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1. DEFINITIONS AND ABBREVIATIONS

1.1. DEFINITIONS:

PETROBRAS	Floating Production Storage and Off-loading (FPSO) contracting and operating company.
PACKAGER	Company responsible for project, assembly, construction, fabrication, test of compressor and project, assembly, tests, integration and furnishing of all other main equipment in the skid, including the auxiliaries' systems.
PURCHASER	Engineering, Procurement and Construction (EPC) company responsible for project, assembly, erection, construction, fabrication, test and furnishing, lift, hook up, installation and integration of all Modules of FPSO, with complete and fully operative systems in accordance with the requirements of this specification, codes and standards referenced therein. PURCHASER matches Module Supplier, Bidder, Integrator and Automation Integrator from I-ET-3010.00-1200-940-P4X-002 – GENERAL TECHNICAL TERMS.
VENDOR	Company hired by the purchaser or packager to supply of equipment, components of equipment, instruments, control systems, etc. that will be part of the main system to be supplied.

1.2. ABBREVIATIONS:

AC	Alternating Current
ADRE	Automated Diagnostics for Rotating Equipment
AEPR	Automation & Electrical Panels Room
AISI	American Iron and Steel Institute
AMS	Asset Management System
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
AS	Anti-surge
ASTM	American Society for Testing and Materials
ASV	Anti-surge Valve
AVM	Anti-Vibration Mounting
BDV	Blow Down Valve
BOM	Bill of Materials
CCR	Central Control Room (located in the Hull Accommodation)
CCR-ATR	Central Control Room – Automation and Turbomachinery Room
CGS	Compressor Governor System
CGS_HMI	Human Machine Interface for Compressor Governor System
CPU	Central Process Unit

CSS	Control and Safety System
Cv	Coefficient flow valve
DGS	Dry Gas Seal
DIO	Optical Internal Distributor
EMI	Electromagnetic Interference
ESD	Emergency shutdown
FAT	Factory Acceptance Test
FCV	Flow Control Valve
FEA	Finite Element Analysis
FGS	Fire and Gas System
FIT	Factory Integrated Test
FPFLFS	Full pressure, full load, full speed test
FPSO	Floating Production Storage and Off-loading
FPU	Floating Production Unit
FST	Factory Stability Test
HAZOP	Hazard and Operability Study
HMI	Human Machine Interface
HSE	Health, Safety and Environment
HVSD	Hydraulic Variable Speed Drive
IEC	International Electrotechnical Commission
IGCR	Inert Gas Compressor Running
I/O	Input/Output
ISO	International Organization for Standardization
LAN	Local Area Network
LSL	Low Level Switch
LSH	High Level Switch
LSHH	High High Level Switch
LV	Level Control Valve
MCC	Motor Control Center
MLO	Mineral Lube Oil
MMS	Machinery Monitoring System
MPA	Automatized Procedures Module (Portuguese: Módulo de Procedimentos Automatizados)
MPS	Machinery Protection System
MRT	Mechanical Running Test
OHSA	Occupational Safety and Health Administration
OPC UA	Open Platform Communications Unified Architecture
PAS	Package Automation System
PCS	Process Control System
PCV	Pressure Control Valves

PDCV	Pressure Differential Control Valve
P&ID	Piping and Instrumentation Diagram
PHA	Preliminary Hazard Analysis
PLC	Programmable Logic Controller
PMS	Power Management System
PO	Purchase Order
PSD	Process Shutdown System
PSV	Pressure Safety Valves
PTFE	Polytetrafluoroethylene
RESD	Emergency Shutdown Relay
RFI	Radio Frequency Interference
RIO	Remote I/O Panel
RTD	Resistance Temperature Detector
SAT	Site Acceptance Test
SDV	Shut Down Valve
SGCS	Seal Gas Conditioning System
SGP	Seal Gas Panel
SI	International System of Units
SLT	Sound Level Test
SIT	Site Integration Test
SOS	Supervision and Operation System
SYAT	Shipyard Acceptance Test
TAP	Performance Acceptance Test
TBE	Technical Bid Evaluation
TCP/IP	Transmission Control Protocol/Internet Protocol
UCP	Unit Control Panel
UCP_HMI	Human Machine Interface for Unit Control Panel
VFD	Variable Frequency Drive
XV	On-off Valve

2. GENERAL

2.1. Centrifugal compressor for Motocompressor package units shall be in accordance with API STD 617 latest edition and Annex B - Additions and Modifications to API 617.

2.2. The complete Motocompressor packages shall be designed for minimum 30 years of operation installed on the FPSO and at least 5 years of uninterrupted operation except HVSD that shall be designed for at least 8 years of uninterrupted operation.

2.3. All documents listed in Material Requisition and specific project's "CENTRIFUGAL GAS MOTOCOMPRESSORS PACKAGE SPECIFICATION", as stated in the DOCUMENT LIST, are mandatory, as well as the electrical, automation and safety requirements for Motocompressor package units described in these documents.

2.4. All components of the system shall be suitable for offshore environment, throughout the whole platform service life, under all operational conditions and submitted to Unit motions and accelerations described in PETROBRAS specifications.

2.5. SI units of measure shall be used in PACKAGER's documentation, except for piping.

2.6. PACKAGER and PURCHASER shall be entirely responsible for material selection on items not specified by PETROBRAS and shall inform material of all main parts according to ASTM code. All bolts and nuts shall be supplied with PACKAGER and PURCHASER certificates and fully marked according to applicable ASTM standard.

2.7. All shop punch lists shall be cleared before shipment.

2.8. Equipment shall be prepared for outdoor storage according to PURCHASER specifications.

2.9. PACKAGER and PURCHASER shall specify the products to be used for preservation of the equipment components and spare parts, their removal and reapplication methods and the application date. Such data shall be summarized on two tags to be securely fastened on all equipment and outside of each crate. If rust preventives are required, volatile products shall not be applied.

2.10. Hazardous and toxic materials with associated adverse health effects shall be avoided or minimized. PACKAGER, PURCHASER and VENDOR are encouraged to promote their replacement. Asbestos, hazardous and toxic components shall not be used in the materials and equipment supplied for this project or for this plant or facility. As the use of such materials will not be tolerated, PETROBRAS strongly recommends PACKAGER, PURCHASER and VENDOR to take all necessary measures to ensure their use is fully avoided throughout this project. Material safety datasheets may be required by PETROBRAS any time, to demonstrate that any particular material has not been used and will not be used throughout all stages of this project.

2.11. All equipment, components and panels shall have a nameplate easy to access, to view and read. Nameplate shall be made in stainless steel AISI 316L and bolted (with stainless steel elements) to the equipment. Layout drawings shall be submitted to PETROBRAS approval. Nameplates shall contain the following information, in Brazilian Portuguese language:

- Client name;
- Client job;
- Client area;
- Supplier name;
- Series number and model;
- Year of manufacturing;
- Main design and test data: pressure, temperature, voltage, rotation, etc.;
- Specific data;
- Tag number;
- Purchaser’s requisition number (RM);
- Purchaser’s request for quotation number (RFQ);
- Purchaser’s order number (PO);
- Empty weight;
- Design code.

2.12. All safety signals shall be in Portuguese language.

3. CONSTRUCTION FEATURES

3.1. Centrifugal compressors shall be radially split case (barrel type) in accordance with API std 617 latest edition.

3.2. Compressor's main process connections shall be flanged and oriented upwards.

3.3. Compressors with mounted tie-bolt impellers are not acceptable.

3.4. Compressors with sidestream are not acceptable.

3.5. Compressors balance line differential pressure shall be monitored by a transmitter. If the balance line is internal to the casing, PACKAGER shall provide casing connections to install the transmitter.

3.6. Compressor bearings shall be hydrodynamic tilting pads type.

3.7. Bearings shall be designed to minimize oil foaming and prevent oil whirl at any operating speed.

3.8. The compressor train centerline shall be oriented in the fore/aft direction in case of installed on a FPSO (Floating Production Storage and Off-loading).

3.9. Connections between pipe flanges and suction and discharge nozzle flanges of compressor shall be provided with removable spools to facilitate compressor removal and disassembly. Removable spools shall not have any process instruments. The removable spool shall have two borescope accesses (suction and discharge), closer to the compressor flanges. These access with blind flange connections shall be quick and easy to open and close.

3.10. Removable spools shall not have any process instruments. Each removable spool shall have one borescope connection, 3/4" size with blind flange, located as close as possible to the compressor nozzle in order to reduce the required lenght of the borescope. PURCHASER shall verify and assure that this branch connection does not introduce any acoustic induced vibration (AIV) due to the gas flow.

3.11. Clamp connections are not acceptable.

3.12. PACKAGER shall consider the gas saturated with water and the presence of corrosive agents for equipment material selection, even when not specified in any compressor operating case. The H_2S content shall be considered 170 ppm or compressor datasheet value, whichever is greater, and the CO_2 content shall be considered 5% vol. or compressor datasheet value, whichever is greater.

3.13. PACKAGER shall also consider, in addition to steady state operation, the transient conditions for material selection, such as: compression system starts and stops; plant pressurization; stopping compressor and depressurizing plant, compressor stopped and plant pressurized.

3.14. PACKAGER shall select the equipment materials based also on the minimum temperature foreseen during depressurization and the depressurization rates. PACKAGER and PURCHASER shall perform the depressurization analysis of the system to determine the minimum temperature and depressurization rates before the material selection.

3.15. All materials that are exposed to hydrocarbons containing hydrogen sulfide shall follow the requirements of ISO 15156 for sour service for the lowest anticipated pH and the highest H_2S partial pressure.

3.16. In case of a skid with two compressor casings, it shall be provided the required maintenance area on the skid and appropriate fixtures to allow the procedure for bundle removal from any casing with no need of removing any of the casings.

3.17. Instrument air flows shall be classified also as essential or non-essential. Essential consumers are fed during ESD-3. Non-essential consumers are not fed during ESD-3. Essential instrument air shall be minimized, whenever possible, since it is limited during ESD-3.

3.18. The instrument air distribution inside the package shall be done using a manifold designed as per document I-ET-3010.00-1200-800-P4X-013 - GENERAL CRITERIA FOR INSTRUMENTATION PROJECTS.

3.19. Instrument air for cooling purposes shall be avoided.

4. ACCESSORIES AND AUXILIARIES

4.1. **Piping**

4.1.1. Except where indicated, all piping and accessories within equipment package limit shall be in accordance with PACKAGER piping specification and international standards.

4.1.2. All auxiliary piping requiring field connections shall be flanged, brought to the skid edge and shall have isolation devices. Manual valves shall be installed at suitable height to be easily operated, especially valves for draining the compressor casing and isolating the lines connected to Flare system. The position of the valves around the skid edges shall be defined together with PURCHASER to avoid having valves obstructed by structures around the skids.

4.1.3. Systems/equipment isolation shall comply with Isolation Guidelines requirements from specific project's document "DESCRIPTIVE MEMORANDUM – PROCESS", as stated in the DOCUMENT LIST.

4.1.4. Bolting for piping and structures in general shall comply with document I-ET-3010.00-1200-251-P4X-001 - REQUIREMENTS FOR BOLTING MATERIALS.

4.1.5. Tubing shall be used only for instrumentation, according to document I-ET-3010.00-1200-800-P4X-013 - GENERAL CRITERIA FOR INSTRUMENTATION PROJECTS.

4.1.6. Manual block valves and spectacle/blind flanges shall be provided at all battery limits such as inlet and outlet nozzles, drain lines, etc. PACKAGER and PURCHASER consider piping standards per each specific project's "PIPING SPECIFICATION FOR TOPSIDES" as stated in the DOCUMENT LIST. Manual valves shall be installed at the skid edge to be operated, especially valves for draining the compressor casing. Access to all manual valves shall be free.

4.1.7. All equipment shall have sufficient flexibility in all pipe and duct connections.

4.1.8. The interconnecting pipework between auxiliary skids and the main skid shall be provided by PURCHASER. The interconnections between the gas lines shall be routed above the skids. The pipes arrangement shall avoid the accumulation of liquid in low points. When it is not possible to avoid accumulation points, drain valves with blind flanges shall be provided and routed to skid edge. Drainage shall occur in all low point of the piping regardless of FPSO motion under all operational conditions and submitted to Unit motions and accelerations described in PETROBRAS specifications.

4.1.9. Valve handles shall have locking provisions. PACKAGER and PURCHASER shall define which valves shall be locked open or locked closed to avoid unintended operation.

4.1.10. A T-type strainer shall be installed in each suction line of the compressor, close to nozzle The strainer is to be kept installed after commissioning, but without the commissioning mesh. Differential pressure transmitter shall be provided by PURCHASER and connected to PACKAGER control system to protect the strainer from collapsing.

4.1.11. In case of water content in gas, an analysis shall be made to verify the possibility of hydrate formation in the recycle line. Hot recycle shall be used, which means that the Anti-Surge Valve line shall be upstream of the discharge process gas heat exchanger.

4.1.12. PACKAGER shall inform the minimum length of straight pipe required at compressor nozzles, suction flow element and Anti-Surge Valves (ASV) to be implemented by PURCHASER.

4.2. Couplings and coupling guards

4.2.1. PACKAGER is responsible for all couplings within the package, including those for auxiliary equipment.

4.2.2. Coupling for main equipment shall be a stainless-steel flexible-element, non-lubricated type.

4.2.3. Couplings and coupling guards shall be according to API 671 latest edition. PACKAGER shall submit to PETROBRAS main equipment coupling data sheet according to API 671 latest Edition.

4.2.4. All coupling guards (including those for auxiliary equipment) shall be rigid, fully enclosed, in non-sparking material. Safety coupling guards (without feet) are also acceptable. In case of failure, guards shall be able to retain broken parts, for personnel protection (OHSA 1910.219 shall be complied). All coupling guards shall be designed to allow removal without disassembling the coupling and shall be constructed so that routine inspections are performed by means of strobe light, with the equipment running.

4.2.5. Coupling guard drains shall have sight glasses in horizontal drain lines. The coupling guard shall not be used as a normal operating lube oil drain path.

4.2.6. Coupling hubs for main equipment shall be integral flange or keyless hydraulically fitted for main equipment, if not defined in PETROBRAS data sheets of the respective equipment.

4.2.7. The couplings shall incorporate a feature that allows the transmission of load for a limited period in the event of a complete flexible element failure to allow safe shutdown of equipment.

4.2.8. Instrument air for coupling guard cooling shall be avoided whenever possible. When necessary, PACKAGER shall provide coupling guard enclosure temperature calculation for PURCHASER and PETROBRAS approval.

4.2.9. Couplings shall be certified for explosive atmosphere.

4.3. Baseplate

4.3.1. Main baseplate shall be capable of supporting the stresses arising from FPSO motions and shall be provided with three (3) point supports and Anti-Vibration Mounting (AVM). FPSO motions are defined preliminary in specific project's document “MOTION ANALYSIS”, as stated in the DOCUMENT LIST, but PURCHASER shall confirm the final values during Detailed Engineering phase.

4.3.2. Baseplate shall be rigid enough to avoid permanent distortion during lifting, shipment and operation. When the baseplate is lifted, with all equipment mounted, beam deflection shall not exceed L/400, being L is the total baseplate length.

4.3.3. Driver, driven machine, transmission, oil system, Seal Gas Panel (SGP) and Remote I/O Panel (RIO) shall be mounted on a single baseplate including auxiliaries. PACKAGER and PURCHASER shall submit layout to PETROBRAS comments and approval.

4.3.4. The top surface of the baseplate shall be made of solid plates to avoid compartmentalized sections or voids. Removable grating can be installed on top of this surface for walking and working areas. The piping, tubing and cable trays may be routed under the removable gratings to free the walking and work areas.

4.3.5. All furnished skids shall be sufficiently stiff to withstand all vibration loads induced by the equipment and transfer them to the deck beams.

4.3.6. Skid mounted assemblies shall be constructed in order to not require equipment or parts to be dismounted for lifting.

4.3.7. Equipment and component shall not protrude beyond the skid limits, especially the terminal box of the main driver motor, to avoid disassembly of the terminal box for transportation and baseplate lifting. Cantilevered structures are considered protrusions as well and shall be avoided. In cases where it cannot be avoided, PACKAGER shall provide protection against mechanical damage to the protruded equipment shall be provided. However, all alternative layouts to avoid protrusions shall be exhausted first.

4.3.8. Each skid shall be provided with facilities for lifting, such as pad-eyes, lugs, bollards and spreader bar, having suitable access for rigging. The estimated lifting load and safety factor for each point shall be informed in PACKAGER proposal. However, all alternative layouts to avoid protrusions shall be exhausted first. Main lifting points shall not be welded to the beam flange unless the strength level is low enough or if the beam flange has a suitable thickness.

4.3.9. All equipment to be mounted on skids shall allow on-field leveling and alignment using jacking screws (in three plane directions) and precision type shims. Total shim thickness shall not exceed 6.35mm and the number of shims shall be kept to a minimum. Any additional height shall be made up of solid stainless-steel plate.

4.3.10. All skid mounted equipment containing liquids that shall be drained onto the skid area shall be fitted with drip pan underneath the equipment and provided with flanged nozzle with sufficient slope. Drip pans draining system shall be designed considering the total deluge flow over the skid. Drain nozzles arrangements shall be provided at the skid edge with appropriate piping, blocking valve, strainer and water seal, in order to perform drainage regardless of FPSO motion.

4.3.11. PACKAGER the required deluge water flow according to document DR-ENGP-M-I-1.3 - SAFETY ENGINEERING GUIDELINE. The quantity and diameter of the nozzles shall be defined according to specific project's document “DRAINAGE SYSTEM GUIDELINES” as stated in the DOCUMENT LIST.

4.3.12. Fasteners (including washers) and shims shall be constructed in stainless steel AISI 316L.

4.3.13. Components, such as pipes, trays and cables, shall not pass through structural elements, such as beams. In cases where this passage cannot be avoided, structural analysis shall be performed to guarantee its structural function.

4.4. Support system

4.4.1. All required supporting systems (including spring supports, structure, etc.) shall be supplied (for on-skid elements) or specified with all design requirements (such as loads, position, forces, etc.) by PACKAGER and PURCHASER.

4.5. Insulation

4.5.1. All required insulation for personnel protection or machine thermal efficiency or noise suppression shall be applied and provided by PACKAGER and PURCHASER.

4.5.2. Insulation shall be provided according to document I-ET-3010.00-1200-431-P4X-001 – THERMAL INSULATION FOR MARITIME INSTALLATIONS.

4.5.3. Insulating shall ensure a temperature below 60˚C over the external surface for personnel protection.

4.5.4. To prevent corrosion under insulation, only non-hygroscopic insulation material shall be used.

4.5.5. Insulation installation shall be done before sail away from PURCHASER’s integration yard during transportation and erection.

4.6. Oil system

4.6.1. The mineral lube oil system shall be designed per API 614 for special purpose applications (latest edition). Special considerations shall be given to the FPSO motion in order to guarantee bearing lube and its oil drainage during normal operation and post-lube:

- for HVSD, the MLO system shall be integrated and provided for lubricating driver, HVSD and driven equipment;
- for gearbox, the MLO system shall be integrated, if possible, and provided for lubricating driver, gearbox, and driven equipment. When MLO system is not possible to be integrated, an independent mineral oil (lube) package system shall be provided for lubricating driver, gearbox and driven equipment, installed nearest main equipment baseplate.

4.6.2. Special consideration shall be given to the presence of dirt, debris, and any foreign matter in sensitive parts (bearings, for instance). Provisions shall be made for by-pass of sensitive parts while system flushing operations are performed.

4.6.3. PACKAGER shall propose its standard oil system configuration, but the configuration of the coolers and filters shall be as Oil System Data Sheet.

4.6.4. Lube oil system shall be monitored with PACKAGER specification, international standards for this system and Oil System Data Sheet.

4.6.5. PACKAGER shall provide sampling points for oil analysis at reservoir bottom, upstream and downstream the lube oil filters and for each, and oil return line of from driver, gearbox/HVSD and compressor. Sampling facilities shall be permanent, allow lube oil sampling during operation, located preferably on turbulent zones such as piping elbows and fitted with valves installed in T-type connections, oil spill and drip collectors and spillback lines to be routed back to oil reservoir. Sampling arrangement shall enable samples taken during operation.

4.6.6. Except for oil pumps, all piping, tubing, wetted metallic parts and appurtenance including lube oil and control oil systems shall be in stainless steel AISI 316L.

4.6.7. Socket welds for piping and tubing is prohibited.

4.6.8. Reservoirs:

- Reservoir shall be provided with filling connections (with filter), oil conditioner connections level indicator sight glass, antifoaming devices, accessible manholes, valve drain at skid edge and include provisions for nitrogen purges;
- All return lines shall be top entry type, extending inlet duct inside the reservoir to below minimum operating level in order to avoid foaming;
- Reservoir shall be designed to facilitate air separation between the bearing return and pump supply;
- Vents shall be fitted with oil vapor separator in order to recover oil due to evaporation losses and environmental protection (PACKAGER shall guarantee maximal oil losses of five (5) ppm). Vents shall be dimensioned with the same size as the oil return header, at least;

- An electric lube oil heater shall be provided, interlocked with a low-level and oil temperature control. This device shall be preferably top mounted to allow removal without having to drain the reservoir or stop the equipment.

4.6.9. The configuration for pumps shall be:

- Main oil pump: Shaft-driven (preferable) or electric motor driven (AC power);
- Stand-by pump: Electric motor driven (AC power);
- Main and stand-by pumps shall have the same capacity;
- If the main pump is electrically driven, then main and stand-by pumps shall be identical.

4.6.10. Oil coolers shall be multi-plate duplex type with changeover valve. Cooler shall have provision for future increase of the number of plates. The cooling water pressure shall be lower than oil pressure at heat exchanger interior. The material shall be selected as following:

- Stainless steel AISI 316L, if closed loop cooling water system;
- Titaniun, if open loop cooling water system.

4.6.11. Oil filters shall be duplex (twin) with changeover valve. The canisters, transfer valves and piping for oil filter system shall be stainless steel AISI 316L construction. Filter element material shall be corrosion and water resistant. There shall be no by-pass around any filter.

4.6.12. Lube oil system shall have rundown tank for emergency conditions. The rundown tank shall have enough capacity for bearing cooling during coast-down time. The oil supply time by rundown tank shall not exceed fifteen minutes after the machine has stopped.

4.6.13. The rundown tank shall have a level gauge in addition to the level transmitter, a breather valve that also prevents the lube oil from spilling outside, a drain valve with blind flange and a lube oil sampling point. The level transmitter shall be accessible. PURCHASER shall provide coaming around the rundown tank to contain leakages.

4.6.14. The rundown filling shall be done automatically during the start-up sequence by an on-off filling valve (XV).

4.6.15. PACKAGER shall inform all data and characteristics of electric load (as power, source, etc.) for each pump driver, heater, etc. in proposal phase. PURCHASER will furnish all electrical utilities required by PACKAGER, considering platform available voltages as stated in I-ET-3010.00-5140-700-P4X-003 – ELECTRICAL REQUIREMENTS FOR PACKAGES FOR OFFSHORE UNITS.

4.6.16. API datasheets for pumps and heat exchangers shall be included in proposal.

4.6.17. All oil vents shall be interconnected, fitted with flame arrestors and routed to a safe area. All oil drains shall also be interconnected and routed to oil reservoir. Flame arrestor material shall be compatible with vent line material.

4.6.18. Vent line shall be designed considering FPSO motion under all operational conditions and submitted to Unit motions and accelerations described in PETROBRAS specifications to avoid liquid seal.

4.6.19. The vent line of the oil vapor separator shall be routed to a location outside hazardous area, preferably to the top of the module, at port or starboard side, in an area capable of dispersing the vapor away from the FPSO, to avoid slippery surfaces. A flame arrestor shall be fitted at the end of the vent line. The flame arrestor material shall be compatible with vent line material. These vents shall be arranged to avoid the ingress of rainwater or other foreign materials.

4.6.20. PACKAGER shall provide all data of oil system equipment and fluid as oil consumption, oil complete specification and filter elements life. Oil system data shall include drawings and lubricant list with complete lube oil and greases specifications and lubrication schedule during the project development shall be provided.

4.7. Gear Units

4.7.1. Hydraulic Variable Speed Drive (HVSD)

4.7.1.1 When specified on the compressor datasheet, HVSD shall be designed as a “stand-alone” unit, whereby no external thrust loads shall be imposed upon the HVSD by other equipment.

4.7.1.2 HVSD shall be designed for all operating cases defined in the compressor datasheet. There is no predominant operating case. The certified point does not represent the most frequent operating point. The hydraulic variable speed driver shall be designed to operate continuously and for a long period at any point in the speed and torque range. VENDOR shall provide the HVSD operating map with the indication of all operating and test cases, operating limits and performance curves, including output torque, output speed, guide vane position and efficiency

4.7.1.3 The guide vane control during start-up shall be evaluated by PACKAGER and VENDOR to avoid staying near any critical speeds, including the compressor. The guide vane position curve during start-up shall be provided also.

4.7.1.4 Nitrogen purge connection for preservation propose of HVSD shall be included on equipment.

4.7.2. Gearbox

4.7.2.1 When specified on the compressor datasheet, the gearbox shall be double helical, single stage designed in accordance with API613 latest edition.

4.7.2.2 A device shall be provided to allow manually rotation of the shafts for maintenance purpose (such as shaft mechanical alignment or borescope inspection). Special adapters shall be provided as special tools.

4.7.2.3 Gearbox shall be designed as a “stand-alone” unit, whereby no external thrust loads shall be imposed upon the gearbox by other equipment.

4.7.2.4 The use of one or two gearboxes shall be defined by vendor. However, dimension limitations for compressor package defined on the compressor datasheet shall be accomplished.

4.7.2.5 Shaft oil seals shall be easily accessible for removal and re-installation without removing the couplings.

4.7.2.6 Bearings shall be pressure lubricated and fully replaceable at field.

4.8. Pressure vessels

4.8.1. Pressure vessels shall be designed as per document I-ET-3010.00-1200-540-P4X-001 - REQUIREMENTS FOR PRESSURE VESSELS DESIGN AND FABRICATION. PURCHASER shall advise PACKAGER about the applicable requirements from Brazilian Government regulations NR-13 and NR-37. The document I-ET-3010.00-1200-970-P4X-013 - COMPLIANCE WITH NR-13 AND SPIE REQUIREMENTS can be used as a guide for understanding the requirements.

4.8.2. For nozzles less than 2” in nominal diameter, forged steel couplings may be used. Couplings shall be at least class 6000#, for socket weld.

4.8.3. All nozzles having a nominal diameter of 2” or greater, shall be flanged, except when specified for butt weld in the piping.

4.8.4. The minimum nominal diameter of nozzles intended for any purpose shall be 3/4”.

4.8.5. Only full penetration welds are permitted.

4.8.6. All shell reinforcements, integral or not, shall always have the same shell P-number.

4.8.7. The minimum degree of radiographic examination for weld inspections according table UW-12 shall be full or spot.

4.9. Dry Gas Seal (DGS) system

4.9.1. All dry gas seal system and components shall be provided by the DGS manufacturer in accordance with API 692 (latest edition), considering all operating conditions (including pressurizing start-up, normal stop and emergency pressurized and depressurized shutdown etc.) and site available utilities.

4.9.2. The seal gas supply shall be available before starting compressor package plant pressurization and continue to operate as long as the pressure in the process plant is greater than 0.3 barg.

4.9.3. PACKAGER shall provide datasheets in API STD 692 format and DGS system components datasheets and drawings shall be provided during the project development.

4.9.4. PACKAGER shall include in proposal a reference list showing his experience with the proposed DGS system, highlighting the units with similar services.

4.9.5. DGS system shall always assure that the seal gas pressure is positive in relation to the balance line pressure and a minimum seal gas flow across the process side labyrinths to avoid seal contamination for all operating conditions such as: pressurization, start-up, steady state operating, normal stop, emergency pressurized and depressurized shutdown.

4.9.6. DGS shall be bi-directional tandem type with intermediate seal gas labyrinth for each shaft end. Primary and secondary seals rotating faces material shall be made of silicon carbide, at least. The conditioned discharge process gas shall be used as primary seal gas supply and conditioned nitrogen shall be used as secondary seal gas supply. Conditioned nitrogen shall be used as primary seal gas during Shipyard Acceptance Test (SYAT).

4.9.7. Conditioned nitrogen shall be used as separation gas supply. Separation seals type selection shall minimize nitrogen consumption in running and stop condition. Available nitrogen flow rate shall be consulted prior to separation seal type selection, and if possible, carbon ring non-contacting is the preferred separation seal type. Labyrinth seal for separation seal type shall not be acceptable.

4.9.8. Primary vents shall be routed to flare system and secondary vents shall be vented to atmosphere, routed to a location outside hazardous area, preferably to the top of the module, at port or starboard side, in an area capable of dispersing the gas away from the FPSO. Secondary vents shall be arranged to avoid the ingress of rainwater or other foreign materials.

4.9.9. Air and nitrogen utilities consumption shall be minimized due FPSO capacity production restriction. Seal and labyrinth shall be designed in order to minimize gas consumption. XV valves with limiter switch and any other required protection layer shall be used in order to automatically reduce consumption whenever not required.

4.9.10. Where different seal designs or pressure ratings are employed in adjacent casings on the same compressor package, the seal cartridge shall be designed to prevent the incorrect mounting in different casings.

4.9.11. All DGS include piping, Pressure Safety Valves (PSV), Pressure Control Valves (PCV), check valves, orifice plates, valves (including internals components) and the other devices shall be made from stainless steel AISI 316L and shall be supplied by PACKAGER.

4.9.12. PACKAGER shall provide a dedicated Seal Gas Panel (SGP) for each compressor casing.

4.9.13. All PSV and check valves on venting piping, downstream each seal, control valves and other necessary valves for DGS system shall be provided by PACKAGER. PSV, or rupture disk, shall be sized to assure venting capacity during a seal failure and minimize potential damage and uncontrolled leakage to atmosphere. When rupture disk is used, monitoring is required to alarm when the disk is ruptured. PACKAGER shall conduct a Vent Study according to Annex A of API 692 Part I to demonstrate venting capacity. PURCHASER shall update the size of the vents under its scope of supply after the completion of the Vent Study, if necessary, and perform a gas dispersion analysis based on the Vent Study results to confirm that the gas release in case of DGS failure scenarios will not represent a risk for safety of personnel and equipment.

4.9.14. The intent of Vent Study is to confirm if system sizing, interlocks, safeguards and the overall design of the seal system was properly done to avoid safety risk during operation. Study to comply with following premises:

- Vent study shall consider pressure drop from piping and piping elements;
- System safeguards (PSHH, rupture disks) shall be considered at the scenarios;
- Casing pressure to be considered at SOP;
- Impact of delayed depressurization (BDV staggered) due to flare restriction shall be evaluated;
- Recommendations from vent study shall be implemented;
- Study shall confirm that gas flow to oil system due to failure will be vented without risk of overpressure at oil reservoir and additional damage;
- Primary vent blockage scenario shall consider the blockage downstream from the pressure transmitter monitoring.

4.9.15. All lines connected to flare system shall be capable to be isolated for maintenance of upstream equipment/accessories by means of an isolation valve (locked open) supplied by PACKAGER.

4.9.16. PACKAGER shall supply the DGS system fully fitted with piping and support on main equipment baseplate.

4.9.17. All piping, valves and fittings shall have insulation and/or heating, where applicable.

4.9.18. PACKAGER and PURCHASER shall guarantee essential instrument air for booster and nitrogen supplying for seal system during all operating conditions including pressurization, start-up, normal stop, emergency pressurized, and depressurized shutdown. Therefore, the nitrogen supply capacity shall be defined during the detailed design in accordance with the Flare System depressurization strategy. Complete high pressure nitrogen storage system including intensifier is acceptable by means to be defined by PURCHASER (nitrogen bottles or pressure vessel).

4.9.19. Low pressure of nitrogen shall inhibit the start-up of the lube oil pump. This includes manual start-up attempts even if the compressor is in stand-by.

4.9.20. The Nitrogen shall be also conditioned by Seal Gas Conditioning System (SGCS).

4.9.21. DGS system shall be provided with all control, monitoring and safeguarding instrumentation, including monitoring primary vent by pressure or flow (trip) and secondary vent by pressure (alarm only) to identify DGS damage.

4.9.22. PACKAGER shall supply any pressure control valves if necessary to guarantee minimum backpressure at DGS primary vent line.

4.9.23. A Seal Gas Conditioning System (SGCS) shall be furnished by DGS supplier and shall be designed to remove all particles and liquids from the compressor discharge gas. This conditioned gas will supply primary seal, avoiding any kind of failure. PACKAGER shall guarantee a clean gas flow, at least 20ºC to the right of depressurized curve tangent to the dew point line (see Figure B.1 – Annex B – API-692), and at least 15 kPa (at upstream of primary seal) higher than compressor end with the higher sealing pressure inboard of the process side labyrinth. The SGCS shall include as a minimum:

- Pressure Differential Control Valve (PDCV) or Flow Control Valve (FCV) to control seal gas supply;
- Seal gas K.O. Drum to collect the condensate with automatic drain by LV and LSH; The restriction orifice plate shall be located at least 1 meter downstream the LV;
- Twin filter separator and coalescer filter arrangement (2x100%) for solid and liquid retention with on-line changeover capability and automatic drain by LV and LSH;
- Twin pneumatic pressure boosters (2x100%) shall be provided to ensure seal gas pressure at 15 kPa (upstream primary seal) above balance line pressure under any operating condition of compression system. Migration of the seal gas to the instrument air and vice versa cannot occur at any time. Standby boosters shall start automatically in case of operating booster failure. Selection of Main/Stand-by booster shall be possible at HMI.
- Electric heater exchanger with 10% spare electrical resistance elements. Sensors for seal gas temperature control shall be installed as close as possible to the DGS inlets. Heater power panel, complying with I-ET-3010.00-5140-741-P4X-004 - SPECIFICATION FOR LOW-VOLTAGE GENERIC ELECTRICAL PANELS FOR OFFSHORE UNITS. When electric heater is not being demanded (depressurized compressor) it shall be kept energized (warmed) by heater panel to avoid low insulation in the resistive elements. Heater panel temperature indications shall be provided at HMI;
- The SGCS components shall be installed according to the sequence stated above (PDCV or FCV, KO drum, filters, boosters and heater exchanger). This is a modification to API STD 692 typical sequence.
- All seal gas lines between the heater exchanger and DGS inlets shall be thermally insulated for heat conservation (HC);
- If other control valves are supplied, beside the required at the inlet of the seal gas treatment system, coalescer filters downstream of the valves shall also be provided. These coalescer filters shall have automatic drain by LV and LSH;

- The SGCS logic control shall be designed to ensure a safe and reliable operation for each compressor casing mounted on the main baseplate for all operating conditions (pressurizing, starting, operation, normal stop and emergency shutdown, during depressurization or when stopped pressurized);
- Automatic drains shall only be opened when the compressor is pressurized.

4.9.24. PACKAGER shall provide a dedicated seal gas conditioning skid for each compressor casing mounted on the main baseplate. However, in order to minimize the DGS system footprint, PACKAGER and PURCHASER may propose keeping all the appurtenances described above a solution integrating the SGP (Seal Gas Panel) with the SGCS (Seal Gas Conditioning System) to be submitted in the technical proposal to PETROBRAS´s approval.

4.9.25. Drains shall be provided for seal gas KO Drum, filters and all seal lines, including primary and secondary vent lines. Drainage shall occur in all lower parts of the piping. The pipes arrangement shall avoid liquid accumulation (siphon).

4.9.26. When primary seal gas flow control method is used, the flow shall be compensated by pressure and temperature measurements upstream the flow element.

4.9.27. Primary vents shall be routed to flare system and secondary vents shall be vented to atmosphere, routed to a location outside hazardous area, preferably to the top of the module, at port or starboard side, in an area capable of dispersing the gas away from the FPSO. Secondary vents shall be arranged to avoid the ingress of rainwater or other foreign materials.

4.10. **Pressure Relief and Drainage**

4.10.1. The seal gas system design shall be at least the same of compressor suction vessel design or the pressure and temperature at the seal gas system when seal gas PDCV failures (fail open), whichever is greater.

4.10.2. PACKAGER shall inform maximum allowable pressure for each shaft-end seal casing.

4.10.3. Compressor shall be able to stop and remain pressurized, at settle-out condition. Compressor shall also be able to restart from settle-out condition. If restart is not possible due to driver sizing, an operational XV valve (different from BDV) shall be used automatically to reduce system pressure. However, this pressure relief (different from settle-out condition) shall be submitted to PETROBRAS approval.

4.10.4. The elastomers applied to compressors and auxiliary systems components such as DGS (Dry Gas Seal), SGP (Seal Gas Panel), SGCS (Seal Gas Conditioning System) etc, in contact with process gas, shall be select from the requirements recommendations and procedures of qualification and testing in according with the criteria established in ISO 23936-2, to prevent explosive decompression of internal components, as well as to exhibit long term resistance behavior under thermal and dynamic cycle conditions, including the depressurization rate recommended in the API 521 standards.

4.10.5. The compressor casing draining operation shall be carried out with either pressurized or depressurized compression plant. Drains with valves shall be provided for all compressor stages (impeller-diaphragm cavity) and inlet and discharger volutes, installed on the edge of the skid. The drain valves shall be configured with double block to closed and opened drains. If drainage of individual stage cannot be accomplished due to design limitations, it shall be demonstrated during the proposal phase (by means of drawings) that all inner parts will have an effective drainage. Manual pressurized drainage piping shall be connected to a liquid collector vessel located under the main baseplate.

4.10.6. Seal gas supply lines drainage operation shall be carried out with either pressurized or depressurized compressor. The primary vent lines and secondary vent lines drainage shall be performed only with depressurized compressor. The seal gas drain shall be configured with double block to closed and opened drain. The primary and secondary vents valves shall be configured with double block to opened drain. All valves shall be installed on the edge of the skid. Manual pressurized drainage lines shall be connected to a liquid collector vessel located under the main baseplate.

4.10.7. Seal gas KO Drum and Coalescer filters drains of SGCS (Seal Gas Conditioning System) and SGP (Seal Gas Panel) shall be carried out with either pressurized or depressurized compressor. The valves shall be configured with double block to closed and opened drains. All valves shall be installed on the edge of the skid. Manual pressurized drainage line shall be connected to a liquid collector vessel located under the main baseplate. Automatic drainage liquid of seal gas KO Drum and Coalescer filters shall be drained to the same piping that will receive the liquid from the compressor suction process KO Drum.

4.10.8. All drains for compression system, like vessels, compressor casings, seal gas KO Drum, filters, seal gas supply lines, primary and secondary vent lines, shall be installed in all lower parts of the piping to enable liquid removal during start-up procedures. The pipes arrangement shall avoid the accumulation of liquid (siphon).

4.10.9. The liquid collector piping shall be provided by PURCHASER to receive the drain lines described above. These drain lines shall have restriction orifice plates and flow sight glasses to verify flow and leakage and to confirm whether the drainage operation is being accomplished or not. The piping shall be installed under the main baseplate and above the main deck of the module, to be easily accessible during all start-up sequences. The piping spec shall be the same of the compressor suction line. The piping shall be connected to the flare system via locked open valve and connected to closed drain system via double block valves and spectable blind (in closed position) in between them to perform manual drainage. The piping shall be equipped with PG, LG and LSH.

4.10.10. Differential pressure transmitters (PDIT) associated with SDVs shall be able to indicate positive and negative values to avoid SDV opening when the differential pressure between upstream and downstream system is higher than ±50kPa.

4.10.11. Compressor casing and primary seal gas supply lines drainage shall be part of the compressor start-up sequences and shall be done after the pressurization of the system is completed.

5. AUTOMATION

5.1. General requirements

5.1.1. Package Automation System (PAS) shall supervise and control the motocompressor, auxiliary systems and its compression process plant. The control is not limited to PACKAGER scope of supply, since many instruments, valves and controllers provided by PURCHASER shall be controlled by PAS. PACKAGER shall refer to the project documentation, especially P&IDs, data sheets and this specification, to check which devices are controlled by PAS.

5.1.2. PACKAGER is responsible for all required control and interlocking interface and communications architecture with the systems/process plant out of its scope of supply, to guarantee the proper start-up, operation, pressurized and depressurized shutdown.

5.1.3. PURCHASER shall advise PACKAGER to properly define the control and interlocking setpoints of instruments out of its scope of supply.

5.1.4. Unit Control Panel (UCP), Remote I/O Panel (RIO), Machinery Protection System (MPS), Machinery Monitoring System (MMS) interface, Compressor Governor System (CGS), Asset Management System (AMS) interface and Device and Field Instrumentation are part of Package Automation System (PAS).

5.1.5. Package Automation System (PAS) shall be designed to ensure safe and reliable operation, performing sequencing, interlocking, protection, control and monitoring during pressurizing, starting, operation, normal stop, emergency shutdown, pressurized stopped, depressurization and depressurized stop. The PAS shall not allow undesirable nor unsafe operations. PAS shall be furnished functionally assembled and tested.

5.1.6. Each compression package shall have its own PAS. Each PAS shall operate independently, so a failure of any component in the compression package train does not affect the availability of any other compressor package train.

5.1.7. Depressurized Emergency Shutdown events shall be minimized.

5.1.8. The Package depressurization shall be requested to CSS-PSD. In case of depressurized ESD event, PAS shall immediately stop the machine and request CSS-PSD to open the BDV. The Package shall be able to be kept pressurized up to the time to be defined during the detail design in accordance with the Flare System depressurization strategy, especially in black shutdown. The BDV shall be used only for safety purpose. For other necessities, such as package purge sequence, the XV parallel to the BDV shall be used.

5.1.9. The PAS shall be designed according to the requirements described in specifications I-ET-3010.00-1200-321-P4X-001 – TECHNICAL SPECIFICATION FOR CENTRIFUGAL COMPRESSOR DRIVEN BY ELECTRIC MOTOR and I-ET-3010.00-1200-800-P4X-002 - AUTOMATION, CONTROL AND INSTRUMENTATION ON PACKAGE UNITS as well as the following specifications:

- I-DE-3010.00-5140-700-P4X-003 - GROUNDING INSTALLATION TYPICAL DETAILS;
- I-DE-3010.00-5140-797-P4X-001 - ELECTRICAL SYSTEM AUTOMATION ARCHITECTURE DIAGRAM;
- I-ET-3010.00-1200-800-P4X-010 - CRITERIA FOR ESTABLISHING CABLE CODES AND CABLE GLAND CODES;
- I-ET-3010.00-1200-800-P4X-013 - GENERAL CRITERIA FOR INSTRUMENTATION PROJECTS;
- I-ET-3010.00-1200-850-P4X-002 - ASSET MANAGEMENT SYSTEM (AMS);
- I-ET-3010.00-5140-700-P4X-001 - SPECIFICATION FOR ELECTRIC DESIGN FOR OFFSHORE UNITS;
- I-ET-3010.00-5140-700-P4X-002 - SPECIFICATION FOR ELECTRICAL MATERIAL FOR OFFSHORE UNITS;
- I-ET-3010.00-5140-700-P4X-003 - ELECTRICAL REQUIREMENTS FOR PACKAGES FOR OFFSHORE UNITS;
- I-ET-3010.00-5140-700-P4X-004 – PN-514001 - POWER MANAGEMENT SYSTEM (PMS) FOR OFFSHORE;
- I-ET-3010.00-5140-700-P4X-005 - REQUIREMENTS FOR HUMAN ENGINEERING DESIGN FOR ELECTRICAL SYSTEMS OF OFFSHORE UNITS;
- I-ET-3010.00-5140-712-P4X-002 - MEDIUM-VOLTAGE INDUCTION MOTORS FOR OFFSHORE UNITS;
- I-ET-3010.00-5140-741-P4X-001 - LOW-VOLTAGE MOTOR CONTROL CENTER AND SWITCHGEAR FOR OFFSHORE UNITS;

- I-ET-3010.00-5140-741-P4X-004 - SPECIFICATION FOR LOW-VOLTAGE GENERIC ELECTRICAL PANELS FOR OFFSHORE UNITS;
- I-ET-3010.00-5140-797-P4X-001 - ELECTRICAL SYSTEM AUTOMATION ARCHITECTURE;
- I-ET-3010.00-5143-700-P4X-001 – ELECTRICAL SYSTEM PROTECTION CRITERIA;
- I-ET-3010.00-5500.854-P4X-001 - MACHINERY MONITORING SYSTEM;
- I-ET-3010.00-5520-800-P4X-004 - AUTOMATION NETWORK REQUIREMENTS;
- I-LI-3010.00-5140-797-P4X-001 - ELECTRICAL SYSTEM AUTOMATION INTERFACE SIGNALS LIST;
- I-ET-3010.00-5140-700-P4X-007 - SPECIFICATION FOR GENERIC ELECTRICAL EQUIPMENT FOR OFFSHORE UNITS
- I-ET-3010.00-5140-700-P4X-009 GENERAL REQUIREMENTS FOR ELECTRICAL MATERIAL AND EQUIPMENT FOR OFFSHORE UNITS
- I-DE-3010.00-5140-797-P4X-002 ELECTRICAL SYSTEM AUTOMATION TYPICAL ACTUATION DIAGRAMS
- I-ET-3010.00-1200-800-P4X-012 – CRITERIA FOR DETAILING DESIGN CAUSE & EFFECT MATRIX
- I-ET-3010.00-1200-800-P4X-010 - CRITERIA FOR ESTABLISHING CABLE CODES AND CABLE GLAND CODES
- I-ET-3010.00-5520-888-P4X-001 - AUTOMATION PANELS
- I-DE-3010.00-1200-800-P4X-001 - PROCESS HOOK UP DRAWINGS
- I-DE-3010.00-1200-800-P4X-002 - PNEUMATIC / HYDRAULIC HOOK UP DRAWINGS
- I-DE-3010.00-1200-800-P4X-003 - ELECTRICAL HOOK UP DRAWINGS
- I-DE-3010.00-5140-700-P4X-002 – POWER INSTALLATION TYPICAL DETAILS.
- I-ET-3010.00-5140-700-P4X-007 – SPECIFICATION FOR GENERIC ELECTRICAL EQUIPMENT FOR OFFSHORE UNITS.
- I-ET-3010.00-5140-700-P4X-009 – GENERAL REQUIREMENTS FOR ELECTRICAL MATERIAL AND EQUIPMENT FOR OFFSHORE UNITS.

5.1.10. Additionally, the PAS shall also be designed according to the requirements described in each specific project's documents stated in the DOCUMENT LIST:

- AUTOMATION INTERFACE OF PACKAGED UNITS
- AUTOMATION AND CONTROL ARCHITECTURE
- INSTRUMENTATION ADDITIONAL TECHNICAL REQUIREMENTS
- FIELD INSTRUMENTATION

- EQUIPMENT LIST
- AUTOMATION AND CONTROL SYSTEM FUNCTIONS
- AUTOMATION NETWORK DESCRIPTION
- AUTOMATION AND CONTROL SYSTEM – SCOPE DEFINITION
- ELECTRICAL SYSTEM DESCRIPTIVE MEMORANDUM
- TOPSIDES UPS AND DC SYSTEMS ONE-LINE DIAGRAM

5.1.11. All instrumentation and alarms/trips mentioned in the data sheets and process plant P&IDs are the minimum required by PETROBRAS. PACKAGER and PURCHASER may indicate other instrumentation and alarms/trip for general protection and monitoring according to their experience and for compliance with Classification Society's requirements and submit in technical proposal to PETROBRAS for approval.

5.1.12. All instrumented valves shall have limit switches with position mismatch alarm and start-up inhibition.

5.1.13. PACKAGER shall supply Unit Control Panels (UCP) and Remote I/O (RIO) panels. UCP will be installed at the Automation and Electrical Panels Room (AEPR) and RIO will be installed in the field by PURCHASER.

5.1.14. All requirements for PAS shall be checked during Factory Acceptance Test (FAT), Shipyard Acceptance Test (SYAT) and Site Acceptance Test (SAT) according to IEC 62381.

5.1.15. PAS shall have its package classification according to Technical Specification I-ET-3010.00-1200-800-P4X-002 - AUTOMATION, CONTROL AND INSTRUMENTATION ON PACKAGE UNITS, and per each specific project, the following documents stated in the DOCUMENT LIST: "AUTOMATION INTERFACE OF PACKAGE UNITS" and "AUTOMATION AND CONTROL SYSTEM FUNCTIONS".

5.1.16. PACKAGER shall provide to PETROBRAS all keys, drivers, manuals, installation media and licenses of all software inside the package, including all development tools and comply with requirements from specific project's document "AUTOMATION AND CONTROL SYSTEM - SCOPE DEFINITION", as stated in the DOCUMENT LIST. Software shall not have any access restrictions.

5.1.17. The PACKAGER/PURCHASER shall perform dynamic simulation to at least confirm Settle Out Pressure (SOP), calculate purge, pressurization and depressurization times, to size anti-surge valve and throttle valves (when specified). The simulation shall evaluate protection from surge during steady state operation, start-up and normal/emergency stop (pressurized or depressurized), considering possible interactions with other packages. The dynamic simulation shall also be used to identify any additional required valves for antisurge system and to avoid compressor rotation during depressurization after the compressor stopped. Supply of additional valves is the responsibility of the PACKAGER/PURCHASER, and their installation is the responsibility of the PURCHASER.

5.1.18. All proper means of electrical and environmental protection shall be applied to all instruments and electrical equipment, particularly those located in hazardous areas and/or an aggressive saline air environment. Instruments and electrical equipment shall comply with IEC-60079 and they shall be at least IP-56.

5.1.19. In order to guarantee adequacy to IEC-61892-7, all instruments, electrical equipment and panels installed in field open areas shall be certified to operate in Zone 2, including certified enclosures against explosive atmosphere are mandatory.

5.1.20. PACKAGER shall provide a local instrumentation board (rack) installed on the equipment baseplate, as mentioned on data sheets and process plant P&IDs. Oil filled gauges shall be provided for analogical instruments subject to high vibration levels.

5.1.21. PAS shall not be restarted without manual acknowledgement of the shutdown conditions.

5.1.22. PAS shall send a “Start Request” hardwired output signal from UCP to PMS to request automatic field forcing in main generators, in order to reduce voltage drop during starting. PAS shall receive “Starting Permission” hardwired input signal from PMS to UCP after the voltage at busbar that feeds the load reach the pre-selected adjustable value, according to Electrical Studies. If starting permission is not received within 60 seconds, the starting sequence shall be aborted.

5.1.23. The FPSO electrical system will supply electric power to compression system according to the I-ET-3010.00-5140-700-P4X-003 – ELECTRICAL REQUIREMENTS FOR PACKAGES FOR OFFSHORE UNITS.

5.1.24. The 220 Vdc power to the PAS shall be guaranteed during black shutdown event in the time required to complete package depressurization. This time shall be defined during detail design in accordance with the Flare System depressurization strategy.

5.1.25. PURCHASER and PACKAGER shall not supply any components (including hardware, firmware, software etc.) for PAS that are obsolete or that has Declaration of Obsolescence.

5.1.26. PACKAGER shall provide during the project development the following documents, at least:

- Control system architecture drawing
- PAS functional description, including process control and auxiliary systems description and start-up and shutdown sequences description and flowcharts.
- Cause & Effect Matrix in accordance with the document I-ET-3010.00-1200-800-P4X-012 - CRITERIA FOR DETAILING DESIGN CAUSE & EFFECT MATRIX.
- Control panels drawings, including part list, nameplate, tag plates, safety signs, lifting drawings and heat dissipation calculations.
- Junction box drawings.

- Instrument data sheet, including all kinds of instruments provided, such as transmitters, gauges, thermowells, restriction orifices, flow elements, vibration probes, RTDs, thermocouples, fire and gas detectors, lamps, pushbuttons etc.
- Control valves drawings and data sheets, including calculations.
- Pressure Relief Valves data sheet, including calculations.
- Instrument list.
- Input / Output list.
- Setpoint list.
- Controllers' communication list (memory map).
- Wiring diagrams for all equipment, control panels, junction boxes and skids.
- Cables and cable glands list.
- Instrumentation hook-up drawing.
- Electrical hook-up drawing.
- Control system software and license list
- Hardware and software manuals.

5.2. PAS hardware

5.2.1. The Unit Control Panels (UCPs), to be located in the Automation and Electrical Panels Room (AEPR), shall have front and rear access doors, IP22 protection level and cable entry from the bottom of the panel. The internal temperature shall be kept bellow 30 ºC. Each UCP shall include, at least:

- One dedicated safety system and one dedicated control system, each system shall be implemented using Programmable Logic Controllers (PLC);
- HMI hardware (UCP_HMI);
- Ventilation exit at the top;
- Network switch and DIO optical fiber;
- Acknowledgment and reset push-buttons;
- Compressor start and stop push-buttons in the HMI. Compressor start and stop and lamp status push-buttons can also be by hardware on the panel front door;
- Emergency shutdown retentive push-button in the HMI. Emergency shutdown retentive push-button shall also be by hardware on the panel front door;
- Auxiliaries devices start-up and stop push-buttons and switches (to define main and stand-by) in the HMI. Auxiliaries devices start-up and stop push-buttons and switches can also be by hardware on the panel front door;
- Sound alarm;
- Start counter and hourmeter in the HMI. Start counter and hourmeter shall also be by hardware in the panel front door;
- Asset Management System (AMS) interface;

- Emergency Shutdown Relay (RESD).

5.2.2. The Remote I/O Panel (RIO), to be located in the field, shall be made of stainless steel AISI 316L and installed in shelters protected from rain, wind and sunlight in the respective compression modules. The panels shall have front and rear access doors, cable entry from the bottom of the panel and IP56 protective level. The panel internal temperature shall be kept bellow 40 ºC. Each RIO shall include, at least:

- I/Os safety system and I/Os control system;
- Network switch and DIO optical fiber;
- Machinery Protection System (MPS);
- Machinery Monitoring System (MMS) interface;
- Asset Management System (AMS) interface;
- Start and stop lamp status;
- Emergency shutdown retentive push-button;
- Emergency Shutdown Relay (RESD).

5.2.3. Compressor Governor System (CGS), located inside the UCP Panel, shall include, at least:

- Capacity control;
- Load-sharing control;
- Anti-surge controls;
- Automatized Procedures Module (MPA) interface;
- Human Machine Interface of Compressor Governor System (CGS_HMI), loose item for installation in CCR.

5.2.4. The network switches shall be industrial manageable type. A package entry switch shall be supplied and installed complying with requirements shown in AUTOMATION NETWORK DESCRIPTION.

5.2.5. Networks for control, safety and monitoring shall be segregated from each other and redundant.

5.2.6. Unit Control Panel (UCP) and the Remote IO Panel (RIO) controlling this package shall be limited to the number of sections and size presented PETROBRAS documents (EQUIPMENT LIST). The panels provided shall not exceed these size limitations.

5.2.7. Safety System PLC shall receive all process variables related to emergency shutdown logics, execute these logics and perform hardwired actuation on final elements in abnormal situation. Control System PLC is responsible for control and monitoring functions of the process variables.

5.3. PAS software

5.3.1. PAS shall enable changes of set points, timer presets and control parameters, input by-passing and output override with the system in operation, without damage to the process.

5.3.2. The control system programming and configuration shall be carried out by the UCP_HMI through a laptop computer not provided by PACKAGER/PURCHASER. The software editors shall be provided by PACKAGER/PURCHASER.

5.3.3. HMI software (with runtime and development licenses) shall be provided.

5.3.4. Access to configuration and programming shall be protected by change management tools, including specific passwords with several levels, such as: general, operation, maintenance and engineering. All passwords shall be delivered to PETROBRAS with NO access restrictions.

5.3.5. The control system programming shall be in accordance with PETROBRAS specifications. PACKAGER proposal shall inform the programming languages used in the system.

5.3.6. HMI alarm annunciation shall comply with ISA-18.1, according to the sequence F2M-1 (manual reset first out with no subsequent alarm flashing and silence pushbutton). Alarm Management Systems shall comply with ISA-18.2.

5.4. PAS system

5.4.1. The PAS shall be capable of carrying out control, interlock, process, start-up, shutdown, normal operation and safety procedures for main machinery and auxiliary equipment, including all the necessary interfaces to connect with Motor Control Center (MCC) and other controls and PETROBRAS security systems, such as: Control and Safety System (CSS), Power Management System (PMS), Asset Management System (AMS) and Machinery Monitoring System (MMS).

5.4.2. Emergency Shutdown Relay (RESD) shall be provided to actuate directly on the Driver and on the process plant SDVs.

5.4.3. The Emergency shutdown retentive push buttons, ESD signals from CSS and ESD from MPS shall actuate the RESD and be used as input for UCP safety PLC. ESD from UCP safety PLC shall also actuate the RESD.

5.4.4. PAS shall include, at least, the following functions:

- Automatic and manual start-up, loading, normal/emergency stop, purge and shutdown sequences without causing any damage to equipment or process instability;
- Indication and recording of unit malfunction/shutdown, event signals and all machinery sequences (such as start-up, normal stop, etc.);
- Monitoring and control of all variables, alarms and shutdown signals with UCP indication as described in PETROBRAS specification (such as temperature, pressures etc. indicated in P&IDs and data sheets);
- Independent hourmeter and starts counter;
- Suction gas flow for each compressor stage in m3/h;

5.4.5. PAS shall send and receive hardwire signals to/from Control and Safety System (CSS) according to I-ET-3010.00-1200-800-P4X-002 – AUTOMATION, CONTROL AND INSTRUMENTATION ON PACKAGE UNITS.

5.4.6. PAS shall have high reliability, integrity and availability for operation in fail safe mode in order to avoid, whenever possible, an unnecessary shutdown or loss any process variable with safety function.

5.4.7. PAS shall include on-line testing and self-diagnosis facilities, in order to allow the maintenance technician to identify failures, enabling corrective maintenance without causing unit shutdown and avoiding operation without any safety function.

5.4.8. In case of power failure, system shall retain all programs and data as well as interface software for a minimum of six months, not being necessary to reconfigure the system after power restore. During a power failure, all outputs shall be automatically changed to their safe position.

5.4.9. Connectivity to external system through open communication protocols shall be MODBUS and OPC UA by Ethernet TPC/IP Protocol. All I/O digital/analogic variables, alarms and trips, controller's signals and parameters (including performance, load sharing, anti-surge and MPS) and events including first-out shall be available.

5.4.10. The UCP interface with Asset Management System (AMS) shall be as described in the specific project's "AUTOMATION INTERFACE OF PACKAGE" as stated in DOCUMENT LIST. UCP controllers shall be HART compatible, without the need for multiplexers.

5.5. Human Machine Interface (HMI) of UCP

5.5.1. UCP_HMI shall allow the operator to view and acknowledge alarms and trips, protections reset, status of each I/O and intermediate variables, software monitoring/modification, system configuring, first-out of alarms and shutdowns, list of set points and parameters, analog variables, variables performance and trend, recording of all relevant data and periodic reports, events, number of starts and operation hours, by-pass of inputs and override of outputs.

5.5.2. UCP_HMI shall comply, at least, with the following requirements:

- Industrial microcomputer installed inside the panel housing;
- Access to HMI shall be provided for onshore access, in accordance with AUTOMATION NETWORK DESCRIPTION. Additional Ethernet network card shall be available for package LAN if necessary.Remote access shall be password protected;
- Read and write access to removable data storage devices shall be disabled. Enabling this access shall be possible with password protection.
- HMI screen shall be on front door of the panel. Minimum 20 inch widescreen LCD color touch screen display. The CPU of HMI shall be independent from the display screen of HMI;
- Historical log:

  a. Daily files - Recording and storing of all digital and analog variables, alarms and events of PAS system with 1 second sample time. Storage shall be at least 72 files (24 days x 3 months);

b. Hourly files - Recording and storing, in high speed (minimum sample time shall be less than 120 milliseconds), of all analog and digital variables, alarms and events of PAS system. Storage shall be at least 72 files (24 hours x 3 days).

- Event and trigger log:
  a. Storing all variables in the minimum sample time (less than 120 milliseconds) during 15 minutes, 10 minutes before and 05 minutes after the programmable event/trigger. Storing at least 150 files per programmable event/trigger;
  b. All events and all analog/digital variables (trigger is reaching a preset value) must be programmable to start storage. ESD or Normal Stop are events that shall already be programmable in UCP_HMI to start storage.
- Trend with capable of playback any stored variables and showing a set of minimum 12 variables at the same time;
- Capable of export of stored variables logs in the CSV standard (data separated by semicolon);
- Listing in chronological order of all alarms, trips, events and user-defined actions with PLC timestamps with milliseconds time resolution. The message of first trip of SD sequence shall be emphasized;
- Display of process plant and auxiliaries PI&Ds with all variables and variables from Compressor Control;
- Display of one page with a general overview of all trains of the same service with the main process variables: suction and discharge pressure and temperature, speed and opening position of the main valves (inlet and outlet SDVs, BDV, XV, ASV and thtotlle valve position, when applicable).
- Display of equipment schematic layout with all variables from Machinery Protection System.
- Display of all CGS variables.

5.5.3. PACKAGER shall provide UCP_HMI supervisory software (runtime and development tool) running on Windows environment, compatible with the size of the application and in its latest version (preferably at 64 bits). Software shall be supplied, installed, configured in the UCP_HMI and provided with complete manuals/electronic media. Software licenses shall also be provided.

5.5.4. Access to configuration and programming shall be protected by change management tools, including specific passwords with several levels, such as: general, operation, maintenance and engineering. All passwords shall be delivered to PETROBRAS with NO access restrictions.

5.5.5. If, for any reason, HMI have some malfunction, the control system shall continue with all its function normally. PACKAGER shall provide a hardware interface (such as a laptop computer connection) in order to establish an external communication with PLC.

5.5.6. English and Brazilian Portuguese languages shall be used on all UCP_HMI screens installed on UCP.

5.5.7. Each UCP_HMI must also be able to allow operation of any further compression train in this compression service, including remote UCP_HMI. All Data (historical trend, event and trigger and alarm and trip logs) shall be synchronized among all HMIs.

5.5.8. All PLCs, HMIs, MPS shall be synchronized. Time synchronism shall be sent from Time Servers, see the specific project's "AUTOMATION NETWORK DESCRIPTION" as stated in DOCUMENT LIST.

5.5.9. UCP_HMI software must be compatible with OSI "Plant Information-PI" software.

5.5.10. One remote UCP_HMI for each compression service shall be provided, with the same functionalities of the UCP_HMI, to be installed at Central Control Room (CCR). This UCP_HMI shall be a 19" rack-mounted PC (at maximum with 2U height). The PC shall have three Ethernet ports, and each port must be connected to the PAS system switch of each compression train.

5.6. Machinery Protection System (MPS)

5.6.1. Machinery Protection System (MPS) shall be according to the API 670 latest edition.

5.6.2. Sensor arrangement for driven equipment, gearbox/HVSD and driver:

- Radial vibration: Two (2) non-contact probes for each radial bearing (X-Y signal);
- Axial position: Two (2) non-contact probes for each axial bearing;
- Phase: One (1) phase reference transducer for every different shaft speed;
- Gearbox casing vibration: One (1) accelerometer for each input and output bearing housings, located horizontally and below the split line of the bearing.
- Main electric motor casing vibration: four (4) accelerometers for electric motor (two (2) for each bearing housing) for motors equipped with journal (or hydrodynamic tilting pads) bearings or two (2) accelerometers for electric motor (one (1) for each bearing housing) for motors equipped with roller bearings.
- When the probes are not externally accessible, they shall be spared according to API STD 670 latest edition.
- Torsional vibration for compressors driven by electric motors with Variable Frequency Drives (VFDs): Non-contacting, phase-shift type torque transducer on low speed coupling, if required at datasheet.

5.6.3. For Compressors with a non-contacting, phase-shift type torque transducer:

- The torque transducer and signal conditioning system shall be capable continuously monitoring both the average and cyclic torque components.
- The cyclic torque signal shall be used for alarm only, and its mal functioning shall not compromise the operation of the equipment.
- The manufacturer shall define the alarm levels for cyclic stress based on the estimated fatigue limit for the component's infinite life.

5.6.4. Probes shall allow gap adjustment.

5.6.5. All bearings must have metal temperature monitoring (two sensors installed, one spare). Only where metal bearing temperature measure is not feasible, PACKAGER shall propose a bearing oil outlet temperature sensor with the same alarm and shutdown signals as indicated for metal bearing temperature in data sheets. Two temperature sensors at active side and two temperature sensors at inactive side shall be provided for thrust bearings. All bearing temperatures shall be directly connected to MPS rack.

5.6.6. Proximitors shall be appropriate for the material or coating of the target area. PACKAGER shall inform in the instrument data sheet which is the material or coating of the target area and the MOD number of the proximitor, when applicable.

5.6.7. Monitors shall be mounted on Remote I/O Panel (RIO) in the field.

5.6.8. RIO shall have internal space for temporary installation of a Machine Data Acquisition System, with minimum dimensions 70 cm x 70 cm x 15 cm (LxWxH). Shall also be provided a 220 Vac plug socket and an ethernet port with connection to AEPR.

5.6.9. All vibration and temperature protection systems shall be according to Original Equipment Manufacturer (OEM) standards and API 670 compliant.

5.6.10. Each monitor channel shall be capable of continuously comparing the input signal to warning set points. The warning system shall comprise at least two (2) levels: alarm and shutdown. The exception is axial position monitor, for which shall be supplied with four (4) independent alarms and shutdown adjustable limits (two (2) for each direction).

5.6.11. The vibration signals (including displacement and accelerometers) of the whole train shall have an unfiltered output at the UCP (one per channel) for recording and maintenance purposes.

5.6.12. Each channel shall be supplied with an electronic configurable time delay to avoid activation of alarm and trip during transient signals.

5.6.13. All wiring shall be protected by flexible conduits to a stainless steel AISI 316L junction box (at skid edge), neatly routed to allow machine maintenance without damaging probes and wire leads.

5.6.14. Extension cables shall be armored.

5.6.15. Oscillator-demodulators shall be mounted in an intrinsically safe junction box, if applicable.

5.6.16. Paired channels (XY) from the two transducers mounted at each bearing for radial shaft vibration monitoring shall be allocated at the same MPS I/O card.

5.6.17. A controlled access set point multiplier function shall be provided with actuation by an external contact closure which causes the alarm (alert) and shut down (danger) set points to be multiplied by a factor. PACKAGER shall detail in the PAS control functional description when the set point multiplier function is enabled. For electric motors subject to PMS starting permission, the set point multiplier function shall be enabled with electric motor starting command, not PMS starting request.

5.6.18. All vibration signals channels shall be allocated at the same MPS monitor of the corresponding phase reference signal channel.

5.6.19. MPS x MMS interface shall not use internal control panel switches. MPS shall be connected directly to MMS panel.

5.7. Machinery Monitoring System (MMS)

5.7.1. The MMS (provided by PURCHASER) shall be designed in according to the requirements described in the items below and in the specification I-ET-3010.00-5500-854-P4X-001 – MACHINERY MONITORING SYSTEM. The MPS shall be integrated in the Machinery Monitoring System (MMS) of the FPSO.

5.7.2. Besides the control and supervisory UCP system, Machinery Protection System shall be integrated in the Machinery Monitoring System (MMS) of the FPSO, provided by PURCHASER, for maintenance purposes. PACKAGER shall provide interface cards installed in the Machinery Protection System to allow the interconnection with the MMS (software and hardware). All vibration signals (including displacement and accelerometers) shall be available with buffer signal output.

5.7.3. All signals from MPS monitoring cards shall be available to send data to MMS through the MPS Communication Card.

5.7.4. In addition to the signal available through the MPS Communication Card, PACKAGER shall make available the required process variable signals presented in the I-ET-3010.00-5500-854-P4X-001 – MACHINERY MONITORING SYSTEM, through the Package Fast Ethernet Network to perform the functions above in the Machinery Monitoring System.

5.7.5. PACKAGER shall provide to MMS VENDOR all documentation related to MPS and MPS configuration files to be used for MMS configuration.

5.8. Compressor Governor System (CGS)

5.8.1. General requirements

5.8.1.1 Compressor Governor System (CGS) consists of the following controls: Capacity, Load sharing and Anti-surge controls and a specific HMI for Compressor Governor System (CGS_HMI). These controls shall be integrated (so any individual corrective action taken by one loop shall not degrade a response from other). CGS shall enable adjustment of all parameters and perform inputs by-pass without causing process disturbances, keeping the plant in safe condition.

5.8.1.2 Capacity, Load Sharing and Anti-surge controls systems shall be implemented by dedicated system and segregated from the Control system and the Safety system PLCs of UCP, with hardwired interlock and network for communication purpose, complying with API670 (5th ed.) item 9.3.5.

5.8.1.3. Special attention shall be given to low gas temperatures, including in recycle line, and possibility of ice formation outside piping and valves. Compressor shall be able to continuously operate with process gas mass flow varying from zero to value presented on datasheet.

5.8.1.4 Anti-surge and throttle (when specified) valves shall be sized according to process dynamic simulation and submitted to PETROBRAS approval.

5.8.1.5 The suction throttle valve (when applicable), shall be installed upstream of the scrubber and located outside of the recycle loop. Whenever throttle valve is associated to speed variation for capacity control, throttling process shall initiate only after speed reaches minimum value.

5.8.1.6 The antisurge valves, throttle valves (when specified) with their associated devices (positioners, air boosters, limit switches and solenoids), pipelines, tubings, instrumentation (flows, pressures and temperatures), orifice plates, and check valves associated with CGS shall be specified by VENDOR and validated Compressor Governor´s VENDOR. The design of controllers, valves, instrumentation, tubings and pipelines associated with CGS shall be submitted to PETROBRAS together with the certificate of approval issued by the Compressor Governor´s VENDOR.

5.8.1.7 PACKAGER shall furnish the anti-surge valves, throttle valves (when specified) with their associated devices such as, positioners, air boosters, limit switches and solenoids, all instrumentation of CGS, including transmitters (flows, pressures and temperatures) and orifice plate.

5.8.1.8 All pressure, flow transmitters and positioner of CGS shall be smart with HART protocol and maximum response time of 100 milliseconds, including dead time. Transmitters shall be installed above the connection to the process piping and piping routing shall not form siphons. The length of the tubing for the flow transmitter may not exceed 3 meters, and for pressure transmitter may not exceed 5 meters.

5.8.1.9 All analog and digital variables and events shall be available for CGS_HMI and UCP_HMI.

5.8.1.10 CGS shall have fallback strategies to allow the capacity, load-sharing and anti-surge system to continue operation in the event of transmitter failure.

5.8.1.11 A detailed system operation and maintenance manual shall be provided, including detailed description of all control strategies, and configuration information for all control blocks, I/O assignments, and any other parameters. The system shall allow modification of the control blocks configurations, I/O assignments, and parameters by Petrobras, allowing complete operation, maintenance, and modifications/upgrades.

5.8.2. **Capacity control**

5.8.2.1 Each compression service type shall have a Capacity control.

5.8.2.2 Capacity control shall maintain the suction pressure and limit the maximum discharge pressure of compressor trains. If the discharge pressure exceeds the set point, the system shall switch from suction pressure control to discharge pressure limit. The control shall operate in automatic and manual modes. Capacity control output is input to load sharing controls. These set points shall be monitored and defined from UCP_HMI of Unit Control Panel (UCP) at Automation and Electrical Panels Room (AEPR).

5.8.2.3 Capacity control shall be mounted on Unit Control Panel (UCP) at Automation and Electrical Panels Room (AEPR).

5.8.2.4 When the compression train operating in parallel, capacity control and load sharing control shall provide appropriate distribution of loads between compression units, so that they keep their Operating Point (OP) proportionally equidistant from their respective Surge Control Line. Special attention shall be given to compression units operating closer to the surge line.

5.8.3. **Load sharing control**

5.8.3.1 Each compression train shall have its Load sharing control.

5.8.3.2 The variable speed driver and/or throttle valve shall be included in Load sharing control loop.

5.8.3.3 Load sharing control will command speed and/or throttle valve (when specified) to maintain the desired suction pressure determined in capacity control. If Capacity control is unavailable or a compression train will work at a different suction pressure than the other compression train of the same service, then the Load sharing control shall perform suction pressure control and limit the maximum discharge pressure.

5.8.3.4 In the motocompressor the load sharing control shall also limit electric motor current.

5.8.3.5 Load sharing control shall operate individually or in parallel with others Load sharing controls at same compression service. Load sharing shall operate with automatic and manual modes. Set points shall be monitored and defined UCP_HMI from UCP at AEPR.

5.8.3.6 The control system shall have anti-reset windup action when the Driver is in limitation and strategies to allow bump less transfer when the Driver leaves the limitation or when the control system returns from manual to automatic. Necessary interface signals between Load Sharing and Speed Controller shall be available.

5.8.4. **Anti-Surge (AS) control**

5.8.4.1 Each compression stage (section) shall have its anti-surge control.

5.8.4.2 For design purpose, PACKAGER shall consider one AS recycle line for each stage in its proposal. Overall recycle line shall not be accepted.

5.8.4.3 PACKAGER/PURCHASER shall furnish the anti-surge control valves with their instrumentation including transmitters (flow, pressure and temperature) for each stage (section). Diaphragm seal shall not be used for these instruments.

5.8.4.4 The volume between discharge compressor, check valve (installed immediately after the "T" of the recycle pipe) and AS valve shall be the smallest possible. A double check valve shall be provided separating each compressor stage.

5.8.4.5 AS valves shall be sized to perform their function in all operating conditions, including transients, avoiding choke zone but not oversized in order to maintain their controllability.

5.8.4.6 The anti-surge valve shall be open at failure type, with linear response, class 5 balanced cage globe and anti-noise technology to attenuate up to 90 dBA @ 1m. The body material shall be according to the AS recycle line material specification for each Gas Compression Piping and Instrument Diagram. Internal components shall be made of stainless steel materials suitable with the fluid characteristics and process conditions and with improved galling resistance, such as with "Stellite" coating or equivalent hardness material. No chromium coating shall be accepted. Materials subjected to galling or any other wear/corrosion mechanism will not be accepted. The anti-surge valve materials and the pneumatic hook-up shall be submitted in the technical proposal for PETROBRAS approval.

5.8.4.7 The anti-surge valve shall be mounted with high speed intelligent positioner and high flow booster to increase the precision and speed of actuation.

5.8.4.8 The use of quick exhaust, or similar system that opens the anti-surge valve in an uncontrolled mode, is not allowed.

5.8.4.9 A three-way solenoid shall be used, between the Booster and the Actuator, with high Kv to allow anti-surge valve smallest stroke. The solenoid shall be energized to allow modulation of the surge valve.

5.8.4.10 The maximum anti-surge valve opening stroke time (0 to 100%) shall be up to 1 second for valves smaller than or equal to 4 ", up to 2 seconds for valves larger than 4" and less than 12 " and up to 3 seconds for valve larger than 12".

5.8.4.11 The minimum anti-surge valve closure stroke time (100% to 0) shall be up to 3 seconds for a valve smaller than or equal to 4 ", up to 5 seconds for valve larger than 4" and less than or equal to 12 " and up to 8 seconds for valve larger than 12”.

5.8.4.12 AS control system shall be furnished with:

- A maximum scan time of 50 milliseconds;
- Compressor surge detector;
- Supervision so that in case of two (2) surge events within fifteen (15) seconds, the AS valve shall be opened through current analog output and three-way solenoid deenergizing, installed between booster and actuator;

- Supervision so that in case of four (4) surge events within thirty (30) seconds, the AS control shall stop the compressor;
- Closed loop control signal with Proportional (P) and Integral (I) action for anti-surge control. P+I controller response shall be started when the Operation Point reaches the Surge Control Line. P+I controller shall be anti-reset windup action;
- Adaptative actions to allow the Surge Control Line to change as a function of the displacement of the operating point, with automatic return to the original position (when operating point reaches the Surge Control Line). The faster the Operation Point moves towards the Surge Control Line the faster the Surge Control Line shall move towards the Operation Point. The Surge Control Line offset rate is a function of Operation Point offset and shall be an adjustable parameter;
- An adaptive open loop response to large and fast disturbances, when Operating Point reaches the line (Trigger Line), located between Surge Control Line and Surge Line. In this case the AS valve opening response shall be immediate;
- AS valve opening shall be proportional to the displacement rate from the Operating Point towards the Trigger Line;
- Maximum opening of the valve shall be an adjustable parameter;
- The open loop response signal shall return to zero proportionally to the inverse function of an exponential;
- The coefficients of the open loop response signal decay function shall be adjustable;
- The delay time for the start of signal return to zero shall be an adjustable parameter;
- An adaptive detection algorithm in order to protect the compressor by establishing new safety margins (more conservative than previous one) when a surge event occurs;
- Decoupling gains to reduce interaction between anti-surge controls of different compression sections and among the other control loops of compression system. Decoupling gains shall be adjustable parameters;
- Control strategy that makes the Surge Line and Surge Control Line independent of variations in gas composition (molecular weight), suction pressure and suction temperature;
- Even when in manual operation, AS control shall be capable to switch-over to automatic operating if close to surge condition;
- Capacity of limiting the maximum pressure and/or maximum discharge temperature and/or minimum suction pressure of compressor through anti-surge valve opening, independently of Capacity control. The performance of these limits shall not affect Anti-surge Control. Limit values shall be adjustable parameters;

- Fallback strategies shall be also available to allow the anti-surge system to continue operation in the event of transmitter failure. In case of flow transmitter failure, AS valve shall be fully opened.

5.8.4.13 In order to achieve good controllability, CGS Vendor shall recommend and review AS line layout.

5.8.4.14 AS control and Capacity control/Load sharing controls from compression service shall have a decoupling capability in order to temporally reduce the Capacity control action when the AS control is performed, especially when opening the valve.

5.8.5. **Automatized Procedures Module (MPA)**

5.8.5.1 The MPA (Automatized Procedures Module) shall be designed in according to the requirements described in the items bellow and in the specification in the specific project's "AUTOMATION INTERFACE OF PACKAGED UNITS" as stated in DOCUMENT LIST.

5.8.5.2 MPA will be defined by PETROBRAS during the detail design, or during operation phase. These systems may use PETROBRAS software package, or third part packages when required, and run on computers in the automation network. The goal of MPA is to assist operators in integrating and coordinating the various compressors in the unit's gas treatment system. MPA system will not be supplied for PACKAGER.

5.8.5.3 PACKAGER shall provide connectivity through MODBUS and OPC UA for the MPA to read all critical variables of the compressor (pressures, temperatures, power, current, speed, etc.).

5.8.5.4 PACKAGER shall be able to receive 4-20mA input signals at Capacity Control for the compressor suction and discharge pressure remote set points. These remote set point signals (4-20mA) will be provided by Process Control System (PCS is scope of the PURCHASER). At UCP_HMI, operator shall select if set points will be defined locally (at UCP_HMI) or remotely (from MPA signals). In this way, the MPA or the operator can command the suction pressure set points.

5.8.5.5 PACKAGER shall be able to receive for each AS recycle valve a 4-20mA input signal in AS control system. This signal will go to a low value selector (override) with the output of the anti-surge (AS) control algorithm. In this way, the MPA or the operator can command the opening of the recycle valve, even if the AS control does not need to open the valve. This override selector shall be implemented in AS control system, but the override signal (4-20mA) will be provided by the Process Control System (PCS is scope of the PURCHASER). At UCP_HMI, operator shall select if this remote ASV command will be enabled or not.

5.8.5.6 PACKAGER shall properly monitor the 4-20 mA input signals from remote setpoints and AS valves opening, so that the failure of these signals disables the action of the MPA on the respective controller.

5.8.6. **Human Machine Interface of Compressor Governor System (CGS_HMI)**

5.8.6.1 PACKAGER/PURCHASER shall supply a dedicated HMI of Compressor Governor System (CGS_HMI) for all compressors services. This CGS_HMI shall be a 19" rack-mounted PC (at maximum with 2U height), shipped loose.

5.8.6.2 CGS_HMI shall have at least the following functionality:

- Programming and configuration interface of Capacity, Load sharing and Anti-surge control systems and Automatized Procedures Module (MPA);
- Historic log:
  a. Daily files - Recording and storing of all analog and digital variables, alarms and events Capacity, Load Sharing and Anti-surge Control Systems and MPA. with 200 milseconds sample time. Storage shall be at least 72 files (24 days x 3 months);
  b. Hourly files – Recording and storing, in high speed (minimum sample time shall be less than 40 milliseconds), of all analog and digital variables, alarms and events Capacity, Load Sharing and Anti-surge Control Systems and MPA. Storage shall be at least 120 files (24 days x 5 days).
- Event and trigger log:
  a. Storing all variables at the minimum sample time (40 miliseconds) during 15 minutes, 10 minutes before and 05 minutes after the programmable event/trigger. Storing at least 150 files per programmable event/trigger;
  b. All events and all analog/digital variables (trigger is reaching a preset value) must be programmable to start storage. Surge and ESD Compressor are events that shall already be programmable in CGS_HMI to start storage.
- Trend with capable of playback any stored variables and showing a set of minimum 12 variables at the same time;
- Capable of export of stored variabels logs in the CSV standard (data separated by semicolon);
- Simplified PI&Ds with all CGS parameters and variables;
- Compressor performance maps of all Operational Cases included in the compressor datasheet (API-617) showing the Operation Point, Surge Line, Trigger Line and Surge Control Line. The following maps are required: Rc x Q (m3/h), Pd (bar) x Q (m3/h), Td (ºC) x Q (m3/h), Hp (kJ/kg) x Q (m3/h), ηp (%) x Q (m3/h), Pot (kW) x Q (m3/h), Rc x QN (Sm3/d at 15.6 ºC and 1 atm);
- Compressor performance map Rc x Invariant flow of suction conditions showing the Operation Point, Surge Line, Trigger Line and Surge Control Line.

5.8.6.3 Access to configuration and programming shall be protected by change management tools, including specific passwords with several levels, such as: general, operation, maintenance and engineering. All passwords shall be delivered to PETROBRAS with NO access restrictions.

5.8.6.4 PACKAGER shall provide CGS_HMI supervisory software (runtime and development tool) running on Windows environment, compatible with the size of the application and in its latest version. Software shall be supplied, installed, configured in the CGS_HMI and provided with complete manuals/electronic media. Software licenses shall also be provided.

5.8.6.5 A fiber optic port shall be available in one of the UCPs of the compression system for this HMI interconnection.

5.8.6.6 Access to HMI shall be provided for onshore access, in accordance with AUTOMATION NETWORK DESCRIPTION. Additional Ethernet network card shall be available for package LAN if necessary. Remote access shall be password protected.

6. ELECTRICAL

6.1. Electrical equipment and materials shall comply with requirements of I-ET-3010.00-5140-700-P4X-002 - SPECIFICATION FOR ELECTRICAL MATERIAL FOR OFFSHORE UNITS, I-ET-3010.00-5140-700-P4X-007 - SPECIFICATION FOR GENERIC ELECTRICAL EQUIPMENT FOR OFFSHORE UNITS, I-ET-3010.00-5140-700-P4X-009 - GENERAL REQUIREMENTS FOR ELECTRICAL MATERIAL AND EQUIPMENT FOR OFFSHORE UNITS and I-ET-3010.00-5140-772-P4X-002 - SPECIFICATION FOR LOW-VOLTAGE FREQUENCY CONVERTERS, SOFTSTARTERS AND INVERTERS FOR OFFSHORE UNITS.

6.2. Electrical installations inside the package and the voltages to be supplied for electrical loads (motors, heaters, control panels, etc.) shall comply with requirements of I-ET-3010.00-5140-700-P4X-003 - ELECTRICAL REQUIREMENTS FOR PACKAGES FOR OFFSHORE UNITS.

6.3. Electrical motors shall comply with requirements of I-ET-3010.00-5140-712-P4X-001 - LOW-VOLTAGE INDUCTION MOTORS FOR OFFSHORE UNITS and I-ET-3010.00-5140-712-P4X-002 - MEDIUM-VOLTAGE INDUCTION MOTORS FOR OFFSHORE UNITS. The electrical motors shall be fed from platform normal panels.

6.4. The electrical communications interfaces of the package shall comply with requirements of I-DE-3010.00-5140-797-P4X-001 – ELECTRICAL SYSTEM AUTOMATION ARCHITECTURE DIAGRAM, I-ET-3010.00-5140-797-P4X-001 – ELECTRICAL SYSTEM AUTOMATION ARCHITECTURE, I-DE-3010.00-5140-797-P4X-002 - ELECTRICAL SYSTEM AUTOMATION TYPICAL ACTUATION DIAGRAMS and I-LI-3010.00-5140-797-P4X-001 – ELECTRICAL SYSTEM AUTOMATION INTERFACE SIGNALS LIST.

6.5. Equipment, accessories, piping and structures shall be grounded according to requirements of I-DE-3010.00-5140-700-P4X-003 - GROUNDING INSTALLATION TYPICAL DETAILS, I-ET-3010.00-5140-700-P4X-001 – SPECIFICATION FOR ELECTRICAL DESIGN FOR OFFSHORE UNITS, IEC 61892-6 and IEC-60092-502. Besides these standards, for installations in hazardous area, the grounding requirements of IEC 61892-7 shall be complied.

6.6. Heater panels and other panels, except Motor Control Center (MCC), shall comply with I-ET-3010.00-5140-741-P4X-004 - SPECIFICATION FOR LOW-VOLTAGE GENERIC ELECTRICAL PANELS FOR OFFSHORE UNITS.

6.7. Other panels, except Motor Control Center (MCC), shall comply with requirements of I-ET-3010.00-5140-741-P4X-004 - SPECIFICATION FOR LOW-VOLTAGE GENERIC ELECTRICAL PANELS FOR OFFSHORE UNITS.

6.8. Variable Speed Driver - Frequency Converter unit shall be designed according to I-ET-3010.00-5140-772-P4X-001 - MEDIUM-VOLTAGE FREQUENCY CONVERTER FOR OFFSHORE UNITS.

6.9. All electrical panel shall comply with I-ET-3010.00-5140-700-P4X-005 - REQUIREMENTS FOR HUMAN ENGINEERING DESIGN FOR ELECTRICAL SYSTEMS OF OFFSHORE UNITS.

6.10. Motocompressor auxiliary loads shall be fed by auxiliary MCCs, provided by PURCHASER (out of scope of PACKAGER). However, PACKAGER shall provide all necessary information about auxiliary loads for Integrator, in order to allow complete and suitable fabrication of auxiliary MCCs. Auxiliary MCCs (Motor Control Center) shall comply with I-ET-3010.00-5140-741-P4X-001 - LOW-VOLTAGE MOTOR CONTROL CENTER AND SWITCHGEAR FOR OFFSHORE UNITS.

7. OPERATION AND MAINTENANCE REQUIREMENTS

7.1. PACKAGER and PURCHASER shall present the applicable recommendations to optimize operation and maintenance, taking into account the remote location and platform general conditions. Any changes to equipment design, materials or specific spares that may improve the equipment operability, availability or reliability shall be submitted to PETROBRAS for review and approval. But PACKAGER and PURCHASER shall always comply with PETROBRAS requirements before suggest any modification.

7.2. The packages shall be designed so that all maintenance can be carried out with standard tools as much as possible.

7.3. PACKAGER shall avoid the use of walkways within auxiliary skids to reduce its footprint. Components from auxiliary skids shall be accessible from the surrounding area of the module as much as possible. Maintenance areas shall be indicated in the general arrangement drawings to allow PURCHASER to correctly position the auxiliary skids in the module.

7.4. Stairs, vertical ladders or ramps shall be provided where the elevation change is greater than 500mm or used as passage over pipes or other equipment. When vertical ladders are used to access the main baseplate provided with AVMs, it shall not be fixed to the module floor to keep the AVMs free to move. Typical vertical ladder details are shown on I-DE-3010.00-1400-140-P4X-002 – STANDARD-STEEL LADDERS – TYPICAL DETAILS.

7.5. Equipment layout shall enable easy and safe access for maintenance to all components and parts. PACKAGER and PURCHASER shall provide suitable walkways, ladders and handrails inside the skids and inside de module, for all packages, including auxiliaries. All equipment and peripherals, especially oil reservoirs, shall have full access and inspection doors/hatches.

7.6. Instruments and piping accessories shall be arranged in proper location in order to allow easy access by maintenance and operation personnel. Installation of piping and cable supports next to couplings, bearings and seals shall be avoided, for instance.

7.7. PACKAGER and PURCHASER shall prepare detailed assembly, disassembly and maintenance procedures, describing the use of all involved lifting and handling apparatus and including all required preventive and corrective maintenance tasks. PACKAGER and PURCHASER shall inform the need for disassembling any component or equipment in order to facilitate access for maintenance. Suitable maintenance routes shall be provided to remove the main components and auxiliaries, avoiding interference with structures, piping, cabling, electric conduits and supports, equipment, etc. This plan shall be submitted to PETROBRAS for approval.

7.8. PACKAGER and PURCHASER shall provide lifting/handling devices and external structure components enabling assembly, disassembly and removal all components inside the package (compressor, HVSD, electric motor rotor, etc.), including internal parts such as compressor bundle, electric motor rotor and HVSD core runner with adequate and certified capacity to handle maximum maintenance weight and/or dimensions. Lifting and handling devices shall be according to the specific project's "TOPSIDE´S MECHANICAL HANDLING PROCEDURES" as stated in the DOCUMENT LIST.

7.9. PACKAGER and PURCHASER shall provide special tools for all maintenance activities including tools for compressor, compressor bundle, driver and driver rotor, to assembly, disassembly and removal.

7.10. PACKAGER and PURCHASER shall include in proposal a schedule stating the expected time between major overhauls.

7.11. PACKAGER and PURCHASER shall provide a HVSD shaft end with an adaptor in order to allow manual turning for maintenance purposes.

7.12. Noise control requirements:

7.12.1. Noise control analysis is a mandatory item to be carried-out. PACKAGER and PURCHASER shall present noise data regarding items included in scope of supply.

7.12.2. The maximum allowable sound level shall be 90 dB(A) at one (1) meter around the unit and up to two (2) meters from the floor.

7.12.3. The noise control system for the package shall consider the noise radiated by inlet/outlet piping, equipment enclosure including ventilation system (if specified) and equipment casings.

7.12.4. Whenever electric motor drivers are used, it shall be verified if motor fan design can be modified (e.g., use of unidirectional blades, etc.) before any apparatus are applied for noise attenuation.

7.12.5. In case of expected noise are higher than allowable limits, the equipment must be furnished with some noise control reduction measure and the maximum noise allowable value will be 85 dB(A). PACKAGER and PURCHASER may consider the best solution, which may include acoustic blanket or acoustic walls (open roof) and safety system requirements. The use of device to comply with noise requirement must be proved to be efficient and submit to PETROBRAS approval.

7.12.6. For all equipment installed without acoustical enclosure, the following data will be required during proposal phase:

- Sound power level of the equipment;
- Sound pressure level, in each of the four main directions and in one point of the top.

7.12.7. For all equipment installed inside acoustic enclosure, the following data will be required during proposal phase:

- Sound power level of the equipment without enclosure;
- Sound pressure level, in each of the four main directions and in one point of the top, for the equipment plus enclosure;
- Acoustical data of enclosure and silencers (when applicable).

8. INSPECTION AND TESTS

8.1. General requirements

8.1.1. The complete scope of inspections and tests to be performed by PACKAGER and VENDORS is marked in the PETROBRAS data sheets of each equipment or system, in PETROBRAS specifications and in International Standards. PACKAGER shall submit an Inspection and Test Plan (ITP) for the entire package for PURCHASER, PETROBRAS and Classification Society approval.

8.1.2. PETROBRAS is entitled to inspect the package anytime during fabrication to ensure that material and workmanship are in accordance with the specifications. PETROBRAS will inform PACKAGER and/or VENDOR and PURCHASER when an inspection is intended to be scheduled.

8.1.3. Inspection of materials and/or equipment will be made by PETROBRAS or its authorized representatives.

8.1.4. Unless otherwise specified, all witnessed tests shall be informed, at least, 90 days before the scheduled dates.

8.1.5. Unless otherwise established by PETROBRAS inspector, all equipment shall be available for inspection in an unpainted state.

8.1.6. All PAS shall be functionally tested at supplier facilities. All control sequences and shutdown logics shall be simulated and tested against the requirements. Details of supplier standard functional test procedures shall be submitted to PETROBRAS approval.

8.1.7. PETROBRAS inspector shall have the right to request inspections to ensure that the equipment complies with the relevant classification society requirements.

8.1.8. In case any defects and/or shortcomings are found, PACKAGER and PURCHASER shall bear the full cost of such inspection and replacement as necessary. Major repair shall previously be approved by PETROBRAS. The subsequent inspection necessary to confirm the satisfactory results will be at PACKAGER and PURCHASER cost. Major repairs are considered as the following: weld repairs, shaft damage repairs, rotating component repairs, rotor clearance repairs, shaft runout repairs, seal repairs and bearing repairs.

8.1.9. All process gas system welds shall be 100% radiographically inspected and submitted to magnetic particle examination.

8.1.10. PACKAGER shall provide test reports and certificates whenever required by PETROBRAS for review, especially for tests not witnessed by PETROBRAS.

8.1.11. PACKAGER and PURCHASER shall submit to PETROBRAS a final inspection report for each package before the delivery to the integration yard. The reports shall contain photographs showing all equipment before and after the packaging for transportation. If the package contains HVSD, PACKAGER shall perform an internal visual inspection of the HVSD and register in the report also.

8.1.12. Hydrodynamic Bearings, if required, and DGS shall be removed by PACKAGER after Factory Acceptance Test of Compressor (FAT) or Factory Integrated Test (FIT) and package separately with clear identification to be delivered with the main equipment in a packing suitable for long term storage for posterior PACKAGER assembly.

8.2. Hydrostatic test (HT)

8.2.1. The compressor hydrostatic test shall be done according to API STD 617 latest edition and Annex B - Additions and Modifications to API 617. Hydrostatic tests for other equipment shall be done as per its respective international standards.

8.2.2. For all trains, parts being tested shall be externally coated with a layer of white lead carbonate or any other suitable powder to help leakage detection.

8.2.3. No vises or clamping devices shall be used for pressing of nozzle flanges.

8.2.4. PTFE tape or thread compounds shall not be used to prevent leakage of threaded plugs and connections.

8.3. Performance Test (PT)

8.3.1. Performance Test shall be performed on each unit and spare bundles according to ASME PTC 10 (type 2).

8.3.2. PACKAGER shall measure balance line flow and division wall flow calculation during performance test. When it is not possible to measure directly the flow (e.g. the balance line is internal to the casing), the leakage shall be calculated by means of a mass balance using other flow measurements, such as suction and discharge flow measurements.

8.3.3. The performance test procedure shall be agreed with PETROBRAS.

8.4. Gearbox Mechanical Running Test

8.4.1. For each Gearbox, when provided, a Mechanical Running Test (MRT) shall be performed and all spare rotors according to API STD 613 latest edition.

8.4.2. Lube oil inlet pressures and temperatures shall be varied through the operational ranges during the test. The following cases shall be verified during the 4 hours test:

- high lube oil pressure & high lube oil temperature;
- high lube oil pressure & low lube oil temperature;
- low lube oil pressure & high lube oil temperature;
- low lube oil pressure & low lube oil temperature.

8.4.3. An Unbalance Response Test (URT) shall be performed in one gearbox of each type during the MRT and the test results shall be used to verify the analytical model.

8.4.4. A part-load test shall be performed.

8.4.5. If the gearbox has auxiliary equipment, such as mechanical lube oil pump and turning gear, they shall be tested during the MRT also.

8.4.6. Job probes, extension cables and proximitors shall be used during the test. The proximitors shall be appropriate for the material or coating of the target area. Frequency ranges shall be configured as per API STD 613.

8.4.7. Testing with the contract coupling or couplings is preferred. If shop coupling is used, a moment simulator shall be used.

8.4.8. The vibration acceptance criteria shall be as per API STD 613 and the bearing temperature acceptance criteria shall be less than 100°C or 90% of the high temperature alarm setpoint, whichever is lower.

8.4.9. Real-time vibration and bearing temperature data shall be recorded using ADRE®. The configuration of the ADRE® shall be checked by the inspectors before the start of the test. A copy of ADRE® records shall be provided to PETROBRAS immediately after the test. In case of ADRE® system is not used for data collecting and monitoring during shop tests, then visualization software (or translation into ADRE® format files) shall be provided as well.

8.4.10. A test bench schematic shall be provided in the test procedure and shall represent all elements installed, not a typical schematic.

8.4.11. A chart speed x time shall be provided in the test procedure showing all steps of the test.

8.4.12. The following data shall be provided during the test and attached to the test report:

- Calibration curves of the set probe+extension cable+proximitor;
- Shop instruments calibration certificates;
- Lube oil cleanliness certificate;
- Runout check certificate;
- Balancing report;
- Backlash and axial clearance report;
- Moment simulator calculation, if shop coupling is used;

- Tooth contact patterns;
- Test logs and calculations;
- Vibration plots: amplitude x time trends, bode plots during accelerations and coastdowns, vibration spectra and shaft orbits for each test step.

8.4.13. A preliminary test report shall be provided immediately after the test. The report shall include, at least, all the required data above and a conclusion with a comparison between as tested values and the acceptance criteria.

8.4.14. The MRT of Gearbox procedure shall be agreed with PETROBRAS.

8.4.15. The MRT of Gearbox shall be witnessed by PETROBRAS.

8.5. Hydraulic Variable Speed Driver Factory Acceptance Test

8.5.1. For each HVSD, when provided, a Mechanical Running Test (MRT) shall be performed at VENDOR's shop.

8.5.2. The following operating points shall be tested, at least:

- Acceleration to trip speed and deceleration to Minimum Operating Speed (MOS);
- Lowest output torque at Minimum Operating Speed (MOS) for at least 60 minutes;
- Highest output torque at Minimum Operating Speed (MOS) for 60 minutes;
- Highest output torque possible at test bench at Trip Speed for 15 minutes;
- Highest output torque possible at test bench at Maximum Continuous Speed (MCS) for 4 hours;
- Highest output torque possible at test bench among all operating speeds for 60 minutes.

8.5.3. Lube oil inlet pressures and temperatures shall be varied through the operational ranges during the test. The following cases shall be verified during the 4 hours test:

- High lube oil pressure & high lube oil temperature;
- High lube oil pressure & low lube oil temperature;
- Low lube oil pressure & high lube oil temperature;
- Low lube oil pressure & low lube oil temperature.

8.5.4. An Unbalance Response Test (URT) shall be performed in one HVSD unit during the MRT and the test results shall be used to verify the analytical model.

8.5.5. If the HVSD has auxiliary equipment, such as a mechanical lube oil pump, they shall be tested also during the MRT.

8.5.6. Job probes, extension cables and proximitors shall be used during the test. The proximitors shall be appropriate for the material or coating of the target area. Frequency ranges shall be configured as per API STD 613.

8.5.7. Testing with the contract coupling or couplings is preferred. If shop coupling is used, a moment simulator shall be used.

8.5.8. The vibration acceptance criteria for input and output shafts and casing accelerometers shall be the same as API STD 613 for gearbox's MRT and the bearing temperature acceptance criteria shall be less than 100°C or 90% of the high temperature alarm setpoint, whichever is lower. The amplitude of any discrete, nonsynchronous vibration shall not exceed 20% of the allowable vibration.

8.5.9. Real-time vibration and bearing temperature data shall be recorded using ADRE®. The configuration of the ADRE® shall be checked by the inspectors before the start of the test. A copy of ADRE® records shall be provided to PETROBRAS immediately after the test. In case of ADRE® system is not used for data collecting and monitoring during shop tests, then visualization software (or translation into ADRE® format files) shall be provided as well.

8.5.10. A test bench schematic shall be provided in the test procedure and shall represent all elements installed, not a typical schematic.

8.5.11. A chart speed x time shall be provided in the test procedure showing all steps of the test.

8.5.12. The operating map shall be provided in the test procedure showing the test operating points.

8.5.13. The following data shall be provided during the test and attached to the test report:

- Calibration curves of the set probe+extension cable+proximitor;
- Shop instruments calibration certificates;
- Lube oil cleanliness certificate;
- Runout check certificate;
- Moment simulator calculation, if shop coupling is used;
- Test logs and calculations;
- Vibration plots: amplitude x time trends, bode plots during accelerations and coastdowns, vibration spectra and shaft orbits for each test step.

8.5.14. A preliminary test report shall be provided immediately4747 after the test. The report shall include, at least, all the required data above and a conclusion with a comparison between "as tested" values and the acceptance criteria.

8.5.15. The following HVSD softening steps shall be performed at VENDOR´s shop facilities:

- Run at 55 to 65% of maximum output torque during 8 hours;
- Run at 70 to 80% of maximum output torque during 8 hours.

Note: Any 'softening phase' beyond 70 to 80% of maximum output torque shall be avoided.

8.5.16. The MRT of HVSD procedure shall be agreed with PETROBRAS, including the acceptance criteria.

8.5.17. The MRT of HVSD shall be witnessed by PETROBRAS.

8.6. Mechanical Running Test (MRT)

8.6.1. MRT shall be performed on each unit and all spares bundles according to API STD 617 latest Edition.

8.6.2. PACKAGER shall submit to PETROBRAS digital files (storage type to be mutually agreed during detailed design) with vibration data recorded during MRT and all test information, including, at least: failed tests, with sweeping, starting/stopping ramp, equipment vibration signature, diagram for all bearing signals and phase angle versus speed.

8.6.3. The MRT procedure shall be agreed with PETROBRAS.

8.7. Full Pressure Full Load Full Speed Test (FPFLFS)

8.7.1. According to the requested by each Compressor Service Data Sheet, Full-pressure, Full-load, Full-speed Test (FPFLFS) shall be performance as per API 617 per compressor type. As a PT and MRT items, the FPFLFS shall also be witnessed. During this test, shop driver may be used.

8.7.2. When requested, one full-pressure, full-load, full-speed test shall be performance as per API 617 item 4.3.8.6 per compressor type during the Mechanical Running Test. As a MRT item, the full pressure/load/speed shall also be witnessed. During this test, shop driver may be used.

8.7.3. The FPFLFS procedure shall be agreed with PETROBRAS including acceptance criteria.

8.8. Factory Stability Test (FST)

8.8.1. According to the requested by each Compressor Service Data Sheet, FST per compressor type shall be performed as described in “Annex B”.

8.8.2. The FST procedures shall be agreed with PETROBRAS.

8.9. Sound Level Test (SLT)

8.9.1. The sound pressure meter shall be class I, according to IEC 61672. The characteristics of the octave filter shall be in accordance with IEC 61260. The sound pressure reading shall be made as equivalent continuous level, for 60 seconds sampling time. The recorded values shall be corrected to the nearest entire value within 1dB. A maximum deviation of 2dB will be allowed, both for the A scale weighted value and for the octave bands between 31.5 Hz and 8000 Hz.

8.9.2. The procedures for sound measurement assume a condition of free field over reflecting floor. This implies that the tests will be preferably performed in an outside area, with a smooth floor made of concrete, asphalt, etc. If this condition is not satisfied, then the correction for measurements in rooms shall be applied.

8.9.3. If the difference between the background noise level and the equipment sound level plus the background is less than 10dB, the measurements shall be corrected.

8.9.4. If the normal operating condition cannot be reached in the test facilities, PACKAGER, PETROBRAS and PURCHASER shall agree with measurements methods and values.

8.9.5. If the values measured and reported during the shop test are higher than the limits submitted by PACKAGER and approved by PETROBRAS in proposal, PACKAGER and PURCHASER shall provide, without extra cost, sound attenuation methods in order to reach this limit, if required by PETROBRAS.

8.10. Factory Integrated Test (FIT)

8.10.1. PACKAGER shall execute one FIT in their installations per compressor service. FIT shall be a functional test including the following contract parts, at least: main electric motor, HVSD/gearbox/VFD, compressor, PAS, oil system and seal gas system including seal gas treatment system.

8.10.2. The FIT procedure, with the steps and duration, shall be similar to the MRT, and shall have, at least, three starts and three stops. The test is without process plant, and therefore the compressor shall be under vacuum. It is not necessary to perform the unbalance test.

8.10.3. Vibration requirements (limits, acceptance, etc.) shall be the same used for MRT.

8.10.4. Motors will be tested according to electrical standards references and PETROBRAS specification. For PACKAGES with VFDs, the tests shall also be performed in minimum and maximum speed:

- Measurement of power factor and efficiency at rated voltage and frequency in accordance with IEC 60031-2-3.
- Measurement of shaft voltage in accordance with IEC 60034-1.
- Windings temperature rise test in accordance with IEC 60034-1.

8.10.5. During the CUT of Compressors driven by electric motors with Variable Frequency Drives (VFDs), the torsional stress spectrum shall be continuously monitored and recorded during the CUT with a frequency range up to 10 times the maximum operating speed. The job monitoring system shall be used for this purpose.

- The calculated primary (coupling) Torsional Natural Frequencies (TNF) shall be identified during the CUT.
- The stress amplitude of any discrete frequency coinciding with a TNF shall be below the pre-defined coupling fatigue limit for any condition within the pump's operational envelope.

8.10.6. Control check shall be done during FIT, as part of functional test.

8.10.7. The FIT procedure shall be agreed with PETROBRAS.

8.11. Shipyard Acceptance Test (SYAT)

8.11.1. Shipyard Acceptance Test (SYAT) is inert gas (N2) functional test onshore, performed on each unit.

8.11.2. Shipyard Acceptance Test (SYAT) shall be performed in the shipyard facilities after compressor and process plant complete commissioning (including N2 and He leakage test of piping system been executed) and complete integration with all systems of FPSO that support the operation of compression system.

8.11.3. PURCHASER shall provide all facilities, support and technical procedures to execute a SYAT, according to Annex C - Inert Gas Centrifugal Compressor Running Test. PACKAGER shall provide technical assistance for all SYAT.

8.11.4. PURCHASER and PACKAGER shall perform a SLT during SYAT.

8.11.5. The SYAT procedure shall be agreed with PETROBRAS including acceptance criteria. However, the acceptance criteria stated at Annex C shall be complied.

8.12. **Site Acceptance Test (SAT)**

8.12.1. Site Acceptance Test (SAT) is an offshore acceptance test to be performed when the motocompressor is able to operate after all commissioning is complete and not pending.

8.12.2. SAT shall be performed according to “Annex A” (Rotating Equipment Reliability Test).

8.12.3. PURCHASER and PACKAGER shall provide all facilities, support and technical assistance for SAT. PURCHASER is responsible for any repairs required during the SAT that are not caused by factors external to the motocompressor system.

8.12.4. The SAT procedure shall be agreed with PETROBRAS.

9. ANNEXES

9.1. Annex A: Rotating Equipment Reliability Test.

9.2. Annex B: Additions and Modifications to API 617.

9.3. Annex C: Inert Gas Centrifugal Compressor Running Test.