PETROBRAS	**TECHNICAL SPECIFICATION**	Nº	I-ET-3010.00-5529-854-PX9-004
	CLIENT: PETROBRAS		SHEET: 1 of 22
	JOB: FLEXIBLE RISER SYSTEMS		
	AREA: FLOATING PRODUCTION UNITS		
SUB	TITLE: **FLEXIBLE RISER MONITORING SYSTEM (MODA) – RISER SCOPE**		**PUBLIC**
			SUB/ES/EDA/EAI

REVISION INDEX

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	Original. This document is based on previous technical specification for MODA: I-ET-3010.00-5529-854-PEK-004

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E
DATE	26/09/2025					
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EXECUTION	DVHV					
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APPROVAL	NTHF					

TABLE OF CONTENTS

1. SUBJECT

This document presents the Technical Specification of the Riser scope of an integrity monitoring system applicable for flexible risers, named MODA.

2. ABBREVIATION

APC	Angle Polished Connector
DMZ	Demilitarized Zone
FAT	Factory Acceptance Test
FBG	Fiber Bragg Grating
FO	Fiber Optic
FPU	Floating Production Unit
FWHM	Full Width Half Maximum
IVT	Installation Verification Test
IP	Ingress Protection
JB	Junction Box
LSZH	Low Smoke Zero Halogen
MD	Descriptive Memorandum
MODA	*Monitoramento Óptico Direto no Arame* (Optical Monitoring Directly on the Wire)
OIL	Optical Insertion Loss
ORL	Optical Return Loss
OTDR	Optical Time Domain Reflectometer
PLSV	Pipe Laying Support Vessel
SIT	System Integration Test
STK	Sensor Test Kit
TSP	Twisted Shielded Pair

3. REFERENCE DOCUMMENTS, CODES AND STANDARDS

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

3.1. International Standards and Patents

[1] I-ET-3010.00-1500-960-PPC-014 REV C – Spyhole end fitting

[2] Patent BR PI1100228-0

[3] ITU-T G.652 – Characteristics of a single-mode optical fiber and cable

[4] ITU-T G.654 – Characteristics of a cut-off shifted single-mode optical fiber and cable

[5] ITU-T L.12 – Optical fiber splices

[6] IEC 60079 - Series Explosive Atmosphere Standards

3.2. Petrobras Technical Specifications

3.3. Petrobras Additional Documents

3.4. Brazilian Documents

4. DEFINITIONS

RISER CONTRACTOR	The company contracted by PETROBRAS to supply flexible risers including the FBG sensors mounted at the wires inside the spyhole end fitting
FPU CONTRACTOR/SELLER	The entity that is responsible for the Engineering, Procurement, and Construction of the Floating Production Unit (FPU), as established in the contract of the FPU
SUBCONTRACTOR	The company contracted by RISER CONTRACTOR to provide and install MODA system, or RISER CONTRACTOR itself if it has the required capability to provide and install the system
FPU OPERATOR	The company responsible for the FPU topside operations
PETROBRAS	Oil operator that uses the MODA system for riser integrity management. Any information to be exchanged with PETROBRAS shall be addressed to the subsea engineering group
MODA OPERATOR	The technical company contracted by PETROBRAS responsible for the support/maintenance of the MODA system during risers' life
MAY	Used when alternatives are equally acceptable
SHOULD	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]	The company contracted by PETROBRAS to supply flexible risers including the FBG sensors mounted at the wires inside the spyhole end fitting

5. TECHNICAL REQUIREMENTS

5.1. SYSTEM OVERVIEW

5.1.1. MODA system consists of an optical extensometer system based on fiber Bragg grating sensors, which monitors the deformations/stresses acting on the external tensile armor wires of the flexible risers to identify broken and/or compromised wires. An optical fiber Bragg grating sensor is installed on each wire of the external tensile armor layer, as illustrated on Figure 1, with which an initial installation reference is made, and from then on, new acquired data is constantly compared with this value.

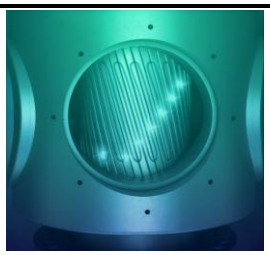

Figure 1: MODA General Functionality

5.1.2. The Fiber Bragg grating sensors work in a similar way to electrical resistance extensometers measuring mechanical deformations and are installed in a similar manner through surface bonding with adhesives. However, unlike electrical extensometers, the absolute values of the Fiber Bragg grating sensors in wavelength are recorded, allowing the initial installation references to be updated and changed depending on the type of analysis to be performed or the type of information to be displayed to the user.

5.1.3. Among the general characteristics of optical fiber sensors, which favor the installation of the MODA system in classified areas of FPUs, the following stand out:

- It is a passive system, as it uses optical sensors that use only light and does not need another auxiliary energy source
- Sensors, fibers and optical cables do not have metallic components
- The system can monitor up to 30 sensors per optical fiber
- The power commonly used in interrogation equipment (Class 1 Laser), gives it the classification of intrinsically safe
- Optical interrogation equipment can be installed over long distances and in an unclassified location

5.1.4. MODA System in Spyhole Type End-Fittings

5.1.4.1. The top end-fittings of the spyhole type already provide access to the external armor layer through its access windows. The sensors can be installed on the surface of the external wires using adhesives, and this process can be done either onshore or in the field.

5.1.4.2. In projects with spyhole end-fittings [1] and [2], optical connectors are foreseen to link the sensors to the optical cable responsible for transporting the signals between the sensors and the optical interrogation equipment, Figure 2.

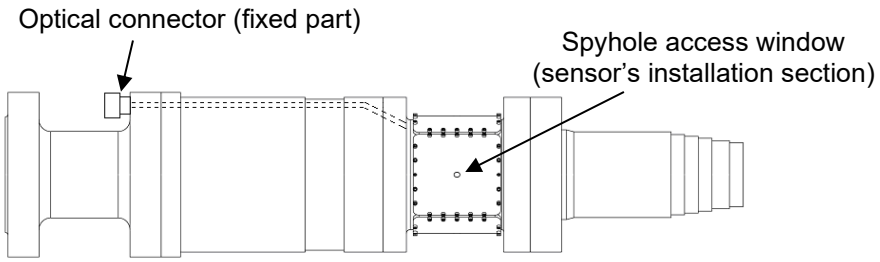

Figure 2: Schematic drawing of MODA basic components for Spyhole end fitting

5.1.5. State and Event Detection with MODA System

5.1.5.1. MODA system can identify changes in the state of the wire in the tensile armor layer through permanent changes associated with relaxation in the state of deformation/tension of the broken wires and overloads in the remaining wires adjacent to the broken one.

5.1.5.2. Additionally, MODA system can identify breakage events through dynamic analysis of the load variation in the wires. Although more complex, this type of analysis can indicate the occurrence of ruptures in the internal armor layers of the riser by detecting the transient disturbance propagated in the external armor.

Figure 3: Spyhole End Fitting with MODA sensors

5.1.6. RISER CONTRACTOR shall supply the FBG sensors (attached to the wires inside the Spyhole End Fitting, see Figure 3), optical cables, test equipment and a submersible dry-mate optical connector mounted at the shoulder of the Top End Fitting body.

5.1.7. RISER CONTRACTOR shall supply PETROBRAS the Riser Optical Cable to interconnect riser dry-mate connector at Top End Fitting and FPU JB.

5.2. RISER SCOPE MODA COMPONENTS

5.2.1. MODA components in RISER CONTRACTOR scope are presented on this document as a standard to perform all sensors installation. The guidelines described here shall be strictly obeyed by RISER CONTRACTOR. When, for any reason, a component substitution is possible or a recommendation is altered, it will be informed by PETROBRAS in a revision of this specification.

5.2.2. The MODA components in RISER SCOPE are:

- Fiber Bragg grating sensors

- Submersible dry-mate optical connector
- Epoxy adhesives
- Riser Optical Cable
- Sensor Test Kit

5.3. FIBER BRAGG GRATING SENSORS

5.3.1. The optical fiber sensors shall comply with the following requirements:

- The sensors shall be based on DTG technology (Draw Tower Gratings)
- The sensors shall have a minimum linear elastic strain range of 1% (1.10^4με) or greater
- The sensors shall be grouped in sets
- The sensors on sets shall be aligned continuously in a single fiber without intermediate splices
- Low bend loss fiber type
- Reflectivity: > 20%
- FWHM: ≤ 200pm
- Wavelength range: 1510 to 1590nm
- Wavelength accuracy: ≤ 0.5nm
- Relative wavelength accuracy: ≤ 0.3nm
- Side lobe suppression: ≥10dB
- Sensor size: 10mm (approximately)
- Fiber attenuation: 8.6dB/km (approximately)
- Mode fiber diameter: 6μm
- Numerical aperture: 0.26
- Cladding diameter: 125μm ± 1μm
- Coating type: ORMOCER®
- Coated fiber diameter: 195μm (approximately)
- Tensile load at break: >50N (> 5% strain)
- Operational temperature range: -180ºC to +200ºC
- The sensors as built, shall have a signal to noise ratio greater than 20 dB, measured in an optical sensing interrogator with a dynamic range of 40dB or greater

5.4. SUBMERSIBLE DRY-MATE OPTICAL CONNECTOR

5.4.1. The optical connector shall comply with the following requirements:

- The connector shall have optical ferrules twice the number of sensors sets at least
- The optical connector shall be supplied in complete configuration (fixed and free parts)
- Designed for single mode fibers only
- The optical connector shall have a watertight pressure protector cup for installation operations
- Dry-mate type
- Resistant up to 3000m water depth (4260psi)
- Operational temperature: -30oC to +100oC (air)
- Insertion loss: < 1.0 dB @1550nm

- Return loss: <-30 dB @1550nm
- Design life: ≥ 30 years

5.4.2. The optical connector shall be placed in hazardous areas. Therefore, its design shall comply and be according to [6].

5.4.3. The place where optical connector is installed is subjected to gas migration by the inner of the end-fitting. As a result, the design of the optical connector shall prevent leakage by its internal components.

5.4.4. The optical connector free part shall be employed to verify and test the full end-fitting instrumentation at the end of the installation. Although this Technical Specification refers only to the MODA components on the end fitting, PETROBRAS considers the free part of the optical connector as a part of it and, therefore, shall be supplied by the manufacturer (for example, the protective cap).

Note: RISER CONTRACTOR shall design the MODA system at the Riser connector end-fitting with only 1 (one) dry-mate optical connector. The number of ways of the dry-mate optical connector selected shall be 12 ways and shall be enough to cover all optical FBG sensors' arrays loops (i.e., both terminations from loops). The pinout for MODA dry-mate optical shall be configured according to Table 1.

Table 1: Dry mate optical connector pin assignment for MODA

Connector Pin Number	MODA Cable Assignment
1	FBG Array Loop 1
2	
3	FBG Array Loop 2
4	
5	FBG Array Loop 3
6	
7	FBG Array Loop 4
8	
9	FBG Array Loop 5
10	
11	FBG Array Loop 6
12	

5.5. EPOXY ADHESIVES

5.5.1. Due to different purpose aspects and physical-chemical properties, sensor adhesion on steel armor wires is made applying two distinct epoxy adhesives. The two purposes are mechanical anchorage and chemical protection.

5.5.2. Mechanical Anchorage Adhesive

5.5.2.1. The adhesive responsible for the mechanical anchorage shall comply with the following specifications:

- Strain range capacity under the foreseen mechanical loads (including pull-in operations)

- A linear elastic behavior under the designed strain range
- High strength and high peel resistance
- Room temperature cure (20ºC to 25ºC) or accelerated cure under specified conditions
- Adhesive's service temperature compatible with flexible riser operating service temperature (recommended T_g-20ºC)

5.5.2.2. To quantify such recommendations, typical properties and performance values of the epoxy adhesive are recommended in Table 2.

Table 2: Mechanical anchorage adhesive properties/performance typical values*

Property/Performance	Typical Values
Tensile Lap Shear (25ºC)	≥3,500psi
Tensile Peel Strength (25ºC)	≥20lb/in
Tensile Strength (25ºC)	≥3,800psi
Tensile Modulus (25ºC)	≥300ksi
Shear Modulus (25ºC)	≥130ksi
Elongation at Break (25ºC)	≥5%
Shore D Hardness (25ºC)	≥75
T_g (glass transition temperature)	≥80ºC

(*) For flexible pipes bore operating temperature up to 60ºC.

5.5.2.3. Any changes in this recommendation shall be fully qualified by the RISER CONTRACTOR, to prove equivalent or superior properties and performance values. Alterations shall be previously notified to PETROBRAS which reserves the right to accept it or not, and all its information (including specifications and properties/performance data) shall be included in the MODA components installation report.

5.5.3. Chemical Resistant Adhesive

5.5.3.1. For protection against chemical contaminants and humidity on the edge between the first epoxy layer and the steel wire, a second layer of epoxy adhesive shall be applied. The chemical resistant adhesive shall comply with the following specifications:

- Good heat, chemical and steam resistance
- Room temperature cure (20ºC to 25ºC) or accelerated cure under specified conditions
- Good resistance to acids, alkalis and solvents
- Do not contain solvents
- Service temperature equal or superior than the mechanical anchorage adhesive

5.5.3.2. To quantify such recommendations, typical properties and performance

values of the epoxy adhesive are recommended in Table 3.

Table 3: Chemical resistance adhesive properties/performance typical values*

Property/Performance	Typical Values
Tensile Lap Shear (23.8ºC)	≥2,000psi
Tensile Strength (23.8ºC)	≥12,000psi
Tensile Modulus (23.8ºC)	≥350ksi
Elongation (23.8ºC)	≤5%
Shore D Hardness (25ºC)	≥75
$T_{g\ (glass\ transition\ temperature)}$	≥80ºC

(*) For flexible pipes bore operating temperature up to 60ºC.

5.5.3.3. Any changes in this recommendation shall be fully qualified by the RISER CONTRACTOR, to prove equivalent or superior properties and performance values. Alterations shall be previously notified to PETROBRAS which reserves the right to accept it or not, and all its information (including specifications and properties/performance data) shall be included in the MODA components installation report.

5.6. RISER OPTICAL CABLE

5.6.1. The Riser Optical Cable is a component of the MODA system supplied by the RISER CONTRACTOR and installed at FPU upper riser balcony in cooperation with the FPU OPERATOR with the following minimum specifications:

- Number of fibers at optical multicable: 12 single mode fibers ([3] or [4])
- Comply with hazardous area classification ([6])

5.6.2. A subsea dry-mate optical connector (male part that matches with the connector installed at the Top End Fitting) shall be mounted at one end of the Riser Optical Cable.

5.6.3. The other end of the Riser Optical Cable shall be delivered with an unterminated optical pigtail. This optical pigtail (as illustrated in Figure 4 and Figure 5) shall be spliced or connectorized during the installation offshore inside the MODA JB at the upper riser balcony. All optical pigtails shall be tagged identifying its correspondence with subsea dry-mate optical connector pins.

5.6.4. More details on the riser optical cable are provided on the specific MD.

5.6.5. After the pull-in of each riser/jumper, RISER CONTRACTOR shall go on board the FPU and execute the following services:

- Repeat tests prescribed on 7.1.3 and compare to data prior shipment.
- Install the Riser Optical Cable optical connector on the riser.
- Lay the Riser Optical Cable at the upper balcony (i.e., on a cable tray).
- Splice the optical pigtails of the Riser Optical Cable with the fibers of a Cabinet Optical Cable and protect them inside the MODA JB.

- Check and certify the integrity of all the splices (spectrum analysis) from MODA Cabinet.

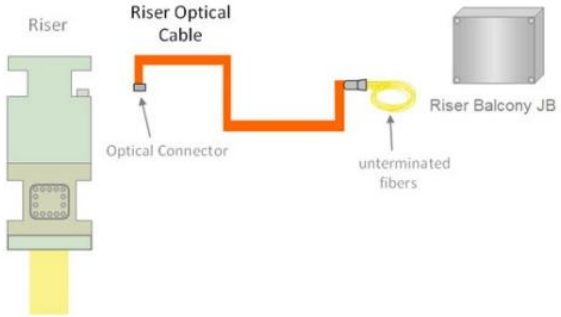

Figure 4: Riser Optical Cable Schematic

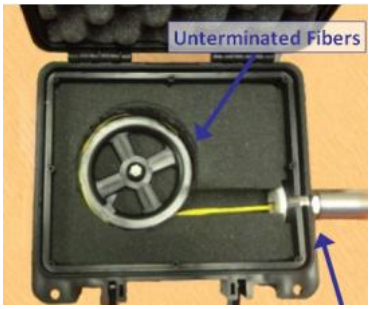

Figure 5: Riser Optical Cable Picture | Unterminated End Picture

5.6.6. Riser Optical Cable drawings shall contain the following detailed information: Cable Manufacturer; optical connector model; n° of pins; total length; type of fiber; number of fibers; type of hose; termination interface with the JB. This shall be part of the deliverable documentation, as stated in 10.

5.6.7. Cabinet Optical Cable runs from the upper riser balcony directly to the MODA Cabinet(s), located on non-classified and temperature-controlled area, as illustrated in Figure 6.

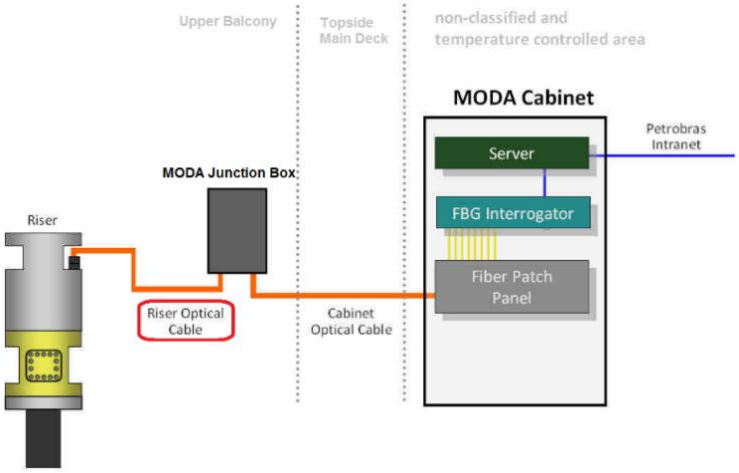

Figure 6: MODA interconnection schematic

5.6.8. On the MODA Cabinet, the optical cable is terminated on a FO patch panel and the fibers are connected to a FBG interrogator that reads the sensors installed on the risers. The data collected by the FBG interrogators shall be processed on server computers installed on the MODA Cabinet and transmitted onshore through PETROBRAS Networks (normally DMZ), as illustrated in Figure 6.

5.7. SENSOR TEST KIT

5.7.1. Sensor Test Kit (STK) shall comprise all electrical and optical hardware to easy test and check MODA system, including FBG sensors and riser optical cables, during on shore and offshore activities. An example of the system is illustrated on Figure 7.

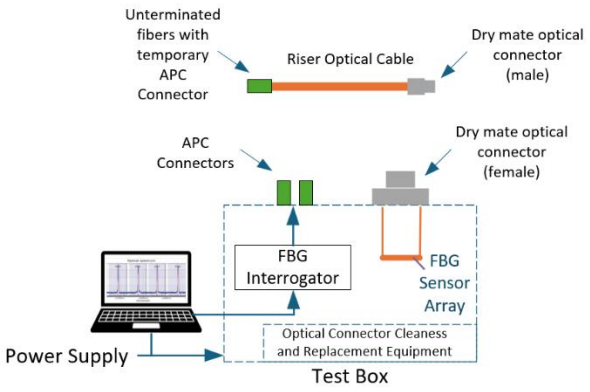

Figure 7: STK System for MODA testing

5.7.2. STK shall have a rugged laptop with Microsoft Windows based solution to gather and visualize all data. STK laptop shall include all power and communication cables.

5.7.3. STK shall be composed of a transportation test box that shall include an FBG Interrogator, FBG Sensor Array, test connectors and any other auxiliary hardware needed (e.g. DC power supply, breakers, surge protectors).

5.7.4. STK shall contain any specific tool and/or feature recommended by the dry mate connector manufacturer for cleaning process.

5.7.5. STK shall contain any specific tool and/or equipment for replacing end fitting dry mate connector in case of failure offshore without any major intervention in the hang-off end-fitting flexible connector.

5.7.6. STK shall contain a fiber optic cable tester pen for checks in the fiber optical path.

5.7.7. FBG Sensor Array shall be supplied by the same manufacturer of the FBG Interrogator and shall have a minimum of 4 (four) FBG sensors at the optical fiber.

5.7.8. FBG Interrogator shall be able to generate results as illustrated on Figure 8. A general specification for the FBG Interrogator is shown below:

- Measurement frequency: 125 Hz or better (per channel)
- Wavelength range: from 1510 to 1590 nm or wider
- Wavelength bandwidth: 80 nm or wider
- Optical channels: 15 or more
- Wavelength accuracy: 10 pm or better
- Wavelength repeatability: 1 pm or better
- Dynamic range (peak): 21 dB or better
- Full spectrum measurement
- Peak detection functionality
- Fanless design
- ATEX certification for sensors operation in Zone 0, 1 or 2 environments as defined on [6]
- SC/APC or LC/APC Optical Connectors
- Ethernet Port
- Sensing Analysis Software (freeware)

5.7.9. STK laptop shall communicate with test box with a standard communication protocol.

5.7.10. STK test box shall be powered by an external voltage supply operating range from 90-240 V_{ac} (+/- 10%), 50/60 Hz and supplied including a protective earth conductor with bipolar circuit and surge protectors.

5.7.11. RISER CONTRACTOR shall provide, during commissioning, all administrator passwords needed to operate and manage STK equipment.

5.7.12. All software shall be provided by RISER CONTRACTOR with its respective license without need of activation after delivery. It means that PETROBRAS shall not depend on RISER CONTRACTOR (or its suppliers) to reinstall the software for future maintenance.

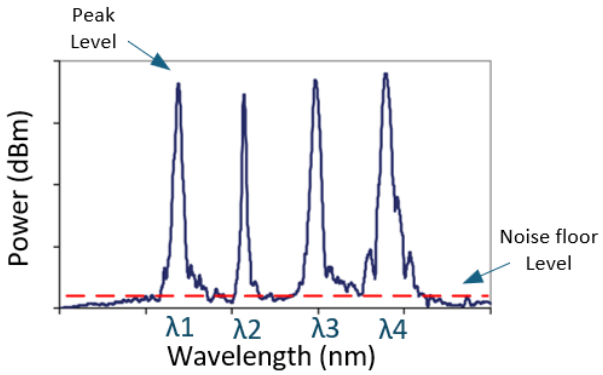

Figure 8: General Overview of the FBG Results

6. INSTALLATION

6.1. INSTALLATION DESIGN OF COMPONENTS INSIDE THE END-FITTING

6.1.1. The installation design shall describe how the sensors are divided on the external tensile armor wire layer and how the optical connector is linked to them. The decision of how many sensors each sensor set contains is a tradeoff between the sensor's wavelength range requirements, wavelength spam available in the interrogator equipment, foreseen strains and handling difficulty for large sensors sets.

6.1.2. All wires on the external tensile armor layer shall have at least, 1 (one) FBG sensor installed on its surface dedicated for strain measurements.

6.1.3. The sensors in sensor sets shall be aligned continuously in a single fiber without any intermediate splice. Spaces between sensors and inlet/outlet fiber lengths shall be considered in the sensor set design, Figure 9.

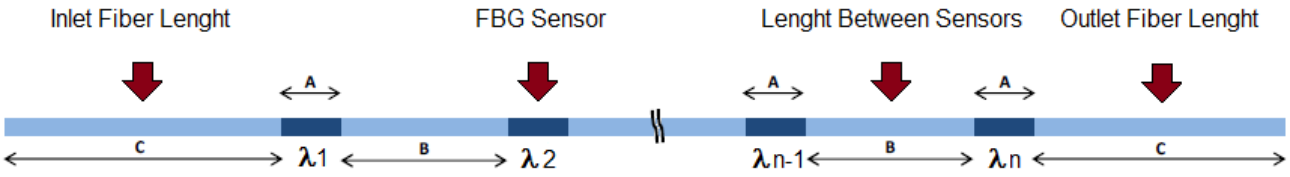

Figure 9: FBG sensor layout design

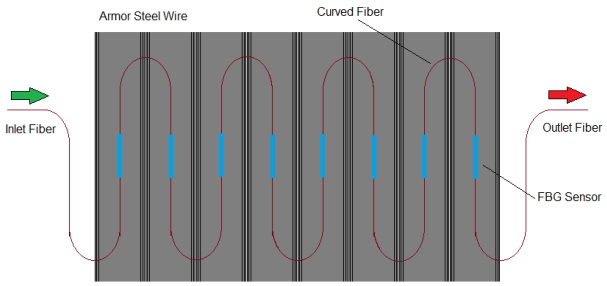

Figure 10: Fiber path

6.1.4. The nominal dimensions of A and B, on Figure 9, shall be calculated according to the flexible pipe structure (*i.e*. wire width, armor angle, etc.), the available physical space and the fiber minimum curvature, which shall not exceed the minimum value recommended by the sensor manufacturer.

6.1.5. Each sensor is fixed on its respective wire through a fiber “zigzag” path, Figure 10. Limitations on the sensor path width, dictated by the minimum required space inside the Spyhole end fitting, shall be observed.

6.1.6. At least 1 (one) FBG sensor for temperature monitoring shall be included in the installation. All temperature compensation sensors shall be clearly identified in the installation design.

6.1.7. As the optical connector position is dependent on each end fitting design, the dimensions and layout of inlet and outlet fibers, legend C on Figure 9, shall be designed by the RISER CONTRACTOR.

6.1.8. Summarizing, the basic variables for an installation design are:

- Sensor’s wavelength
- Number of strain sensors
- Number of temperature compensation sensors
- Number of sensors sets
- Sensor’s size
- End fitting design
- Number of optical channels
- Dimension of the wires
- Armor wires angle
- Fiber minimum bending radius
- Fiber overlength for inlet and outlet splicing
- Optical connector specifications
- Number of optical splices

6.2. INSTALLATION PROCESS OF COMPONENTS INSIDE END-FITTING

6.2.1. Sensor’s installation

6.2.1.1. Prior to the installation all sensor sets shall be verified, and results shall be in accordance with baseline measurements (7.1.1).

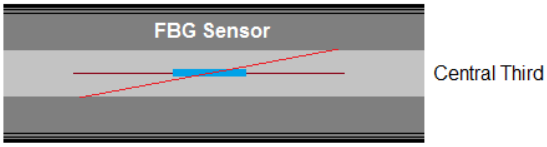

Figure 11: Sensor position

6.2.1.2. Steel wires surface shall be prepared according to epoxy adhesive recommendations. The flexible riser manufacturer shall be consulted about the surface preparation procedures and shall formally agree with such procedures.

6.2.1.3. Sensors shall be placed longitudinally to each wire aligned to its axis (0º±5º), and the sensors position on the wire width shall be within the central third, Figure 11. For sensors positioning, adhesive tapes may be used. The compatibility between adhesive tapes and steel wires material shall be verified with the RISER CONTRACTOR.

6.2.1.4. As part of the fiber installation, RISER CONTRACTOR shall elaborate a document containing a clear correspondence between each sensor on the fiber loop and each wire. The dry mate connector location shall be used as a zero-reference point and then each wire is numbered on counterclockwise direction. A simple schematic considering a 56-wire flexible riser and 4 fiber optical loops is shown on Figure 12. This document shall be delivered to PETROBRAS and attached to the installation report.

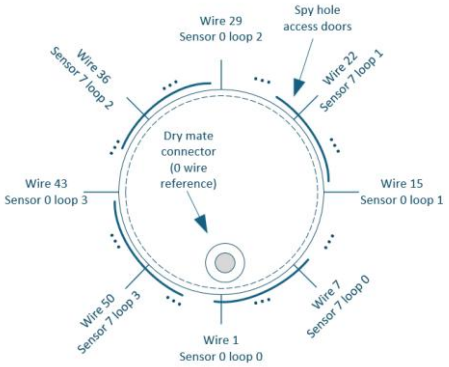

Figure 12: Installation Correspondence schematic

6.2.2. Adhesive application

6.2.2.1. With sensors in position the first epoxy layer, the mechanical anchorage adhesive, shall be applied. After the first layer is cured, the second epoxy layer, the chemical resistant adhesive, shall be applied, Figure 13. The environmental conditions and the cure requirements (cure time, temperature and humidity) for both epoxy layers shall be strictly obeyed according to the adhesive's specifications and recommendations. The compatibility between the adhesive and steel wires material shall be verified with the RISER CONTRACTOR.

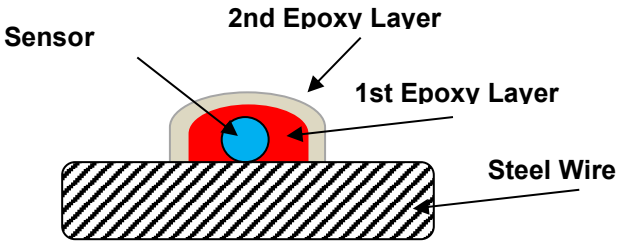

Figure 13: Sensor bonding scheme

6.2.3. Splice operations

6.2.3.1. Splices are critical points on MODA components installation, as they affect not only the quality of measurements, but also their entire operation. All sensor sets shall be linked to the optical connector through electric arc fusion splices. The sensor sets shall be spliced into optical connector ferrules in both of its ends, Figure 14, considering the inlet fiber side as the lower wavelength sensor side.

6.2.3.2. The splices for MODA installation are regular arc fusion splices for single mode fibers. The standard ITU recommendations for fiber splicing shall be followed [5].

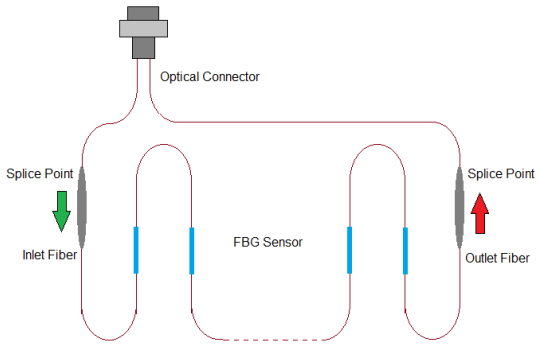

Figure 14: Sensor set with both ends spliced

6.2.4. Optical connector assembly

6.2.4.1. The optical connector assembly on the Spyhole end fitting shoulder shall be executed following the connector manufacturer's recommendations. Sealing verification tests shall be executed according to end fitting design specifications.

6.2.4.2. All mechanical tools and force-pressure equipment shall be calibrated by an INMETRO's accredited laboratory, if applicable.

6.2.4.3. RISER CONTRACTOR shall perform a visual inspection of the connector and perform any type of cleanliness process, in accordance with connector manufacturer's recommendations. Cleanliness equipment shall be part of the STK as described on 5.7.4.

6.2.4.4. After visual inspection and preliminary verifications, if RISER CONTRACTOR identifies any issues with the end fitting dry mate connector, RISER CONTRACTOR shall be able to replace this connector using tools and features

included in the STK as described on 5.7.5.

6.2.5. Anticorrosion finishing

6.2.5.1. After the sensor installation is concluded, a thin layer of lubricant shall be applied over the steel wires for corrosion protection. The compatibility between the lubricant and steel wires material shall be verified with the RISER CONTRACTOR.

7. VERIFICATION AND ACCEPTANCE TESTS

7.1. MODA PRE CHECKS

7.1.1. FBG sensors shall be visually inspected and tested prior to installation after pull-in. Tests shall be performed at factory, base and PLSV and shall contain as a minimum the spectrum analysis using STK (See Figure 8) and any other test considered relevant for integrity purposes. Levels shall be within the expected range for the correct operation of the system without any major variation between each test phase. A signal to noise ratio better than 20dB (defined as the power difference between sensor's peak and noise floor) measured using STK equipment is expected.

7.1.2. RISER CONTRACTOR shall use the results from 7.1.1 as a baseline for installation activities. Results shall be delivered to PETROBRAS and shall be part of the final installation report.

7.1.3. Riser Optical Cable shall be visually inspected and tested prior to installation (at factory, base and PLSV). Tests shall be performed at factory, base and PLSV and shall contain as a minimum the spectrum analysis using STK (See Figure 8) and any other test considered relevant for integrity purposes. Levels shall be within the expected range for the correct operation of the system without any major variation between each test phase. A signal to noise ratio better than 20dB (defined as the power difference between sensor's peak and noise floor) measured using STK equipment is expected.

7.1.4. Since one end of the Riser Optical cable is provided with unterminated fibers, the fibers shall be temporarily mated to a test SC/APC or LC/APC connector for testing (see Figure 7). After testing, fibers shall be delivered unterminated for fiber fusion at the JB.

7.1.5. RISER CONTRACTOR shall use the results from 7.1.3 as a baseline for installation activities. Results shall be delivered to PETROBRAS and shall be part of the final installation report.

7.1.6. For tests at 7.1.1 and 7.1.3, RISER CONTRACTOR shall include, as part of the test reports, pictures of the spectrum, noise floor level and clear identification of each peak wavelength and power level.

7.1.7. After installation procedures are executed (Section 6.2), two tests shall be performed by the RISER CONTRACTOR. The Installation Verification Test (IVT) and the Factory Acceptance Test (FAT). The final installation is considered approved when both tests are successfully performed.

7.2. INSTALLATION VERIFICATION TEST (IVT)

7.2.1. The purpose of the IVT is to ensure that all sensor sets are installed properly. Due to natural fiber curvatures between sensors and splices, some attenuation is expected but shall not compromise the perfect readings of the sensors.

7.2.2. As part of the IVT, two measurements shall be taken: The first one before starting the cure of the adhesives and the second after the cure is done.

7.2.3. The IVT shall be executed with the optical connector already installed on the end fitting. Tests performed without the optical connector are not acceptable. The acceptance criterion for the IVT is 100% of the sensors with signal to noise ratio better than 20dB (defined as the power difference between sensor's peak and noise floor) measured using STK equipment.

7.2.4. Fiber Optic Channels Integrity (FO connectors/cabling/optical splices) shall be tested as a minimum considering the spectrum analysis using STK (See 5.7.11) and any other test considered relevant for integrity purposes. Levels shall be within the expected range for the correct operation of the system without any major variation between each test phase.

7.2.5. A report including all IVT data shall be issued.

7.3. FACTORY ACCEPTANCE TEST (FAT)

7.3.1. The purpose of the FAT is to verify the correct adhesion of sensors on flexible riser steel wires. For this, a mechanical or thermal load shall be applied generating a minimum wavelength variation. Depending on if mechanical or thermal load methodology is chosen, some conditions shall be observed and followed.

7.3.2. For FAT performed using mechanical loads, the applied strain shall sensitize 100% of steel wires. However, a set of different loads capable of sensitizing wires partly are acceptable as long the manufacturer or RISER CONTRACTOR (as per contract), prove that all wires are tested. The minimum wavelength variation required is 100pm in each wire.

7.3.3. For FAT performed using thermal loads, the applied temperature gradient shall sensitize 100% of steel wires. The test shall prove that wavelength variations are due to steel wire thermal expansion only and not from coupled thermal effects on FBG sensors and epoxy's self-thermal expansion. The minimum wavelength variation required is 100pm in each wire.

7.3.4. The FAT shall be executed with the optical connector already installed on the end fitting. Tests performed without the optical connector are not acceptable. The FAT acceptance criterion for both methods is 100% of the sensors with adhesion proven, with signal to noise ratio better than 20dB (defined as the power difference between sensor's peak and noise floor) measured using STK equipment.

7.3.5. Fiber Optic Channels Integrity (FO connectors/cabling/optical splices) shall be tested as a minimum considering the spectrum analysis using STK (See 5.7.11) and any other test considered relevant for integrity purposes. Levels shall be within the expected range for the correct operation of the system without any major variation

between each test phase.

7.3.6. A report including all FAT data shall be issued.

7.4. INSTALLATION REPORT

7.4.1. After tested and accepted, the MODA components installation is considered complete. An Installation Report shall be issued by the RISER CONTRACTOR to PETROBRAS including the following:

- Complete installation design of MODA components inside end-fitting
- All components information, specifications, serial numbers and data sheets
- Component drawings (if applicable)
- Component's qualification (if applicable)
- All sensor sets readings recorded before the installation (Section 7.1) – Spectrum measurement and sensor peak streaming (≥1min), including digital media
- A detailed description of the installation procedure (Section 6.2)
- Detailed photographic register of all major stages (connector assembly before/after cure process, tests at each stage)
- A full reading of all sensors sets recorded after the installation – Spectrum measurement and sensor peak streaming (≥1min), including digital media
- Correspondence document as described on Section 6.2.1.4.
- All Riser Optical cable measurements (Section 7.1).

7.5. ACCEPTANCE REQUIREMENTS

7.5.1. The following acceptance requirements are established for the installation steps of the MODA system (Riser Scope):

- The sensors shall have reflectivity greater than 20%
- The sensors shall have FWHM less than 1.5 nm
- Two subsequent sensors, on the same optical fiber, shall have a difference greater than 3 nm in wavelength
- After installing the sensors, the signal-to-noise ratio of the complete system (including sensors and optical connector) shall be better than 20dB, measured using STK equipment.

7.5.2. Fiber Optic Channels Integrity (FO connectors/cabling/optical splices) shall be tested as a minimum considering the spectrum analysis using STK (See 5.7.11) and any other test considered relevant for integrity purposes. Major levels shall be within the expected range for the correct operation of the system without any major variation between each test phase.

7.5.3. Any deviations to meet these criteria shall be previously discussed and justified with PETROBRAS, and acceptance of these new conditions is exclusively up to

PETROBRAS.

7.6. STORAGE REQUIREMENTS

7.6.1. As the MODA components installed within the spyhole end fitting are sealed and protected, the storage requirements are to prevent damages in the optical connector's pressure cap. All necessary protection covers shall be applied to avoid mechanical damages in this component during the whole period of storage.

7.6.2. All riser optical cables (which are supplied along with the riser) shall be supplied inside IP-65 boxes, all of them shall be identified for traceability purposes, and before riser installation, stored by RISER CONTRACTOR in a dry, dust free environment at ambient temperature. These components shall also be protected against damaging effects like thermal radiation, direct solar radiation, mechanical damage, and solvent organic influence. All spare riser optical cables with IP-65 boxes shall be supplied to PETROBRAS storehouse defined during contract.

8. SCOPE OF RISER CONTRACTOR

8.1. SCOPE OF SUPPLY

8.1.1. RISER CONTRACTOR shall supply, for each flexible riser with Spyhole End Fitting in its scope:

- MODA sensors installed at spyhole End Fitting as detailed in items 5 and 5.7.
- Submersible dry-mate optical connector as detailed in item 5.4.
- Riser Optical Cable to interconnect dry-mate connector and FPU structure in item 5.6.

8.1.2. RISER CONTRACTOR shall supply STK equipment in accordance with 5.7.

8.1.3. RISER CONTRACTOR shall provide all documentation as detailed in item 10.

8.1.4. RISER CONTRACTOR shall supply spare equipment in accordance with respective MD.

8.2. SCOPE OF SERVICE

8.2.1. RISER CONTRACTOR shall install MODA sensors observing installation requirements of item 5.7.

8.2.2. RISER CONTRACTOR shall perform all tests as required in item 7.

8.2.3. RISER CONTRACTOR shall install riser optical cable as detailed in item 5.6.

8.2.4. In all storage over its responsibility, the RISER CONTRACTOR shall observe storage requirements at item 7.6.

8.3. GENERAL SCOPES AT FPU

8.3.1. General overview scopes from RISER CONTRACTOR, FPU

CONTRACTOR/OPERATOR and MODA OPERATOR will be presented in the specific MD.

9. SUBCONTRACTOR REQUIREMENTS

9.1.1. The MODA system SUBCONTRACTOR shall meet the following criteria:

a) Have knowledge to install Fiber Bragg grating sensors

b) Have experience with measurement with Fiber Bragg grating sensors

c) Qualification demonstrated with PETROBRAS

d) Have trained and qualified technicians and in sufficient number to work in marine facilities

e) Have the ability to calibrate the sensors

f) Have the ability to assemble optical components (connectors)

g) Have the ability to perform quality and loss verification tests

h) Have the ability to specify cables and optical fibers

i) Have all the necessary equipment and tools to perform the activities

9.1.2. Any deviations to meet these criteria shall be previously discussed and justified with PETROBRAS, and acceptance of these new conditions is exclusively up to PETROBRAS.

10. DOCUMENTATION REQUIREMENTS

10.1.1. In accordance with PETROBRAS' specifications, the supplier shall deliver, in a detailed and complete manner, the following documents referring to the MODA System – Riser Scope:

- System specifications
- Project reports
- Technical drawings
- Materials and components specifications
- System installation procedures
- System maintenance procedures
- Qualification testing reports and procedures
- Test report of optical components (sensors and optical connector)

Test reports of optical components (sensors and optical connectors) after installation

10.1.2. During the executive design shall be issued to PETROBRAS approval a Technical Proposal of the RISER CONTRACTOR scope, including Datasheets, manuals and certificates for all equipment/cabling supplied by RISER CONTRACTOR.