PETROBRAS	**TECHNICAL SPECIFICATION**	**Nº:** I-ET-3010.00-1200-751-P4X-001	
	CLIENT: SRGE		**SHEET:** 1 **of** 13
	PROJECT:		-
	UNIT:		
SRGE	**TITLE:** **ANODES SPECIFICATION FOR MECHANICAL EQUIPMENT**		INTERNAL ESUP

MICROSOFT WORD / V. 2003 / I-ET-3010.00-1200-751-P4X-001_0.DOC

INDEX OF REVISIONS

REV.	**DESCRIPTION AND/OR REVISED SHEETS**
0	ORIGINAL ISSUE
A	WHERE INDICATED

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	APR/1/2020	OCT/15/22							
DESIGN	ESUP	ESUP							
EXECUTION	CJH4	CJH4							
CHECK	ASWG	CSM0							
APPROVAL	U32N	U32N							

SUMMARY

1 SCOPE

This technical specification establishes the additional requirements to DNV-RP-B401 to be adopted during the design, manufacture and assembly of the cathodic protection (CP) system of topside equipment. CPS with impressed current system is not a part of the scope of this document.

DNV-RP-B401 paragraphs not mentioned in this Standard are considered as fully applicable.

2 NORMATIVE REFERENCES AND DESIGN SPECIFICATIONS

2.1 GENERAL

2.1.1 The CPS system shall comply with the requirements of this technical specification and references stated below.

2.1.2 As a general guideline, in case of conflicting requirements between this technical specification and other cited references, the most stringent shall prevail. If necessary, the SELLER may revert to BUYER for clarification.

2.2 CLASSIFICATION SOCIETY

2.2.1 SELLER shall perform the work in accordance with the requirements of Classification Society.

2.2.2 SELLER is responsible for submitting to the Classification Society all documentation in compliance with stated Rules.

2.2.3 Classification Society rules may only be waived upon the formal approval from the Classification Society itself and from BUYER.

2.3 CODES AND STANDARDS

2.3.1 The following codes and standards include provisions that, through reference herein, constitute provisions of this specification. The latest issue of the references shall be used unless otherwise agreed.

2.3.2 Other recognized international standard may be used, whether they meet or exceed the requirements of the standards referenced below. Formal approval from BUYER and from the Classification Society is also required.

ISO 8501-1	Preparation of Steel Substrates Before Application of Paints and Related Products - Visual Assessment of Surface Cleanliness - Part 1: Rust Grades and Preparation Grades of Uncoated Steel Substrates and of Steel Substrates After Overall Removal of Previous Coatings
DNV-RP-B101	Corrosion Protection of Floating Production and Storage Units
DNV-RP-B401	Cathodic Protection Design
EN 12496	Galvanic Anodes for Cathodic Protection in Seawater and Saline Mud

NORSOK M-503	Cathodic Protection
ISO 12473	General principles of cathodic protection in seawater

2.4 GOVERNMENTAL REGULATION

2.4.1 Regulatory Standard are mandatory and shall prevail, if more stringent, over the requirements of this specification and other references herein

NR-10	Brazilian Regulatory Standard - Safety in Electrical Facilities and Services
NR-13	Brazilian Regulatory Standard - Boilers, Pressure Vessels, Pipes and Metallic Storage Tanks
NR-37	Brazilian Regulatory Standard - Safety and Health in Petroleum Platforms

2.5 DESIGN SPECIFICATIONS

I-ET-3010.00-1200-956-P4X-002	GENERAL PAINTING
I-ET-3010.00-1200-955-P4X-001	WELDING
I-ET-3010.00-1200-940-P4X-002	GENERAL TECHNICAL TERMS

3 DEFINITIONS AND ABBREVIATIONS

3.1 DEFINITIONS

Definitions are in accordance with the technical specification I-ET-3010.00-1200-940-P4X-002 - GENERAL TECHNICAL TERMS, with the following additions:

COATING EFFICIENCY (E)

Fraction of the surface effectively protected by the anti-corrosive coating of a component, which causes a percentage reduction of the protection current necessary for the coated surface polarization in comparison to a non-coated surface.

INITIAL CURRENT (I_i)

Intensity of the current needed to polarize a component under cathodic protection.

AVERAGE CURRENT (I_m)

Intensity of the current needed to maintain polarization of a component throughout the useful life of the cathodic protection system.

FINAL CURRENT (I_f)

Intensity of the current needed to protect the component during the end of its useful life to the cathodic protection system.

3.2 ABREVIATIONS

A	internal cross-section area of pipe/tube
CP	cathodic protection
CPS	cathodic protection system
ΔE	driving voltage [mV]
HIC	hydrogen induced cracking
HAT	highest astronomical tide
MIC	microbiological induced corrosion
RCP	resistor controlled cathodic protection
SMYS	specified minimum yield strength
SS	stainless steel
R_a	anode resistance or anode bank resistance [ohm]
R_{af}	anode resistance or anode bank resistance at final condition [ohm]
i	design current density [mA/m²]
i_{cf}	final current density [mA/m²]
f_c	coating breakdown factor
f_{cf}	final coating breakdown factor
ρ	Environmental resistivity (ohm m)

4 DESIGN REQUIREMENTS

4.1 GENERAL DESIGN REQUIREMENTS

4.1.1 The CPS design methodology shall be in accordance with DNVGL-RP-B401.

4.1.2 The CPS system shall be designed with due regard to environmental conditions, as well as to adjacent structures, equipment and their services.

4.1.3 The design shall comply with safety premises, taking the offshore unit hazardous areas plan into account.

4.1.4 The design of CPS for the sea water lift pumps and start-up sea water lift pump shall consider, at least, submerged Centrifugal Pump/Motor, pipe stack and the caisson where the pump is installed.

4.2 DESIGN LIFE

4.2.1 The design life adopted for the galvanic cathodic protection system shall comply with the requirements of Table 1 or as stated in specific document of equipment.

Table 1 - Design Life for Galvanic CPS

Installation	*CPS design life to be considered*
Pressures vessel and tanks	Lifetime of the pressure vessel unless there is a suitable access for anode replacement. In this case, a minimum of 5 years shall be adopted as the design life
Filter	A minimum of 5 years shall be adopted as the design life
Pump	Period in between predictive pump maintenance, with a minimum of 5 years shall be adopted as the design life

4.3 POTENTIAL REQUIREMENTS

4.3.1 The CPS system shall have sufficient capacity to polarize carbon steel and low alloy exposed to process fluid to a potential more negative than -800mV vs. Ag/AgCl/sea water reference electrode.

4.3.2 The maximum negative potential shall be -1150mV vs. Ag/AgCl/sea water reference electrode.

4.3.3 High strength steel (SMYS > 550 MPa), as well as martensitic, duplex and superduplex stainless steels may be subject to embrittlement by hydrogen in potentials more negative than -850 mV (Ag / AgCl). For these materials the anodes shall be selected so that the potential will be in the range from -780 to -830 mV vs. Ag/AgCl/sea water (Low Voltage Anodes).

4.4 COATING BREAKDOWN FACTORS

4.4.1 Coating breakdown factors for CPS design, DNV-RP-B401 shall be complied with. The Table 2 determine the factors for *a* and *b* for each type of equipment.

Table 2 - Coating Breakdown factors

Installation	*a*	*b*
Filters	0.02	0.03
Vessels and others	0.02	0.02

4.4.2 SELLER may specify more stringent factors for CPS design.

4.5 VELOCITY FACTOR

4.5.1 The Table 3 states the velocity factor that shall be considered in the CPS design

Table 3 - Velocity Factor X Component/Electrolyte Relative Velocity

Speed (m/s)	*Velocity factor*
0 to 1,5	1,0
1,5 to 3,5	1,1
> 3,5	1,2

4.6 ELECTRICAL RESISTIVITY OF ELECTROLYTE

4.6.1 The Table 4 states the resistivity of electrolyte that shall be considered in the CPS design. Resistivity of fluid not established herein, shall be determined by SELLER.

Table 4 - Electrical Resistivity of Electrolyte

Fluid	*Resistivity of electrolyte (Ω.cm)*
Seawater	25
Produced water	25
Oily water / Slop	25
Diesel	25
Fresh water	2000
Closed circuit cooling water	1000

4.7 CURRENT DENSITY

4.7.1 Current density (mA/m^2) values change according to the parameters, type of structure, coating and water temperature. Requirements from DNV RP-B401 shall be followed.

4.8 DESIGN PROCEDURES

4.8.1 Anodes for galvanic current shall be distributed as per protection area criteria and experiences acquired through similar projects.

4.8.2 The design of cathodic protection system shall be provided with drawings indicating the anode distribution in the equipment.

4.8.3 The initial, mean and final current densities of components heated by internal fluid shall be increased by 1 mA/m² per °C of the temperature of the external wall of equipment in addition to the room temperature. The temperature of the internal fluid can be used, conservatively, when the outside wall temperature is not available.

4.8.4 Areas to be protected shall be specified for each equipment material type (carbon steel, stainless steel, etc.) to be cathodically protected, considering that, when calculating the current required to protect the equipment, each area demands one part of this current.

4.8.5 Anodes distribution must not interfere with the regular operations during interventions and equipment operation.

4.8.6 It is recommended the use of a numeric simulation software to determine the correct distribution of anodes, to ensure a uniform distribution of the current and uniform potential at equipment; and to confirm the inexistence of harmful potential electrochemical potentials.

4.9 CALCULATION PROCEDURES

4.9.1 For the conventional CPS calculation procedures shall follow the guidance included in DNV-RP-B401, complemented by this technical specification. The estimated life cycle values, coating breakdown factor, cathodic protection current density, electrical resistivity of electrolyte and velocity factor shall be used for CPS designing.

4.9.2 Calculate the total initial current (I_i) from the following formula:

$$I_i = S_{sr}.D_i + S_{cr}.D_i(1-E_i).f_v$$

Where:

I_i - total initial current, in A;
S_{sr} - surface area to be protected with no coating, in m^2;
S_{cr} - surface area to be protected with coating, in m^2;
D_i - initial current density, in A/m^2;
E_i - initial coating efficiency;
f_v - velocity factor.

4.9.3 Calculate the total mean current (I_m) from the following formula:

$$I_m = S_{sr}.D_m + S_{cr}.D_m(1-E_m).f_v$$

Where:

I_m - total mean current, in A;
S_{sr} - surface area to be protected with no coating, in m^2;
S_{cr} - surface area to be protected with coating, in m^2;
D_m - mean current density, in A/m^2;
E_m - mean coating efficiency;
f_v - velocity factor.

4.9.4 Calculate the total final current (I_f) from the following formula:

$$I_f = S_{sr}.D_f + S_{cr}.D_f\left(1 - E_f\right).f_v$$

Where:

I_f - total final current, in A;
S_{sr} - surface area to be protected with no coating, in m^2;
S_{cr} - surface area to be protected with coating, in m^2;
D_f - final current density, in A/m^2;
E_f - final coating efficiency;
f_v - velocity factor.

4.9.5 Calculate the required anode weight (mass) from the following formula:

$$M = \frac{8760.I_m.V}{C.F_u}$$

Where:

M - anode weight (mass) in Kg;
V - life cycle of cathodic protection system in years;
I_m - mean current, in A;
C - current capacity in A.h/kg, as per 5.2.1;
F_u - utilization factor, as per DNVGL-RP-B401.

4.9.6 Select anodes of aluminum or zinc alloys. Determine the minimum quantity of anodes (n) in order to find out the anode weight (mass) calculated as per 4.9.5.

$$n = \frac{M}{M_{net}}$$

Where:

n - minimum quantity of anodes;
M - anode weight (mass) calculated as per 4.9.5, in kg;
M_{net} - net weight (mass) of the chosen anode, in kg.

4.9.7 Determine the initial current produced ($\bar{I}_i$) by the anode selected in 4.9.6, from the formula below:

$$\overline{\mathrm{I}}i = \frac{\Delta E}{R_i}$$

Where:

$\bar{I}_i$ - initial current produced, in A;
ΔE - 0.25 V for submersed anodes and 0.15 V for buried anodes;
R_i - initial resistance of anode-electrolyte contact, in Ω.

4.9.8 The value of initial resistance (R_i) for anodes of aluminum alloy or zinc alloy with square cross section is calculated from the following formula:

$$R_i = \frac{\rho}{2\pi.L_i}\left[\ln\left(\frac{4L_i}{r_i}\right) - 1\right]$$

Where:

R_i - initial resistance of anode-electrolyte contact, in Ω;
ρ - electrical resistivity of electrolyte, in Ω.m;
L_i - initial length of anode, in m;
r_i - initial equivalent radius of anode, in m.

NOTE: The value of initial equivalent radius of anode (*r_i*) is calculated with the anode dimensions given by means of the following expression:

$$r_i = \frac{c_i}{2 \cdot \pi}$$

Where:

r_i - initial equivalent radius of anode, in m;
c_i - perimeter of the initial cross section of the anode, in m.

4.9.9 The value of (R_i) for flat anodes of aluminum alloy or zinc alloy is calculated from the following formula:

$$R_i = \frac{\rho}{2.Le_i}$$

Where:

R_i - initial resistance of anode-electrolyte contact, in Ω;
ρ - electrical resistivity of electrolyte, in Ω.m;
Le_i - average between the final length and width of the anode, in m.

NOTE: This formula is used when the length of the anode is, at least, twice its width.

4.9.10 The initial current supplied to each anode ($\bar{I}_i$), calculated in 4.9.7, shall be compared to the total initial current calculated in 4.9.2 (I_i), and shall match the following requirements:

$$n \cdot \bar{I}_i \geq I_i$$

4.9.11 Determine the final current produced ($\bar{I}_f$) by the anode selected in 4.9.6, from the following formula:

$$\overline{\mathrm{I}}_f = \frac{\Delta E}{R_f}$$

Where:

$\bar{I}_f$ - final current produced, in A;
ΔE - 0.25 V for submersed anodes and 0.15 V for buried anodes;
R_f - final resistance of anode-electrolyte contact, in Ω.

4.9.12 The final resistance value of anode-electrolyte contact (R_f) for anodes of aluminum alloy or zinc alloy with square cross section is calculated from the following formula:

$$R_f = \frac{\rho}{2\pi.L_f}\left[\ln\left(\frac{4L_f}{r_f}\right) - 1\right]$$

Where:

R_f - final resistance of anode-electrolyte contact, in Ω;
ρ - electrical resistivity of electrolyte, in Ω .m;
L_f - final length of anode, in m;
r_f - final equivalent radius of anode, in m.

NOTE: The value of R_f is calculated with the reduced dimensions of the anodes at the end of the system's life cycle, considering a utilization factor of 90% and yet the reduction of length by 1% for each 10% of reduction in anode's volume. The reduced dimensions are obtained as follows:

Final length (L_f): $L_f = 0{,}910 \times L_i$

Final equivalent radius (r_f): $r_f = \dfrac{c_f}{2\pi}$

Where:

c_f - perimeter of the cross section at the end of the anode's life cycle, considering the final circular section, obtained through the sum of the volume of anode core and 10% of the initial volume of the anode alloy material, divided by the final length of the anode;
r_f - final equivalent radius.

4.9.13 The value of R_f for flat anodes of aluminum alloy or zinc alloy is calculated from the following formula:

$$R_f = \frac{\rho}{Le_f}$$

Where:

R_f - final resistance of anode-electrolyte contact, in Ω;
ρ - electrical resistivity of electrolyte, in Ω.m;
Le_f - average between the final length and width of the anode, in m.

NOTE: This formula is used when the length of the anode is, at least, twice its width.

4.9.14 The final current supplied by anode ($\bar{I}f$) calculated in 4.9.11 shall be compared to the total final current (If) calculated in 4.9.4, and shall match the following requirements:

$$n \cdot \bar{I}_f \geq I_f$$

4.10 SPECIFIC REQUIREMENTS FOR AUSTENITIC, DUPLEX AND SUPERDUPLEX STAINLESS STEEL EQUIPMENTS

4.10.1 Where specifically stated in the equipment materials specification I-ET-MATERIAL SPECFICATION (document provided by BUYER specifically for the project), a complementary anode protection shall be provided.

4.10.2 For this materials, the requirements stated at ISO 12473 are mandatory.

4.10.3 As CPS for austenitic stainless steel can result in extremely high anode consumption rates, Resistor Controlled Cathodic (RCP) protection systems may be applied to achieve the required design life.

4.10.4 Where RCPS is selected, the system design shall be performed by a company with proven expertise. BUYER approval is required on the company and on the system design.

4.10.5 SELLER shall provide a descriptive report detailing the analyses performed and obtained results which ensure adequate cathodic protection of equipment.

5 ANODES

5.1 GENERAL REQUIREMENTS

5.1.1 Galvanic anodes of aluminum or zinc alloys shall be specified as per EN 12496. DNV-RP-B401 may also be used.

5.1.2 Anodes made from different materials or alloys shall not be used in the CPS design for protection of the same area (mixing is prohibited).

5.1.3 Flush mounted anodes may be used in places subject to hydrodynamic efforts. In this case, previous BUYER approval is necessary.

5.1.4 Equipment with cathodic protection shall be protected only by galvanic anodes made with aluminum or zinc alloy. Magnesium alloy anode is forbidden.

5.1.5 Zinc alloy anodes shall not be used in equipment with operation temperature above 50ºC, except for anodes type Alloy Z 4, in accordance with EN 12496.

5.1.6 Aluminum alloy anodes shall not be used in equipment with explosive atmosphere if the result from multiplication of the anode installation height (m) by its gross weight (kgf) is higher than 28 kgf.m. The height must be measured from the bottom of the equipment to the anode center.

5.1.7 Cathodic protection is not applicable to drinking water vessels.

5.2 CURRENT CAPACITIES

5.2.1 The cathodic protection system shall be sized based on the following current capacities:

Table 5 - Design project for galvanic anodes

Type of anode	*Anode[1] surface temperature (ºC)*	*Submerged in sea water*	
		Ag/AgCl Potential mV	*Current capacity: A.h/Kg*
Aluminum	≤ 30	- 1050	2000
	60	- 1050	1500
High Temp Alloy	80	- 970	690
Zinc[2]	50[2]	- 1030	780

Note:
1- For temperatures between the established limits, current capacity can be interpolated;
2- Zinc anodes temperature shall not exceed 50 ºC.

5.2.2 Possible correction to anode current capacity and protection current density, due to operation temperature shall be according DNVGL-RP-B401 and DNVGL-RP-B101.Other parameter may be proposed by the contractor for BUYER approval.

5.3 ANODE MANUFACTURE, RECEIPT AND STORAGE

5.3.1 The short-term test described in Appendix B of DNVGL-RP-B401 shall always be used for quality control of galvanic anodes.

5.3.2 As an acceptance criteria for the current capacity of galvanic anode, using short-term test, the following table shall be assumed.

Table 6 - Current Capacity for Short-Term Test

Anode type	*Minimum current capacity (A.h/Kg)*	*Potential to open circuit (mV vs Ag/AgCl)*
Aluminum	2600[1]	1050
Zinc	780	1030
Note: Any value less than 2500 Ah/Kg obtained from the objects that underwent testing is unacceptable		

5.3.3 The receipt inspection shall inspect the anode in accordance with Annex A of EN 12496.

5.3.4 The anodes shall be stored in a clean place, away from the soil, and laid over wood, and to be carefully handled, preventing them from crashes, brakes, or general mechanical damages.

5.4 ANODES DISTRIBUTION

5.4.1 SELLER is responsible for the distribution of anodes in a manner that allows correct operation of equipment. In case of non-sufficient space for anode allocation as CPS design foresees, BUYER shall be consulted to in other to reevaluate design life of CPS.

5.4.2 Distribution of anodes shall be as established in design drawings.

5.4.3 A higher mass of anodes shall be installed near stainless steel components, noble alloy and noble metallic coatings, since these components are not generally coated, needing a higher initial current density in order to be polarized.

5.5 ANODE INSTALLATION

5.5.1 The connection of anodes to the equipment shall be fixed by bolts, in this case all nuts, washers and bolts shall be made of SS 316 or same material as equipment internals.

5.5.2 Anodes supports shall be welded, according to I-ET-3010.00-1200-955-P4X-001-WELDING. Anodes core and the burned areas shall be treated and painted similarly to the rest of the vessel.

5.5.3 In regions for welding the anode supports to the component, the anti-corrosive coating must be removed, if any, and the surface must be grinded and/or brushed until reaching an equivalent cleaning pattern at least in accordance to ISO 8501-1. Anode attachment shall be performed through continuous weld bead, with no intermittent welding allowed.

5.5.4 Welding must be performed in accordance to qualified procedure and personnel.

5.5.5 Visual inspection of the welds shall be performed on 100% of the weld lengths. Acceptance criteria shall be as stablished on the component design code.

5.5.6 The coating scheme, where applicable, must be removed only in welding places and after welding, it must be repaired as per the original.

5.5.7 Coating cut-back (removal) for anode support welding shall be at least 100 mm measured from the edge of the supports.

5.5.8 Measure the anode angular position in relation to the position provided in project designs, assuming a tolerance of ± 5° after attached.

5.5.9 Upon completion of the anode installation services, a general inspection shall be carried out at welds and ensuring electrical continuity between anodes and the structure to be protected.

5.5.10 Paint system shall be according to I-ET-3010.00-1200-956-P4X-002 – GENERAL PAINTING.

5.6 ELECTRICAL CONTINUITY TEST

5.6.1 Each and every item of the equipment must be necessarily electrically connected to the CPS system, except in special cases, where BUYER must previously approve.

5.6.2 In cases where the electrical continuity is ensured by fasteners, serrated washers must be used while assembling.

5.6.3 For moving components (stems, etc.), where there may be difficulties to maintain the electrical continuity, there must be provided the installation of stainless steel or copper span-wires connecting these components.

NOTE: An alternative to replace the span-wires is installing individual anodes in each moving component. [Recommended Practice]

5.6.4 Electrical continuity between anodes and the assembly must be tested and the resistance between each component and the nearest assembly or anode must not be higher than 1 ohm (resistance of multimeter cable is not included in this value).