PETROBRAS	TECHNICAL SPECIFICATION	Nº I-ET-3000.00-5529-850-PEK-003	
	CLIENT: PETROBRAS		SHEET 1 of 37
	JOB: RIGID RISER SYSTEMS		
	AREA: –		
SUB	TITLE: **TIPT RISER MONITORING SYSTEM (TRMS) – FULL SCOPE**		NP-1 SUB/ES/EECE/ECE

REVISION INDEX

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	Original
A	Changes in items 6.4, 6.5 and 7.2

Note: This technical specification has been done with collaboration works and technical assistance of:

CENPES/PDISO/TMEC
SERGIO RICARDO KOKAY MORIKAWA

SUB/ES/EDD/EDR
ANTONIO PINHEIRO GUIMARÃES ROMERO
FABIO MAGALHÃES FERREIRA
RAFAEL CESAR DE OLIVEIRA GOES

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	30/07/2020	27/08/2020							
DESIGN	EECE/ECE	EECE/ECE							
EXECUTION	RENATO	RENATO							
CHECK	AIRES	AIRES							
APPROVAL	ALAN	ALAN							

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1 INTRODUCTION

This document presents the Technical Specification of the RISER CONTRACTOR scope of an integrity monitoring system applicable for TiPT risers installed in Spread Mooring FPSO.

1.1 RISER SYSTEMS

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

1.1.1 Steel Lazy Wave Riser (SLWR)

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

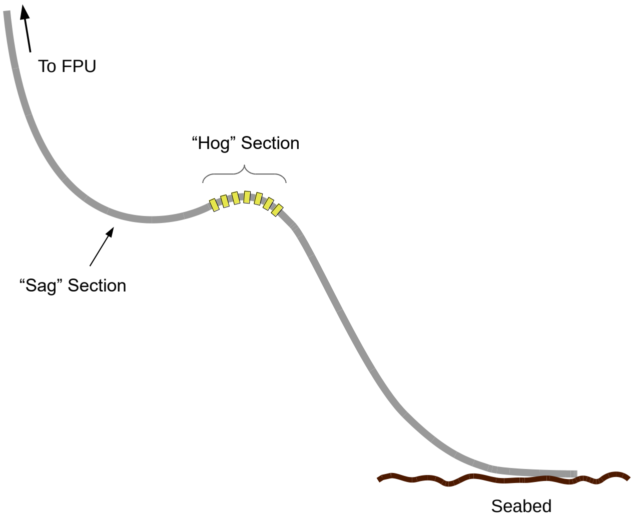

Figure 1 — SLWR illustration

1.1.2 Steel Catenary Riser (SCR)

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

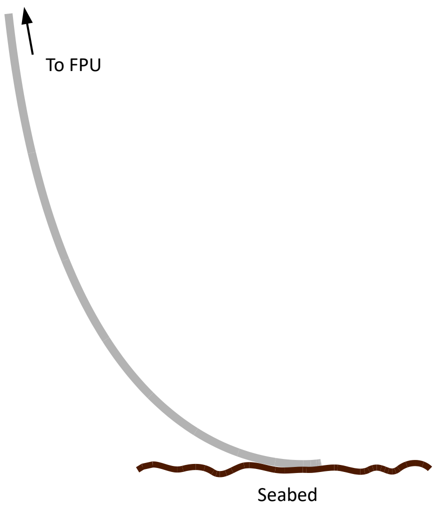

Figure 2 — SCR illustration

1.1.3 TiPT Riser

1.1.3.1 TiPT is an ancillary component welded at the top of a steel riser, composed by a set of pipes and two stress joints made of titanium alloy 6Al-4V-0.1Ru ELI (ASTM B381 grade F29 – UNS R56404), as well as a pup piece, a transition spool and an adaptor cap made of steel. The TiPT allows the connection of rigid risers in a typical flexible line support, i.e., I-tube + Bell mouth.

1.1.3.2 The figure 3 shows the typical TiPT set for Spread Mooring FPSO, with its main parts. This set is expected to be assembled, tested and externally coated prior to the offshore installation.

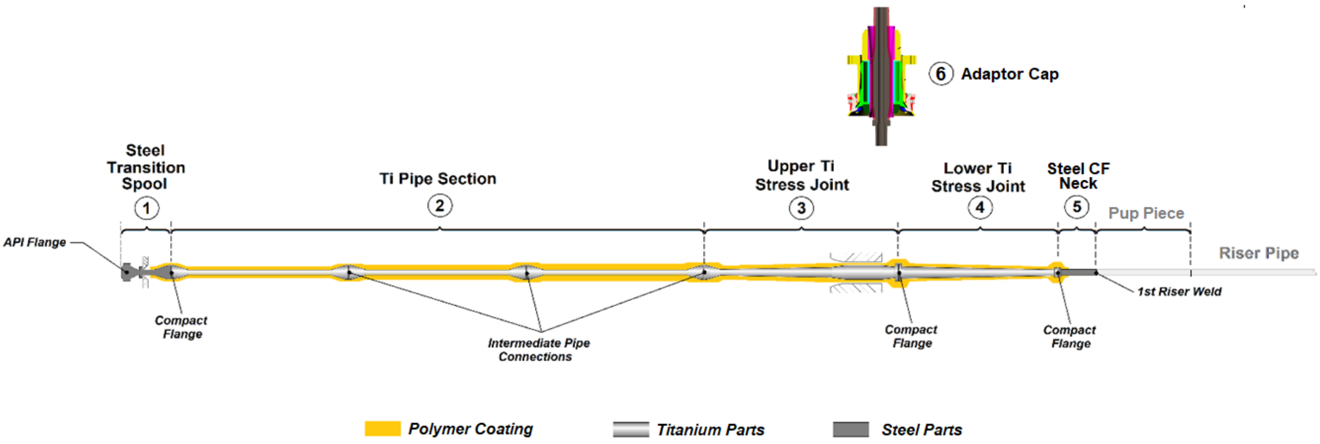

Figure 3 — Schematic View of the Titanium Stress Joint Assembly and its Main Parts.

2 ABBREVIATION

AHRS	Attitude and Heading Reference System
DMZ	Demilitarized Zone
FAT	Factory Acceptance Test
FBG	Fiber Bragg Gratting
FO	Fiber Optic
FPU	Floating Production Unit
GPS	Global Positioning System
IMU	Inertial Measurement Unit
I/O	Input/Output
IP	Ingress Protection
JB	Junction Box
LSZH	Low Smoke Zero Halogen
OPC	Open Platform Communications (from OPC Foundation)
OPC UA	OPC Unified Architecture
OTDR	Optical Time-Domain Reflectometer

PSU	Power Supply Unit
RDCS	Riser Data Collection System
SCR	Steel Catenary Riser
SCU	Strain Conditioning Unit
SIT	System Integration Test
SLWR	Steel Lazy Wave Riser
TiPT	Titanium Pull in Tube
TRMS	TiPT Riser Monitoring System
TSP	Twisted Shielded Pair
UPS	Uninterruptible Power Supply
VAC	Voltage Alternating Current
VDC	Voltage Direct Current

3 REFERENCE DOCUMENTS, CODES AND STANDARDS

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

API 17F	Standard for Subsea Production Control Systems
API 17Q	Recommended Practice on Subsea Equipment Qualification
ASME B16.5:2013	Pipe Flanges and Flanged Fittings
ASTM A320:2015	Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
DNVGL-RP-B401:2017	Cathodic Protection Design
IEC 60079 (latest revision)	Series Explosive Atmosphere Standards
IEC 60092 (latest revision)	Electrical installations in ships - ALL PARTS
IEC 60502-1 (latest revision)	Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) – Part 1: Cables for rated voltages of 1 kV (U_m = 1,2 kV) and 3 kV (U_m = 3,6 kV);
IEC 60529 (latest revision)	Degrees of Protection Provided by Enclosures (IP Code)
NMEA 0183 V 4.10	Standard for Interfacing Marine Electronics Devices

4 DEFINITIONS

RISER CONTRACTOR	The company contracted by PETROBRAS to design, supply and install the risers, including the monitoring system (focus of this technical specification)
FPU	The company contracted to perform FPU topside work activities to support TRMS installation.
MAY	Is used when alternatives are equally acceptable

SHOULD	Is used when a provision is not mandatory, but is recommended as a good practice
SHALL	Is used when a provision is mandatory
DRY-MATE [CONNECTOR]	Subsea connector designed for plugging/mating in dry environments
WET-MATE [CONNECTOR]	Subsea connector designed for plugging/mating in underwater environments
COVERAGE INTERVAL	Interval containing the set of true values of a measured quantity with a stated probability, based on the information available
COVERAGE PROBABILITY	Probability that the set of true values of a measured quantity is contained within a specified COVERAGE INTERVAL
MODA	Flexible riser monitoring system (Portuguese acronym to Optical Monitoring Directly on Wire)
MODA CABINET	Cabinet already installed in FPU designated to monitoring flexible riser. Depending FPU, this cabinet(s) can have another names like RIMS or RIMTWS.
TRMS CABINET	Space inside a MODA Cabinet dedicated to TRMS equipment

5 TECHNICAL CHARACTERISTICS

5.1 DESIGN AND FABRICATION

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

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

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

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

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

5.2 QUALIFICATION

5.2.1 All subsea equipment shall be qualified in accordance with API 17Q.

6 TECHNICAL REQUIREMENTS

6.1 SYSTEM OVERVIEW

6.1.1 Figure 4 presents a general diagram of the riser monitoring system.

6.1.2 The system is composed of:

- Subsea sensors and accessories (riser monitoring components), i.e. top inclination (section 6.3) and top strain measurement (section 6.4) and TiPT body cabling (section 6.5);

- Topside deck infrastructure – deck/balcony JBs (section 6.6);
- Topside processing system – TRMS Cabinet (section 6.7).

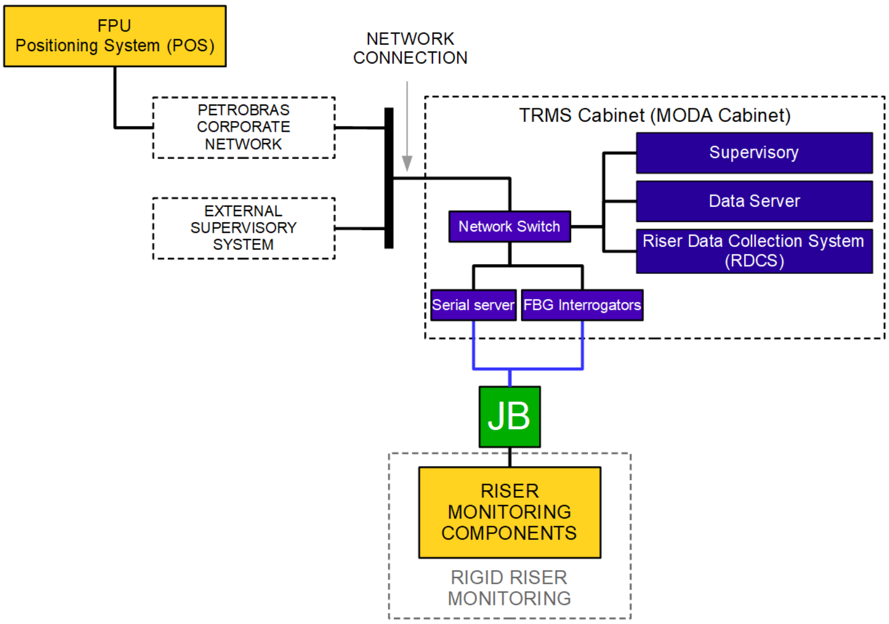

Figure 4 — General system diagram

6.2 GENERAL REQUIREMENTS

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

6.2.2 The purpose of rigid riser monitoring is to assess fatigue life consumption due to cyclic loading during operational life.

6.2.3 The Figure 5 presents an overview of riser topology installation at riser balconies.

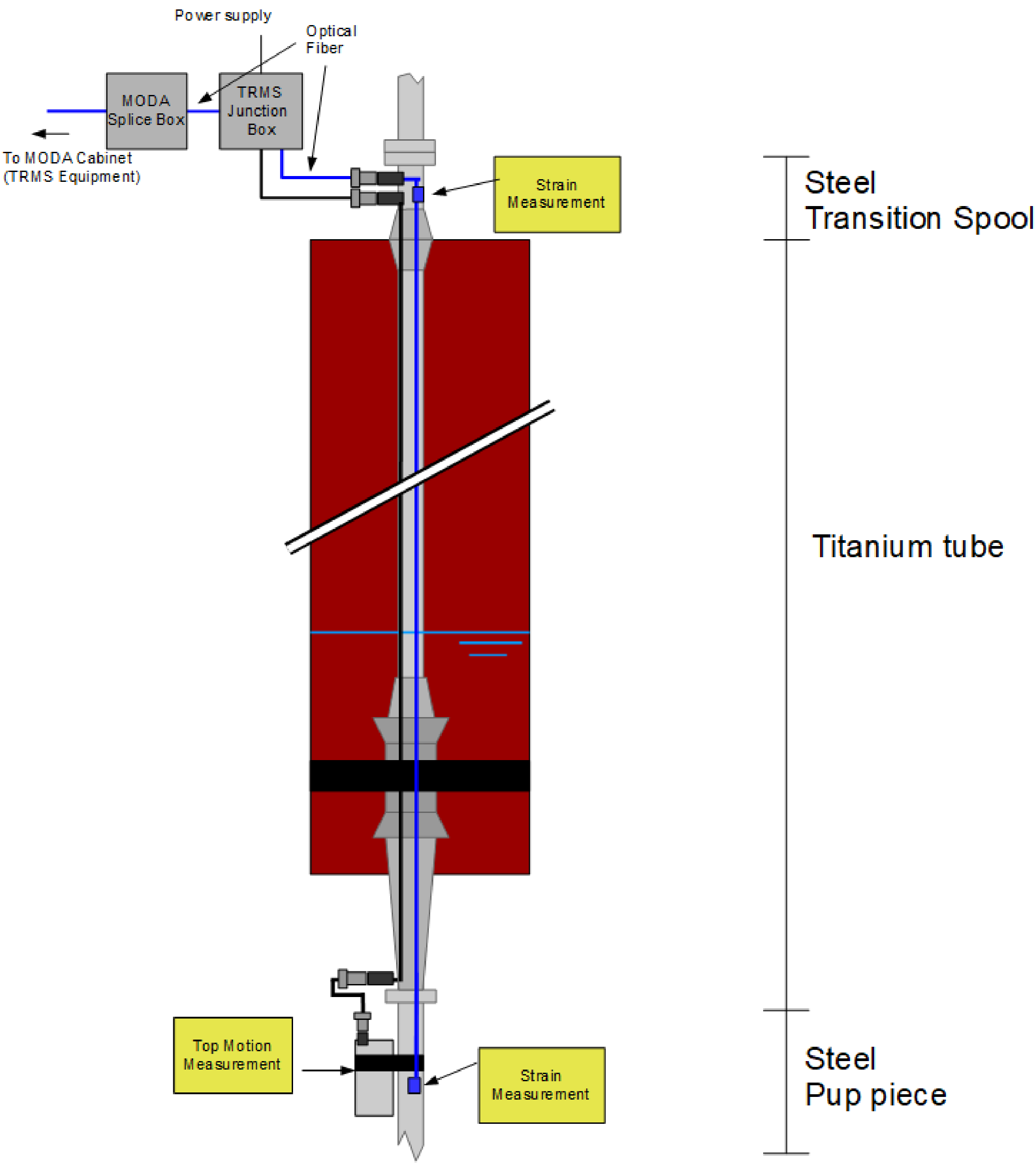

Figure 5 — TiPT riser connection scheme

6.3 TOP INCLINATION MEASUREMENT

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

6.3.2 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.

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

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

6.3.5 The IMU sensor shall reside in a subsea-proof enclosure rated for a minimum depth of 100 m or a higher depth if it goes through depths higher than 100m during pull-in installation. IMU weight shall not exceed 10 kg in water, in order to be compatible for handling by divers without the necessity of any buoyancy module.

6.3.6 An appropriate clamp shall be supplied to firmly attach each IMU to the riser at an appropriate location at steel pup piece aligned with the FBG stain sensor index #1 (see Figure 6). The IMU shall be installed before the pull-in inside a mechanical protective enclosure (blister). This enclosure shall permit diver access in order to replace IMU sensor and electrical jumper if necessary.

6.3.7 The upper flange neck of TiPT (at Steel Transition Spool in the upper riser balcony) shall have a tag embossed line mark indicating the direction of IMU installation. This information is needed to considerate, at the inclination algorithm, the misalignment of IMU related to riser catenary azimuth (see Annex B: Rigid Riser Top Angles Calculation).

6.3.8 The IMU sensor shall be connected at upper balcony by an electrical dry mate connector mounted at the Steel Transition Spool forged collar structure, and then connected to the TRMS JB (see item 6.5.4.3).

6.3.9 Inside the TRMS JB shall be installed media converters in order to use existent fiber cables between riser balcony (MODA Splice boxes) and MODA Cabinets.

6.3.10 The IMU shall be powered by TRMS Junction Box with 24VDC.

6.3.11 The IMU attached to each rigid riser shall communicate with the RDCS by means of 2-wire RS-485. Other options may be proposed and subjected to PETROBRAS approval and shall be compatible with the type and length of specified cabling.

6.3.12 The IMU communication to TRMS cabinet shall be:

- Serial half duplex 2-wire RS-485 format;
- NMEA 0183 protocol;
- Using one pair for power supply and one pair for serial data link.

6.3.13 RISER CONTRACTOR shall inform the data format (string) and protocol parameters (i.e. baud rate) used for communication to IMU data link.

6.3.14 The Riser Data Collection System (RDCS) shall be able to edit the mask of datagram received from each IMU sensor. This functionality allows communication with different models of IMU in case of replacement after delivery of TRMS system.

6.3.15 RISER CONTRACTOR shall not provide customized hardware in IMU. All components (or the IMU itself) chosen shall be available equipment off-the shelf by three manufacturer at least.

6.4 TOP STRAIN MEASUREMENT

6.4.1 Axial tension and bending moments acting at the top of rigid risers selected by PETROBRAS shall be monitored in two sections of TiPT Riser:

- Steel Transition Spool (one set of sensors)
- Steel pup piece (two set of sensors)

6.4.2 In steel pup piece shall be installed two sets of sensors (as item 6.4.4) in order to guarantee redundancy for cabling and instrumentation to attend this pipe area. However, in this section (steel pup piece), Riser Data collector System shall be connected only to one set of sensors.

6.4.3 Strain sensors shall be optical fiber Bragg grating (FBG) type. . Each set of sensors (see item 6.4.4) shall be connected in series in a fiber optical loop and all sensors sets shall be aligned according to the positions presented in Figure 6.

6.4.4 Each sensors set (as illustrated in Figure 6) shall have:

- Sixteen (16) FBG sensors, installed around the riser section in two layers (hoop and longitudinal), equally spaced at 45° from each other, to measure hoop and longitudinal stresses at each point around the riser pipe, as illustrated in Figure 7.
- Four (4) body FBG temperature sensors at the strain monitoring location, equally spaced at 90° from each other, to be used for correction of thermal expansion effects.

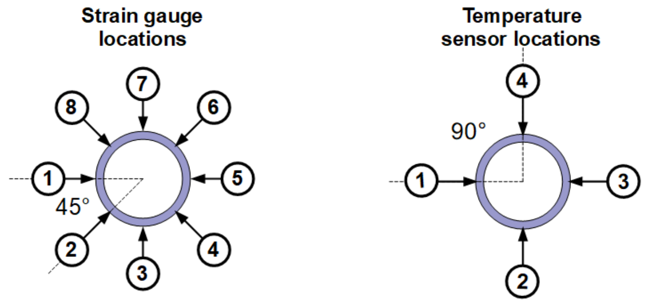

Figure 6 — Illustration of sensor positioning around rigid riser (cross-section view from top)

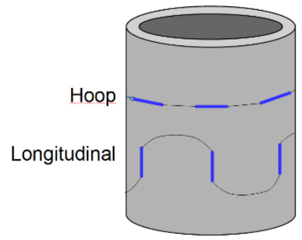

Figure 7 — Schematic view of strain sensing around riser pipe

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

6.4.6 The FBG sensor attachment method shall be suggested and subjected to PETROBRAS approval. However, spot weld methods of attachment shall be avoided.

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

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

6.4.9 The temperature and strain sensors in each set shall be numbered starting from index #1 and increasing in the counter-clockwise direction, looking from above, as depicted in Figure 6.

6.4.10 The maximum permissible error in temperature measurement, for 95% coverage probability, shall be of ± 0.2 °C in a measurement range of -20ºC to +70ºC.

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

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

6.4.13 At Steel Pup Piece, the strain measurement sensors set should be protect by the same mechanical protective enclosure (blister) from IMU sensor (see item 6.3.6).

6.4.14 At Steel Transition Spool, the strain measurement sensors set shall be mechanical protected by a forged collar structure that also shall be responsible for TiPT riser hang off at upper balcony riser slot.

6.4.15 The sensors shall be connected at upper balcony by an optical dry mate connector mounted at the Steel Transition Spool forged collar structure, and then connected to the topside signal acquisition unit (FBG Interrogator), which shall acquire and digitalize sensor signals.

6.4.16 All mechanical protective enclosures shall be designed to permit access to the FBG sensors array loop during the full-scale calibration procedures.

6.4.17 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.

6.4.18 At the algorithm to compute axial tensions and bending moments, it shall be possible to selectively enable/disable the data input from each FBG strain sensor and temperature sensor.

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

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

6.4.20 Considering data from both strain sensor sections and from inclination unit, the system shall be able to calculate the loads transferred by the TiPT to the riser support on the lower riser balcony, and the loads at the flanged connection along the TiPT (especially at the flange between the two Stress Joints). RISER CONTRACTOR shall present a TiPT analytical model and the algorithm proposal to calculate these loads and the associated uncertainties, and include in Annex A - OPC Interface Requirements, the respective TAGs in OPC map.

6.5 TIPT BODY CABLING

6.5.1 The monitoring units (IMU and Fiber strain sensors) shall be connected to FPU through optical and electrical cables installed underneath the TiPT protection cover, detailed as follows:

- Electrical cables in order to power supply and communicate to IMU;
- One fiber optical cable (one pair) for each set of strain/temperature sensors (Item 6.4.4).

6.5.2 RISER CONTRACTOR shall evaluate a redundancy of this cabling in its design and present a proposal for PETROBRAS approval.

6.5.3 For the optical cabling, RISER CONTRACTOR shall evaluate to divide optical pairs in separated cables installed in different positions along the pipe section and present a proposal for PETROBRAS approval.

6.5.4 Electrical Cabling

6.5.4.1 In order to downsize the thickness needed, shall be provided 4 (four) electrical cables, each one with a conductor cross section area of 1.5 mm2. Two conductors shall be used to power supply IMU, and the other two conductors used to serial communication.

6.5.4.2 Electrical cable shall be appropriated to support the process of TiPT protection cover installation.

6.5.4.3 At the upper side of steel transition spool, the electrical cable shall be terminated in a dry-mate bulkhead connector with the following requirements:

- Be housing made with stainless steel material (AISI 316L);
- Be suitable for operation at temperature range of -20^{0}C to +70^{0}C;
- Be suitable for operation in the foreseen environment, able to operate in a 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.

6.5.4.4 On the lower side, the electrical cable shall be terminated in a bulkhead wet-mate connector with the following requirements:

- Be diver operated;
- Be suitable for operation in the foreseen environment, able to operate in a 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

6.5.4.5 The wet-mate connector 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:

- 4-way Tronic DigiTRON+ Diver Connector
- 4-way ODI Nautilus Manual-Mate
- 4-way Seacon CM 2000 Diver Mate Connector

6.5.4.6 An electrical jumper shall be provided to connect IMU and lower electrical connector. The cable shall be adequate to foreseen environment. The connector of IMU shall be dry-mate, observing requirements in item 6.5.4.3.

6.5.4.7 If it's not possible to install a bulkhead wet-mate connector on the lower side, RISER CONTRACTOR shall present alternative to allow the replacement of IMU unit after riser installation. This alternative shall be submitted to PETROBRAS approval.

6.5.5 Optical Cabling

6.5.5.1 RISER CONTRACTOR shall provide one fiber pair to connect FBG sensors in each set. These fibers shall be terminated in a dry-mate bulkhead connector at the upper side of Steel Transition Spool (See figures 9 and 10). This dry mate connector shall follow requirements in item 6.5.4.3.

6.5.5.2 Each optical cable shall have 2 or more fiber cores, standard single mode fibers (ITU-T G.652 or ITU-T G.654 – water blocked).

6.5.5.3 Fiber cable shall be appropriated to support the process of installation covering of TiPT.

6.5.6 RISER CONTRACTOR design shall guarantee that optical/electrical cabling will support the bending moments of the lower stress joint segment at the final installation during project operational life.

6.5.7 If RISER CONTRACTOR needs to segment TiPT for production or installation process, the TiPT body cables shall be spliced, observing the following requirements:

- Electrical Cables shall be spliced, isolated and fixed in structure. Before the final field joint coating, the cables shall be tested (isolation and continuity test).

- Fiber Cables shall be spliced (with properly equipment) and properly protected. Before the final field joint coating, the fiber shall be tested and certificated with OTDR.

  NOTE: PETROBRAS recommends the use OTDR to check fiber optic channels integrity for TRMS sensors operation. Typical measurements to check optical integrity are an optical insertion loss (OIL) better or equal to 1.5dB @1550nm and an optical return loss (ORL) better or equal than -50dB @1550nm.

6.5.8 Figure 8 shows a wiring diagram of sensors' connection.

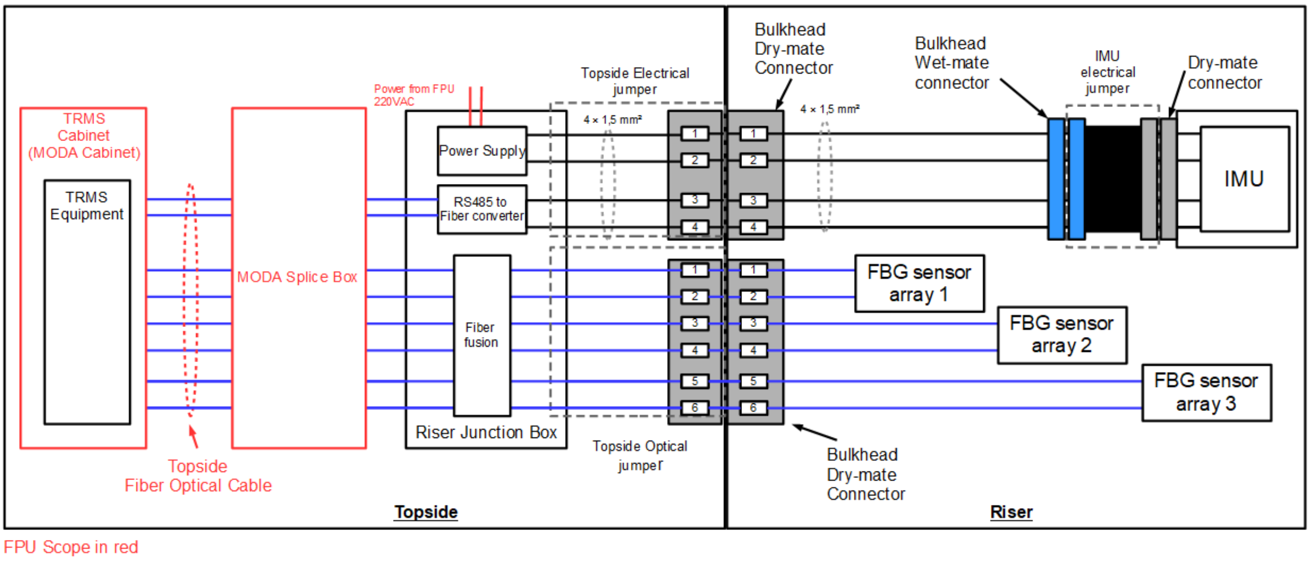

Figure 8 — Connection diagram for TiPT riser cabling

6.5.9 At the Steel Transition Spool, connectors (optical and electrical) shall be installed at the upper side of hang-off, with easy access to connect Topside Jumpers. Figure X examples a connector installation. Figure 10 shows a sketch of connectors' installation on TiPT.

Figure 9 – Connector installation example

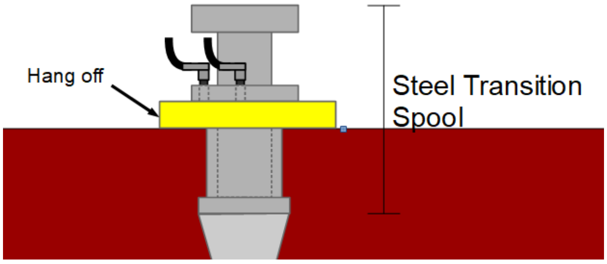

Figure 10 – Connectors' position on steel transition spool (sketch)

6.6 TOPSIDE DECK INFRASTRUCTURE

6.6.1 RISER CONTRACTOR shall provide one JB (named TRMS JB) for each riser. This JB has the function to aggregate fibers to IMU (by media converter) and FBG sensors, furthermore housing media converter, splice tray and power supply (to IMU sensor and media converter).

6.6.2 At upper riser balcony, the existent deck optical fiber cables (each one with 16 fibers) are terminated in junction boxes (named as MODA splice box) close to each riser position. In these junction boxes there is one hole to install an optical cabling from TRMS JB. RISER CONTRACTOR shall use the available hole to install its cable (with properly cable glands) to connect to TRMS Cabinet (see figure 11).

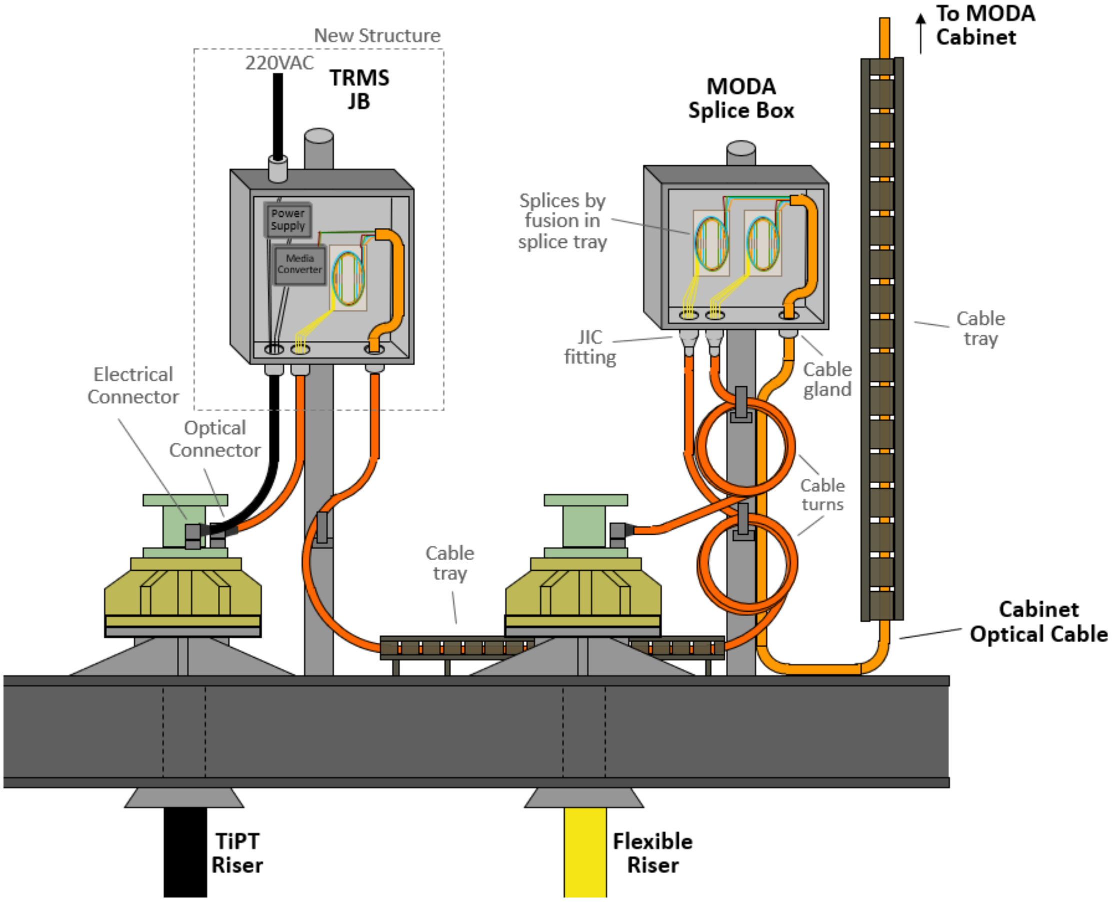

Figure 11 – Riser Balcony structure to monitoring system

6.6.3 Once there is only one hole available in MODA Splice box, RISER CONTRACTOR shall use TRMS JB (in its scope) to aggregate all fibers from FBG Sensors and IMU communication in one single cable (see figure 7).

6.6.4 RISER CONTRACTOR shall splice the used fiber pairs inside MODA splice box and TRMS JB and protect it at the optical splice trays.

6.6.5 Once, there is no electrical cable available between TRMS Cabinet and riser balcony, RISER CONTRACTOR shall provide a media converter in order to use fiber cable to communication between IMU and TRMS processing equipment.

6.6.6 TRMS Junction Box shall be installed close to upper riser termination and MODA Splice box, in a zone 1 hazardous area. RISER CONTRACTOR shall provide an IP-66 (ingress protection degree) equipment (TRMS JB and its internals) able to be installed in this environment.

6.6.7 RISER CONTRACTOR shall provide jumpers to connect risers (dry-mate connectors) and TRMS JB, herein named as: topside TRMS electrical jumper and topside TRMS optical jumper.

6.6.8 Topside TRMS Electrical Jumper shall have 4 (four) conductors with a cross section area of 1.5mm2 each (flame retardant 100% LSZH).

6.6.9 Topside TRMS Optical Jumper shall have 3 or more fiber cores pairs, standard single mode fibers (ITU-T G.652 or ITU-T G.654 – water blocked – flame retardant 100% LSZH).

6.6.10 Topside TRMS jumpers shall be connected in dry-mate connectors in one side, and the other side shall be supplied with pigtails in order to be terminated inside TRMS JB.

6.6.11 The maximum cable length between Riser dry mate connectors and TRMS JB shall be 20 meters.

6.6.12 RISER CONTRACTOR shall provide Topside TRMS Interface Optical cable to connect TRMS JB and MODA Splicebox.

6.6.13 The maximum cable length between TRMS JB and MODA Splicebox shall be 20 meters.

6.7 TOPSIDE PROCESSING SYSTEM

6.7.1 TRMS Cabinet

6.7.1.1 TRMS processing equipment shall be installed by RISER CONTRACTOR inside existent cabinet, locally labeled as MODA Cabinet.

6.7.1.2 There are existent fiber cables, between MODA Cabinets and riser balcony. RISER CONTRACTOR shall use these cables to connect upper riser balcony and TRMS equipment.

6.7.2 The FPU processing system shall have a three-layered architecture:

- The Riser Data Collection System (RDCS) shall be responsible for collecting data from the various sensors and positioning system.

- The data server shall concentrate all functionalities related to data storage (SQL, OPC, etc), working as data repository.
- The Supervisory shall act as a supervisory system, serve data to external clients, process acquired data, issue alarms and log access data.

6.7.3 All components in item 6.7.1 shall run in a same physical server, running as independent virtual machines.

6.7.4 RISER CONTRACTOR shall provide a physical server with the minimum requirement as follow:

- Processor: 2x Intel Xeon-G 5220 18-Core (2.20GHz 24.75MB L3 Cache) or superior;
- RAM memory: RAM: 32GB DDR4-2933 or superior;
- 2 hard disk drives (SSD) of at least 1TB each in RAID-1 mode;
- Support to RAID technology (Implemented by disk controller);
- Remote management by dedicated LAN card, able to:
  - Turn on/off equipment
  - Remote diagnosis;
  - KVM;
  - Support SNMP and RSYSLOG;
- Redundant power supply;
- Power Supply, Hard Disks and fans hot-swap type;
- Windows Server Standard (one of the last two versions at least);
- Support to VMWare ESXi (the last two versions at least);

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

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

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

6.8 RISER DATA COLLECTION SYSTEM (RDCS)

6.8.1 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.

6.8.2 All serial data (RS-485) shall be concentrated in serial servers (Serial to Ethernet) before be forwarded to RDCS. RDCS shall receive serial data by local LAN network.

6.8.3 The Riser Data Collection System (RDCS) shall be able to edit the mask of datagram received from each IMU sensor. This functionality allow communication with different models of IMU in case of replacement after delivery of TRMS system.

6.8.4 RISER CONTRACTOR shall provide FBG Interrogators for each FPU in order to collect data from FBG sensors.

6.8.5 The **FBG Interrogators** shall have the following minimum requirements:

- Swept wavelength laser scan frequency: 100 Hz or better (per channel simultaneously);
- Wavelength range: from 1460 to 1620 nm or wider including this range;
- Optical channels: 16 channels per interrogator;
- Wavelength accuracy: 2 pm or better;
- Wavelength repeatability: 1 pm or better;
- Dynamic range (peak): 21 dB or better;
- Full spectrum measurement;
- Peak detection functionality (at hardware firmware);
- ATEX certification for sensors operation in Zone 0, 1 or 2 environments (Ex op is T4 Ga) as defined on IEC 60079-28 [2];
- SC/APC or LC/APC Optical Connectors;
- Ethernet Port;
- Sensing Analysis Software;
- Rack Mounted or supplied with rack mount kit;
- Height: 70 mm or less.

6.8.6 RISER CONTRACTOR shall design the system to receive data from 16 (sixteen) risers per FPU, independent of number of TiPT risers of this contract, observing the capacity of media converter, serial server and RDCS in general.

6.8.7 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)*) by LAN network.

6.8.8 PETROBRAS shall inform TCP-IP and LAN parameters to achieve Positioning data during RISER CONTRACTOR executive project design.

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

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

6.8.11 Angles measured by top inclination measurements unit (IMU) shall be converted in accordance to Annex B: *Rigid Riser Top Angles Calculation*.

6.8.12 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.

6.8.13 Annex A: *OPC Interface Requirements* presents a summary of the variables to be monitored. Additional data (like cabinet equipment housekeeping) shall be acquired in the OPC map as necessary for the monitoring system to keep track of the status of every unit and communication channels alike.

6.8.14 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.

6.9 SUPERVISORY AND DATA SERVER

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

6.9.2 The use of a well-established integrated supervisory solution able to provide all required functionalities is strongly advised.

6.9.3 Dedicated supervisory screens shall report the value of every monitored variable as they are acquired, along with the status of communication channels (Positioning System, FBG Interrogator and Serial Server). The minimum set of monitoring variables is specified in § A.1.

6.9.4 Supervisory system and data server for each FPU shall be design considering data input for 16 (sixteen) risers. The system shall be able to receive data from future TiPT risers. The system shall permit to set at least the following parameters of each riser:

- Riser data (name, position, function, etc);
- Datagram map from IMU;
- Calibration parameters of FBG sensors;
- Source of IMU data (Serial Server port);
- Source of FBG sensor data (FBG interrogator port);

6.9.5 Supervisory system shall permit disable monitoring of TiPT risers not installed.

6.9.6 A 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.

6.9.7 The database shall operate on a circular buffer pattern, whereby older records shall gradually be overwritten by newer samples once the database reaches its capacity. 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.

6.9.8 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.

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

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

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

6.9.12 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.

6.9.13 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.

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

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

6.9.16 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.

6.9.17 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.

6.9.18 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).

6.9.19 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.

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

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

6.9.22 Alarms shall also be issued for monitoring system failure conditions, including loss of communication to any component and detection of faulty sensors.

6.9.23 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 thread to integrity.

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

6.9.25 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.

6.9.26 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*.

6.9.27 Historical data stored on the local database 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*.

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

6.9.29 The provided interfaces shall be ready for use by external systems from the PETROBRAS corporate network which are allowed through FPU network firewalls.

6.10 TRMS CABINET AND EQUIPMENT

6.10.1 The complete topside processing system shall be supplied by RISER CONTRACTOR.

6.10.2 TRMS equipment shall be installed inside MODA Cabinet, in a designated space denominated as TRMS Cabinet. RISER CONTRACTOR shall use up to 20 U of one MODA Cabinet (there are usually three) and shall provide all accessories to fixate the equipment in its scope.

6.10.3 FPU CONTRACTOR shall provide only the physical cabinet to RISER CONTRACTOR install its equipment scope. TRMS cabinet is located in Electrical Module of FPU.

6.10.4 The TRMS 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 3000 W. It shall be treated as a regular load, i.e. neither essential nor emergency.

6.10.5 Inside TRMS cabinet, FPU shall provide power supply. RISER CONTRACTOR shall provide a local UPS to maintain TRMS equipment during 30 min at least in case of power failure.

6.10.6 The TRMS UPS shall provide power to all other components of the monitoring system inside the cabinet, each protected by dedicated circuit breakers.

6.10.7 RISER CONTRACTOR shall provide media converters inside TRMS Cabinet and prioritize installation using 19-inch multi-slot rack.

6.10.8 RISER CONTRACTOR shall provide optical patch cords to connect existent patch panels (where are terminated all cabling from Risers) to FBG interrogator and Media Converters. Depending FPU and Risers position, the maximum distance of these connection is 6 meters.

6.10.9 FPU shall provide a LAN Network connection (Cat-6 network cable) inside TRMS Cabinet. This connection shall permit remote access by corporative network and communication to Positioning system.

6.10.10 The cabinets are installed in a non-classified, temperature-controlled room allowing frontal access only.

6.10.11 User interface devices, including keyboard, mouse and monitor, shall be provided 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.

6.11 CONNECTION ARCHITECTURE

6.11.1 The interconnection layout of main processing components is illustrated Figure 4.

6.11.2 RISER CONTRACTOR shall provide a network switch that shall connect all LAN equipment.

6.11.3 The network switch shall have the following minimum requirements:

- Gigabit Ethernet ports to accommodate all equipment and servers computers from the TRMS Cabinet.
- Support Spanning Tree Protocols, Virtual Local Area Networks, Link Aggregation, Flow Control, Class of Service, Remote Access, Simple Network Management Protocol, Remote Network Monitoring;
- Rack Mounted;
- Height: 1U.

6.11.4 Any protocol converters and network switches shall be off-the-shelf, industrial-grade components. All physical interfaces/cards shall have added redundancy.

6.11.5 The IP address range used in TRMS shall be designated by PETROBRAS during the executive design.

6.11.6 All equipment shall be able to be accessed remotely by PETROBRAS LAN network.

6.11.7 The firewalls shall be configured to allow access from the PETROBRAS corporate network to TRMS 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.

7 SERVICE REQUIREMENTS

7.1 SITE SURVEY

7.1.1 RISER CONTRACTOR shall make a site survey in each FPU in order to collect information to design phase, as:

- TRMS JB (available space, power supply, support, etc);
- Interface between TRMS JB and Riser slot position (distance, cable routing, etc);
- Interface between TRMS JB and MODA splicebox (distance, cable routing, cable gland, etc);
- TRMS Cabinet (Fiber cable termination, available space, power supply, length cables, etc);

7.1.2 This survey shall be done as soon as possible, with PETROBRAS coordination, considering that will provide needed information to design phase.

7.2 QUALIFICATION TESTING

7.2.1 All subsea equipment shall be qualified in accordance with API 17Q.

7.2.2 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.

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

7.2.4 RISER CONTRACTOR shall qualify the TiPT body cabling considering mechanical contact pression, bending moment and axial strain during pull-in operation.

7.3 FACTORY ACCEPTANCE TESTING

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

7.3.2 All strain measurement sensors sets shall be calibrated with their thermal insulation layer/coating and (if possible) mechanical protective enclosures. Calibration reports shall be presented to demonstrate performance requirements are met. Neither new insulation layer/coating installed after full-scale calibration over the FBG sensors installation section shall be accepted by PETROBRAS.

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

7.3.4 Dimensional and electrical checks shall be performed on all sensor units.

7.3.5 Specific requirements are detailed in the next sections.

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

7.4 SYSTEM INTEGRATION TESTING

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

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

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

7.4.4 The system integration test shall be performed with the actual components of the system. RISER CONTRACTOR may use FBG sensor arrays to simulate the strain measurement sections.

7.4.5 RISER CONTRACTOR shall test and commission all inputs of Topside Processing system for future risers.

7.4.6 Simulators may be used in place of the FPU positioning system and TiPT body cabling. Simulators for cables shall be RLC circuits.

7.4.7 The proper operation of external data interfaces (OPC UA) shall be attested with a connection to a test computer running client data acquisition software.

7.5 INSTALLATION AND COMMISSIONING REQUIREMENTS

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

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

7.5.3 RISER CONTRACTOR shall install and commissioning all equipment and cables included in its scope (including redundancies). PETROBRAS shall inform about requirements to onboard activities.

7.5.4 RISER CONTRACTOR shall provide all tools, accessories and consumables required for these activities.

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

7.5.6 RISER CONTRACTOR shall test and commission all inputs of Topside Processing system for future risers.

7.5.7 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.

7.5.8 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.

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

8 SCOPE OF SUPPLY

8.1.1 The General Topology in Figure 12 summarizes the supply scope division between FPU and RISER CONTRACTOR.

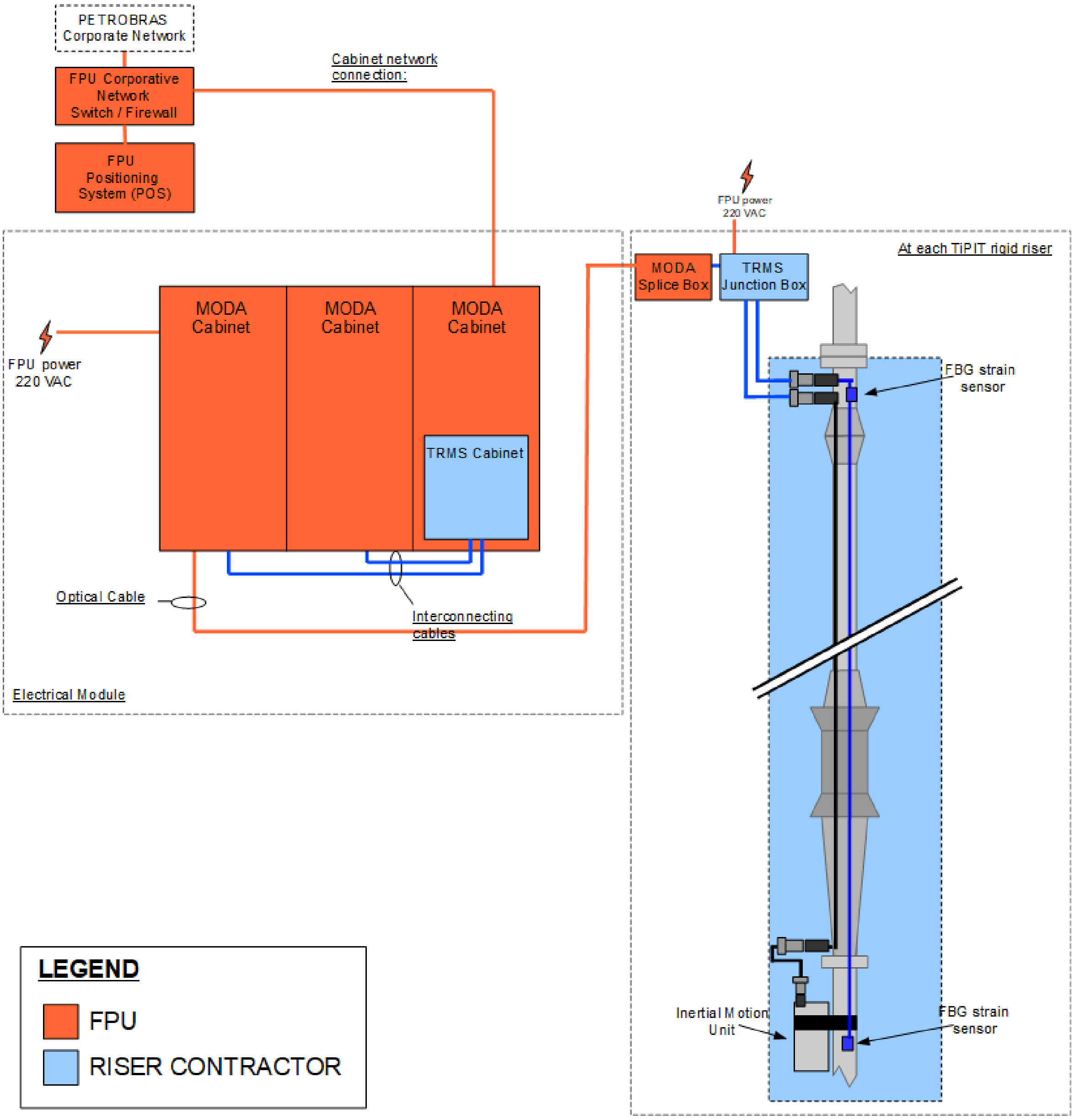

Figure 12 – Scope of Supply

8.1.2 RISER CONTRACTOR shall design, supply and install the topside processing system as described in item 6.

8.1.3 The minimum equipment of topside processing system to each FPU is listed bellow:

- 1 x Server (Item 6.7.4).
- 2 x FBG Interrogator (Item 6.8.5).
- 1 x KVM (Keyboard, Video, Mouse)
- 1 x Network Switch (item 6.11.3)
- 1 x UPS (item 6.10.5)
- 16 x Media Converters (Item 6.10.7)
- Serial to Ethernet Server (Item 6.8.2). Quantity needed to attend the 16 risers.

8.1.4 Design, supply and install the equipment inside TRMS Cabinet.

8.1.5 RISER CONTRACTOR shall design, supply and install IMU sensor, and all needed structure for each riser as section 6.3.

8.1.6 RISER CONTRACTOR shall design, supply and install strain and temperature FBG sensors, and all needed structure for each riser as section 6.4.

8.1.7 RISER CONTRACTOR shall supply the topside structure for each TiPT riser:

- TRMS JB (with accessories and internals);
- Cable glands to interconnect to MODA Splice box and TRMS JB;
- Topside TRMS Interface Optical Cable
- Topside TRMS Optical Jumper
- Topside TRMS Electrical Jumper;

8.1.8 Define, supply and install any additional necessary interconnecting cabling between the TiPT Riser and the TRMS Cabinet.

8.1.9 Supply the following spare units related to TiPT risers. The quantity is designated in Material Requisition:

8.1.9.1 IMU sensor;

8.1.9.2 IMU sensor cabling;

8.1.9.3 Topside TRMS Electrical Jumpers;

8.1.9.4 Topside TRMS Optical Jumpers;

8.1.9.5 Topside TRMS Interface Optical Cable;

8.1.9.6 TRMS JB internal components;

8.1.10 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.

9 SCOPE OF WORK

9.1.1 RISER CONTRACTOR shall make site survey (see item 7.1).

9.1.2 RISER CONTRACTOR shall design the entire TRMS system as described in item 6.

9.1.3 RISER CONTRACTOR shall provide all qualification needed to attend this technical specification (see item 7.2).

9.1.4 RISER CONTRACTOR shall provide Factory Acceptance Test to TRMS System (see item 7.3).

9.1.5 RISER CONTRACTOR shall provide integration test (see item 7.4);

9.1.6 The General Topology in Figure 13 summarizes the installation scope division between FPU and RISER CONTRACTOR.

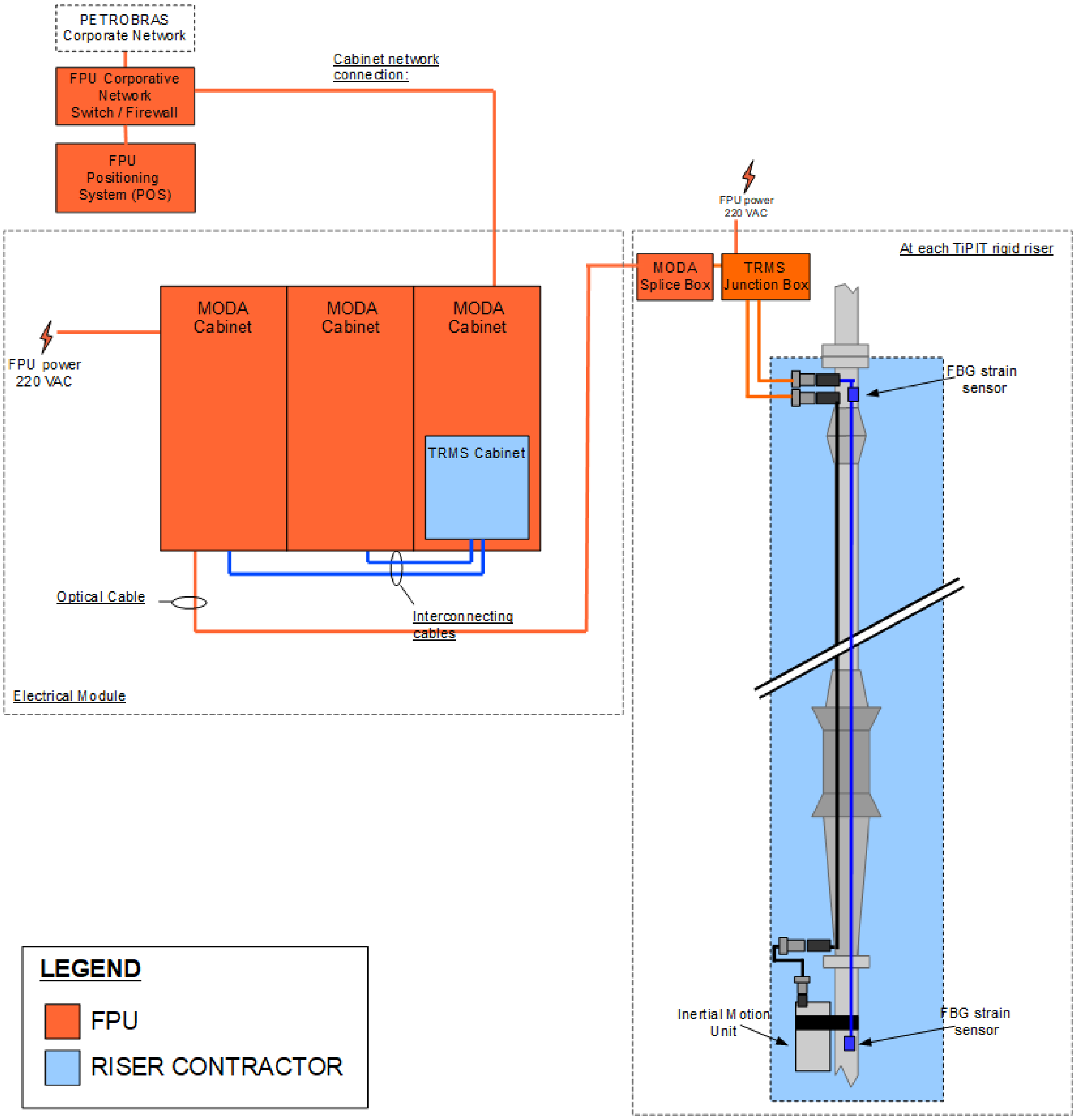

Figure 13 – Scope of installation

9.1.7 FPU shall install TRMS JB supplied by RISER CONTRACTOR.

9.1.8 FPU shall provide cable trays, lay all cabling (supplied by RISER CONTRACTOR) at FPU riser balcony/main deck and install respective cable glands.

9.1.9 RISER CONTRACTOR shall connect both optical/electrical drymate connectors from TiPT riser at the TRMS jumpers.

9.1.10 RISER CONTRACTOR shall terminate all cables inside respective JBs (TRMS JB and MODA Splicebox), including all fiber splicing needed.

9.1.11 RISER CONTRACTOR shall install all TRMS processing equipment inside MODA cabinet, providing all consumable needed to accommodate and interconnect all equipment.

9.1.12 RISER CONTRACTOR shall interconnect TRMS processing equipment and fiber patch panel at MODA Cabinet.

9.1.13 RISER CONTRACTOR shall commission the entire TRMS system (see item 7.5).

9.1.14 RISER CONTRACTOR shall provide documentation and training as defined at sections 10 and 11.

9.1.15 Before the TRMS executive design, RISER CONTRACTOR shall submit to PETROBRAS approval a Technical Proposal of the TRMS, including the design basis of technical solution, presenting evidences of attending main points of item 6.

10 DOCUMENTATION REQUIREMENTS

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

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

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

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

10.1.4 The TRMS 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. wavelength) into engineering values, along with all coefficients used in

conversion, for all sensors;

- Detailed system arrangement, including but not limited to, electrical diagrams, cable layout and equipment interconnection diagrams;
- LAN diagram and Complete descriptions of all communication protocols used between equipment;
- Detailed definition and specification of the 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 maintenance 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.

11 TRAINING REQUIREMENTS

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

11.1.2 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.

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

11.1.4 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;
- Diving operations (IMU retrieval and replacement);
- Supervisory system operation;
- Storage and conservation of spare equipment.

ANNEX A: OPC INTERFACE REQUIREMENTS

A.1 Data Tags

A.1.1 Table 1 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`, `a`, `b` and *c*) shall be substituted for the respective numbers, formatted in decimal base with no leading zeroes (e.g. 1, 2, 3, …).

Tag	Data Type	Description	Unit	Alarm Type	OPC Alarm Source	Logged in HDB
TRMS_INTERF_REV	8-bit integer	TRMS interface revision (constant) Must be 1 for this version	N/A	–		–
NUM_RIG	8-bit integer	Number of monitored rigid risers Valid indices (n) for rigid riser data tags (TIPT_n_xxx) shall be in the range 1..NUM_RIG	N/A	–		–
FPU_EASTING	32-bit floating-point	FPU absolute easting, as supplied by POS system	m	–		Yes
FPU_NORTHING	32-bit floating-point	FPU absolute northing, as supplied by POS system	m	–		Yes
FPU_ROLL	32-bit floating-point	FPU roll angle, as supplied by POS system	°	–		Yes
FPU_PITCH	32-bit floating-point	FPU pitch angle, as supplied by POS system	°	–		Yes
FPU_HEADING	32-bit floating-point	FPU heading with respect to true north, as supplied by POS system	°	–		Yes
TIPT_n_NAME	String	Rigid riser *n* descriptive name	N/A	–		–
TIPT_n_ROLL	32-bit floating-point	Rigid riser *n* filtered top roll angle at reference frame	°	Range		Yes
TIPT_n_PITCH	32-bit floating-point	Rigid riser *n* filtered top pitch angle at reference frame	°	Range		Yes
TIPT_n_MON	Boolean	Whether monitoring is implemented for rigid riser n	N/A	–		–
TIPT_n_UPPER_TEMP_a_STATUS	Boolean	Temperature Sensor Status Riser *n (slot)* Upper section sensor (steel transition spool) Temperature sensor a (1 to 4) Status (Active / Inactive)	N/A	–		Yes
TIPT_n_UPPER_TEMP_a_RAW	32-bit floating-point	Temperature Tag - Raw data (FBG Wavelenght) Riser *n (slot)* Upper section sensor (steel transition spool) Temperature sensor a (1 to 4) Wavelenght	nm	range		Yes
TIPT_n_UPPER_TEMP_a_TEMP	32-bit floating-point	Temperature Tag Riser *n (slot)* Upper section sensor (steel transition spool) Temperature sensor a (1 to 4) Temperature Value (ºC)	°C	range	"TIPT_n"	Yes
TIPT_n_UPPER_HOOP_b_STATUS	Boolean	Hoop Strain Sensor Status Riser *n (slot)* Upper section sensor (steel transition spool) Hoop Strain Sensor *b (1 to 8)* Status *(Active / Inactive)*	N/A	-		Yes
TIPT_n_UPPER_HOOP_b_RAW	32-bit floating-point	Hoop Strain Sensor Value - Raw data (FBG Wavelenght) Riser *n (slot)* Upper section sensor (steel transition spool) Hoop Strain Sensor *b (1 to 8)* Wavelenght	nm	range		Yes
TIPT_n_UPPER_HOOP_b_STRAIN	32-bit floating-point	Hoop Strain Sensor Value - Final data (strain) Riser *n (slot)* Upper section sensor (steel transition spool) Hoop Strain Sensor b *(1 to 8)* Strain	µstrain	range		Yes
TIPT_n_UPPER_LONG_c_STATUS	Boolean	Long Strain Sensor Status Riser *n (slot)* Upper section sensor (steel transition spool) Long Strain Sensor c *(1 to 8)* Status *(Active / Inactive)*	N/A	-		Yes
TIPT_n_UPPER_LONG_c_RAW	32-bit floating-point	Long Strain Sensor Value - Raw data (FBG Wavelenght) Riser n (slot) Upper section sensor (steel transition spool) Long Strain Sensor c (1 to 8) Wavelenght	nm	range		Yes
TIPT_n_UPPER_LONG_c_STRAIN	32-bit floating-point	Long Strain Sensor Value - Final data (strain) Riser n (slot) Upper section sensor (steel transition spool) Long Strain Sensor c (1 to 8) Strain	µstrain	range		Yes

Table 1 — Standard data tags

Tag	Data Type	Description	Unit	Alarm Type	OPC Alarm Source	Logged in HDB
TIPT_n_LOWER_TEMP_a_STATUS	Boolean	Temperature Sensor Status Riser n (slot) Lower section sensor (steel transition spool) Temperature sensor a (1 to 4) Status (Active / Inactive)	N/A	–	"TIPT_n"	Yes
TIPT_n_LOWER_TEMP_a_RAW	32-bit floating-point	Temperature Tag - Raw data (FBG Wavelenght) Riser *n (slot)* Lower section sensor (steel transition spool) Temperature sensor a (1 to 4) Wavelenght	nm	range		Yes
TIPT_n_LOWER_TEMP_a_TEMP	32-bit floating-point	Temperature Tag Riser n (slot) Lower section sensor (steel transition spool) Temperature sensor a (1 to 4) Temperature Value (ºC)	°C	range		Yes
TIPT_n_LOWER_HOOP_b_STATUS	Boolean	Hoop Strain Sensor Status Riser n (slot) Lower section sensor (steel transition spool) Hoop Strain Sensor b (1 to 8) Status (Active / Inactive)	N/A	-		Yes
TIPT_n_LOWER_HOOP_b_RAW	32-bit floating-point	Hoop Strain Sensor Value - Raw data (FBG Wavelenght) Riser n (slot) Lower section sensor (steel transition spool) Hoop Strain Sensor b (1 to 8) Wavelenght	nm	range		Yes
TIPT_n_LOWER_HOOP_b_STRAIN	32-bit floating-point	Hoop Strain Sensor Value - Final data (strain) Riser n (slot) Lower section sensor (steel transition spool) Hoop Strain Sensor b (1 to 8) Strain	µstrain	range		Yes
TIPT_n_LOWER_LONG_c_STATUS	Boolean	Long Strain Sensor Status Riser n (slot) Lower section sensor (steel transition spool) Long Strain Sensor c (1 to 8) Status (Active / Inactive)	N/A	-		Yes
TIPT_n_LOWER_LONG_c_RAW	32-bit floating-point	Long Strain Sensor Value - Raw data (FBG Wavelenght) Riser n (slot) Lower section sensor (steel transition spool) Long Strain Sensor c (1 to 8) Wavelenght	nm	range		Yes
TIPT_n_LOWER_LONG_c_STRAIN	32-bit floating-point	Long Strain Sensor Value - Final data (strain) Riser n (slot) Lower section sensor (steel transition spool) Long Strain Sensor c (1 to 8) Strain	µstrain	range		Yes
TIPT_n_UPPER_AXIAL_STRESS	32-bit floating-point	Rigid riser *n* upper section overall axial stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_UPPER_HOOP_STRESS	32-bit floating-point	Rigid riser *n* upper section mean hoop stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_UPPER_MAX_BENDING_STRESS	32-bit floating-point	Rigid riser *n* upper section maximum bending stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_UPPER_AXIAL_TENSION	32-bit floating-point	Rigid riser *n* upper section axial tension calculated from pipe model.	kN	Range		Yes
TIPT_n_UPPER_BENDING_MOMENT	32-bit floating-point	Rigid riser *n* upper section bending moment calculated from pipe model.	kN·m	Range		Yes
TIPT_n_UPPER_BENDING_DIR	32-bit floating-point	Rigid riser *n* upper section bending direction Counter-clockwise from strain sensing position #1.	°	Range		Yes
TIPT_n_LOWER_AXIAL_STRESS	32-bit floating-point	Rigid riser n lower section overall axial stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_LOWER_HOOP_STRESS	32-bit floating-point	Rigid riser n lower section mean hoop stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_LOWER_MAX_BENDING_STRESS	32-bit floating-point	Rigid riser n lower section maximum bending stress calculated from pipe model.	kN/m²	Range		Yes
TIPT_n_LOWER_AXIAL_TENSION	32-bit floating-point	Rigid riser n lower section axial tension calculated from pipe model.	kN	Range		Yes
TIPT_n_LOWER_BENDING_MOMENT	32-bit floating-point	Rigid riser n lower section bending moment calculated from pipe model.	kN·m	Range		Yes
TIPT_n_LOWER_BENDING_DIR	32-bit floating-point	Rigid riser n lower section bending direction Counter-clockwise from strain sensing position #1.	°	Range		Yes

Table 2 — Standard data tags (cont.)

ANNEX B: RIGID RISER TOP ANGLES CALCULATION

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

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

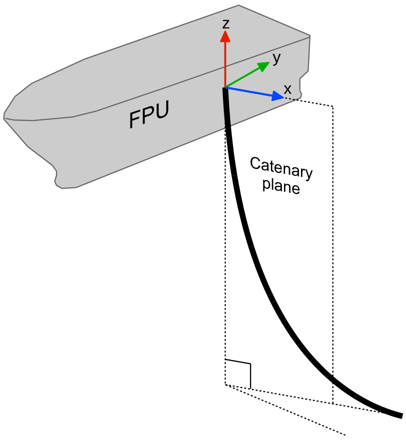

Figure B1 — Illustration of coordinate system for rigid riser top angle calculation

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

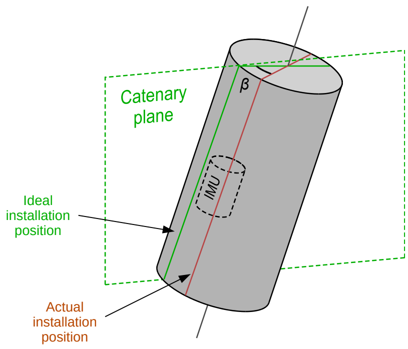

Figure B2 — Illustration of IMU misalignment with respect to rigid riser catenary plane

B.3 In order to measure the angle of misalignment ($\boldsymbol{\beta}$) for each IMU, it shall use the upper flange neck tag indication (see item 6.3.7) and FPU POS AHRS data. RISER CONTRACTOR shall confirm this misalignment correction with the calculated bending plane direction from Steel Pup Piece strain sensors set.

B.4 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_{sens}: number of longitudinal and hoop strain sensors around riser pipe
- $\varepsilon_{\ell i}$: longitudinal strain sensor i reading; $i = 1,2, \dots N_{sens}$
- ε_{hi}: hoop strain sensor i reading; $i = 1,2, \dots N_{sens}$
- 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)
- ν: Poisson coefficient (material property)
- α: 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 ($\varepsilon_{\ell i,\mathrm{raw}}$) from each sensor around the riser pipe shall be acquired and properly converted using stored calibration data.

   The individual raw strain readings $\varepsilon_{\ell i,\mathrm{raw}}$ shall be output in data of OPC map.

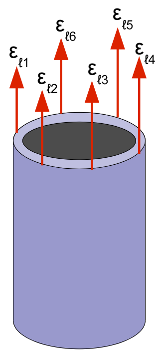

Figure B3 — Individual longitudinal strain measurements around riser pipe

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

   The individual raw strain readings $\varepsilon_{hi,\text{raw}}$ be output in data of OPC map.

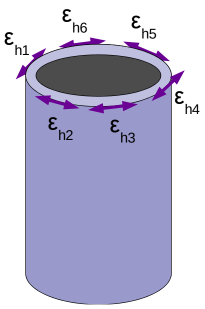

Figure B4 — Illustration of riser hoop strain measurements

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

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

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

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

5. Longitudinal and hoop stresses shall be calculated as:

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

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

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

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

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

   Let matrix M be defined as

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

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

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

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

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

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

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

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

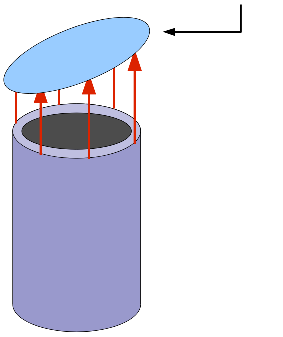

Figure B5 — Illustration of plane fit over longitudinal stress measurements

7. The estimated longitudinal stress distribution around the pipe $\sigma_{fit}(\phi)$ (where ϕ is the azimuth) resulting from application of the plane fit shall be decomposed into:

   - The overall axial stress, σ_a, which represents the strain induced by pure axial tensioning of the pipe, and shall be computed as:

     $$\sigma_a = a$$

     The quantity σ_a shall be output in data of OPC map.

   - A bending stress component, which represents the superimposed effect of pipe bending. The output maximum bending strain, σ_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 σ_b shall be output in data of OPC map.

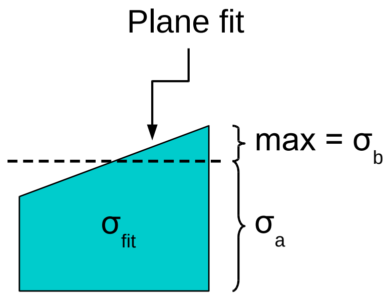

Figure B6 — Illustration of longitudinal stress profile (side view)

8. The overall hoop stress σ_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 σ_h shall be output in data of OPC map.

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

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

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

The quantity θ_b shall be converted to degrees (in the range $-180° < \theta_b \leq 180°$) and output in data of OPC map.

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

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

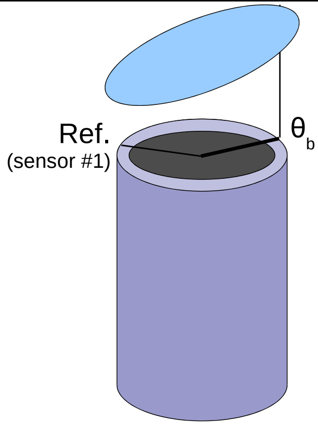

Figure B7 — Illustration of riser bending direction

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

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

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

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

The quantities F_a and M_b shall be output in data of OPC map.