

GENERAL SPECIFICATION

STRUCTURAL

GS EP STR 603

Hull and Mooring monitoring

00	11/2015	First issue
Rev.	Date	Purpose of the revision

Owning entity: DSO/TEC	Managing entity: DSO/TEC/STR
------------------------	------------------------------

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 2 of 49

Contents

1. Scope	5
2. Reference documents	6
3. Classification	7
4. Definitions	7
5. Abbreviations	7
6. Functional requirements	8
7. General conditions	10
7.1 Units	10
7.2 Time tagging	10
7.3 Long-term data quality and obsolescence	10
7.4 Responsibilities	10
7.5 Planning	11
7.6 Training	11
8. Methodology	11
8.1 Principles	11
8.2 Alarm in case of mooring line failure	11
8.3 Triggered events	11
8.4 Statistics and status of the sensors	12
8.5 Lifetime consumption	12
8.6 HMMS Methodology specification	14
9. Data	14
9.1 Raw data	17
9.2 Converted data	19
9.3 Design data	20
9.4 Derived data	22
9.5 Reported data	23
10. Software	24

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

Page: 3 of 49

10.1	Architecture.....	24
10.2	Data acquisition	24
10.3	Data conversion	24
10.4	Data qualification	25
10.5	Data processing	26
10.6	Data storage and export.....	27
10.7	Data reporting	27
10.8	Graphic User Interface	27
10.9	Data exporting.....	28
10.10	Process data server	28
10.11	Operating system.....	28
11.	HMMS Sensors	28
11.1	On main deck.....	28
11.2	At cold spots	29
11.3	On chain connectors	29
12.	Structural Sensors technical specification.....	30
12.1	General accuracy considerations	30
12.2	General requirements	32
12.3	Temperature sensitivity for strain measurements	32
12.4	Bondable strain gauges	32
12.5	Spot weldable strain gauges	34
12.6	Fibre optic strain gauges.....	34
12.7	Vibrating wire strain gauge.....	36
12.8	Inclinometer	36
12.9	Displacement gauge: LVDT	36
12.10	Accelerometers	37
12.11	Life Time Sensor.....	37
13.	Hardware.....	37
13.1	Introduction	37
13.2	General specification.....	37
13.3	Components	39

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

Page: 4 of 49

14. Interfaces	41
14.1 With the hull design team	42
14.2 With the mooring design team.....	42
14.3 With Load Master package.....	42
14.4 With I3MS package	42
14.5 With Process Data Server package.....	43
14.6 With ICSS package	43
15. Testing and calibration requirements	43
15.1 Testing specification	43
15.2 Factory Acceptance Test	43
15.3 Site Acceptance Test	44
15.4 Calibration.....	45
16. Commissioning	45
16.1 Pre-commissioning	45
16.2 Commissioning	46
16.3 Start-up period	46
16.4 Training.....	46
17. Maintenance	46
17.1 During project phase	46
17.2 Spare part lists	47
17.3 During operation	47
18. Technical Documentation.....	47
Bibliography.....	49

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 5 of 49

1. Scope

This specification is applicable to the hull and mooring monitoring system (HMMS) for FPSO as required per **GS EP STR 652** and **GS EP STR 661**.

The primary objectives of the HMMS are to:

- Prevent crisis and sudden failures resulting in loss of production by providing real-time information on FPSO's structural integrity in an operator friendly and easily understandable format
- Archive and process FPSO data for use in:
 - Optimization of Inspection, Repair and Maintenance (IRM) programs
 - Refine assessment of life time
 - Improve design
 - Support decision for life time extension
 - Failure analysis (black box function).

This specification is intended to define Company's requirements to be fulfilled by Contractor and its Vendors for:

- Design; Engineering; Manufacture
- Protection; Shipment; Installation; Testing; Calibration
- Commissioning; Start-up; Operation
- Training; Maintenance; Warranty.

Essentially the HMMS shall be designed to operate:

- Practically - the system shall be practical and fit for purpose
- Robustly - information shall be confirmed i.e. there shall be no doubt about the quality of the measurement
- Efficiently - the system shall be efficient in performing the required functions
- Redundantly - the system needs a level of redundancy suited to each component
- Reliably - all aspects of the system shall be reliable.

The HMMS aims to monitor the hull, the mooring lines and the turret bearing if any.

The present document establishes the requirements for the HMMS package from Company detailed for the relevant discipline:

- Structure: methodology and data section 8 and section 9, and dedicated sections to structural sensors section 11 and section 12
- Instrumentation: software, hardware, interfaces, testing, commission and maintenance.

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

Page: 6 of 49

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the effective date of this document.

Reference	Title
Not applicable	

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published in the applicable yearly collection.

Reference	Title
GS EP EXP 131	Design and installation of Process Data Server - Creation and administration of Asset Model using Field Share™ method
GS EP EXP 201	Operations preparation during project - Maintainability & Inspectability criteria
GS EP EXP 203	Maintenance and Inspection documentation preparation during project phase
GS EP EXP 205	Requirement to MIE Team for Spare Parts
GS EP EXP 207	Installation description structure
GS EP EXP 311	Plant integrity - Minimum inspection requirements
GS EP GEO 505	Monitoring of Metocean Conditions for Offshore Units
GS EP INS 101	Instrumentation Design
GS EP INS 102	Instrumentation Identification
GS EP INS 106	Instrument Installation
GS EP INS 109	Instrument cabinets
GS EP INS 115	Instrument Earthing
GS EP INS 116	Instrument Cables
GS EP INS 118	Instrument Troubleshooting Loop Diagrams (TSLDs)
GS EP INS 135	Cybersecurity Requirements for Industrial Information Systems (SII)
GS EP INS 140	Instrumentation for monitoring packages
GS EP POS 001	Offshore surface positioning works

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

Page: 7 of 49

Reference	Title
GS EP POS 004	The use of Differential Global Navigation Satellite System
GS EP SPS 019	Subsea production control system
GS EP SPS 021	Subsea mateable electrical/optical connectors
GS EP STR 652	F(P)SO - Steel hull design requirements
GS EP STR 661	FPSO - Design requirements for mooring and anchoring systems
GS EP TEC 007	Obsolescence and Lifetime Cycle Management

3. Classification

Hull and Mooring Monitoring System does not require Classification Society approvals however part of the system shall comply with Classification Society requirements and can be reviewed by the appointed Classification Society:

- Monitoring of deck strain (HULL-MON requirements from Bureau Veritas or equivalent for other recognized Classification Society)
- Monitoring of mooring line tension (POSA requirements from Bureau Veritas or equivalent for other recognized Classification Society).

4. Definitions

Company	Is defined in the relevant contract.
Contractor	Is defined in the relevant section of the contract with Company.
Vendor	The package Vendor sub-contracted by Contractor or by Company.
Supplier	The Party that manufactures or supplies equipment, either individually or as a Packaged unit for the project.

5. Abbreviations

AC	Alternating Current
COG	Center of Gravity
DMZ	Demilitarized zone
DOF	Degree Of Freedom
FAT	Factory Acceptance Test
FBG	Fiber Bragg Gratings
FFT	Fast Fourier Transformation
FPSO	Floating Production Storage Offloading
GNSS	Global Navigation Satellite System
HF	High Frequency

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

Page: 8 of 49

HMMS	Hull and Mooring Monitoring System
I3MS	Integration Metocean and Motion Monitoring System
ICSS	Integrated Control and Safety System
IRM	Inspection Repair Maintenance
IV	Instantaneous Value
LAN	Local Area Network
ML	Mooring Line
MT	Mid Term
OLE	Object Linked Embedding
OPC	OLE for Process Control
PC	Personal Computer
PDS	Process Data System
RAO	Response Amplitude Operator
RFC	Rainflow Counting Value
RTK	Real Time Kinematic
SWBM	Still Water Bending Moment
SWSF	Still Water Shear Force
TSLD	TroubleShooting Line Diagram
UPS	Uninterruptible Power Supply
UTC	Universal Time

6. Functional requirements

The Hull and Mooring Monitoring System (HMMS) (also called structural monitoring system) consists in the following components as specified in **GS EP STR 652** and **GS EP STR 661**:

- A methodology that shall be approved by Company based on the actual structural design of the hull and chain connectors (for the mooring part)
- A package of equipments comprising
 - An array of sensors for hull monitoring (including accelerometers, relative wave height...)
 - An array of sensors for mooring monitoring (including accelerometers, inclinometers...)
 - A main process unit
 - One or more visual display unit
 - A data storage and recording facility
 - A link to the package I3MS (Integrated Monitoring of Metocean and Motion parameters System)

Hull and Mooring monitoring

Rev.: 00

Effective date: 11/2015

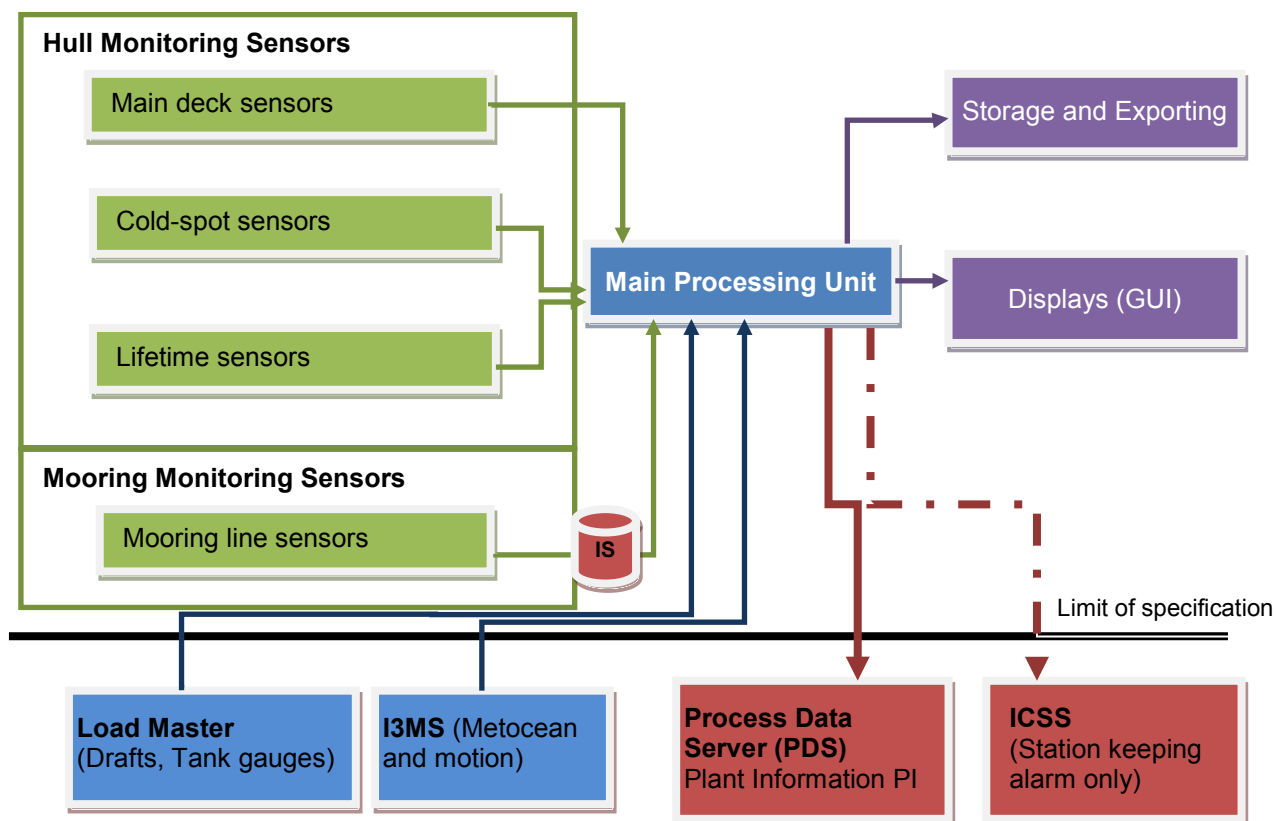
Page: 9 of 49

- A link to the package Load Master (tank gauges and draft, heel and trim)
- A link to the process data system (PI server)
- A link to the ICSS (Station keeping Alarm)
- A link through the instrumentation swivel to transfer the mooring monitoring data to the main process unit
- Required Cabling and Junction boxes.
- A validated software including Graphical User Interface, data acquisition, data processing, data storage and data reporting based on the approved methodology
- A set of data derived during the detail engineering/testing/commissioning of the FPSO
- Spare parts.

HMMS structural sensors are positioned at least:

- On Main deck (4 locations)
- At Cold spot (4 locations)
- On Chain connectors of each mooring line.

Figure 1 - Block Diagram of HMMS package



IS: Instrumentation Swivel

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 10 of 49

7. General conditions

7.1 Units

Units shall be approved by Company.

Time references shall be given in UTC. For ease of operation local user interfaces may show local time or UTC provided that the display clearly indicates which is being displayed.

Local coordinate system(s) used shall be fully defined.

If different coordinate systems are used, transformation parameters to and from each system shall be provided.

7.2 Time tagging

All data shall be tagged with a time stamp provided by the GNSS data from the I3MS system.

7.3 Long-term data quality and obsolescence

One of the main objectives of the HMMS is fatigue management of the hull and mooring system therefore shall be designed such as a high level of data quality is ensured. The duration of operation between each maintenance visit shall be carefully chosen, with consideration for the sensors wear during lifetime, and that of the acquisition system.

For each measurement system (the sensor and its packaging), the normal lifetime on site shall be determined, as well as the expected sensor drift.

Calibration coefficients shall be clearly documented and saved in the HMMS acquisition system, as they will be required for validating the archived data.

Sensors (such as subsea strain gage or wave rider buoy) are known to have a low reliability that implies complex operations for maintenance. Additional sensor systems permitting to derive the same data indirectly shall be included in the HMMS and long term calibrated through systematic data cross-check shall be performed.

All the requirements from **GS EP TEC 007** shall apply to the Hull and Mooring Monitoring System.

7.4 Responsibilities

Contractor is responsible for the performance of the work specified in this document. Contractor shall select the required Vendors to perform the work and each of them shall be approved by Company.

Each Vendor shall provide performance guarantee with on-site assistance, software upgrades and troubleshooting for a period of two years.

Contractor is responsible for the interface between each Vendor but also between each discipline involved in the design, manufacturing, installation and commissioning of the HMMS.

Each Vendor shall specify interfaces which are required for HMMS but are out of its scope of work. This is subject of approval by the Company and Contractor is responsible of these interfaces.

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 11 of 49

7.5 Planning

Contractor shall provide a comprehensive overall schedule of project activities in a bar chart format indicating deliverables as well as start and end of each activity.

7.6 Training

Contractor shall supply a detailed package describing the proposed training program for the Company. The training details shall be supplied before system commissioning.

8. Methodology

8.1 Principles

Practically, the objectives of the HMMS are:

- Generate alarm in case of failure (mooring lines mainly)
- Identify triggered events and provide an easily understandable set of information for these events based on the trigger of selected parameters
- Provide friendly information about the measurements (statistics) and the status of the sensors
- Provide friendly information about the lifetime consumption (developed in this section)
- Store and archive data for further analysis (IRM, design improvement, lifetime extension).

8.2 Alarm in case of mooring line failure

A mooring line failure indicator for each cluster shall be derived and implemented in the Plant Data System (PDS) based on the following principles:

- A mooring line failure is detected based on a decreasing tension on one of the line of the cluster and a concomitant increasing tension on the other lines of the cluster
- The indicator is based on the product of the tension slope in each cluster
- The indicator is multiplied by the variation of the heading and the variation of easting and northing
- Alarm is triggered by the combination of the tension slopes and variation of easting, northing and heading.

If the tension is not available on all the line of the cluster, the indicator shall be identified as degraded and the global positioning indicator shall be used.

The Contractor shall define the trigger in the alarm based on mooring numerical simulations without environmental conditions. An alarm definition reports shall be produced to document the analysis.

8.3 Triggered events

Based on the analysis performed during detail design, some significant events shall be specifically and automatically recorded for further analysis. Hence a set of thresholds shall be defined to trigger the recording and analysis of these events.

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 12 of 49

For each system (hull, mooring and turret bearing), thresholds shall permit to identify 10 to 12 events per year.

List of triggered events and associated thresholds shall be established by Contractor and approved by Company.

8.4 Statistics and status of the sensors

A set of statistics of measured values shall be derived to permit the analysis of the trends of the measured data.

Special attention shall be paid to develop also a set of indicators permitting to provide the health status of the sensors.

8.5 Lifetime consumption

8.5.1 General

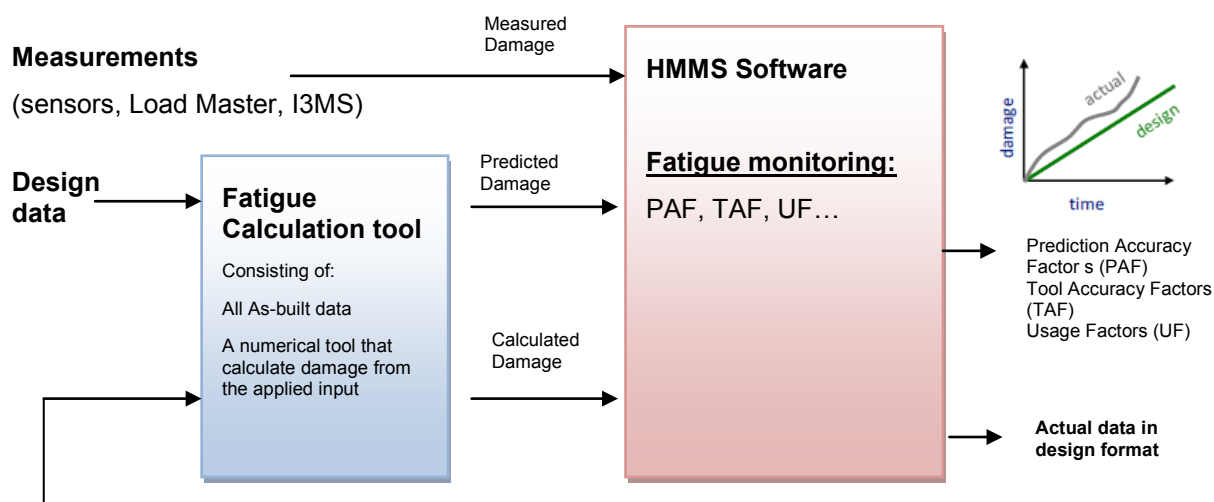
Knowledge of the actual lifetime consumption based on stress measurements like the knowledge of fatigue cracks based on inspections allows assessing the risk of fatigue failure. However it does not explain why the actual lifetime consumption differs from the predicted one.

The basis for the guidance shall be the following factors:

- **Prediction Accuracy Factors** (PAF) that compare the predicted lifetime consumption (predicted damage) with the calculated lifetime consumption based on measured input (calculated damage).
- **Tool Accuracy Factors** (TAF) that compare the measured lifetime consumption (measured damage) with the calculated lifetime consumption based on measured input (calculated damage).
- **Usage Factors** (UF) that compare the mean, nominal and allowable lifetime consumption with the predicted lifetime consumption (predicted damage).

UF's indicate actual level of structural integrity whereas PAFs and TAFs help to explain that level.

Figure 2 - Fatigue Monitoring Methodology in the HMMS Data Processing



8.5.2 Hull fatigue

As per Company standard (see [GS EP STR 652](#)), hull fatigue shall be based on spectral method, therefore during the performance of the fatigue analysis, Contractor hull design team shall:

- Define the cold spot locations and their relation with the most critical hot spots
- Determine the stress RAO's for the cold spot locations
- Determine the RAO's for stress, global shear force and bending moment on main deck stress measurements locations.

8.5.3 Mooring fatigue

As per Company requirements (see [GS EP STR 661](#)), verification of fatigue on the mooring lines shall account for:

- Tension-tension fatigue in the most critical part of the line (from chain connector to anchor)
- Tension bending fatigue on the top chain.

Strain monitoring at the chain connectors shall permit to analyze both phenomena. Mooring design team shall perform all the required analysis and post-treatment to achieve this goal, including but not limiting to:

- Determination of the relations between the stress in the chain connector and the stress in the mooring line critical location for tension-bending fatigue and tension-tension fatigue.
- Calculation of all the required tabulation to permit indirect calculation of the tension (from angle, position...).
- Determination of all the relevant output for the analysis of the strain measurements: SCF, stress RAO's if spectral fatigue is performed for all the possible parameters (draft, sea states, offset...).

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 14 of 49

Typically bending-tension calculation is a very non linear phenomenon and rainflow analysis of the stress on the critical location of the chain is required based on:

- SCF in tension and dynamic tension
- SCF in out-of-plane bending and out-of-plane moment (from OPB angle)
- SCF in in-plane bending and in-plane moment (from IPB angle).

8.6 HMMS Methodology specification

Contractor shall issue as early as possible in the frame of the detail design phase two documents:

- Hull monitoring methodology specification
- Mooring monitoring methodology specification.

These two documents shall be approved by Company prior to commit with Vendors for any item related to HMMS.

The content of these documents shall be based on the following section 9 and shall detail specifically for the project:

1. The measured data (type, frequency, technology...)
2. The design data (list, document references, drawing references...). The requirements in terms of analysis and post-treatment that shall be performed by the Contractor to establish the design data shall be precisely defined
3. The Fatigue calculation Tool (Theoretical basis and main algorithm, developed for the project/monitoring system or actual design tool interfaced with the HMMS software)
4. The measurement analysis with a special attention to “the actual data in design format” section
5. The alarms with their associated levels
6. The criteria for triggered events (high stress, high tension, squalls, large offset...)
7. The reporting outlines (PAF, TAF, UF...).

In this document, Contractor relevant design team (hull structure, mooring, weathervaning equipment) shall identify the main causes of extreme or fatigue load and ensure that the monitoring system permits to assess the FPSO's condition with respect to these causes.

9. Data

The HMMS acquires and processes data into operational information. The following types of data are distinguished:

- **Raw data** are the data as-acquired from sensors of the HMMS or transferred from the Load Master, I3MS...
- **Converted data:** data that are calculated at each time step based on the combination of several recorded or design data (tension from angle, position and draft, tension from strain

General Specification		GS EP STR 603
Hull and Mooring monitoring		
Rev.: 00	Effective date: 11/2015	Page: 15 of 49

measured by the calibrated strain gauges), hot spot stress signal (cold spot stress signal times SCF).

- **Recorded data** are data that have been converted and qualified and that are sampled at the relevant sampling frequency for analysis (an indicator of data quality is typically associated to the data).
- **Design data** are data that are stored in a data base and have been established during detail engineering based on as-built calculations, drawings, reports and calibration tests.
- **Derived data** are data that are issued from the analysis of the recorded data:
 - **Statistical data:** classical min, max, mean and RMS but also RAO's obtained by cross spectrum analysis or spectrum
 - **Actual data in design format:** amongst the derived data, there shall be identified a special category of data that shall specially be formatted to permit the calculation of the calculated damage based on the actual data typically sea state parameters or stress RAO's
 - **Damage data** including calculated damage using the fatigue calculation tool and measured damage using Rainflow counting of stress signal.
- **Report data** are data that summarize the state of the monitored system and are based on a longer duration (typically a day to a month) based on statistics or cumulation.

List of data given in the next sections are not exhaustive, the full list shall be issued by Contractor and approved by Company.

The following processes transfer the raw data into report data:

- Data conversion
- Data qualification
- Data processing
- Data reporting.

Next chart clarifies the data flow and highlights the importance of the design data at each stage of the data flow.