

Cathodic protection

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Foreword	2
Introduction	2
1 Scope	3
2 Normative and informative references	3
2.1 Normative references	3
2.2 Informative references	3
3 Terms, definitions, abbreviations and symbols	3
3.1 Terms and definitions	3
3.2 Abbreviations and symbols	4
4 Cathodic protection design	4
4.1 General	4
4.2 Electrical continuity requirements	5
4.3 Mud zone	5
4.4 Protection of concrete structures	5
5 Design parameters	5
5.1 Design life	5
5.2 Current density requirements	5
5.3 Coated surfaces	6
5.4 Mud mats, skirts and piles	7
5.5 Current drain to wells	7
5.6 Current drain to anchor chains	7
5.7 Electrolyte resistivities	7
5.8 Sacrificial anodes	8
6 Anode manufacturing	8
6.1 Pre-production test	8
6.2 Coating	8
6.3 Inert-steel materials	9
6.4 Aluminium anode/materials	9
6.5 Zinc anode/materials	10
7 Anode inspection, testing and tolerances	10
8 Cathodic protection of submarine pipelines	10
8.1 General	10
8.2 Pipeline design requirements	11
9 Inspection of anode installation	12

Foreword

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK standards are normally based on recognised international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, NORSOK standards will be used to provide the Norwegian industry input to the international standardisation process. Subject to development and publication of international standards, the relevant NORSOK standard will be withdrawn.

The NORSOK standards are developed according to the consensus principle generally applicable for most standards work and according to established procedures defined in NORSOK A-001.

The NORSOK standards are prepared and published with support by The Norwegian Oil Industry Association (OLF), The Federation of Norwegian Industry, Norwegian Shipowners' Association and The Petroleum Safety Authority Norway.

NORSOK standards are administered and published by Standards Norway.

Introduction

Edition 3 of this NORSOK standard is made to reflect the introduction of the International Standard ISO 15589-2, *Petroleum and Natural Gas Industries – Cathodic Protection of Pipeline – Offshore Pipelines*, for CP of submarine pipelines, the update of DNV RP B401 and recent experiences with hydrogen induced cracking for high strength high alloyed pipeline materials.

Specific requirements to submarine pipeline systems are given in clause 8.

1 Scope

This NORSOK standard gives requirements for CP design of submerged installations and seawater containing compartments, and manufacturing and installation of sacrificial anodes.

Specific requirements to submarine pipeline systems are given in clause 8.

2 Normative and informative references

The following standards include provisions and guidelines which, through reference in this text, constitute provisions and guidelines 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 the requirements of the referenced standards.

2.1 Normative references

ASTM D1141,	Specification for Substitute Ocean Water
AWS D1.1,	Structural Welding Code - Steel
DNV-RP-B401,	Cathodic Protection Design
EN 287-1,	Qualification test of welders - Fusion welding - Part 1: Steels
EN ISO 15607,	Specification and qualification of welding procedures for metallic materials – General rules (ISO 15607:2003)
EN ISO 15609-1,	Specification and qualification of welding procedures for metallic materials – Welding procedure specification – Part 1: Arc welding (ISO 15609-1:2004)
EN ISO 15614-1,	Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2004)
EN 10204,	Metallic products - Types of inspection documents
ISO 1461,	Metallic coatings - Hot-dip galvanized coating on fabricated ferrous products - Requirements
ISO 8501-1,	Preparations 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
ISO 15589-1,	Petroleum and natural gas industries – Cathodic protection of pipeline transportation systems – Part 1: On-land pipelines
ISO 15589-2,	Petroleum and natural gas industries – Cathodic protection of pipeline – Part 2: Offshore pipelines
NORSOK M-001,	Materials selection
NORSOK M-501,	Surface Preparation and Protective Coating

2.2 Informative references

DNV-RP-F112,	Design of duplex stainless steel subsea equipment exposed to cathodic protection
EN 10002-1,	Metallic materials – Tensile testing – Part 1: Method of test at ambient temperature
NORSOK M-WA-01,	Design guideline to avoid hydrogen induced stress cracking in subsea duplex stainless steels

3 Terms, definitions, abbreviations and symbols

For the purposes of this NORSOK standard, the following terms, definitions, abbreviations and symbols apply.

3.1 Terms and definitions

3.1.1

shall

verbal form used to indicate requirements strictly to be followed in order to conform to this NORSOK standard and from which no deviation is permitted, unless accepted by all involved parties

3.1.2**should**

verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required

3.1.3**may**

verbal form used to indicate a course of action permissible within the limits of this NORSOK standard

3.1.4**can**

verbal form used for statements of possibility and capability, whether material, physical or casual

3.1.5**galvanic anode**

electrode that provides current for cathodic protection by means of galvanic action.

NOTE The anode, which is the current source for the CP system, will be consumed and is therefore often referred to as sacrificial anode.

3.2 Abbreviations and symbols

Ag/AgCl	silver/silver chloride
CP	cathodic protection
HISC	hydrogen induced stress cracking
ΔE_A	electrolytic voltage drop [mV]
ΔE_{Me}	metallic voltage drop [mV]
R_{Anode}	anode resistance [ohm]
i	current density [mA/m ²]
f_c	coating breakdown factor
f_{cm}	mean coating breakdown factor
f_{cf}	final coating breakdown factor
D	linepipe outer diameter [m]
ρ_{Me}	specific resistivity of linepipe material [ohm m]
L	anode spacing [m]
d	linepipe wall thickness [m]

4 Cathodic protection design**4.1 General**

The CP system shall be designed with due regard to environmental conditions, neighbouring structures and other activities. The CP 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 after detailed design prior to 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 CP system shall be capable of polarizing all submerged steel of the installations to a potential between -800 mV and -1100 mV vs. the Ag/AgCl/seawater reference electrode, and to maintain the potential in this interval throughout the design life of the installations.

The use of impressed current CP systems may be considered. Requirements to impressed current systems are not covered by this NORSOK standard, but ISO 15589-2 provides requirements relevant for pipelines.

The CP system shall be designed for the lifetime of the installation. Retrofitting may be planned for if this is documented to be practical. The calculation procedure described in DNV-RP-B401 shall be used for all CP systems, except for pipelines, where the requirements in clause 8 shall apply. Computer models can be used in the detailed design to determine distribution of anodes and to verify the protection of parts with complicated

geometry. Examples, where computer models are useful, are in the pile area for jackets, conductor guide frames and J-tube bell-mouths, skirts and other parts exposed to sediments where the anodes are seawater exposed. Computer models can also be used to evaluate any interference effects between anodes and/or between structures.

In the design calculation data given in clause 5 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, e.g. 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 carbon steel materials (specified minimum yield strength > 550 MPa and maximum actual yield strength 750 MPa) a special evaluation is required with respect to HISC. The impact can be documented according to EN 10002-1. For alloyed materials the recommendations in DNV-RP-B401 regarding HISC shall apply. Relevant guidelines regarding HISC and material utilization are given in NORSOK M-WA-01 and DNV-RP-F112. See also clause 8 for submarine pipelines.

Permanent monitoring systems of cathodically protected structures shall be according to NORSOK M-001, if used.

4.2 Electrical continuity requirements

All items to be protected shall have a welded or brazed connection to an anode. Bolted or clamped assemblies with surface area below 1 m² may be protected by neighbouring anodes, provided that an electric resistance of less than 0,10 ohm to the anode is verified by actual measurements. Coating on contact surfaces shall be removed prior to assembly.

If the contact is made by using copper cables welded/brazed at each end, these shall be stranded and have a minimum cross section of 16 mm². If cable shoes are used, the copper cable shall be brazed to the cable shoe.

4.3 Mud zone

Steel parts buried in the seabed mud shall be cathodically protected by sacrificial anodes. The anodes should be freely exposed to seawater.

4.4 Protection of concrete structures

In order to achieve CP of embedded steel in metallic 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 seawater and which are in electrical contact with the rebar system. Mechanical connections may be considered adequate in order to obtain electrical continuity in 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 given 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 1. The current densities shall be used for steel, stainless steel, aluminium and other metallic materials.

Measurements at the actual location should be governing if these indicate higher current density needs than indicated in Table 1.

Table 1 - Design current densities valid for seawater exposed bare metal surfaces with temperatures up to 25 °C

Depth m	North Sea (up to 62 °N)			Norwegian waters (north of 62 °N)		
	Initial mA/m ²	Mean mA/m ²	Final mA/m ²	Initial mA/m ²	Mean mA/m ²	Final mA/m ²
0 to 30	200	100	130	250	120	170
>30 to 100	170	80	110	200	100	130
>100 to 300	190	90	140	220	110	170
>300	220	110	170	220	110	170

These design current densities account for harsh weather conditions, including waves and sea currents, but not for erosive effects on calcareous layers by silt or ice.

On surfaces with operating temperatures exceeding 25 °C, the current density shall be increased with 1 mA/m² for each °C difference between operating temperature and 25 °C. This addition shall be made before any effect of coating is included.

For freely flooded compartments and for closed compartments with free access to air, design current densities for 30 m to 100 m, given in Table 1, are recommended. Closed and sealed flooded compartments do not normally need CP. Reference is also made to NORSOK M-001.

For bare steel surfaces buried in sediments, a design current density (initial/final and average) of 20 mA/m² is recommended irrespective of geographical location and depth.

For components coated with either aluminium or zinc, a design current density of 10 mA/m² is recommended for initial/final as well as average values. The design current density shall be increased by 0,2 mA/m² for each °C that the surface temperature is assumed to exceed 25 °C.

For embedded steel in concrete structures the design current densities given in Table 2 shall be used. The numbers refer to the steel reinforcement surface area and not to the surface area of concrete.

Table 2 - Initial/final and average current densities for protection of embedded steel in concrete structures

Depth m	North Sea (up to 62 °N)	Norwegian waters (north of 62 °N)
	mA/m ²	mA/m ²
0 to 30	1,0	0,8
>30 to 100	0,8	0,6
>100	0,6	0,6

For seawater filled concrete shafts, CP shall be provided from both sides. For external protection of shafts that are normally empty, the design current densities in Table 2 shall be multiplied with a factor of 1,5.

When the actual embedded steel surface area (m²) to reinforced concrete volume (m³) ratio, B, exceeds 5, an adjustment factor 5/B may be applied to the design current densities in Table 2.

5.3 Coated surfaces

For coated structures where the coatings are selected and applied according to NORSOK M-501, system no. 7, the current densities given in 5.2 shall be multiplied by a coating breakdown factor.

The coating breakdown factor, f_c , describes the anticipated reduction in cathodic current density due to the application of a coating. The coating breakdown factor is a function of coating properties, environment and time.

f_c can be expressed as:

$$f_c = a + b \times t \quad (1)$$

where t (years) is the design lifetime and a and b are constants that are dependent on coating properties and the environment. For NORSOK M-501 coating systems no. 3B and no. 7, the values given in Table 3 shall be used. The constants in Table 3 do not account for significant damage to paint coatings during fabrication and installation. If such damage is anticipated, the affected surface area is to be estimated and included in the design calculations as bare metal surface.

Table 3 - Recommended constants a and b for calculation of paint coating breakdown factors

Depth m	a	b
0 to 30	0,02	0,012
> 30	0,02	0,008

Once a and b are defined, mean and final coating breakdown factors, f_{cm} and f_{cf} , respectively, to be used for CP design purposes are to be calculated by introducing the CP design life, t_f (years). The following equations apply:

$$f_{cm} = a + b \times \frac{t_f}{2} \quad (2)$$

$$f_{cf} = a + b \times t_f \quad (3)$$

For submerged components with high quality coatings similar to those used on pipelines, coating breakdown factors specified in clause 8 shall apply.

For conductors and other components subjected to wear, the initial coating breakdown factor should be given special consideration.

5.4 Mud mats, skirts and piles

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

- surfaces of mud mats, skirts and piles exposed to sediments: 20 mA/m² based on outer surface area (both sides);
- 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 five times the internal diameter. The current drain shall be based on seawater current density criteria.

5.5 Current drain to wells

In the design of the CP system 5 A per well shall be included for platform wells. For subsea wells the current addition shall be 8 A 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 should 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 CP 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 the mooring point shall be accounted for in the CP design for each chain.

5.7 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 1,50 ohm m.

5.8 Sacrificial anodes

5.8.1 Electrochemical properties

The sacrificial anodes shall comply with the requirements given in clause 6 and clause 7. For design purposes, the data given in Table 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 4 - Design values for sacrificial anodes

Anode type	Seawater		Sediments		Temperature limits °C
	Potential/Ag/ AgCl/seawater mV	Current capacity Ah/kg	Potential Ag/AgCl/seawater mV	Current capacity Ah/kg	
Aluminium	-1050	2000	-1000	1500	Max. 30
Zinc	-1030	780	- 980	750 580	Max. 30 30 to 50

5.8.2 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 anodes shall be designed in such a way that a utilization factor of minimum 0,9 can be achieved.

Flush-mounted anodes and bracelets anodes shall be designed in such a way that a utilization factor of minimum 0,8 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. 0,9) 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 should 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 clause 7.

For deliveries below 15 tonnes 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.

Anode legs for stand off anodes shall be coated in compliance with NORSOK M-501, coating system no. 7, unless otherwise specified.

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:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (4)$$

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

$$CE = C + \frac{Mn}{6} + 0,04 \quad (5)$$

The insert steel shall be certified 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 287-1 or AWS D1.1. Qualification of welding procedures shall be in accordance with the requirements of EN ISO 15607, EN ISO 15609-1, EN ISO 15614-1 or 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 2½ 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 5.

Table 5 - Chemical composition of aluminium anode materials

ELEMENT		MAX %	MIN %
Zinc	(Zn)	5,75	2,5
Indium	(In)	0,040	0,015
Iron	(Fe)	0,09	-
Silicon	(Si)	0,10	-
Copper	(Cu)	0,003	-
Others	(Each)	0,02	
Aluminium	(Al)	Reminder	

6.4.2 Electrochemical characteristics

The electrochemical properties shall be qualified according to DNV-RP-B401, Annex C.

For the alloy specified in 6.4.1 the requirements in Table 4 shall apply.

6.5 Zinc anode/materials

6.5.1 Chemical composition

The chemical composition of the material shall be in accordance with ISO 15589-2. Other alloys can be used if properly documented.

6.5.2 Electrochemical characteristics

The electrochemical characteristics shall be documented for seawater and conform to the requirements in Table 4.

7 Anode inspection, testing and tolerances

For pipeline anodes, the requirements in ISO 15589-2 shall apply. The term “should” in ISO 15589-2, clause 9, shall be read as “shall”.

Anodes for other installations shall comply with the requirements in DNV-RP-B401 and the additional requirements given below.

Electrochemical quality control testing shall be in compliance with the requirements in DNV-RP-B401. The test procedure shall be according to DNV-RP-B401, Annex B, and the testing solution shall be synthetic seawater according to ASTM D1141.

The closed circuit potentials and the capacity shall comply with the criteria stated in Table 6 or an agreed deviation based on the test method.

Table 6 - Requirements to electrochemical performance (production testing) at all current densities

	Electrochemical capacity Average Ah/kg	Maximum closed circuit potential (Ag/AgCl seawater) mV
AlZnIn	2600 ^a	-1070
Zn	780	-1030
^a Single values of minimum 2 500 Ah/kg are acceptable.		

The electrochemical test data shall be included in the material certificate.

8 Cathodic protection of submarine pipelines

8.1 General

Unless otherwise stated in this NORSOK standard, the design criteria, design parameters, fabrication, and installation shall be in accordance with ISO 15589-2.

The reference numbers given in brackets in the headings and text below refer to the clause or subclause in ISO 15589-2 to which alternative or specific requirements shall apply.

Evaluation of hydrogen impacts for high strength steels shall be done for steels with specified minimum yield strength (SMYS) > 550 MPa.

8.2 Pipeline design requirements

8.2.1 General (see ISO 15589-2, 5.1)

Use of isolating joints shall be evaluated between

- offshore pipelines and land pipelines,
- offshore pipelines and gas/oil terminals,
- cathodically protected pipelines and non-protected facilities or equipment,
- CP systems with different design potentials.

If isolating joints are selected, the requirements for isolation joints given in ISO 15589-1 shall apply.

8.2.2 Selection of CP system (see ISO 15589-2, 5.2)

Cathodic protection shall be achieved using galvanic anodes.

8.2.3 Potential criteria (see ISO 15589-2, 6.2.2)

For martensitic 13Cr steels and 22Cr and 25Cr duplex stainless steels, the negative critical potential limit shall be -800 mV (Ag/AgCl) to minimize the risk for HISC.

When using martensitic 13Cr steels and duplex stainless steels at a CP potential down to a limit of -1100 mV (Ag/AgCl), a special assessment of risk for HISC shall be made. As a minimum, the requirements described below shall be fulfilled.

For pipes and components such as bends, T-connections, flanges and hubs with standard girth welds and no fillet welds, thermite welding or other methods shall not be used directly on to martensitic or duplex stainless steel materials. This implies that no doubler plates, electrical cables or supports that can introduce local stress or strain shall be fixed to the pipe using the methods mentioned.

8.2.4 Design current densities (see ISO 15589-2, 6.4)

The current density for design shall be in accordance with the upper curve given in ISO 15589-2, Figure 2.

For current load imposed by the well casing below the mudline, 5 A per well shall be included in the total design current density requirements.

8.2.5 Coating breakdown factors (see ISO 15589-2, 6.5)

The design coating breakdown factors for the field joint coating area shall be considered increased if the field joint coating does not offer protection and durability compatible with the factory applied coating.

For flexible pipelines, anodes can only be connected to the flexible pipe at the flanges. The length of the flanged pipe sections can be determined by the CP requirements given in this NORSOK standard. The current drain to the armour steel of flexible pipelines shall be included by 0,5 mA/m², related to the outer surface area.

For pipeline components painted with thin film coatings according to NORSOK M-501, the coating breakdown factor shall be according to 5.3..

8.2.6 Design of system (see ISO 15589-2, 7.1)

Anode spacing shall comply with the requirements in ISO 15589-2, 7.1. This includes the requirements that anode spacing shall be close enough to maintain an adequate protection in the event of mechanical or electrical loss of a single anode. Anode spacing exceeding 300 m shall be justified by mathematical modeling in compliance with 8.2.9.

Whenever the calculated distance between anodes for buried pipelines exceeds 300 m, the calculations shall be supported by actual soil resistivity data from the pipeline route.

8.2.7 Galvanic anode installation (see ISO 15589-2, 10)

The attachment between an anode and the pipe steel wall is for electric contact only. Mechanical forces between the pipe and the anode shall not be applied through this connection and the mechanical connection

between the pipe and the anode shall prevent any relative movement. Compression of the coating due to the hydrostatic pressure shall be taken into consideration.

8.2.8 Current demand calculations (see ISO 15589-2, A.4)

The total current demand as calculated in accordance with ISO 15589-2, (A.1), shall be increased by a factor of 2 for the first 1 000 m from sub sea installations, platforms and onshore installations to which they are electrically connected. The distance includes the length of any flexible end jumpers and risers. The increased current requirement is to compensate for interferences and subsequent current drain.

For critical and strategic pipelines such as major trunk lines, the total current demand as calculated in accordance with ISO 15589-2, (A.1), shall be multiplied with 1,5 as a safety factor. For these pipelines the safety factor within the first 1 000 m from subsea installations, platforms and onshore installations to which they are electrically connected shall be 3.

This factor shall be used for determining total net anode weight, final current output capacity and anode spacing.

8.2.9 Attenuation of protection (see ISO 15589-2, A.10)

As an alternative to ISO 15589-2, A.10, the procedure given in the following may be used for determining maximum distance between anodes. For calculations in accordance with this NORSOK standard, and equation (6) and equation (7), the whole area with coating breakdown shall be assumed to be located halfway between the anodes. Accordingly, all CP current shall be assumed to enter half way between anodes.

Equation (6) gives the voltage drop (or potential increase) between two anodes for design based on distributed anodes along the pipeline.

$$\Delta E_{Me} + \Delta E_A = \frac{L^2 \times \rho_{Me} \times i \times f_{Cf} \times D}{4 \times d \times (D - d)} + (R_{Anode} \times i \times \pi \times D \times f_{Cf} \times L) \quad (6)$$

For anodes distributed along a pipeline, loss of an anode shall be taken into account when calculating the maximum distance between anodes, see also 8.2.6.

In the event anode banks are located at the pipeline ends only, equation (7) can be used as basis for the calculations. The equation gives the voltage drop (or potential increase) between the anode banks.

$$\Delta E_{Me} + \Delta E_A = \frac{L^2 \times \rho_{Me} \times i \times f_{Cf} \times D}{4 \times d \times (D - d)} + \frac{R_{Anode} \times i \times \pi \times D \times f_{Cf} \times L}{2} \quad (7)$$

Equation (7) is only directly valid if the pipeline section and the anode banks are unaffected by other installations at the pipeline ends. If this condition is not fulfilled and such structures can draw current from the anodes, the last part of the equation, which describes voltage drop from the anode, shall be further developed to reflect this situation. Also, if the pipeline is protected from anodes on a structure at the pipeline end, a special assessment of the anode voltage drop is needed.

In cases where end mounted anodes are used in combination with anodes or anode spools along the pipeline, a combination of equation (6) and equation (7) shall be used.

9 Inspection of anode installation

At the end of the fabrication phase, electrical continuity between anodes and the items to be protected shall be verified. Actual electrical continuity measurements shall be conducted for all items not having a welded or brazed connection to an anode.

At the end of the fabrication phase, installation of all galvanic anodes in compliance with final issue of design drawings shall be verified.

Requirements given in DNV-RP-B401 and ISO 15589-2 regarding inspection and anode installation shall also apply.

