NORSOK STANDARD

COMMON REQUIREMENTS

CATHODIC PROTECTION

M-503

Rev. 2, September 1997

FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and remove unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and are jointly issued by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered by NTS (Norwegian Technology Standards Institution).

The purpose of this industry standard is to replace the individual oil company specifications for use in existing and future petroleum industry developments, subject to the individual company's review and application.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of this standard will be used to provide input to the international standardisation process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

INTRODUCTION

Revision 2 of this standard is made to reflect an agreement with the authorities regarding cathodic protection for large subsea pipeline systems.

1 SCOPE

This Standard gives requirements for cathodic protection design of submerged installations and seawater containing compartments, and manufacturing of sacrificial anodes.

2 NORMATIVE REFERENCES

The following standards include provisions which, through reference in this text, constitute provisions of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements of the standards referenced below.

ASTM D 1141	Specification for Substitute Ocean Water.
AWS D1.1	Structural Welding Code - Steel.
DNV RP B401	Cathodic Protection Design.
EN 287	Approval testing of welders - Fusion welding - Part 1.
EN 288	Specification and approval of welding procedures for metallic materials - Part 1, 2, 3.
EN 10002	Metallic materials. Tensile testing. Part 1: Method of test (at ambient temperature).
EN 10204	Metallic products - Types of inspection documents.
ISO 1461	Metallic coatings - Hot-dip galvanized coating on fabricated ferrous products - Requirements.
ISO 8501	Preparations of steel substrates before application of paints and related products - Visual assessment of surface cleanliness.
NORSOK M-501	Standard for Surface Preparation and Protective Coating.
NORSOK M-505	Standard for Corrosion Monitoring Design (presently M-CR-505).
NACE RP0387	Metallurgical and Inspection Requirements for Cast Sacrificial Anodes for Offshore Applications.
NACE RP0492	Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes.
U.S. Mil. Spec. MIL-A-18001	Military Specification for Anodes, Corrosion preventive, Zinc; slab disc and rod shaped.

3 DEFINITIONS

Can	Can requirements are conditional and indicates a possiblilty open to the user of the standard.
May	May indicates a course of action that is permissible within the limits of the standard (a permission).
Normative references	Shall mean normative in the application of NORSOK standards.
Shall	Shall is an absolute requirement which shall be followed strictly in order to conform with the standard.
Should	Should is a recommendation. Alternative solutions having the same functionality and quality are acceptable.

4 CATHODIC PROTECTION DESIGN

4.1 General

The cathodic protection system shall be designed with due regard to environmental conditions, neighbouring structures and other activities. The cathodic protection system design should be based on sacrificial anodes. Both stand-off, flush-mounted and bracelet anodes may be used. The exact location and distribution of the different types of anodes shall be part of the detailed corrosion protection design. The design shall be subject to verification at the end of the fabrication phase. When stand-off anodes are used precautions shall be taken in the installation and distribution of these anodes so they do not impede subsea intervention operations.

The cathodic protection system shall be capable of polarizing all submerged steel of the installations to a potential between -800 mV and -1050 mV vs the Ag/AgCl/seawater reference electrode, and to maintain the potential in this interval throughout the design life of the installations.

Recommendation:
The use of impressed current cathodic protection systems can be considered for floating production units.

The CP system shall be designed for the lifetime of the installation using the calculation procedure described in DNV RP B401. Retrofitting can be planned for if this is documented to be cost effective. Computer models can be used in the detailed design to verify the protection of parts with complicated geometry e.g. in the pile area for jackets, conductor guide frames and J-tube bellmouths and to evaluate any interference effects between anodes and/or between structures.

In the design calculation, data given in clause 6 of this document shall be used. For calculation of surface areas, the latest revisions of drawings shall be used, and all areas below the mean water level shall be included. Reference to drawings and revision numbers shall be given.

Items covered in the design shall be listed, with description of surface treatment (bare, painted, rubber coated etc.). Items not covered in the design shall also be listed, i.e. temporary items to be removed. Items to which current drain is allowed shall be listed.

For high strength steel materials (minimum specified yield strength >700 MPa, maximum actual yield strength 950 Mpa) a special evaluation is required, with respect to hydrogen impact. The impact can be documented according to EN 10002.

Monitoring of cathodically protected structures shall be according to NORSOK Standard M-505, if used.

4.2 Electrical continuity requirements

All items to be protected shall be electrically connected and should have a welded or brazed connection to an anode. All bolted/clamped components with surface area exceeding 1 m^2 shall have an all welded/brazed connection to an anode. For all bolted/clamped assemblies without an all welded/brazed electrical grounding, it shall be verified that the electric resistance is less than 0.10 ohm. Coating on contact surfaces shall be removed prior to assembly.

If the contact is made by using the copper cables welded/brazed at each end, these shall be stranded and have a minimum cross section of 16 mm^2. The copper cable shall be brazed to the cable shoe.

4.3 Mud zone

Steel parts exposed to seabed mud shall be cathodically protected by sacrificial anodes, if possible installed in the submerged zone. Rock-dumping of pipelines shall be considered equivalent with mud zone exposure.

4.4 Protection of concrete structures

In order to obtain cathodic protection of embedded steel in contact with exposed items, all steel (embedded steel and exposed steel) shall be polarized. This polarization shall be achieved by sacrificial anodes.

The sacrificial anodes supplying current to the rebar system shall be mounted on permanent steel items or special embedment plates exposed to sea water and which are in electrical contact with the rebar system through a welded connection. It shall be verified by measurements that electrical continuity is achieved throughout the rebar system.

5 DESIGN PARAMETERS

5.1 Design life

The design life shall be as specified in the contract documents. Due regard shall be taken to the fabrication, outfitting and installation phase before normal production starts.

5.2 Current density requirements

The current densities to be used in the design are given in table 5.1. The current densities shall be used for steel, stainless steel, aluminium and other metallic materials.

Table 5.1 - Current densities in mA/m^2 for cathodic protection design, valid for bare steel surface temperatures up to 25 °C.

	Current Densities, mA/m^2		
	Initial	Mean	Final
Southern North Sea (Up to 57 °N)	160	80	105
Northern North Sea (57 - 62 °N)	180	90	120
Norwegian Sea (62 °N - 68 °N)	200	100	130
Internally in flooded compartments	160	80	95
Pipelines if burial is specified	50	40	40
Sediments (mud)	25	20	20

For the first 20 meters below mean water level, the values in table 5.1 shall be increased by 10%.

On surfaces with operating temperatures exceeding 25°C, the current density shall be increased with 1 mA/m^2 per °C difference between operating temperature and 25°C. This addition shall be made before any effect of coating is included.

For embedded steel in concrete structures the following current densities shall be used for the surface area of embedded steel. The values are applicable for initial, final and mean current densities.

Concrete seawater exposed on one side below -10 m: 2 mA/m^2 embedded steel
Concrete seawater exposed on both sides below -10 m: 1 mA/m^2 embedded steel

For surfaces at elevation -10m to +5 m these values shall be increased by 50%.

For light weight aggregate concrete or other concrete grades with equivalent pore structure, the design current densities can be reduced by 30%.

When the actual embedded steel surface area (m^2) to reinforced concrete volume (m^3) ratio, B, exceeds 6, an adjustment factor 6/B may be applied to the design current densities.

5.3 Coated surfaces

For coated structures where the coatings are selected and applied according to NORSOK Standard M-501 Surface Preparation and Protective Coating, the current densities given in clause 5.1 may be multiplied by a factor given in table 5.2.

For design according to table 5.2 the initial current density ratio shall be assumed equal to 0.02.

Table 5.2 - Current density ratio for thin-film coated structures.

Design life, years	Mean	Final
10	0.05	0.10
20	0.10	0.20
30	0.18	0.40
40	0.28	0.65
50	0.40	1.00

For conductors and other components subjected to wear, the initial current density ratio should be given special consideration.

Table 5.3 - Current density ratio for pipeline coatings and pipeline heat insulation coatings.

Design life, years	Asphalt + concrete		Rubber		Polypropylene	
	Mean	Final	Mean	Final	Mean	Final
10	0.023	0.026	0.012	0.014	0.018	0.021
20	0.033	0.052	0.017	0.029	0.030	0.048
30	0.052	0.095	0.026	0.060	0.048	0.088
40	0.070	0.140	0.039	0.099	0.067	0.132
50	0.090	0.170	0.056	0.150	0.085	0.160

The values in table 5.3 shall be used for pipelines and when these coatings are used on items other than pipelines. The coating quality should be according to commonly applied industry standards.

5.4 Mudmats, skirts and piles

In addition to current supply to the sea water exposed surfaces, extra anode capacity shall be included to supply current drain as follows:

- Surfaces of mudmats, skirts and piles exposed to sediments: 20 mA/m^2 based on outer surface area.
- If the top end of the piles cannot be closed, the internal surface to be included in the design shall be calculated for the top 5 times the internal diameter. The current drain shall be based on sea water current density criteria.

5.5 Current drain to wells

In the design of the cathodic protection system 5 Amps per well shall be included for platform wells. For subsea wells the current addition shall be 8 Amps per well. The anodes for this current drain shall be installed on the structure (for platform completed wells) or the subsea equipment for subsea wells. Permanent electrical contact from the anodes to the wells must be secured.

5.6 Current drain to anchor chains

For anchor systems with mooring topside only, 30 m of each chain shall be accounted for in the cathodic protection design. For anchor system with mooring point below sea level, the seawater exposed chain section from sea level to mooring point and 30 m from mooring point shall be accounted for in the cathodic protection design for each chain.

5.7 Pipelines

Anode spacing should not exceed 200 m. Amount of anodes shall be increased by a factor of 2 for the first 500 m from platforms and subsea installations.

The current drain to the armour steel of flexible pipelines shall be included by 0.5 mA/m^2, related to outer surface area.

5.8 Electrolyte resistivities

Actually measured resistivities for seawater and bottom sediments/mud shall be used as far as possible. If such measured values are not available for the installation site, the seawater resistivity shall be set to 0.30 ohm m at all depths, and the seabed mud resistivity shall be taken as 1.30 ohm m.

5.9 Sacrificial anodes

5.9.1 Electrochemical properties

The sacrificial anodes shall comply with the requirements given in clause 6 and 7. For design purposes the data given in table 5.4 shall be used unless otherwise documented. If higher values for current capacity of aluminium anodes are documented, a lower amount of anode material can be used.

Table 5.4 - Design values for sacrificial anodes.

Anode type	Seawater		Sediments		Temperature limits °C
	Potential/mV Ag/AgCl/ Seawater	Current Capacity Ah/kg	Potential/ mV Ag/AgCl/ Seawater	Current Capacity Ah/kg	
Aluminium	-1050	2000	-1000	1730 1)	Max. 30
Zinc, U.S. Mil Spec 18001	-1030	780	- 980	750 580	Max. 30 30-50
NOTE 1) At temperatures above 30°C, the design values given in DNV RP B401, shall be used.					

5.9.2 Anode Shape and Utilization Factor

Stand-off anodes shall be used as far as possible with a minimum distance to the steel surface of 300 mm. The insert steel should protrude through the end faces. The utilization factor shall be 0.90.

Flush-mounted anodes except bracelets shall have a utilization factor of 0.90.

Bracelet anodes shall be designed in such a way that a utilization factor of minimum 0.80 can be achieved.

Bracelet anodes used on steel jackets to reduce wave loads shall be designed in such a way that the same utilization factor as for stand-off anodes (i.e. 0.90) can be achieved.

The dimensions and shape of insert steel and attachments shall be designed to withstand mechanical loads that may act on the anodes, for instance wave loads, loads by water currents or vibration caused by piling operations, or loads that will act on the anodes when penetrating into the sea bottom sediments.

When protecting a coated structure, the anode legs shall also be coated.

6 ANODE MANUFACTURING

6.1 Pre-production test

Prior to the commencement of the works, a preproduction test shall be carried out to ascertain that all moulds inserts, casting equipment and other components are in accordance with applicable codes of practice, governing drawings and data sheets. Test casting shall be carried out to demonstrate that all the specified requirements can be met. At least one test anode shall be inspected destructively as described in 7.8. For deliveries below 15 ton net alloy and/or a limited number of anodes, the extent of testing is subject to special agreement.

6.2 Coating

The exposed (external) surface of the anode shall be free from coating.

Flush mounted anodes shall be coated on the side facing the mounting surface. Bracelet anodes shall also be coated on the sides facing cement or lining. The coating shall be minimum 100 microns epoxy mastic.

6.3 Insert-steel materials

Inserts shall be fabricated from weldable structural steel plate/sections according to a recognized standard. Rimming steels shall not be used.

The carbon equivalent of insert materials shall be compatible with the structural elements to which it is attached, and not exceed a value of 0.41. The carbon equivalent value shall be calculated using the formula:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

The following carbon equivalent formula may be used as an alternative if all elements are not known.

$$CE = C + \frac{Mn}{6} + 0.04$$

Certificate shall be according to EN 10204, 3.1B.

All fabrication welding of steel inserts shall be in accordance with relevant requirements of AWS D1.1 or an equivalent standard, and performed by welders qualified according to EN 287/AWS D1.1. Qualification of welding procedures shall be in accordance with the requirements of EN 288/AWS D1.1, or equivalent.

Insert steel for aluminium sacrificial anodes shall be blast cleaned to Sa 2½ ISO 8501-1 prior to casting. The cleanliness of the surface shall be maintained to casting commences.

Insert steel for zinc anodes shall be blast cleaned to minimum standard Sa 2 ½ ISO 8501-1 or galvanized according to ISO 1461 or equivalent. Rust discolouration and/or visual surface contamination of zinc coated surface shall not be permitted. The finish shall be maintained until casting.

6.4 Aluminium anode/materials

6.4.1 Chemical composition

The aluminium anode material shall be of the AlZnIn type conforming to table 6.1.

Table 6.1 - Chemical composition of aluminium anode materials.

ELEMENT		MAX %	MIN %
Zinc	(Zn)	5.5	2.5
Indium	(In)	0.040	0.015
Iron	(Fe)	0.09	-
Silicon	(Si)	0.10	-
Copper	(Cu)	0.005	-
Others	(Each)	0.02	
Aluminium	(Al)	Remainder	

6.4.2 Electrochemical characteristics

The electrochemical properties shall be qualified according to DNV RP B401, Appendix B, Free running test. Closed circuit resistance shall be adjusted to give a nominal anodic current density of 1.0 ± 0.1 A/m^2. Minimum 16 samples from full scale anodes shall be used.

The electrochemical characteristics shall be documented for seawater at 5 - 12°C. For the alloy specified in 6.4.1 the requirements in table 5.4 shall apply.

6.5 Zinc anode/materials

6.5.1 Chemical composition

The chemical composition of the material shall be in accordance with US Military Specification Mil - 18001. Other alloys can be used if properly documented.

6.5.2 Electrochemical characteristics

The electrochemical characteristics shall be documented for seawater and conform with the requirements in table 5.4.

7 ANODE INSPECTION, TESTING AND TOLERANCES

7.1 Steel inserts

All welds shall be visually inspected.

Required surface finish shall be verified by visual inspection immediately prior to casting.

7.2 Chemical analysis

Two samples from each batch shall be taken for chemical analysis.

The samples shall be taken in the beginning and at the end of casting from the pouring stream.

For smaller alloying furnaces (max 500 kg) it is acceptable to take one sample per batch. The sample shall be taken in the beginning of the first batch and at the end of the second batch, then in the beginning of the third batch and so on.

The samples shall be analyzed to verify required chemical composition.

All anodes from batches whose chemical composition do not meet the requirements stated in 6.4.1 and 6.5.1, respectively, shall be rejected.

7.3 Anode weight

Individual anodes of each type shall have a weight within +/- 3% of the nominal weight for anodes with total weight above 50 kg. Minimum 10% of the number of anodes shall be weighed, either individually or in small batches, to confirm general compliance with this requirement.

The total contract weight shall be no more than 2% above and not below the nominal contract weight.

7.4 Anode dimensions and straightness

7.4.1 Stand-off and flush

Dimensional tolerances shall conform to NACE RP0387.

7.4.2 Bracelet

Dimensional tolerances shall conform to NACE RP0492.

7.5 Insert dimensions and position

Tolerances on insert position within the anode shall be prepared by the anode manufacturer and comply with utilization factor requirements. Anode insert protrusions, fixing centers, and any other critical dimensions shall be measured.

7.6 Anode surface irregularities

Anode surface irregularities shall be according to NACE RP0387 and RP0492 with the following additional requirements.

- Shrinkage depressions which exposes the insert are not acceptable.
- Cold shuts or surface laps shall not extend over a total length of more than 150 mm.

All anodes shall be inspected visually to confirm compliance with the above requirements.

7.7 Cracks

Zinc anodes shall be free from cracking.

Cracks can be accepted in aluminium anodes provided the cracks will not cause any mechanical failure during installation, transportation or service of the anode. The combination of cracks and lack of bond to the anode core is not accepted.

Cracks in the area where the anodes are not fully supported by the anode core are not acceptable.

1. Stand-off and flush anodes

- Cracks within the section of an anode supported by the insert are not acceptable if the length is more than 100 mm and/or the width more than 2 mm.
- Cracks penetrating to the steel inserts or through the anode are not permitted.
- Maximum 10 cracks pr. anode.

2. Bracelet anodes

- For sections of anodic material not wholly supported by the anode insert, no visible cracks shall be permitted.
- Cracks penetrating to the steel inserts or through the anode are not permitted
- Cracks with a length of more than 200 mm and/or width greater than 5 mm are not acceptable

Provided the above is satisfied, the following cracks are acceptable in transverse direction:

- Cracks with a length of less than 50 mm and width less than 5 mm.
- Cracks with a length between 50 mm and 200 mm and width less than 1 mm.
- Cracks with a length of 50-200 mm shall be limited to 2 per half bracelet or 4 per anode.
- Cracks which follow the longitudinal direction of the anodes shall not exceed 100 mm in length or/and 1 mm in width.

3. Others

- Acceptance criteria for other anodes not defined above shall be established by the anode manufacturer.

7.8 Internal defects, destructive testing

At least two anodes of each size shall be subject to close inspection by destructive testing (sectioning) for lack of bond between the steel inserts and the anode material and to verify that the requirements of NACE RP0387 and RP0492 to internal defects are met. For smaller anode deliveries the extent of testing within each anode type/size shall take account of anode design and number of anodes. If one or both anodes fails, two additional anodes shall be subject to destructive testing. If these do not satisfy specified requirements, the whole anode lot shall be rejected.

For non-tubular cores (e.g. bracelet anodes) where prevention of voids may be particularly difficult, the limits shall be prepared by anode manufacturer and agreed with Purchaser prior to manufacture.

The insert position within the anode shall be confirmed by measurement on the cut faces.

7.9 Electrochemical quality control testing

The following shall be tested:

- Closed circuit potential.
- Consumption rate.
- Visual examination of corrosion pattern (uneven consumption, intergranular attack, etc.)

The tests are to be carried out for each 15 tonnes of anodes produced. The electrochemical test data shall be included in the material certificate.

The closed circuit potentials and the capacity shall comply with the criteria stated in table 7.1. or an agreed deviation based on the test method. For capacity of aluminium anodes single values down to 2500 Ah/Kg are acceptable, while average for each batch shall be minimum 2600 Ah/Kg.

The test procedure shall be according to DNV RP B 401, Appendix A. The test shall be carried out in natural seawater or artificial seawater according to ASTM D1141.

Table 7.1 - Requirements to electrochemical performance (production testing) at all current densities

	Electrochemical Capacity Average (Ah/kg)	**Closed circuit potential, mV (Ag/AgCl Seawater)**
AlZnIn	2600*	-1070
Zn	780	-1030
NOTE - * Single values of min. 2500 Ah/kg are acceptable.		