<td>RIG_n_NUM_POS</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n Transponder/absolute easting (SIRGAS), before filtering</td>
<td>i = 1..RIG_n_NUM_POS</td>
<td>m</td>
<td>&quot;RIG_n&quot;</td>
</tr>
<tr>
<td>RIG_n_NUM_POS</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n Transponder/absolute northings (SIRGAS), post-filtering</td>
<td>i = 1..RIG_n_NUM_POS</td>
<td>m</td>
<td>&quot;RIG_n&quot;</td>
</tr>
<tr>
<td>RIG_n_NUM_POS</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n Transponder/absolute eastings (SIRGAS), post-filtering</td>
<td>i = 1..RIG_n_NUM_POS</td>
<td>m</td>
<td>&quot;RIG_n&quot;</td>
</tr>
<tr>
<td>RIG_n_TENSION</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n position transponder / depth</td>
<td>i = 1..RIG_n_NUM_POS</td>
<td>m</td>
<td>Range</td>
</tr>
<tr>
<td>RIG_n_BATT_CHARGE</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n Battery module remaining charge, in the range 0..100%</td>
<td>%</td>
<td>Range, LLS only</td>
<td></td>
</tr>
<tr>
<td>RIG_n_NAME</td>
<td>String</td>
<td>Hybrid riser n descriptive name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_ROLL</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n filtered roll angle at reference frame</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_PITCH</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n filtered pitch angle at reference frame</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_STAION_MON</td>
<td>Boolean</td>
<td>Whether strain monitoring is implemented for rigid riser</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_NUM_STRAIN</td>
<td>8-bit integer</td>
<td>Hybrid riser n number of pipe temperature sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_TEMPERATURE (1)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n pipe temperature measurement</td>
<td>( \mu \text{ strain} )</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_NUM_STRAIN</td>
<td>8-bit integer</td>
<td>Hybrid riser n number of longitudinal/hoop strain sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_RAW_LONG_STRAIN</td>
<td>32-bit integer</td>
<td>Hybrid riser n raw quantized (ADAC) longitudinal strain value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_RAW_HOOD_STRAIN</td>
<td>32-bit integer</td>
<td>Hybrid riser n raw quantized (ADAC) hoop strain value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIG_n_RAW_LONG_STRAIN (2)</td>
<td>32-bit integer</td>
<td>Hybrid riser n raw longitudinal strain measurement</td>
<td>( \mu \text{ strain} )</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_RAW_HOOD_STRAIN (2)</td>
<td>32-bit integer</td>
<td>Hybrid riser n raw hoop strain measurement</td>
<td>( \mu \text{ strain} )</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_MAX_BENDING_STRESS (2)</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n maximum bending stress calculated from pipe model</td>
<td>kN/m²</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_AXIAL_TENSION</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n axial tension calculated from pipe model</td>
<td>kN</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_BENDING_MOMENT</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n bending moment calculated from pipe model</td>
<td>kN/m</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>RIG_n_BENDING_DIR</td>
<td>32-bit floating-point</td>
<td>Hybrid riser n bending direction</td>
<td></td>
<td>Range</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

1. Applicable for BSRs or HRTs only (which are fitted with an AHRS), as indicated by tag \( \text{HYB}_n \_AIRS \).
2. Applicable for strain-monitored rigid risers only, as indicated by tag \( \text{RIG}_n \_STRAIN_MON \).

Table 7 — Standard data tags
ANNEX B: RIGID RISER TOP ANGLES CALCULATION

B.1.1 Top inclination angles shall be reported in the order yaw-pitch-roll, that is, extrinsic rotations around axes z, y and x in that order. For each riser, the reference frame shall be defined as follows (see Figure 25).

- 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 25 — Illustration of coordinate system for rigid riser top angle calculation](image)

B.1.2 Corrections shall be carried out to compensate for the misalignment of the IMU around the riser (see Figure 26) so that pitch and roll angles are measured in the reference frame defined in B.1.1.

![Figure 26 — Illustration of IMU misalignment with respect to rigid riser catenary plane](image)
In order to measure the angle of misalignment ($\beta$) for each IMU, a specific measurement tool shall be designed to be inserted firmly into the same clamp receptacle housing the IMU for each riser.

This tool shall be equipped with an AHRS able to position the clamp with respect to a known referential (the FPU reference frame for instance). Maximum permissible errors, for 95% coverage probability, shall be:

- Roll and pitch: $\pm 0.05^\circ$
- Heading: $\pm 0.3^\circ$ secant latitude

The mechanical interface for the measurement tool shall be keyed so as to ensure proper alignment when inserted in the clamp receptacle, in the same orientation as the IMU.

The misalignment measurement tool shall be contained in a lightweight subsea enclosure, weighing up to 10 kg in water (with the addition of built-in buoyancy if necessary), and allowing operation at a depth of up to 50 meters.

The misalignment measurement tool shall be powered by rechargeable batteries allowing up to 2 hours of autonomous operation; no power or data connections to surface shall be necessary during diver operations.

The misalignment measurement tool shall present external 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 connectors shall be properly covered with caps during underwater deployment.

The tool’s weight, size and format shall be designed to be suitable and safe for diver operation.

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

All necessary calculations for correction of inclination measurements, given the determined misalignment angle for each riser, shall be implemented in the RDCS.
ANNEX C: RIGID RISER STRESS CALCULATION ALGORITHM

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

C.1 Requirements

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

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

C.2 Inputs

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

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

C.3 Algorithm Steps

C.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 ($\epsilon_{\ell_i,\text{raw}}$) from each sensor around the riser pipe shall be acquired and properly converted using stored calibration data.

   The individual raw strain readings $\epsilon_{\ell_i,\text{raw}}$ shall be output as data tags RIG$_n$$_n$$_n$$_n$ LONG STRAIN$_i$.
2. Raw hoop strain readings ($\varepsilon_{hi,raw}$) from each sensor (strain gauge) around the riser pipe shall be acquired and properly converted using stored calibration data. The individual raw strain readings $\varepsilon_{hi,raw}$ shall be output as data tags RIG_n_HOOP_STRAIN_i.

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

$$
\varepsilon_{li} = \varepsilon_{li,raw} - \alpha(T - T_0)
$$

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

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

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

5. Longitudinal and hoop stresses shall be calculated as:

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

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

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

$$\sum_{i=1}^{N_f} (\sigma_{fi} - \sigma_{fit}(x_i, y_i))^2$$

Where $\sigma_{fit}(x, y) = a + bx + cy$ is the plane fit function at point $(x, y)$. Let matrix $M$ be defined as

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

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

$$\phi_{fi} = \frac{2\pi(i - 1)}{N_f}$$

$$x_i = R \cos(\phi_{fi})$$

$$y_i = R \sin(\phi_{fi})$$

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

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = M^+ \begin{bmatrix} \sigma_{f1} \\ \sigma_{f2} \\ \vdots \\ \sigma_{fN_{sens}} \end{bmatrix}$$

Where the operator $[\ ]^+$ 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.

![Plane fit](image)

**Figure 29 — 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 30 — Illustration of longitudinal stress profile (side view)](image)

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:

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

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 31.

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

---

$^1$ atan2$(x,y)$ is formally defined as:

$$\text{atan2}(y,x) = \begin{cases} 
\arctan\left(\frac{y}{x}\right) & x > 0 \\
\arctan\left(\frac{y}{x}\right) + \pi & y \geq 0, x < 0 \\
\arctan\left(-\frac{y}{x}\right) - \pi & y < 0, x < 0 \\
\frac{\pi}{2} & y > 0, x = 0 \\
-\frac{\pi}{2} & y < 0, x = 0 \\
\text{undefined} & y = 0, x = 0 
\end{cases}$$
From the calculated stresses, the overall axial tension $F_a$ and bending moment $M_b$ shall be computed:

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

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

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.
ANNEX D: SCOPE OF WORK DRAWINGS

This annex presents pictorial representations of the scope of work of each involved party. The drawings presented herein are intended for guidance and to aid in understanding the scope division only.

Any disagreement with the remainder of this Technical Specification is unintentional, and the requirements presented textually elsewhere in this document override any information presented in the drawings.

The drawings are shown in the next pages.
D.1 Design & Supply Scope

- Motion/Heading Measurement (for HRT and BSR only)
- Depth Measurement
- Acoustic Communication
- Data Acquisition Unit (DAU)
- Power/comms umbilical SUT (Subsea Umbilical Termination - Integral to Umbilical)
- Buoyancy Tank
- Thrust Measurement
- Power/comms from ROV
- Acoustic Positioning
- Batteries
- Subsea cables
- Hull conduits
- Diver-mate connectors
- Protected pins on FPU side
- Acoustic Modem
- Acoustic Positioning Transducer
- FPU support structure
- Subsea cable
- Hull conduit
- Diver-mate connectors
- Top Motion Measurement
- Strain Measurement (where applicable)
- Protected pins on FPU side
- Umbilical end FPU power 220 VAC
- FPU POS data cables:
  - 2 x 3 x TSP
- Cabinet network connection:
  - 2 x Cat 6 Ethernet
- Umbilical JB cables:
  - 4 x power cores
  - 8 x TSP
  - 4 x FO
- Rigid riser cables:
  - 2 x power cores
  - 5 x TSP
- Acoustic system cables:
  - 6 x power cores
  - 10 x TSP
  - 8 x FO
- RHMS Cabinet
- FPU POS
- FPU Network Switch / Firewall
- Umbilical JB
- RCT laptop
- ROV umbilical

See § 3.3
See § 3.2
See § 3.1
See § 4.3
See § 4.2
See § 3.2.7
See § 4.2.1
See § 4.4.3
See § 4.4.4
See § 4.4.5
See § 4.3.1
See § 4.1.5
See § 4.1.4
See § 4.2.4
See § 4.2.6
See § 4.2.7

LEGEND
- RISER CONTRACTOR
- FPU CONTRACTOR
- PETROBRAS
- SPACE & SUPPORT
- MONITORING UNITS ON SCRS (FOR BSR ONLY)
- Rigid Riser Cabling Cabinet (if applicable)
- Interconnecting cables
- FPU power 220 VAC
- See § 4.1.5
D.2 Installation Scope

**Title:**
Rig & Hybrid Riser Monitoring System (RHMS)

**Installation Scope:**

- **Motion/Heading Measurement** (for HRT and BSR only)
- **Depth Measurement**
- **Power/comms umbilical**
- **SUT** (Subsea Umbilical Termination - Integral to Umbilical)
- **Power/comms from ROV**
- **Subsea cables**
- **Hull conduits**
- **Diver-mate connectors**
- **Protected pins on FPU side**
- **Acoustic Modem**
- **Acoustic Positioning Transducer**
- **FPU support structure**
- **Subsea cable**
- **Hull conduit**
- **Diver-mate connectors**
- **Protected pins**
- **Umbilical JB cables:**
  - 4 x power cores
  - 8 x TSP
  - 4 x FO

**Legend:**
- FPU CONTRACTOR
- RISER CONTRACTOR
- PETROBRAS
- DIVING TEAM