Cathodic protection of submarine pipelines
FOREWORD

DNV GL recommended practices contain sound engineering practice and guidance.

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Any comments may be sent by e-mail to rules@dnvgl.com

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CHANGES – CURRENT

General

This document supersedes DNV-RP-F103, October 2010.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

On 12 September 2013, DNV and GL merged to form DNV GL Group. On 25 November 2013 Det Norske Veritas AS became the 100% shareholder of Germanischer Lloyd SE, the parent company of the GL Group, and on 27 November 2013 Det Norske Veritas AS, company registration number 945 748 931, changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS”, “Det Norske Veritas”, “DNV”, “GL”, “Germanischer Lloyd SE”, “GL Group” or any other legal entity name or trading name presently owned by the DNV GL Group shall therefore also be considered a reference to “DNV GL AS”.

Main changes July 2016

— Inclusion of new section (Sec.5) dedicated to the purchaser specification of detailed CP design, anode manufacture and anode installation, respectively.
— Anode material design parameters and recommended chemical composition are included in Table 6-3 and Table 6-1 respectively.
— Several changes in the CP design parameters (Sec.6): highlighted use of ‘design factor’, design current densities for pipeline operating at elevated temperature have been increased by a factor of up to 2, some coating breakdown factors have been increased due to changes in ISO 15589-2 (2012) and some new systems have been included, equation for maximum anode distance between successive anodes has been modified to assume unevenly distributed CP current.
— Inclusion of a new sub-section ([6.6]) with requirements and guidance to anode design.
— Welding qualification during anode installation refers to DNVGL-ST-F101.
— Inclusion of figures defining seawater resistivity as a function of temperature and salinity (App.B).
— Inclusion of an inspection and testing plan (ITP) format (App.C).
— Inclusion of a detailed procedure for the execution and documentation of CP design calculations (App.D).

Editorial corrections

In addition to the above stated main changes, editorial corrections may have been made.
## CONTENTS

<table>
<thead>
<tr>
<th>Sec.</th>
<th>General</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Introduction</td>
<td>6</td>
</tr>
<tr>
<td>1.2</td>
<td>Scope of this document</td>
<td>7</td>
</tr>
<tr>
<td>1.3</td>
<td>Objectives and use</td>
<td>8</td>
</tr>
<tr>
<td>1.4</td>
<td>Structure of this document</td>
<td>8</td>
</tr>
<tr>
<td>1.5</td>
<td>Relation to DNVGL-ST-F101 and other DNV GL documents on pipeline corrosion control</td>
<td>9</td>
</tr>
<tr>
<td>1.6</td>
<td>Relation to other standards on submarine pipeline corrosion control (ISO 15589-2 and EN 12474)</td>
<td>9</td>
</tr>
</tbody>
</table>

### Sec.2 References

| 2.1 | DNV GL | 11 |
| 2.2 | European Standards | 11 |
| 2.3 | International Organisation for Standardization | 11 |

### Sec.3 Definitions

| 3.1 | Definition of terms | 12 |
| 3.2 | Definition of verbal forms | 12 |

### Sec.4 Abbreviations and symbols

| 4.1 | Abbreviations | 13 |
| 4.2 | Symbols for cathodic protection design parameters | 14 |

### Sec.5 Specification of cathodic protection design, anode manufacture and anode installation

| 5.1 | General | 15 |
| 5.2 | Purchase specification for cathodic protection design | 15 |
| 5.3 | Purchase specification for anode manufacture | 15 |
| 5.4 | Purchase specification for anode installation | 16 |

### Sec.6 Cathodic protection detailed design

| 6.1 | General | 17 |
| 6.2 | Calculation of mean current demand for cathodic protection | 18 |
| 6.3 | Calculation of final current demand for cathodic protection | 21 |
| 6.4 | Calculation of total net anode mass to meet mean current demand | 21 |
| 6.5 | Calculation of total anode current output to meet final current demand | 23 |
| 6.6 | Anode design | 24 |
| 6.7 | Distribution of anodes | 25 |
| 6.8 | Documentation of completed cathodic protection detailed design | 29 |

### Sec.7 Anode manufacture

| 7.1 | General | 31 |
| 7.2 | Manufacturing procedure specification | 31 |
| 7.3 | Pre-production test | 32 |
| 7.4 | Quality control of production | 33 |
| 7.5 | Materials and casting | 33 |
| 7.6 | Inspection and testing of anodes | 34 |
| 7.7 | Traceability and marking | 36 |
SECTION 1 GENERAL

1.1 Introduction

1.1.1
Submarine pipelines are designed with an external coating as the primary system for corrosion control. Still, a cathodic protection (CP) system is normally provided as a back-up to account for any deficiency in the coating system. Such deficiencies may include holidays during coating application, damage to the coating during transportation and installation of coated linepipe, and mechanical damage or other coating degradation during operation of the pipeline. In defining the required capacity of the CP system, the detailed design of the applicable pipeline coating systems and the provisions for quality control during their application are consequently the primary factors.

Guidance note:
Pipeline coatings may have other objectives in addition to corrosion control, including mechanical protection, thermal insulation and/or anti-buoyancy. In its widest sense, the term ‘pipeline coating’ includes ‘linepipe coating’ (also referred to as ‘parent coating’ or ‘factory coating’) applied on individual pipe joints in a factory, field joint coating (FJC) and coating field repairs (CFR). In this RP, the term ‘coating application’ includes quality control of coating materials being purchased by the applicator, surface preparation, inspection and repair of applied coating in addition to the actual application of coating materials.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

1.1.2
Cathodic protection of pipelines can be achieved using galvanic (also referred to as sacrificial) anodes, or impressed current from one or more rectifiers. For submarine pipelines, galvanic anode systems are most commonly applied. Such systems have traditionally been designed as self-supporting systems with all anodes installed directly on the pipeline itself using bracelet type anodes clamped around the pipeline and individually electrically connected to the pipe. However, the CP design in this document (as in ISO 15589-2) allows for CP by anodes installed on adjacent structures electrically connected to the pipeline such as platform sub-structures, subsea templates and riser bases. For pipelines in corrosion resistant alloys (CRA's) being susceptible to hydrogen induced stress cracking (HISC) by CP, this concept has the main advantage that the installation of anodes on the pipeline itself can be fully avoided for shorter lines (up to 10 - 30 km depending on linepipe material and dimensions, in addition to coating systems used). This RP encourages the use of this concept for CP of in-field flowlines in CMn-steel as well as CRA which however, requires use of high standard coatings and more stringent control of coating quality.

Guidance note:
Apparently all failures of CRA pipelines due to HISC have been related to the welding of anodes to the pipeline causing stress concentrations, susceptible microstructure and/or defect coating. The concept of installing anodes on adjacent structures also has the advantage for all types of linepipe material that the complete anode surfaces are exposed to seawater, increasing the anode electrochemical performance and the anode current output compared to those for anodes partly or fully covered by seabed sediments. Moreover, the potential for damage to the pipeline coating due to mechanical interactions with bracelet anodes during installation is reduced.

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1.1.3
The design of pipeline CP systems is mostly carried out in two steps; ‘conceptual’ and ‘detailed’ CP design. The conceptual CP design will typically include selection of anode material, tentative calculations of net mass and dimensions/numbers of anodes, and selection of a concept for fastening of anodes. The conceptual design should further take into account any potential detrimental effects of CP such as the pipeline materials’ intrinsic susceptibility to HISC by CP and the magnitude of local stresses/strain induced during installation, commissioning and operation of the pipeline that may lead to damage by HISC. During the detailed CP design (i.e. as covered in this document), the final net anode mass and dimensions of anodes, and their distribution on the pipeline are defined. Detailed CP design will further include the specification of anode manufacture and installation, preferably as two separate documents (purchase specifications) in addition to a CP design report.
1.1.4

CP design, anode manufacture and anode installation are typically carried out by three different parties; all referred to as contractor in this RP. The party issuing a contract (purchaser) may be either the pipeline installation contractor or the pipeline owner. For definition of contracting parties and associated terms, see Sec.3.

1.2  Scope of this document

1.2.1

The CP calculation procedures in this RP generally comply with the requirements and recommendations in the applicable sections of ISO 15589-2, although the approach to the importance of pipeline coating systems’ design and the quality control of their application, especially for FJC, differs from that of the ISO standard (see [1.2.3]). The same applies to the relative importance of seawater ambient temperature and internal fluid temperature on design current densities (see [6.2.4]).

DNVGL-RP-F103 is applicable to submarine pipeline systems as defined in DNVGL-ST-F101, except riser sections above mean water level for which cathodic protection is not practical. For any landfall sections to be protected by impressed current CP, reference is made to the latest revisions of ISO 15589-1 and EN 12954.

1.2.2

The present document covers the detailed design of CP for submarine pipeline systems using galvanic anodes, either Al or Zn based, and the manufacture and installation of such anodes. For CP of subsea manifold templates, riser bases and other subsea structures where components of a pipeline system are electrically connected to major surfaces of structural C-steel, use of DNVGL-RP-B401 is recommended for CP design (see [1.5.3]). For conceptual CP design, Sec.6 is applicable to preliminary calculations of the anode net mass and anode distribution. For requirements to anode steel inserts and the inspection and testing during anode manufacture in Sec.7, reference is made to the applicable sections in ISO 15589-2.

1.2.3

By referring to requirements to the design and quality control of specific coating systems for linepipe, field joints and field repairs in DNVGL-RP-F102 and DNVGL-RP-F106 (see [1.5.2]), individual coating breakdown factors for linepipe and field joint coating, respectively are recommended in this RP (App.A). The primary purpose of this approach is to ensure that the CP design is adequate for the actual combination of coating systems to be applied and to enable a CP design without any arbitrary allowance for deficiencies associated with the design and quality control of such coatings. The RP emphasises the importance of documentation of quality control and gives comprehensive advice and guidance related to CP design, anode manufacture and installation. This guidance covers both purchaser’s specification and contractor’s execution of QA/QC.

1.2.4

Full conceptual design of CP (see [1.1.3]), detailed design of impressed current CP systems, and the operation of pipeline CP systems are not addressed in this document. For these items, reference is made to the general guidelines in DNVGL-ST-F101 and the somewhat more detailed recommendations in ISO 15589-1, ISO 15589-2 and EN 12474. For electrochemical testing of galvanic anode materials for the purpose of either qualification or quality control, reference is also made to DNVGL-RP-B401 App.C and DNVGL-RP-B401 App.B, respectively.

1.2.5

Considerations related to safety and environmental hazards associated with galvanic anode manufacture and installation are beyond the scope of this document.
1.3 Objectives and use

1.3.1
This recommended practice (RP) has been prepared to facilitate the execution of detailed CP design and the specification of galvanic anode manufacture and installation. While the requirements and recommendations are general, the document contains advice on how amendments can be made in a project document or inquiry to include specific project requirements.

1.3.2
The objectives of this RP are to:

— provide procedures for the execution and documentation of submarine pipeline GACP design, anode manufacturing with emphasis on quality control and the installation of anodes
— provide default design parameters for GACP design covering most relevant combinations of linepipe and field joint coating
— serve as a contractual reference document between purchaser and contractor (including inquiry) with or without project specific amendments/deviations
— serve as a basis for verification of pipeline corrosion control based on this RP.

If purchaser has chosen to refer to this RP in a purchase document, then contractor should consider all requirements in this document as mandatory (see Sec.3), unless superseded by amendments and deviations for the specific contract.

1.3.3
A primary purpose of this RP is to facilitate the CP design of shorter pipelines for infield transportation of well fluid, injection fluids and processed fluids using galvanic anodes installed on adjacent structures and utilising advanced pipeline coating systems based on e.g. FBE and PE/PP with high requirements to coating design and quality control of application. This RP contains a formula for calculation of CP protective range from adjacent structures that is not included in ISO 15589-2 and the derivation of which is explained in [6.7]. The CP design of pipelines based on galvanic anodes installed on an adjacent structure as well as conventional CP design utilizing bracelet anodes is addressed in App.D Procedure for the execution and documentation of CP design.

1.3.4
An overall objective is to increase the reliability of corrosion control of submarine pipelines by use of this RP in combination with the detailed requirements to pipeline coating design and quality control of their application in DNVGL-RP-F106 and DNVGL-RP-F102. A further objective is to avoid project schedule delays during the manufacture and installation of pipeline bracelet anodes by use of deficient purchase specifications.

1.3.5
When reference is made to ‘accepted by owner’ in this RP, purchaser other than owner (see Sec.3) shall ensure that such owner acceptance is documented in the final documentation; e.g. as an accepted concession request.

1.4 Structure of this document

1.4.1
Sec.5 lists the project specific information that purchaser shall specify for CP design, anode manufacture and anode installation. Requirements and recommendations for detailed CP design, anode manufacture and anode installation are contained in Sec.6, Sec.7 and Sec.8, respectively. Recommendations for coating breakdown factors are given in App.A, App.B shows the relation between seawater resistivity and the salinity and temperature in two graphs, App.C gives a recommended format for an inspection and testing
plan (ITP) for anode manufacture and a detailed procedure for the execution and documentation of CP design calculations is given in App.D.

1.5 Relation to DNVGL-ST-F101 and other DNV GL documents on pipeline corrosion control

1.5.1
DNVGL-ST-F101 (currently the following references still adhere to DNV-OS-F101) Sec.6 D500, gives general guidelines to the design of CP systems. Sec.9, D and E contain some requirements and recommendations associated with anode manufacture and installation, respectively, in addition to application of pipeline coatings (Sec.9 B). Inspection of CP systems in operation is briefly addressed in Sec.11 D300 of the same document.

1.5.2
DNVGL-RP-F106 Factory applied coatings for external corrosion control and DNVGL-RP-F102 Pipeline field joint coating and field repair of linepipe external coatings provide detailed requirements to the design and quality control of pipeline coatings. Both documents refer to ISO 21809 and comply with the minimum requirements of this standard giving additional requirements to the design and quality control of coating application.

1.5.3
DNVGL-RP-B401 Cathodic protection design covers CP of other offshore structures than pipelines. However, it is applicable for certain components of a pipeline system like those installed on manifold templates and riser bases (see [1.2.2]).

1.5.4
DNVGL-RP-F112 Design of duplex stainless steel subsea equipment exposed to cathodic protection covers recommendations for design of subsea duplex stainless steel components (including pipelines) for which susceptibility to HISC induced by CP requires assessment of acceptable stress and strain.

1.6 Relation to other standards on submarine pipeline corrosion control (ISO 15589-2 and EN 12474)

1.6.1
The 2003 revision of this RP was prepared for compliance with ISO/FDIS 15589-2 (2003) and references to this standard was used for certain CP design parameters, CP design calculation procedures and for some requirements to anode manufacturing and installation. In this 2016 revision of DNVGL-RP-F103, reference to specific requirements in ISO 15589-2 are only made for fabrication of anode inserts and to the inspection and testing associated with anode manufacturing (see [7.1.1]).

1.6.2
The concept for design current densities for calculation of CP current demands of this DNVGL-RP-F103 differs from those of ISO 15589-2 (see guidance notes to [6.2.4]) and EN 12474. Those in the ISO/EN standards are based on bare steel surfaces being freely exposed to flowing seawater of ambient temperature or seabed sediments whilst design current densities in this RP refer to ‘leakage’ of CP current at pores and narrow cracks or crevices in the coating, primarily in connection with field joints. Also the concept of defining coating breakdown factors in this RP differs from that in ISO 15589-2 (see [6.2.7]) and EN 12474. Hence, in this RP, CP current demands are to be calculated separately for the actual pipe surfaces being coated by linepipe coating and FJC, respectively; furthermore the overall requirements to coating design and quality control are assumed to comply with DNVGL-RP-F106 and DNVGL-RP-F102, respectively. DNVGL-RP-F101 and this RP consider all submarine pipelines to be potentially exposed to an anaerobic environment of seabed sediments and “possibility of SRB activity” (see Sec.7.2.1 of ISO 15589-2). An IR-free potential (i.e. protection potential recorded essentially free of or compensated for any electrolytic or
metallic voltage drop) more negative than −0.80 V rel. Ag/AgCl/seawater is then considered to give adequate protection for such conditions for CMn steel linepipe material. This potential is also used as the design protective potential for calculation of required number and size of anodes to provide CP, and as protection potential criterion for calculation of protection range from anode assemblies according to [6.7] of this RP for CMn steel linepipe material.

1.6.3
The requirements to anode chemical composition (see [6.1.7]) and anode performance data to be used for CP design calculations (see [6.4.3]) as well as requirements to quality control of anode manufacturing and installation exceed those of ISO 15589-2.

1.6.4
For certain combinations of pipeline coatings, design lives and environmental parameters, CP calculations according to DNVGL-RP-F103 may result in a significantly lower requirement to minimum anode net mass than calculations according to ISO 15589-2. This applies for e.g. larger diameter pipelines with a linepipe coating of asphalt enamel or FBE and with concrete coating on top to be installed in cold waters. Large increases in design parameters in ISO 15589-2 (2012) have resulted in larger differences between DNVGL-RP-F103 (2016) and ISO 15589-2 (2012) than in the preceding revisions. The main reason for these changes is the increased coating breakdown factors in ISO 15589-2 (see guidance note in [6.2.7]). For use of coating breakdown factors according to App.A, DNVGL-RP-F103 requires that all damage to the linepipe coating shall be repaired prior to installation and the RP has detailed requirement to QA/QC during application of linepipe coating and FJC (see [6.2.7]). The coating breakdown factors have thus not been increased to the same extent in DNVGL-RP-F103 as in ISO 15589-2 as the justification for increased coating breakdown factors in ISO refers to allowance for damage to pipeline coatings during fabrication, handling, transportation and installation.

Guidance note:
With the requirement for a maximum distance of 300 m between subsequent anodes (see [6.7.1]) and the use of a typical anode size (min. 50 mm thickness and length minimum half the external pipe diameter), the resulting anode mass will in some cases exceed that calculated based on design current densities and coating break-down factors for either of the standards. Hence, for some gas/oil export pipelines, the required maximum anode distance of 300 m is the governing CP design parameter.

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1.6.5
For in-field flowlines to be used for routing of production, injection and utility fluids as well as for shorter inter-field gathering lines with coating based on PE/PP applied on top of FBE (i.e. both linepipe and FJC), the coating breakdown factors recommended in this RP result in significantly lower CP current demands than by use of coating breakdown factors in ISO 15589-2. This is important to enable CP of such pipelines to be based on anodes installed at adjacent structures (see [1.3.3]). The lower coating breakdown factors for such coating systems are then justified by the more stringent requirements to coating design and quality control of coating materials and their application as defined in DNVGL-RP-F102 and DNVGL-RP-F106, being most significant for the more advanced coating systems.

Guidance note:
In DNVGL-RP-F102 and DNVGL-RP-F106 (and contrary to ISO 15589-2) all basic requirements in ISO 21809-3 and ISO 21809-1 are mandatory. In addition, some requirements to coating design in the ISO 21809 standards (e.g. minimum FBE, LE and PE/PP thickness) are exceeded, preparations of APS, ITP, Daily Log and Final Documentation Index for purchaser acceptance are mandatory, as well as the execution of a PQT (for FJC also a PPT) with detailed requirements to scope and contents/format of documentation being defined in the RP’s.

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## SECTION 2 REFERENCES

### 2.1 DNV GL

#### Table 2-1 DNV GL references

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
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<tr>
<td>DNVGL-ST-F101</td>
<td>Submarine pipeline systems (planned published in 2016, currently published as DNV-OS-F101)</td>
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<tr>
<td>DNVGL-RP-B401</td>
<td>Cathodic protection design (planned published in 2016, currently published as DNV-RP-B401)</td>
</tr>
<tr>
<td>DNVGL-RP-F102</td>
<td>Pipeline field joint coating and field repair of linepipe external coating (planned published in 2016, currently published as DNV-RP-F102)</td>
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<tr>
<td>DNVGL-RP-F106</td>
<td>Factory applied external pipeline coatings for corrosion control (planned published in 2016, currently published as DNV-RP-F106)</td>
</tr>
<tr>
<td>DNVGL-RP-F112</td>
<td>Design of duplex stainless steel subsea equipment exposed to cathodic protection (planned published in 2016, currently published as DNV-RP-F112)</td>
</tr>
</tbody>
</table>

Guidance note:
DNV GL is in a transition period w.r.t. numbering of standards. The listed DNV GL documents refer to acronyms that will be introduced during 2016. New acronyms of these documents do not imply that all of them have been revised since the previous revision.

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### 2.2 European Standards

#### Table 2-2 EN references

<table>
<thead>
<tr>
<th>Document code</th>
<th>Title</th>
</tr>
</thead>
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<tr>
<td>EN 10204</td>
<td>Metallic Products – Types of Inspection Documents</td>
</tr>
<tr>
<td>EN 12474</td>
<td>Cathodic Protection of Submarine Pipelines</td>
</tr>
<tr>
<td>EN 12954</td>
<td>Cathodic Protection of Buried or Immersed Metallic Structures General Principles and application for pipelines</td>
</tr>
<tr>
<td>EN 15257</td>
<td>Cathodic Protection. Competence Levels and Certification of Cathodic Protection Personnel</td>
</tr>
</tbody>
</table>

### 2.3 International Organisation for Standardization

#### Table 2-3 ISO references

<table>
<thead>
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<th>Document code</th>
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</tr>
</thead>
<tbody>
<tr>
<td>ISO 8501-1</td>
<td>Preparation of Steel Substrate Before Application of Paint 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.</td>
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<tr>
<td>ISO 8503-2</td>
<td>Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Substrates. – Part 2: Method for the Grading of Surface Profile of Abrasive Blast-Cleaned Steel – Comparator Procedure</td>
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<td>ISO 10005</td>
<td>Quality Management – Guidelines for Quality Plans</td>
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<td>ISO 10474</td>
<td>Steel and Steel Products – Inspection Documents</td>
</tr>
<tr>
<td>ISO 13847</td>
<td>Petroleum and Natural Gas Industries- Pipeline Transportation Systems – Welding of Pipelines</td>
</tr>
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<td>ISO 15589-1</td>
<td>Petroleum and Natural Gas Industries- Cathodic Protection of Pipeline Transportation Systems – Part 1: Onshore Pipelines (see [1.3.1])</td>
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<td>ISO 15589-2</td>
<td>Petroleum and Natural Gas Industries- Cathodic Protection of Pipeline Transportation Systems – Part 2: Offshore Pipelines (see [1.3.1])</td>
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<td>ISO 21809-1</td>
<td>Petroleum and Natural Gas Industries- External Coatings for Buried or Submerged Pipelines Used in Pipeline Transportation Systems – Part 1: Polyolefine Coatings (3-Layer PE and 3-Layer PP)</td>
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<tr>
<td>ISO 21809-2</td>
<td>Petroleum and Natural Gas Industries- External Coatings for Buried or Submerged Pipelines Used in Pipeline Transportation Systems – Part 2: Fusion-Bonded Epoxy Coatings</td>
</tr>
<tr>
<td>ISO 21809-3</td>
<td>Petroleum and Natural Gas Industries- External Coatings for Buried or Submerged Pipelines Used in Pipeline Transportation Systems – Part 3: Field Joint Coatings</td>
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<tr>
<td>ISO 21809-5</td>
<td>Petroleum and Natural Gas Industries- External Coatings for Buried or Submerged Pipelines Used in Pipeline Transportation Systems – Part 5: External Concrete Coatings</td>
</tr>
</tbody>
</table>
### SECTION 3 DEFINITIONS

#### 3.1 Definition of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>owner</td>
<td>party legally responsible for design, construction and operation of the pipeline. Other legislative terms used for this role are e.g. operator, duty holder.</td>
</tr>
<tr>
<td>purchaser</td>
<td>party (owner or main contractor) issuing inquiry or contract for engineering, manufacturing or installation work</td>
</tr>
<tr>
<td>contractor</td>
<td>party to whom the work has been contracted</td>
</tr>
<tr>
<td>agreed agreement</td>
<td>refers to a written arrangement between purchaser and contractor (e.g. as stated in a contract)</td>
</tr>
<tr>
<td>report and notify</td>
<td>refers to an action by contractor in writing</td>
</tr>
<tr>
<td>accepted</td>
<td>refers to a confirmation by owner/purchaser in writing</td>
</tr>
<tr>
<td>certificate</td>
<td>refers to the confirmation of specified properties issued by contractor or supplier of materials according to EN 10204:3.1, ISO 10474:3.1.B or equivalent</td>
</tr>
<tr>
<td>purchase</td>
<td>refers to an inquiry/tender, or a purchase/contract specification, as relevant</td>
</tr>
<tr>
<td>manufacture</td>
<td>refers to work associated with anode manufacture or installation, including qualification of a MPS (i.e. PQT) and IPS (incl. WPS), respectively</td>
</tr>
<tr>
<td>supplier</td>
<td>refers to supply of materials or equipment for manufacture or installation of anodes</td>
</tr>
<tr>
<td>heat</td>
<td>a specific amount of molten metal alloy prepared in a furnace and to which final alloy additions have been made prior to pouring direct into the moulds</td>
</tr>
<tr>
<td>anode tab</td>
<td>part of anode cores protruding from the anode surface and to be used for anode fastening by welding or bolting</td>
</tr>
</tbody>
</table>

#### 3.2 Definition of verbal forms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>shall</td>
<td>verbal form used to indicate requirements strictly to be followed in order to conform to the document</td>
</tr>
<tr>
<td>should</td>
<td>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</td>
</tr>
<tr>
<td>may</td>
<td>verbal form used to indicate a course of action permissible within the limits of the document</td>
</tr>
</tbody>
</table>
### SECTION 4 ABBREVIATIONS AND SYMBOLS

#### 4.1 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDS</td>
<td>coating data sheet</td>
</tr>
<tr>
<td>CFR</td>
<td>coating field repair</td>
</tr>
<tr>
<td>CP</td>
<td>cathodic protection</td>
</tr>
<tr>
<td>CR</td>
<td>concession request</td>
</tr>
<tr>
<td>CRA</td>
<td>corrosion resistant alloy</td>
</tr>
<tr>
<td>FJC</td>
<td>field joint coating</td>
</tr>
<tr>
<td>FPSO</td>
<td>floating production storage and offloading</td>
</tr>
<tr>
<td>GACP</td>
<td>galvanic anode cathodic protection</td>
</tr>
<tr>
<td>HT</td>
<td>high temperature</td>
</tr>
<tr>
<td>HISC</td>
<td>hydrogen induced stress cracking</td>
</tr>
<tr>
<td>HSS</td>
<td>heat shrink sleeve</td>
</tr>
<tr>
<td>HV</td>
<td>vicker hardness</td>
</tr>
<tr>
<td>IPS</td>
<td>installation procedure specification (see [8.2])</td>
</tr>
<tr>
<td>ICCP</td>
<td>impressed current cathodic protection</td>
</tr>
<tr>
<td>ITP</td>
<td>inspection and testing plan (see [7.4.2])</td>
</tr>
<tr>
<td>LE</td>
<td>liquid epoxy</td>
</tr>
<tr>
<td>APS</td>
<td>(coating) application procedure specification</td>
</tr>
<tr>
<td>MPS</td>
<td>(anode) manufacturing procedure specification (see [7.2])</td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers (Houston)</td>
</tr>
<tr>
<td>PE</td>
<td>polyethylene</td>
</tr>
<tr>
<td>PP</td>
<td>polypropylene</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinylchloride</td>
</tr>
<tr>
<td>PU</td>
<td>polyurethane</td>
</tr>
<tr>
<td>PPT</td>
<td>pre-production test (see [7.3])</td>
</tr>
<tr>
<td>PQT</td>
<td>(coating) procedure qualification trial</td>
</tr>
<tr>
<td>RP</td>
<td>recommended practice</td>
</tr>
<tr>
<td>SMYS</td>
<td>specified minimum yield stress</td>
</tr>
<tr>
<td>SRB</td>
<td>sulphate reducing bacteria</td>
</tr>
<tr>
<td>WPQ</td>
<td>welding procedure qualification</td>
</tr>
<tr>
<td>WPS</td>
<td>welding procedure specification</td>
</tr>
</tbody>
</table>
## 4.2 Symbols for cathodic protection design parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_s [m²]</td>
<td>surface area (see [6.2.1])</td>
</tr>
<tr>
<td>a</td>
<td>constant (see [6.2.6])</td>
</tr>
<tr>
<td>b</td>
<td>constant (see [6.2.6])</td>
</tr>
<tr>
<td>D [m]</td>
<td>linepipe outer diameter (see [6.7.4])</td>
</tr>
<tr>
<td>d [m]</td>
<td>linepipe wall thickness (see [6.7.5])</td>
</tr>
<tr>
<td>E_a° [V]</td>
<td>design closed circuit anode potential (see [6.5.1])</td>
</tr>
<tr>
<td>E_p° [V]</td>
<td>design protective potential (see [6.7.3] and [6.5.1])</td>
</tr>
<tr>
<td>E_p [V]</td>
<td>protection potential criterion (see [6.7.3] and [6.7.11])</td>
</tr>
<tr>
<td>E'c [V]</td>
<td>global protection potential (see [6.7.8])</td>
</tr>
<tr>
<td>ΔE_A [V]</td>
<td>electrolytic voltage drop (see [6.7.9])</td>
</tr>
<tr>
<td>ΔE_Me [V]</td>
<td>metallic voltage drop (see [6.7.3])</td>
</tr>
<tr>
<td>ε [A·h/kg]</td>
<td>anode electrochemical capacity (see [6.4.1])</td>
</tr>
<tr>
<td>f_cm</td>
<td>mean coating breakdown factor (see [6.2.5])</td>
</tr>
<tr>
<td>f'_cf</td>
<td>final coating breakdown factor (see [6.3.2])</td>
</tr>
<tr>
<td>f''_cf</td>
<td>mean final coating breakdown factor (see [6.6.4])</td>
</tr>
<tr>
<td>I_{af} [A]</td>
<td>final anode current output (see [6.5.1])</td>
</tr>
<tr>
<td>I_{c} [A]</td>
<td>current demand (see [6.2.1])</td>
</tr>
<tr>
<td>I_{cm} [A]</td>
<td>mean current demand (see [6.2.1])</td>
</tr>
<tr>
<td>I_{cm} (tot) [A]</td>
<td>total mean current demand (see [6.2.9])</td>
</tr>
<tr>
<td>I_{cf} [A]</td>
<td>final current demand (see [6.3.1])</td>
</tr>
<tr>
<td>I_{cf} (tot) [A]</td>
<td>total final current demand (see [6.3.1])</td>
</tr>
<tr>
<td>i_{cm} [A/m²]</td>
<td>design mean current density (see [6.2.3])</td>
</tr>
<tr>
<td>k</td>
<td>design factor (see [6.1.5])</td>
</tr>
<tr>
<td>L [m]</td>
<td>length of pipeline to be protected from one anode (see [6.7.3])</td>
</tr>
<tr>
<td>L_{tot} [m]</td>
<td>length of pipeline section (see [6.7.9])</td>
</tr>
<tr>
<td>M [kg]</td>
<td>total net anode mass (see [6.4.1])</td>
</tr>
<tr>
<td>M_a [kg]</td>
<td>individual net anode mass (see [6.7.9])</td>
</tr>
<tr>
<td>N</td>
<td>number of anodes (see [6.5.3])</td>
</tr>
<tr>
<td>R_Me [ohm]</td>
<td>metallic resistance (see [6.7.3])</td>
</tr>
<tr>
<td>R_{af} [ohm]</td>
<td>anode final resistance (see [6.5.1])</td>
</tr>
<tr>
<td>r</td>
<td>ratio: length of cutbacks (2 off) to linepipe coating per pipe joint (see [6.7.4])</td>
</tr>
<tr>
<td>ρ_Me [ohm-m]</td>
<td>resistivity of linepipe material (see [6.7.4])</td>
</tr>
<tr>
<td>t_d [years]</td>
<td>design life (see [6.2.6])</td>
</tr>
<tr>
<td>u</td>
<td>anode utilisation factor (see [6.4.2])</td>
</tr>
</tbody>
</table>
SECTION 5 SPECIFICATION OF CATHODIC PROTECTION DESIGN, ANODE MANUFACTURE AND ANODE INSTALLATION

5.1 General

5.1.1 Besides any reference to this RP in a purchase document as defined in Sec.3, the information given in [5.2], [5.3] and [5.4] relating to the detailed CP design, anode manufacture and anode installation, respectively, shall be enclosed in the purchase specifications.

5.1.2 The specification for CP design, anode manufacture and anode installation shall preferably be prepared by owner or main contractor acting on his behalf.

5.2 Purchase specification for cathodic protection design

5.2.1 For CP detailed design the following information and documentation shall be provided by purchaser:

— owner and/or project specific requirements to CP design (if applicable); e.g. max. distance between bracelet anodes (see [6.7.1]) and use of design factor larger than 1 (see [6.1.5])
— conceptual CP design report, if completed (see [6.1])
— relevant data from pipeline design basis, including e.g. information on pipe material and dimensions, installation conditions, internal fluid temperature, marine environmental conditions relevant to CP design, degree of burial or rock-dumping, design of linepipe, field joint (including cutback length) and concrete (if applicable) coating, design life. For more detailed information on CP design premises, see [D.2].
— requirements to documentation and any third party verification, including schedule for supply of documentation (see [6.8]).

Guidance note:
The type of linepipe coating and FJC is crucial for the CP design calculations and for detailed CP design it is thus important that Purchaser specifies the type of linepipe and FJC as required to define the applicable coating breakdown factors. Preferably the linepipe and FJC specifications should be completed prior to the CP detailed design.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.3 Purchase specification for anode manufacture

5.3.1 For anode manufacture the following information and documentation shall be provided by purchaser:

— anode material type (i.e. Al or Zn based) and any detailed requirements to chemical composition of anode material (see [6.1.7])
— outline anode drawing (including anode cores) with tentative tolerances and arrangements for anode fastening and provisions for electrical continuity to pipeline (see [6.6.2])
— pipeline OD with tolerances and coating thickness (including concrete coating if applicable) with tolerances
— project specific requirements to pre-production testing (PPT), including schedule for notification and supply of documentation, number of anodes to be cast and tested destructively for each casting mould (see [7.3])
— any special requirements to manufacturing procedure specification (MPS) (see [7.2.1]) or inspection and testing plan (ITP) (see [7.4.2])
— requirements for frequency of destructive testing during production, and for verification of bracelet anode tab positions by measurements and/or anode fit-up test on a dummy pipe sample (see [7.6.4])
— any specific requirements to contractor’s management of non-conformities and concession requests (see [7.5.6])
— retaining of anode material specimens (see [7.6.1])
— requirements to marking of anodes (see [7.7])
— any specific requirements to handling, storage and shipping of anodes (see [7.8])
— project specific requirements to final documentation, including schedule for supply (see [7.9.4]).

5.4 Purchase specification for anode installation

5.4.1
For anode installation the following information and documentation shall be provided by purchaser:

— anode installation design requirements, including anode drawing(s) (tentative from CP conceptual or detailed design report, subsequently to be replaced by anode manufacturer’s drawing(s))
— design premises affecting anode installation, e.g. linepipe dimensions, type of linepipe coating, pipeline installation concept
— location of anodes in relation to pipe ends and field joints (see [8.6.2])
— any special requirements to qualification of anode installation (PPT), including e.g. verification of anode integrity during pipeline installation, application of in-fill and repair of linepipe coating associated with anode installation, as relevant (see [8.3])
— any special requirements to quality control, e.g. use of IPS (see [8.2.1]) and daily log (see [8.4.2])
— any specific requirements to handling and storage of anodes and materials for anode installation (see [8.5.3])
— project specific requirements to final documentation, including schedule for supply (see [8.8.3]).
SECTION 6  CATHODIC PROTECTION DETAILED DESIGN

6.1  General

6.1.1  The detailed design of a pipeline CP system is normally preceded by a conceptual design activity (see [1.1.3]), during which the type of CP system and type of galvanic anode material to be used have been defined. A concept for anode attachment will normally also be selected, considering requirements for the integrity of anodes during pipeline installation and provision of electrical connection of anode material to the pipeline. If no CP conceptual report has been prepared, then the premises and basic concepts for detailed CP design should be defined by purchaser in some other reference document to be included in purchase documentation.

Guidance note:
Owner or project specific requirements to CP design additional to or exceeding those in DNVGL-RP-F103 may apply. The applicable document(s) defining such requirements should then be referenced in the project design basis and all documents related to CP design. The execution and verification of CP design should be performed by personnel with adequate competence. Certification schemes according to EN 15257 and NACE are adequate for documentation of such competence.

6.1.2  Any pipeline conceptual design will normally define the generic type of pipeline coatings to be utilised for linepipe and pipeline components, and for coating of field joints. Based on this, it is common practice to carry out a preliminary calculation of current demands for cathodic protection and the associated total net mass of anode material required, resulting in a preliminary sizing and distribution of individual anodes (see [1.1.3]). This is referred to as a conceptual CP design.

6.1.3  In addition to a reference to owner or project specific requirements and the conceptual CP design report (if completed), the project design basis should contain all project specific input parameters relevant to the execution of detailed CP design. Purchaser shall ensure that the valid revision of the design basis is available to contractor during the design work.

6.1.4  This section defines and explains the design parameters and equations to be used for CP design making extensive use of guidance notes. In [6.8], items to be included in the CP detailed design report are listed. A detailed procedure for the execution and documentation of CP design calculations is contained in App.D.

6.1.5  It is strongly recommended that any additional conservatism for CP design is introduced by use of a design factor, $k$, rather than modification of one or more of the CP design parameters specified in this RP. This factor may account for e.g. a probable life exceeding the design life, uncertainties of the actual current demand and/or the performance of anode material. To include such conservatism, a value of $k$ larger than 1 (one) shall be included in calculations of current demand; i.e. equation (1) and equation (3). $k$ shall be specified or accepted by owner and shall be 1 if no value is given by owner.

6.1.6  All electrochemical potentials associated with CP in this section refer to the Ag/AgCl/seawater reference electrode.

Guidance note:
"Seawater" refers to water with a salinity of about 35‰ (30 - 40‰). At the equivalent concentration of chloride ions (i.e. about 1.9% by weight), the potential of the Ag/AgCl/seawater reference electrode is approximately equal to that of the saturated calomel electrode (SCE). Another reference electrode being used for CP is Ag/AgCl/saturated KCl. This reference electrode has a potential -50 mV vs. the Ag/AgCl/seawater reference electrode. For CP design, the potentials referring the Ag/AgCl/seawater reference...
electrodes are applicable also for CP in brackish waters (salinity 5 - 30‰). (Reference electrodes used for monitoring of CP in brackish as well as in full salinity water typically utilise an internal electrolyte and corrections for chloride content of the external seawater as referred to in Sec.7.2.1 of ISO 15589-2 are then not relevant).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.1.7

The chemical composition of the anode material shall be specified as a part of the detailed CP design. Recommended values for alloying and impurity values are contained in Table 6-1. Any deviations from these compositional limits shall be justified in the CP design report and accepted by Owner before being implemented for anode manufacture.

Table 6-1 Recommended compositional limits for anode materials

<table>
<thead>
<tr>
<th>Element</th>
<th>Al-Zn-In anodes</th>
<th>Zn anodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min. (%)</td>
<td>max. (%)</td>
</tr>
<tr>
<td>Al</td>
<td>remainder</td>
<td>0.10</td>
</tr>
<tr>
<td>Zn</td>
<td>4.50</td>
<td>5.75</td>
</tr>
<tr>
<td>In</td>
<td>0.016</td>
<td>0.030</td>
</tr>
<tr>
<td>Cd</td>
<td>0.002</td>
<td>0.025</td>
</tr>
<tr>
<td>Fe</td>
<td>0.090</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Si</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.006</td>
<td></td>
</tr>
</tbody>
</table>

Guidance note:
For Al-Zn-In anode materials, the compositional limits are narrower than those referred to as "typical" in ISO 15589-2 and reflect the compositional limits currently specified by purchasers of pipeline anodes. The ISO standard specifies max. 0.02% for "other" elements; however, other specific elements will normally not be analysed and reported unless actually specified by the purchaser.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.2 Calculation of mean current demand for cathodic protection

6.2.1

For the detailed CP design, a pipeline shall normally be divided into sections based on variations in fluid and environmental parameters (e.g. fluid temperature and burial conditions) that affect the current demand, \( I_c \) [A] for CP.

The mean current demand, \( I_{cm} \) [A/m²] for a specific pipeline surface area, \( A_c \) is calculated from:

\[
I_{cm} = A_c \times f_{cm} \times i_{cm} \times k
\]  

(1)

\( i_{cm} \) and \( f_{cm} \) are defined in [6.2.3] and [6.2.5], respectively. \( k \) equals 1 or is > 1 as defined in [6.1.5]).

6.2.2

In this RP, the surface area associated with field joint coating at girth welds shall be calculated separately and the associated current demand according to equation (1) is then added to the current demand for the pipeline covered by linepipe coating and for any pipeline components with other types of coating. The calculations shall use the actual cut-back of the linepipe coating or 0.20 m minimum.

Guidance note:
Since the surface area associated with field joints is only a few percent of the total pipe area, it is not strictly necessary to subtract the FJC area when calculating the current demand for surfaces with linepipe coating.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.2.3

In equation (1) above, \( i_{cm} \) [A/m²] is the design mean current density, i.e. the mean cathodic current density at the coating/steel interface exposed to the environment; i.e. seawater or marine sediments (see guidance note 2 to [6.2.4]). "mean" refers to an average value for the design life. The design current density in Table 6-2 is independent of the coating system.
6.2.4

Table 6-2 gives recommended mean design current densities for buried and non-buried pipelines (or sections of a pipeline) as a function of the fluid temperature but independent of depth and geographic location. ‘Buried’ refers to pipeline sections to be subjected to trenching and backfilling. Pipelines (or pipeline sections) to be installed in very soft soil for which complete self-burial can be demonstrated (e.g. by calculations) may also be considered as ‘buried’. For compliance with this RP, sections for which incomplete self-burial is expected shall be designed such that the number of anodes to be installed shall be sufficient to cover both complete burial and full exposure to seawater. When current demand has been calculated for either seawater or buried conditions, also the anode current output (see [6.5]) and anode material electrochemical efficiency (see [6.4]) shall be calculated for the same type of exposure (seawater or sediment). Pipeline sections without trenching but covered by rock/gravel dumping may further be considered as ‘buried’. For compliance with this RP, design calculations based on ‘partial burial’ shall not apply; neither for calculations of CP current demand, nor for calculation of anode current output according to [6.5] of this RP.

The design current densities in Table 6-2 are applicable for pipelines with linepipe coating and FJC/CFR as defined in DNVGL-RP-F106 and DNVGL-RP-F102, respectively. For any pipeline components or parts of pipelines designed without such coatings, design current densities in DNVGL-RP-B401 are recommended for calculations of CP current demands. The design current densities in this paragraph (and in DNVGL-RP-B401) are applicable to CRA’s as well as CMn-steel linepipe and ordinary C-steel.

<table>
<thead>
<tr>
<th>Exposure conditions</th>
<th>Internal fluid temperature [ºC]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤ 25</td>
</tr>
<tr>
<td>Non-buried (*)</td>
<td>0.050</td>
</tr>
<tr>
<td>Buried (*)</td>
<td>0.020</td>
</tr>
</tbody>
</table>

**) See definition in [6.2.4]

Guidance note 1:
The design current densities in Table 6-2 should be considered as minimum values. Compared to the 2003 revision of this RP, the design current densities for pipeline operating at elevated temperatures have been increased by a factor of up to 2. This is to recognise the internal fluid temperature as the primary environmental factor for pipeline CP design and for better compliance with design current densities in ISO 15589-2 which have been increased in the 2012 revision for fluid temperatures above 25°C. The internal fluid temperature may decrease with time but it is normal practice to use the initial (high) value as a conservative approach to CP design. The design current densities in Table 6-2 of this RP are based on the internal fluid temperature as decisive for the actual temperature at the steel/coating interface.

Guidance note 2:
The current demand associated with cathodic protection of pipelines is related to leakage of CP current at pores and narrow cracks or crevices in the coating, primarily in connection with field joints. Hence, there is normally no direct exposure of steel surfaces to seawater and the temperature at the metal/electrolyte interface is close to that of the internal fluid temperature. The cathodic current is then primarily related to hydrogen production, even for unb Buried pipeline sections, whilst reduction of dissolved oxygen has only a minor contribution to the cathodic reaction, if any at all. As a consequence, seawater parameters affecting oxygen supply (e.g. dissolved content of oxygen and seawater flow), hydrostatic pressure and seawater ambient temperature are less important. In ISO 15589-2, design current densities are related to bare steel surfaces freely exposed to flow of oxygen containing seawater whilst in this RP the cathodic current is considered to be primarily determined by diffusion and migration processes in the pores and crevices being controlled by temperature. For pipelines operating above ambient seawater temperature, the temperature of the internal fluid is then the decisive factor for the current demand.

6.2.5

$f_{cm}$ in equation (1) is a dimensionless factor ($≤ 1$) termed mean coating breakdown factor, describing the assumed capability of the coating to reduce the current demand for CP. “mean” refers to an average value for the design life. See also guidance notes to [6.2.7], [6.3.1] and [6.3.2].
6.2.6

The mean coating breakdown factor $f_{cm}$ is given by the equation:

$$f_{cm} = a + 0.5 \times b \times t_f$$  (2)

where $t_f$ [years] is the design life. $a$ and $b$ are defined in [6.2.7] and [6.2.8]. The design life to be used for CP detailed design shall be defined or accepted by owner and should be a conservative estimate of the maximum expected lifetime of the pipeline. In case this lifetime is likely to exceed the pipeline’s design life as specified in the design basis, use of a design factor should be considered (see [6.1.5]). Any significant period of time between installation and start of pipeline operation shall be included in the design life.

6.2.7

$a$ and $b$ in equation (2) are constants. Table A-1 and Table A-2 in App.A give recommendations for constants to be used for linepipe coating and FJC systems, respectively, together with reference to detailed design and requirements to quality control as defined in DNVGL-RP-F106 and DNVGL-RP-F102, and for the maximum operating temperatures. Use of generic type coatings at higher temperatures shall be qualified. These constants further assume that any damage to the linepipe coating during transportation and fabrication resulting in exposure of bare steel is repaired (CFR) in accordance with DNVGL-RP-F102 prior to installation, and that the compatibility of installation systems with the linepipe and FJC has been verified by testing or calculations. Furthermore, it is assumed that the pipeline is protected by weight coating, burial or rock/gravel dumping if required for mechanical protection to avoid damage in operation causing significant exposure of bare metal. FJC to be used in areas with trawling activity shall be qualified for resistance to trawl board impacts.

Guidance note 1:

The constant $a$ defines the assumed initial capability of the coating to reduce the current demand for CP, whilst the constant $b$ defines the assumed degradation of this capability over time ("coating breakdown") although the coating may appear visually unaffected. In this RP, CP current demands are calculated separately for the actual pipe surfaces being coated by linepipe coating and FJC, respectively. The overall requirements to coating design and quality control are assumed to comply with DNVGL-RP-F106 and DNVGL-RP-F102 for linepipe coating and FJC, respectively. In the 2004 issue of the ISO 15589-2, the FJC design was not considered to affect the CP current demand but in the 2012 revision, coating breakdown factors specified "for consideration" are based on certain combinations of generic types of coating systems for linepipe and FJC, assuming "coating quality being in accordance with the various parts of ISO 21809 or with other commonly applied industry standards specifying an equal level of quality coatings".

The constants $a$ and $b$ defined in Table A-1 and Table A-2 of this RP were initially selected for overall compliance with ISO/FDIS 15589-2 (2003). In the 2012 revision of ISO 15589-2, the $a$ and $b$ constants for coating breakdown factors for asphalt enamel, FBE and 3LPE/3LPP were increased by a factor of 3, 4 and 2, respectively; the reason for which is stated to be to "include some allowance for damage to pipeline coatings during fabrication, handling, transportation, installation or operation such as third-party damage". Such damage is not included in DNVGL-RP-F103. Nevertheless, due to changes in the 2012 revision of the ISO standard, the constants for calculation of coating breakdown factors for concrete coated asphalt enamel and FBE coating have been increased by a factor of 3 in this revision of DNVGL-RP-F103. However, for most pipelines with concrete coating the recommended maximum distance of 300 m is governing to the CP design, see [6.7.1]. Disbondment of polychloroprene coating has occurred at risers on some projects and the constants for coating breakdown factors have therefore been increased by a factor of 10 for polychloroprene in this revision of DNVGL-RP-F103.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:

It is not practical to record pipeline coating breakdown factors and they are accordingly selected based on (subjective) engineering judgement. In DNVGL-RP-F103 this fact is reflected by the use of coating breakdown constants differing by a factor of 3 (i.e. 0.00003, 0.0001, 0.0003, 0.001, 0.003, 0.01, 0.03, 0.1, 0.3). If project specific conditions are considered to justify a more conservative design with respect to the expected coating breakdown than recommended in this RP, it should be included either as a quantitative estimate of bare steel surface area (with CP current demands to be calculated using design current densities in DNVGL-RP-B401, see [6.2.8]) or by use of a design factor (see [6.1.5]).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.2.8

The current demand of surfaces without pipeline coatings as defined in DNVGL-RP-F106 and DNVGL-RP-F102, e.g. components protected by "ordinary" marine coating systems based on liquid epoxy or polyurethane (dry film thickness \( \geq 150 \mu m \)), shall be calculated using the design current densities and coating breakdown factors recommended in DNVGL-RP-B401 (see [1.2.2]).
6.2.9
Based on the design current densities and coating breakdown factors as defined above, the current demand contributions from coated linepipe, field joints and any pipeline components with “ordinary” marine coating are calculated individually according to equation (1) and then added to make up the total mean current demand $I_{cm \text{ (tot)}}$ [A].

6.3 Calculation of final current demand for cathodic protection

6.3.1
The total final current demand, $I_{cf \text{ (tot)}}$ [A] for a specific pipeline section is calculated by adding the current demands for coated linepipe, field joints and pipeline components calculated from:

$$I_{cf} = A_c \times f_{cf} \times i_{cm} \times k \quad (3)$$

as described in [6.2] above. Values for $i_{cm}$ are given in Table 6-2 and $f_{cf}$ is given in [6.3.2]. $k$ is 1 (one) or as defined according to [6.1.5].

Guidance note:
The design “initial” and “final” current densities as defined in DNVGL-RP-B401 refer to the anticipated current demand (at a fixed protection potential of $-0.80$ V) for the initial polarisation of a bare steel surface, and for re-polarisation of a bare steel surface that has become depolarised due to the mechanical removal of surface layers (calcareous deposits). For pipelines coated with the systems defined in DNVGL-RP-F106 and DNVGL-RP-F102, the requirement to such polarising capacity is not considered relevant and $i_{cm}$ is used in equation (3).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.3.2
The final coating breakdown factor $f_{cf}$ is given by the equation:

$$f_{cf} = a + b \times t_f \quad (4)$$

using the a and b constants in Table A-1 and Table A-2 in App.A.

Guidance note:
It is the coating breakdown factor used for CP design that mainly determines the magnitude of the calculated current demand. Compared to this factor, the effect of variations of other design parameters such as design current densities and those associated with the anode performance is relatively small.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.4 Calculation of total net anode mass to meet mean current demand

6.4.1
Using the calculated total mean current demand $I_{cm \text{ (tot)}}$ in A, the total net anode mass $M$ [kg] required is calculated from:

$$M = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \quad (5)$$

where $u$ (dimension less) is the anode utilisation factor and $\varepsilon$ (in A·h/kg) is the electrochemical capacity of the anode material. (8760 is the number of hours per year).

The total net anode mass calculated from equation (5) shall be considered as an absolute minimum value.

Guidance note:
If a default anode distance of 300 m is adopted (see [6.7.1]), typical bracelet anode dimensions will normally give a significantly higher anode mass than required to meet the current demands in this RP and ISO 15589-2. Any excess anode mass installed can then be utilised as a contingency in case the calculated current demand was underestimated due to e.g. pipeline components not included in the current demand calculations, or unforeseen mechanical damage to the coating during installation and/or operation, or if the design life of the pipeline is extended. (For inclusion of contingency in pipeline CP design, see [6.1.5]).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---
6.4.2
The design anode utilisation factor \( u \) (dimensionless) shall be maximum 0.80 for bracelet anodes (minimum thickness 50 mm), and maximum 0.90 for elongated stand-off type of anodes placed on other subsea structures for protection of the pipeline.

**Guidance note:**
\( u \) depends on the anode core arrangement and for special anode designs the actual value may be smaller than the default values defined above; e.g. for bracelet anodes with a thickness < 50 mm, a consumption to a utilisation factor of 0.80 may lead to the exposure of anode steel cores. Candidate anode manufacturers should be consulted in such cases to assess the need for reduction of the \( u \) value. Hence, it shall be ensured that the anode inserts can support, and provide electrical contact to, the remaining anode material when the anode has been consumed to its design utilisation factor.

---end---of---guidance---note---

6.4.3
The anode material electrochemical capacity \( (\varepsilon) \) and closed circuit potential \( (E_a) \) to be used for CP design shall be selected according to Table 6-3 which largely complies with the default values in ISO 15589-2. The data are applicable for type Al-Zn-In and Zn anodes with chemical composition according to Table 6-1 of this RP.

**Guidance note 1:**
Data on anode electrochemical capacity from laboratory examinations (including long term testing according to Annex C of the ISO standard or DNVGL-RP-B401 App.B) will typically result in values close to the theoretical limit (e.g. > 2500 Ah/kg for Al-Zn-In material). This is due to the relatively high anodic current densities that are utilized for testing. For compliance with this RP, such data shall not replace the design values for electrochemical capacity in Table 6-3 unless specified or accepted by owner. (In the ISO standard they are “recommended” and can be replaced if “properly documented”).

---end---of---guidance---note---

**Guidance note 2:**
In the previous revision of this RP, electrochemical capacities for Al-Zn-In anodes referred to those in the 2004 revision of ISO 15589-2 but implementing a reduction factor of 0.80. In the 2012 revision of the ISO standard, electrochemical capacities for Al-Zn-In anode material exposed to seawater or sediment at ambient temperature and in sediments at 30°C have been reduced by a factor close to 0.80 whilst those for 80°C have remained the same as in 2004. In this revision of the RP, the recommended values in Table 6-3 are the same as the preceding revision of the RP. Due to the changes in ISO they comply with those in ISO 15589-2 for seawater exposure up to 60°C whilst for 80°C and for sediment exposure at 60°C the value is still up to 20% lower (i.e. more conservative) than recommended in the 2012 version of ISO 15589-2.

---end---of---guidance---note---

6.4.4
For anodes on pipelines defined as ‘non-buried’ for calculation of current demand (see [6.2.4]), the surface temperature of the anode shall be selected as the mean temperature of the ambient seawater (\( \leq 30°C \)). For anodes on buried sections (see [6.2.4]), the internal fluid temperature may be used as a conservative estimate of the anode surface temperature. As an alternative, the anode surface temperature may be estimated by heat transfer calculations taking into account any thermal insulation applied between anode and steel surface, in addition to external environmental parameters. For surface temperatures in the ranges 30 - 60°C and 60 - 80°C, current capacities may be estimated based on interpolation of the data in Table 6-3. Use of design parameters for temperatures exceeding the maximum/minimum limits in the table shall be specified or accepted by owner.
6.5 Calculation of total anode current output to meet final current demand

6.5.1
Based on the required total net anode mass \( M \) [kg] for the pipeline or pipeline section as calculated from equation (5) and the pipeline outer diameter (including coating), a tentative pipeline anode dimension can be defined. The final anode current output \( I_{af} \) [A] of an anode (with tentative dimensions) at the end of its design life shall be calculated using the equation

\[
I_{af} = \frac{\Delta E_A}{R_{af}} = \frac{(E_a^0 - E_a^0)}{R_{af}}
\]

where \( E_a^0 \) [V] is the design closed circuit anode potential. The design values in Table 6-3 shall apply. \( E_c^\circ \) [V] in equation (6) is the design protective potential of the linepipe material to be protected (see [6.7.11]) and \( R_{af} \) [ohm] is the final anode resistance, see [6.5.2]. Equation (6) assumes that the metallic resistance in the pipeline is much smaller than the anode electrolytic resistance, \( R_{af} \). This assumption is applicable to all types of pipelines with pipeline coatings as defined in DNVGL-RP-F106 and DNVGL-RP-F102 and with a distance from the anode of up to 600 m as a maximum (i.e. 300 m by design and including loss of one anode, see. [6.7.1]).

6.5.2
The final anode resistance \( R_{af} \) in equation (6) shall be calculated according to equation (7); \( \rho \) [ohm-m] being the resistivity of the seawater or seabed sediment and \( A \) [m²] being the exposed surface area of the anode. The final current output shall be calculated based on the remaining exposed surface area when the anode has been consumed to its utilisation factor. For bracelet anodes the final exposed area shall be assumed to be equivalent to the initial area facing the surface to be protected. For pipelines defined as 'non-buried' in [6.2.4], the ambient temperature seawater resistivity (annual average) is applicable for calculation of \( R_{af} \). Based on seawater salinity and temperature, the seawater resistivity may be estimated based on Figure B-1 and Figure B-2 in App.B. For buried pipeline anodes, an actually measured soil resistivity for the specific pipeline section should preferably be applied, corrected for any significant annual temperature variations. As an alternative, a default value of 1.5 ohm-m may be used for full salinity seawater (min. 30‰). For compliance with this RP, calculation of anode resistance for pipeline sections with 'partly burial' shall not be performed, as the anodes shall be considered as either completely exposed or completely buried, see [6.2.4].

\[
R_{af} = 0.315 \cdot \frac{\rho}{\sqrt{A}}
\]

6.5.3
From the final (individual) anode current output \( I_{af} \), and the total final current demand \( I_{cf(tot)} \) for cathodic protection of a pipeline section, the required number \( N \) of anodes becomes

\[
N = \frac{I_{cf(tot)}}{I_{af}}
\]

The calculation of the final number will typically involve some adjustment(s) of the initially selected (tentative) anode dimensions and re-iterative calculations in order to meet the requirements for both total net anode mass \( M \) and total final anode current output \( N \cdot I_{af} \).
6.6 Anode design

6.6.1
The scope of this section is limited to pipeline anodes (bracelet or saddle type). For pipelines, or sections of pipelines, to be protected by anodes installed on adjacent structures, the project specifications for anode installation on such structures will apply.

Guidance note:
For pipeline bracelet anodes to be installed on top of the pipeline coating, the design of anode installation devices should be addressed already during the pipeline conceptual design and completed during the detailed design. Purchaser of anodes should consider the need for verification of the final anode design by the pipeline installation contractor prior to casting of anodes.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.6.2
For each anode size, an outline anode drawing shall be prepared showing tentative locations of anode cores and dimensions. The drawing shall reflect the requirements to tolerances associated with linepipe dimensions and tolerances of any coating under the anode. Provisions for anode attachment (e.g. welding of anode tabs) and electrical connection (e.g. cables) shall be indicated in the drawing. It shall be ensured that the locations of anode cores are such that they are not exposed when the anode has been consumed to its utilisation factor.

Guidance note:
For pipelines to be installed with concrete coating, anodes may be installed either prior to or after completed application of the concrete and a reference to the concrete coating specification is pertinent. For large bracelet anodes the benefits of sectioning of anode half shells in two pieces (with shared anode core) may be considered.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.6.3
Bracelet anodes shall be attached to the pipe by bolting or welding of anode core tabs. For any bolting materials to be used, specified minimum yield strength (SMYS) shall not exceed 720 MPa (to prevent HISC by CP) and quality control shall be specified to ensure a hardness of max HRC 35. See [8.7.2] for requirements to welding qualification of anode core tabs.

6.6.4
It shall be ensured that the dimensions of anodes to be mounted on concrete coated pipes are such that metallic contact of anodes to steel reinforcement is prevented; a minimum distance of 25 mm being recommended in ISO 15589-2. (Reference to be made to cut-back dimensions specified in the concrete coating specification).

6.6.5
It is recommended that the integrity of bracelet anodes attached by clamping on top of linepipe coating is verified by calculations or testing, simulating maximum shear stresses during installation operations.

6.6.6
Unless specified or accepted by purchaser, anode fastening by fusion welding to linepipe or pressure containing pipeline components in corrosion resistant alloys (CRA) shall be avoided (even if doubler plates are applied). Electrical continuity to the pipeline is preferably to be provided using brazing, thermite (alumino-thermic) welding or explosion welding. The heat input from a thermite or brazing process shall be controlled so that excessive heat input is prevented (see [8.3.2]). See [8.7.1] for requirements to welding qualification for pin brazing and alumino-thermic welding.

6.6.7
Cables for electrical connection of anodes to pipeline shall have a core of stranded copper wire with a minimum cross section of 16 mm². Each anode unit shall have two cables connections to the pipe; two anode half shells forming a bracelet anode being considered as one unit. The cables shall have a polymeric
sheathing and brazed connections to cable shoes in copper or steel. Any cables included in the scope of supply shall have a soldered connection to cable shoes. The design shall ensure that anode cables are protected, e.g. by use of suitable infill materials during transportation of pipe joints with anodes attached and the subsequent pipeline installation. The detailed CP design report shall further specify requirements to any repair of linepipe coating due to cable attachment and infill. For linepipe coating field repairs, see DNVGL-RP-F102.

6.6.8

Bracelet anodes shall be coated on surfaces facing pipe and concrete coating using a marine grade liquid epoxy with a minimum nominal dry film thickness of 100 μm (or other coating/lining specified or accepted by purchaser).

6.7 Distribution of anodes

6.7.1

In ISO 15589-2, Sec.8.1 a default maximum anode distance of 300 m is advised for pipeline CP design and has been adopted for this RP. It is presumed in the ISO standard that this distance will ensure sufficient anode current output in the event of an adjacent anode being lost such that the actual anode distance becomes up to 600 m. This assumption is applicable to all types of pipelines with pipeline coatings as defined in DNVGL-RP-F106 and DNVGL-RP-F102. For larger anode distances than 300 m (i.e. by design without assuming any loss of anodes), the effect of the metallic resistance in the pipe wall shall be taken into account, assuming loss of one anode (i.e. doubling the design distance). Calculation of maximum anode distance between bracelet anodes (2L) is described in [6.7.9].

Guidance note 1:

For medium and long distance export pipelines with concrete coating, the concept of using pre-installed anodes and with a default maximum distance of 300 m is recommended for most purposes. Except for very long design lives (> 30 years), a typical bracelet anode size (i.e. as convenient for anode casting) will then give an installed anode net mass that exceeds the calculated required net anode mass. The anode distance of maximum 300 m will in most cases be governing in the design calculations for these pipelines. In brackish water, however, the total number of anodes required may be determined by the requirement for total final current output and the maximum anode distance may have to be reduced accordingly.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:

Some caution should be exercised when optimising (i.e. reducing) the number of anodes based on attenuation calculation of maximum allowed anode distance. Any contingency to account for underestimated current demand or lifetime extension may then be lost.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 3:

For surfaces without pipeline coating as defined in DNVGL-RP-F106 and DNVGL-RP-F102 (e.g. spools protected by “ordinary” marine coating) attenuation calculations may be required also for bracelet anodes with maximum 300 m anode distance. For input to current demand and coating breakdown factors in these calculations, see [6.2.8].

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.2

According to this RP, relatively short pipelines (< 10 - 30 km approximately depending on the design and operating conditions) may be protected by installing anodes on subsea structures located at the pipeline termination(s) and to which the pipeline is electrically connected. Examples of such structures are subsea production templates, riser bases and platform substructures. Calculation of maximum attenuation lengths (L) for anodes installed on subsea structures are given in [6.7.6] to [6.7.8].

More than one bracelet anode may be located on the same pipe joint but it shall than be ensured that the distance is sufficient (tentatively min. 3 pipe diameters) to ensure no significant interaction reducing their current output capacity.

Anodes (elongated type) may also be installed on a dedicated structure (sledge) with a cable connection for electrical continuity to the pipeline. Calculations of anode current output from anode arrangements on sledges shall take into account the significance of a voltage drop in the cable connection and any interaction...
between closely spaced anodes affecting their electrolytic resistance (i.e. “anode resistance” according to [6.5.2]).

Guidance note:
Also ISO 15589-2 encourages CP of “short” pipelines by anodes located at each end of the pipeline. To calculate the protective length of such anodes, this standard recommends a so-called attenuation calculation contained in its Annex B, Sec.B.2. This formula is fairly complicated and contains the pipe-to-electrolyte insulation resistance as the most critical parameter and which “should be selected based on practical experience”. This RP, however, offers a simplified approach with specification of all required design parameters. (A similar approach has been included in Sec.B.3 of ISO 15589-2. It should be noted though that whilst the definition of the protective length \( L \) from an anode (or assembly of anodes) is the same in Sec.B.2 as in this RP, it is defined as \( L/2 \) in Sec.B.3 of the ISO standard.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.3
The length of a pipeline \( L \) [m] that can be protected by anodes located on a secondary structure (with excess CP capacity) is determined by the global protection potential \( E'_c \) [V] at this structure, the protection potential criterion \( E_p \) [V] of the linepipe material, the metallic voltage drop \( \Delta E_{Me} \) [V] associated with the electrical current \( I_{cf} \) in the pipeline and its metallic resistance \( R_{Me} \) [ohm]. It follows from Ohm’s law:

\[
\Delta E_{Me} = E_p - E'_c = R_{Me} \cdot I_{cf} \quad (9)
\]

\( E_p \) [V] of the linepipe material is specified in [6.7.11] and \( E'_c \) [V] is specified in [6.7.8] for uncoated and coated subsea structures and platform sub-structures, \( I_{cf} \) [A] is defined in [6.7.4] (equation (10)) and \( R_{Me} \) [ohm] is defined in [6.7.5] (equation (12)).

Guidance note:
The length of cut-back refers to the corrosion protective coating, irrespectively of any concrete coating. For cutbacks with length < 0.20 m, a default minimum value of 0.20 m is recommended. With this default value, and for a pipeline section with all joints of 12 m length approximately, \( r = 0.033 \) and \( f'_{cf} = f_{cf} \) (linepipe) + 0.033 \( f_{cf} \) (FJC).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.4
The total cathodic current \( I_{cf} \) [A] entering the pipe section with a length of \( L \) [m] becomes:

\[
I_{cf} = L \cdot D \cdot \pi \cdot f'_{cf} \cdot i_{cm} \cdot k \quad (10)
\]

where

\( D \) [m] is the linepipe outer diameter and \( f'_{cf} \) (dimensionless) is the mean final coating breakdown factor calculated as a mean value for linepipe and field joint coating according to

\[
f'_{cf} = f_{cf} \text{ (linepipe)} + r \cdot f_{cf} \text{ (FJC)} \quad (11)
\]

In equation (11), \( r \) is the ratio of the lengths of the cutbacks and the linepipe coating for the specific pipeline or pipeline section.

Guidance note:
The length of cut-back refers to the corrosion protective coating, irrespectively of any concrete coating. For cutbacks with length < 0.20 m, a default minimum value of 0.20 m is recommended. With this default value, and for a pipeline section with all joints of 12 m length approximately, \( r = 0.033 \) and \( f'_{cf} = f_{cf} \) (linepipe) + 0.033 \( f_{cf} \) (FJC).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.5
The metallic resistance \( R_{Me} \) [ohm] is calculated from:

\[
R_{Me} = \frac{L \cdot \rho_{Me}}{\pi \cdot d \cdot (D - d)} \quad (12)
\]

where \( d \) [m] is the pipe wall thickness and \( \rho_{Me} \) [ohm·m] is the resistivity of the linepipe material. Values for relevant linepipe materials \( \rho_{Me} \) is given in [6.7.10].

Guidance note:
The length of cut-back refers to the corrosion protective coating, irrespectively of any concrete coating. For cutbacks with length < 0.20 m, a default minimum value of 0.20 m is recommended. With this default value, and for a pipeline section with all joints of 12 m length approximately, \( r = 0.033 \) and \( f'_{cf} = f_{cf} \) (linepipe) + 0.033 \( f_{cf} \) (FJC).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.6
Assuming that the cathodic current is largely uniformly distributed on \( L \) [m], and inserting equation (12) and the integrated current in equation (10) in equation (9):

\[
\Delta E_{Me} = E_p - E'_c = \frac{L^2 \cdot \rho_{Me} \cdot f_{cf} \cdot i_{cm} \cdot k \cdot D}{2 \cdot d \cdot (D - d)} \quad (13)
\]
and $L$ [m] becomes

$$L = \frac{2 \cdot \Delta E_{Me} \cdot d \cdot (D - d)}{\rho_{Me} \cdot D \cdot f_{cf} \cdot i_{cm} \cdot k}$$

(14)

The above equation gives a simplified method to assess the voltage drop associated with a cathodic current in a pipeline.

6.7.7

In case the cathodic current is expected to be unevenly distributed along $L$ [m], it may be assumed conservatively that all current enters at $L$ and equation (12) in equation (9):

$$\Delta E_{Me} = E_p - E'_c = \frac{L^2 \cdot \rho_{Me} \cdot f_{cf} \cdot i_{cm} \cdot k \cdot D}{d \cdot (D - d)}$$

(15)

and $L$ [m] becomes

$$L = \frac{\Delta E_{Me} \cdot d \cdot (D - d)}{\rho_{Me} \cdot D \cdot f_{cf} \cdot i_{cm} \cdot k}$$

(16)

Guidance note:
The above equation is simulating that all the current is to enter the pipeline at one point (e.g. a defect FJC) farthest away from the structure where the anodes are installed.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.8

For cathodic protection by anodes on coated subsea structures freely exposed to seawater, a design global protection potential ($E'_{c}$) of $-0.95$ V is recommended as a reasonably conservative default value in equation (13)/(15). For structures with major areas in bare steel (e.g. platform sub-structures) $-0.90$ V is recommended as a default value in equation (14)/(15).

Guidance note 1:
Unless extra contingency has been included in the calculation of the final current demand, it is recommended that the more conservative approach of equation (16) in [6.7.7] is implemented for calculation of attenuation for anodes installed on a subsea structure and/or a platform at the ends of a pipeline).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:
A pipeline CP design based on anodes located on adjacent structures must ensure that the CP systems of these structures have sufficient capacity. Hence, towards the end of the life of a CP system, the global protective potential may increase to values less negative than those assumed above. For new structures, the CP system can be designed with an additional conservatism (e.g. extended CP design life). For an existing structure with marginal CP capacity, monitoring of the global protection potential and ultimately retrofitting of anodes may be required. (Note also that even with dedicated pipeline anodes, a pipeline electrically connected to structures with marginal CP may suffer premature anode consumption and ultimately under-protection).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.9

If CP is to be provided by bracelet anodes, and the default value of maximum 300 m according to [6.7.1] shall not apply, then the maximum distance between successive anodes may be calculated using equation (20) below. For a pipeline section with a length of $L_{tot}$ [m] to be protected by $N$ bracelet anodes, the maximum distance between anodes becomes $2L$ [m]:

$$2L = \frac{L_{tot}}{N}$$

(17)
$L$ [m] may be calculated taking into account both the electrolytic voltage drop $\Delta E_A$ [V] and the metallic voltage drop $\Delta E_{Me}$ [V] for which the following relation applies:

$$\Delta E_A + \Delta E_{Me} = E_p - E_a^o$$  \hspace{1cm} (18)

Inserting equation (6), equation (15), equation (8) and equation (17) into equation (18):

$$\Delta E_A + \Delta E_{Me} = E_p - E_a^o = \frac{L^2 \cdot \rho_{Me} \cdot f' \cdot i_{cm} \cdot k \cdot D}{d \cdot (D - d)} + \frac{2 \cdot I_{c(tot)} \cdot R_{af} \cdot L}{L_{tot}}$$  \hspace{1cm} (19)

and $L$ [m] becomes:

$$L = \frac{d \cdot (D - d)}{\rho_{Me} \cdot D \cdot f' \cdot i_{cm} \cdot k \cdot L_{tot}} \cdot \left[ -R_{af} \cdot I_{c(tot)} \cdot L_{tot} \right] + \sqrt{\left( \frac{R_{af} \cdot I_{c(tot)}}{L_{tot}} \right)^2 + \frac{\rho_{Me} \cdot i_{cm} \cdot k \cdot f' \cdot D}{d \cdot (D - d)}} \cdot (E_p - E_a^o)$$  \hspace{1cm} (20)

$L$ in equation (20) shows the maximum anode distance provided sufficient anode current output when the loss of an anode is taken into account. (If no loss of anodes can be ensured, maximum anode distance will be 2$L$).

It is subsequently to be confirmed that the individual net anode mass $M_a$ [kg] meets the total net anode mass requirement (M):

$$N \cdot M_a = M$$  \hspace{1cm} (21)

**Guidance note:**

Equation (20) is equivalent to equation (B.4) in ISO 15589-2. The maximum anode distance ($L$) calculated from equation (20) should be considered as an absolute maximum value and not an optimum distance. The definition of distance between bracelet anodes (i.e. other than the default value of 300 m recommended in [6.7.1]) will be dependent on the anode design, the installation concept (onshore/offshore installation) and the minimum net anode mass required (see [6.4.1]).

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.10

The following default values for specific electrical resistivity ($\rho_{Me}$) of the linepipe material (applicable to all practical pipeline operating temperatures) and to be used for calculation of $L$ are recommended:

- CMn-steel linepipe $\quad 0.2 \cdot 10^{-6}$·ohm·m
- Type 13Cr linepipe $\quad 0.8 \cdot 10^{-6}$·ohm·m
- Type 22Cr/25Cr linepipe $\quad 1.0 \cdot 10^{-6}$·ohm·m

6.7.11

The following design protective potentials, $E_{c^o}$, shall be used for calculations of final current demand (see [6.5.1], equation (6)) and are recommended as protection potential criteria, $E_p$, for calculation of $L$ [m] according to equation (14), (16) and (20):

- For CMn steel linepipe $\quad -0.80$ V
- For martensitic stainless steel type 13 Cr linepipe $\quad -0.60$ V
- For ferritic-austenitic (duplex) stainless steel linepipe $\quad -0.50$ V

The potentials above refer to an Ag/AgCl/seawater reference electrode and are applicable to both buried and unburied pipelines. These values do not include any allowance for IR drops associated with recordings of pipe potentials.

**Guidance note 1:**

ISO 15589-2 recommends a protection potential for CMn steel linepipe material of −0.80 V and −0.90 V for seawater and sediments, respectively; the more negative value being justified by ‘possibility of SRB activity’. DNV GL considers that such exposure will apply to all submarine pipelines; still a protection potential of −0.80 V is recommended for CMn steel linepipe material to achieve adequate protection both for seawater and sediment exposure. DNV GL is not aware of any published evidence that a potential between −0.80...
V and −0.90 V (recorded free of IR drop, see [1.6.2]) has resulted in corrosion damage to carbon steel exposed to marine sediments normally being anaerobic due to bacterial activity.

Guidance note 2:
Ordinary Al-Zn-In and Zn anode materials may provide protection potentials approaching a negative limit of −1.15 V and −1.05 V respectively. It may be decided during the conceptual pipeline design (see [1.1.3]) to restrict such negative potentials to avoid or reduce the risk of hydrogen induced stress cracking (HISC) of susceptible pipeline materials. This can be achieved by special anode alloys or installation of diodes, however, practical experience from such potential control is largely lacking. An alternative approach is to include restrictions on maximum permissible stress/strain according to DNVGL-RP-F112 (although the recommendations in this standard are defined for duplex stainless steels only).

6.7.12
Pipeline anodes connected to large offshore structures to which electrical continuity is established, will typically suffer premature anode consumption at the end(s) of the pipeline being connected also when the connected offshore structure is protected with a dedicated CP system. This is due to the fact that the pipeline bracelet anodes, especially for relatively small diameter pipelines, have a higher current density in relation to the net anode mass compared to large stand-off type anodes used on such structures.

Guidance note 1:
Interference between platform and pipeline anodes cannot be prevented by installing an extra pipeline anode at the ends of the pipeline as recommended in ISO 15589-2. On the other hand, such current drain will not normally be harmful to the integrity of the pipeline since the structure(s) involved will have sufficient CP capacity to compensate for the depletion of some pipeline anodes. In case interaction leading to premature consumption of pipeline anodes at interfaces to other CP systems is to be fully prevented, the CP systems will have to be electrically insulated by use of monolithic insulating joints.

Guidance note 2:
Additional anodes at the end of the pipeline may be useful in case a new pipeline is connected to an existing offshore structure with lack of adequate CP system (e.g. poorly designed CP or end of lifetime). However, for such cases a dedicated study should be performed where it is evaluated if some additional pipeline anodes are adequate or if other type of retrofitting of anodes on the dedicated structure may be required.

Guidance note 3:
Special precautions should be made in case pipelines with bracelet anodes are installed in connection with offshore structures with ICCP system (e.g. FPSOs) as a less negative potential on the FPSO than on the bracelet anodes will result in depletion of bracelet anodes. There may be a need for installation of monolithic insulating joint to disconnect ICCP FPSO system and subsea CP in order to control the depletion of anodes on the pipeline. The insulation joint should then be installed above water.

6.7.13
Crossing of pipelines with galvanic anode CP and crossing of current transmission cables will not interfere with the CP system of the pipeline concerned. However, single cable transmission of direct current using the seawater for return of current may damage anodes and ultimately the pipeline. The distance between the pipeline and any of the land terminations of the single cable transmissions should be identified and possible detrimental interference should be evaluated already during the conceptual design (if applicable).

6.8 Documentation of completed cathodic protection detailed design

6.8.1
The following documentation shall be contained in the CP detailed design report:

— references to relevant standards and project specifications (including revision number)
— calculation of average and final current demands for individual sections of the pipeline
— calculation of total anode net mass for the individual sections, to meet the average current demand(s)
— selection of bracelet anode and/or anodes on adjacent structure as concept for CP of the pipeline
— calculations of pipeline metallic resistance to verify the feasibility of CP by anodes on adjacent structure(s) as the final CP concept or a bracelet anode spacing exceeding the default maximum value of 300 m recommended in ISO 15589-2 (i.e. if any of these options apply)
— calculation of final anode current output to verify that the final current demand can be met for the individual sections of the pipeline
— number of anodes for the individual pipeline sections, and resulting total net anode mass to be installed on each section
— outline drawing(s) of anodes with fastening devices (and dimensions/materials of continuity cables, if applicable), including tentative tolerances and requirements to repairs of pipeline coating for cable attachment (if applicable). Location of anode in relation to pipe ends and any continuity cable in relation to parent/concrete coating cut-back to be indicated
— chemical composition of anode material for pipeline bracelet anodes (e.g. reference to Table 6-1 of this RP)
— standard for anode manufacture and installation (e.g. reference to Sec.7 and Sec.8, respectively of this RP)
— any special requirements to anode manufacture and installation.

**Guidance note:**
The detailed CP design documentation should be subjected to independent third party verification. Anode design may have major implications for pipeline installation and should be reviewed and accepted by the pipeline installation contractor.
SECTION 7  ANODE MANUFACTURE

7.1  General

7.1.1  This section covers the manufacture of galvanic anodes, including preparation of anode cores. The requirements and guidelines in this section are in compliance with those in ISO 15589-2, Sec.9 and Sec.10, giving some amendments, mostly related to quality control. The following references to specific requirements in ISO 15589-2 have been made:

- materials, welding, surface preparation and inspection of anode cores, see Sec.9.3 and Sec.10.2 in ISO 15589-2
- testing and inspection of anodes; see Sec.10 in ISO 15589-2.

7.1.2  This section is intended for manufacture of pipeline (bracelet type) anodes. For manufacture of other anodes located on adjacent structures being electrically connected to the pipeline and intended for pipeline CP, reference is made to DNVGL-RP-B401 Sec.8.

7.1.3  A certified/certifiable quality management system should be in place to ensure compliance with the requirements to anode manufacture in this RP.

7.2  Manufacturing procedure specification

7.2.1  All work associated with the manufacture of galvanic anodes, including any qualification of the manufacturing procedure by a pre-production test (PPT, see [7.3]) shall be described in a manufacturing procedure specification (MPS). This document shall include as a minimum:

- specification of anode core materials, including requirements to certification
- specification of aluminium or zinc raw materials (including max. contents of impurity elements; as a minimum those referred to in Table 6-1)
- procedure for receipt, handling and storage of materials, including any requirements to certification of other materials (e.g. paint coating)
- specification of maximum and/or minimum contents of anode material alloying elements and max contents of impurity elements in cast anodes
- detailed anode drawing with anode inserts and provisions for fastening and electrical continuity, including tolerances for anode dimensions, gross and net weight and location of anode cores
- welding procedure specification and reference to qualification test (WPQ) for welding of anode cores, and qualification requirements for welders
- description of preparation of anode cores prior to casting
- description of anode casting, including control of temperature and addition of alloying elements
- definition of anode heat, batch/lot as referred to in MPS
- procedures for inspection and testing of anodes
- re-testing and other actions in case of failure to meet acceptance criteria in ITP
- procedure for fastening of anode cables to anode tabs, if applicable, including qualification of any associated brazing or welding
- procedure for coating of bracelet anode surfaces facing pipeline and any concrete coating
- procedure for handling, storage and shipping of anodes
- procedure for marking, traceability and documentation.
Anode chemical composition limits, detailed anode drawings and procedures for the last two items are all subject to acceptance by purchaser.

**Guidance note:**
Anode cables are typically included in the scope of supply for anode manufacturer, not installation contractor.

---END---OF---GUIDANCE---NOTE---

7.2.2

Purchaser may specify (see [5.3.1]) that more detailed procedures for testing/inspection (e.g. electrochemical testing) and other information relevant to quality control, handling of nonconformities (see [7.6.7]) and concession requests (see [7.5.6]) are included in the MPS.

### 7.3 Pre-production test

#### 7.3.1

The primary objective of the pre-production test (PPT; also referred to as e.g. procedure qualification test or procedure qualification trial, PQT) is to verify that the MPS is adequate to achieve the specified anode properties. Of particular interest are those aspects that require destructive testing and hence cannot be frequently verified during regular production. The PPT shall use the specific materials and equipment as for regular production.

**Guidance note:**
It is strongly recommended that the requirement for a PPT of pipeline bracelet anodes is not waived, that the PPT is performed in due time prior to start of the production, and that it is witnessed by a competent person engaged as an independent verifier.

---END---OF---GUIDANCE---NOTE---

#### 7.3.2

Each mould to be used for production shall be subject to qualification by PPT. Specific requirements to the PPT, including e.g. number of anodes to be cast for each mould and subsequently being inspected (including those for destructive examination), schedule for notification and reporting, shall be specified in the purchase documents.

#### 7.3.3

An MPS and an inspection and test plan (see [7.4.2]) specific for the PPT, together with a detailed schedule for anode casting, inspection and/or testing and reporting shall be submitted to purchaser in a timely manner (as per the purchase document) prior to start-up of the qualification activities.

#### 7.3.4

Data sheets and calibration certificates for instruments essential to quality control (e.g. temperature sensors) shall be available for purchaser’s review during the PPT.

#### 7.3.5

Results from all inspection, testing and calibrations during qualification, recordings of essential operational parameters for casting and material certificates shall be compiled in a PPT report. All inspection/testing shall be traceable to the specific anode ID. Unless otherwise agreed, the report shall be accepted by purchaser prior to start of production.

**Guidance note:**
The report should include a section where the results are summarized and concluded with reference to the different certificated/spreadsheets as attachments. Number of anodes and anode ID for all anodes included in the PPT should be listed in the beginning of the report.

---END---OF---GUIDANCE---NOTE---

#### 7.3.6

In case a new anode mould (or modified/repaired mould) is to be utilised during current production, a new PPT shall be performed prior to start of production to verify that weight, dimensions and location of anode cores (destructive test) comply with specification.
7.4 Quality control of production

7.4.1
Prior to start-up of regular production, contractor shall submit the following documents to purchaser for acceptance:

— a PPT report, see [7.3.5]
— a project specific MPS updated to reflect the process parameters used during the completed and accepted PPT
— a project specific inspection and testing plan (ITP) updated to reflect the process parameters used during the completed and accepted PPT
— a daily log format (see [7.6.8])
— a final documentation index (see [7.9.4])
— a description of responsibilities of personnel involved in quality control (e.g. in anode manufacturer’s quality manual).

7.4.2
The ITP shall be in tabular form, defining all quality control activities associated with receipt of materials, preparation of anode cores (and anode cables, if applicable), casting, inspection, testing and marking of anodes. The activities shall be listed in consecutive order, with each activity assigned a unique number and with reference to the applicable standards, contractor’s procedures or specific tools to be used for verification. Furthermore, frequency and/or extent of inspection and testing, acceptance criteria and reporting document shall be defined in the plan. The ITP shall further contain a column for inspection codes, (e.g. inspection, witnessing and hold points) indicating the involvement of contractor, purchaser and any 3rd party. Purchaser shall identify any hold points for witnessing in the ITP and inform contractor accordingly. A recommended format for an ITP is contained in App.C.

Guidance note:
It is recommended that the ITP also reflects the relevant manufacturing steps, in addition to the inspection and testing activities, all in the consecutive order they occur during production

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7.4.3
The MPS, ITP, and daily log shall be in English, unless otherwise agreed.

7.4.4
Procedures and work instructions referenced in the ITP, and applicable acceptance criteria, shall be available to all persons concerned with the associated work and in a language of which they have a working knowledge.

7.4.5
Purchaser shall have the right to inspect any activity associated with the work throughout production and to carry out audits of contractor’s QA/QC system.

7.5 Materials and casting

7.5.1
Unless otherwise specified or accepted by owner, the compositional limits (alloying and impurity limits) for galvanic anode materials in Table 6-1 of this RP shall apply.
**Guidance note:**
The compositional limits in Table 6-1 of this RP meet the requirements in ISO 15589-2 but the minimum content of Zn for Al-Zn-In anodes has been substantially increased; other changes being marginal. The increased Zn content is primarily to improve the performance of anodes in cold seawater.

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**7.5.2**
Contractor shall verify that all materials received for anode manufacture are in accordance with the specified requirements. The verification may include actual testing or review of supplier’s certificates. Review of certificates and any verification testing to be performed by contractor shall be included in the ITP. Any materials checked and found non-conforming shall be marked and quarantined.

**7.5.3**
Materials, welding, surface preparation and final inspection of anode cores shall comply with ISO 15589-2, Sec.9.3 and Sec.10.2. All general requirements to design of anode cables in [6.6] of this RP shall apply, if anodes cables are included in the scope of supply for the anode manufacturer.

**7.5.4**
Requirements to coating on surfaces facing pipe and any concrete coating as described in [6.6.8] shall apply. Materials to be used for surface preparation and coating shall be contained in their original packing until use and shall be adequately marked, including:

- supplier’s (i.e. coating manufacturer’s) name and location of manufacture
- material type and product designation
- batch/lot number
- date of manufacture (and shelf life, if applicable)
- manufacturing standard (if applicable)
- instruction for storage and handling (including health and safety notes).

**7.5.5**
Contractor shall ensure that materials for anode casting, coating and surface preparation are stored and handled so as to avoid damage by environment or other effects. Supplier’s (i.e. coating manufacture’s) recommendations for storage and use shall be readily available for purchaser’s review.

**7.5.6**
All work associated with preparation of anode cores and casting of anodes shall be carried out according to the qualified MPS, describing equipment and procedures to be used. Once the MPS has been qualified, any changes shall be formally accepted by purchaser through a concession request (CR).

**7.5.7**
Equipment for monitoring of process parameters critical to quality (e.g. temperature sensors) shall be calibrated at scheduled intervals as specified in the ITP (see [7.4.2]).

**7.5.8**
All anodes produced shall be traceable to certificates for anode core and coating materials.

### 7.6 Inspection and testing of anodes

**7.6.1**
Chemical composition of produced anodes shall be verified at a frequency as defined in ISO 15589-2, Sec.10.3; i.e. two samples from each heat > 500 kg (one in the beginning and one at the end) and minimum one sample for each heat < 500 kg (beginning of first heat, end of second heat etc.). For spectrometric analyses of anode chemical composition, reference standards with a chemical composition (i.e. for the
specified contents of alloying and impurity elements) certified by an independent party shall be used. Purchaser shall have the right to require anode sample material for verification testing in an independent laboratory, or to present samples for testing by contractor. Purchaser may further specify that Contractor shall retain sample material for any additional chemical analyses and/or electrochemical testing (to be specified in the ITP).

7.6.2
Sampling for electrochemical testing shall be carried out for each heat produced. Electrochemical testing of anodes shall be carried out at a frequency as specified in Sec.10.10 of ISO 15589-2; i.e. minimum one set of test for each 15 tons of anodes produced. The testing shall be performed according to a detailed manufacturer specific procedure meeting the general requirements in Annex E of ISO 15589-2 or DNVGL-RP-B401 App.B and the following acceptance criteria shall apply:

**Aluminium based anodes:**
- electrochemical capacity: minimum 2500 Ah/kg
- closed circuit potential: $\leq -1.05$ V at the end of the 4th testing period.

**Zinc based anodes:**
- electrochemical capacity: minimum 780 Ah/kg
- closed circuit potential: $\leq -1.03$ V at the end of the 4th testing period.

**Guidance note:**
The test method in Annex E of ISO 15589-2 is equal to the test method in DNVGL-RP-B401 App.B. Testing of anodes at ambient temperature according to ISO 15589-2, Annex E and DNVGL-RP-B401 App.B are adequate for quality control of anodes with a chemical composition meeting the requirements in Table 6-1. The testing performed in synthetic or natural seawater (salinity min. 30‰) at 20 ± 3°C is appropriate for any seawater ambient temperature and for brackish water with salinity down to at least 12‰ and 5‰ for Al and Zn based anodes, respectively. Hence, testing at reduced temperature/salinity is not actually required. It is normal practice to carry out testing at room temperature for quality control also to be exposed at temperatures exceeding seawater ambient temperature. For use of laboratory reference electrodes (including SCE and Ag/AgCl/sat KCl), see guidance note in [6.1.6].

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7.6.3
For verification of anode dimensions and weight and visual examination of anode surfaces for cracks/pores, including frequency of testing and acceptance criteria, reference is made to ISO 15589-2, Sec.10.4 - Sec.10.8. Visual examination (inspection of cracks and surface irregularities) shall be performed on every anode and dimension and weight control shall be performed on minimum 10% of the anodes.

**Guidance note:**
As far as practical, acceptance criteria for surface defects should be defined in MPS/ITP in quantitative terms (reference to e.g. “smooth” or “crack-free” surfaces should be avoided).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.6.4
Requirements for destructive testing of anodes during production and fit-up tests for verification of bracelet anode tab locations (e.g. fit-up test on dummy pipe sample) shall be specified in purchase order, including frequency, acceptance criteria and consequences of any nonconformity. Purchaser shall have the right to select anodes for such batch-wise testing. Destructive testing for internal defects and core position shall meet requirements for testing and acceptance criteria in ISO 15589-2, Sec.10.9.

**Guidance note:**
A common frequency for destructive testing and fit-up test during production is one anode half shell every 50 or 100 anodes.

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7.6.5
Failures during testing which are obviously due to defective sampling or operational errors of testing equipment may be disregarded and testing repeated on the same anode.
7.6.6
In case of failure during fractional testing (e.g. destructive testing of one per 50 anodes) and unless otherwise agreed, the preceding and following anodes shall be tested individually until at least 3 successive anodes are acceptable.

7.6.7
In case of repeated failures to meet specified properties, production shall be discontinued, contractor shall issue a nonconformity report and the cause of the failure shall be determined. Nonconforming anodes (individual or batches) shall be marked and quarantined.

7.6.8
All data from inspection and testing of anodes and calibration of testing and monitoring equipment shall be noted in the daily log. For anode specific data, reference shall be made to the unique anode number and heat (see [7.7.2]). The log shall be up-dated on a daily basis and shall be available for purchaser’s review at any time during manufacturing.

7.7  Traceability and marking

7.7.1
Specific requirements to marking and documentation format shall be specified in purchase document. Contractor’s marking shall be described in the MPS and included as a specific activity in the ITP.

7.7.2
All results from inspection and testing during qualification and production shall be traceable to a unique anode number and heat of anodes (as applicable), certificates for anode core materials and coating materials.

7.8  Handling, storage and shipping of anodes

7.8.1
Anodes shall be handled and stored such that damage to anode material and tabs is avoided, and in accordance with any special requirements in purchase documents. A procedure shall be contained in the MPS and is subject to acceptance by purchaser.

7.8.2
Any special requirements for packaging or other means of protection of anodes for shipping shall be defined in the purchase documents.

7.9  Documentation

7.9.1
Schedule for documentation to be provided prior to PPT and start of production (e.g. MPS and ITP) should be specified in purchase documents.

7.9.2
Prior to PPT (see [7.3]), contractor shall submit the following document to purchaser

— manufacturing procedure specification (MPS) for PPT (purchaser acceptance is required for special items, see [7.2.1])
— inspection and testing plan (ITP) for PPT (see [7.4.2])
— tentative daily log format (see [7.6.8]).
7.9.3
Prior to start of production, contractor shall submit the following document to purchaser for acceptance:

- PPT report (see [7.3.5])
- manufacturing procedure specification (MPS) for production (see [7.2.1])
- inspection and testing plan (ITP) for production (see [7.4.2])
- daily log format (see [7.6.8])
- final documentation index.

7.9.4
Contractor shall issue as final documentations (also referred to as “as-built documentation” or “final data book”). Unless otherwise agreed, this documentation shall contain the following:

- pre-production test (PPT) report (see [7.3.5])
- manufacturing procedure specification (MPS) for production (see [7.2.1])
- inspection and testing plan (ITP) for production (see [7.4.2])
- welding procedure qualification tests
- material data sheets (e.g. coatings)
- anode core and coating material certificates (see [7.5.8])
- complete inspection and testing data from daily logs (see [7.6.8])
- any accepted CR’s (see [7.5.6])
- any nonconformity reports (see [7.6.7]).
SECTION 8  ANODE INSTALLATION

8.1  General

8.1.1  This section covers the installation of galvanic anodes. The requirements and guidelines in this section are in compliance with those in ISO 15589-2, Sec.11, giving some amendments, mostly related to quality control. For general requirements to materials and welding/brazing associated with fastening of anodes and provision of electrical connection, see [6.6].

8.1.2  This section is primarily intended for installation of pipeline (bracelet type) anodes. For pipelines, or section of pipelines, to be protected by anodes installed on adjacent structures electrically connected to the pipeline, the project specifications for anode installation on such structures shall apply.

8.2  Installation procedure specification

8.2.1  All work associated with the installation of galvanic anodes on pipelines, including any qualification of the manufacturing procedure by a pre-production test (PPT) shall be described in an installation procedure specification (IPS). This document shall include, as a minimum:

— specification of materials and equipment to be used, including material data sheets
— procedure for receipt, handling and storage of anodes and materials for anode installation
— detailed drawing of anode installation (fastening to pipeline and any cables for electrical continuity), including tolerances
— procedures for inspection and testing of anode fastening
— description of documentation of design, materials and inspection records.

8.3  Pre-production test

8.3.1  A PPT shall be performed unless otherwise specified/agreed with purchaser. The primary objective of the pre-production test (PPT) is to verify that the IPS is adequate to achieve the specified properties. Of particular interest are those aspects that require destructive testing and hence cannot be frequently verified during regular production. Furthermore, it shall be demonstrated that anode installation does not damage any adjacent coating and that removal of coating for anode installation can be repaired according to specified requirements. Any application of PU infill in the gap between anode half shells shall also be qualified during the PPT.

8.3.2  Only qualified welders and/or operators of brazing equipment shall be used. The heat input from a thermite or brazing process shall be controlled so that excessive heat input is prevented. All welding and/or brazing procedures associated with anode installation shall be qualified according to DNVGL-ST-F101. Requirements to welding qualification are given in [8.7.1].

8.3.3  An IPS specific for the PPT, together with a detailed schedule shall be submitted to purchaser in a timely manner (as per purchase document) prior to start-up of the qualification activities.

8.3.4  Results from all inspection, testing and calibrations during qualification, welding procedure qualification...
tests, material data sheets and certificates, manuals for brazing equipment, inspection and testing of coating repairs and any other relevant items shall be compiled in a PPT report. Unless otherwise agreed, the report shall be accepted by purchaser prior to start of regular production.

Guidance note:
The PPT report should include a section where the results are summarized and concluded with reference to the different inspection reports/certificated/spreadsheets as attachments.

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8.4 Quality control during production

8.4.1 Prior to start-up of anode installation, contractor shall submit to purchaser for acceptance a project specific IPS, updated to reflect the process parameters used during the completed PPT.

8.4.2 For more complicated anode installation work; e.g. involving repair of linepipe coating, the following additional documentation shall be included:

- a project specific inspection and testing plan (ITP) for production
- a daily log format (see [7.6.8])
- a description of responsibilities of personnel involved in quality control.

8.5 Receipt and handling of anodes and materials for installation

8.5.1 Prior to installation, all anodes supplied by purchaser shall be inspected by contractor to confirm no significant damage or other adverse effects. Non-conforming anodes and other materials shall be quarantined.

8.5.2 Contractor shall ensure that anodes and other materials for anode installation are stored and handled so as to avoid damage by environment or other effects. Supplier’s recommendations for storage and use shall be readily available for purchaser’s review.

8.5.3 Purchaser may specify special requirements to verification and handling of received anodes and installation materials.

8.6 Anode installation

8.6.1 All work associated with anode installation shall be carried out according to the qualified IPS and WPS, describing equipment and procedures to be used. Once the IPS/WPS has been qualified (in compliance with relevant requirements of DNVGL-ST-F101); any changes shall be formally accepted by purchaser through a CR.

8.6.2 The location of anodes in relation to pipe ends or field joints shall be as specified (or accepted) by purchaser. For anodes to be installed on concrete coated pipes, provisions shall be made to prevent any electrical contact between anodes and the steel reinforcement (to be addressed in IPS and ITP); a minimum distance of 25 mm being recommended in ISO 15589-2.
8.6.3
For requirements to any bolting materials to be used, requirements in [6.6.3] shall apply.

8.6.4
For martensitic and ferritic-austenitic (duplex) stainless steels and for other steels with SMYS > 450 MPa, no welding for anode fastening (including installation of doubling plates) shall be carried out on linepipe or other pressure containing components, unless specified by or accepted with owner.

Guidance note:
The requirement above is an amendment to ISO 15589-2. Most CP related HISC damage to pipeline components in CRA’s have occurred at welded connections of galvanic anodes to the pipe walls. To secure adequate fastening of pipeline bracelet anodes for compatibility with the applicable installation techniques, forced clamping of anodes is applicable in combination with electrical cables attached to anodes and pipeline by brazing. However, for many applications, CP can be provided by anodes attached to other structures electrically connected to the pipeline (see [1.3.3] and [6.7.2]). For installation of anodes on such structures, reference is made to DNVGL-RP-B401.

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8.6.5
Electrical continuity to the pipeline is preferably to be provided using brazing, thermite (alumino-thermic) welding or explosion welding. The heat input from a thermite or brazing process shall be controlled so that excessive heat input is prevented (see [8.3.2]).

8.6.6
Any repair of linepipe coating and application of infill materials associated with anode installation shall be carried out according to the applicable sections of DNVGL-RP-F102 unless otherwise agreed.

8.7  Inspection and testing of anode installation

8.7.1
Requirements to welding qualification for pin brazing and aluminothermic welding of anode cables are given in DNVGL-ST-F101 App.C E500 (electrical resistance, mechanical strength, copper penetration, hardness and pull test).

8.7.2
Requirements to qualification of welding procedure of fillet weld in doubler plates and anode pads are given in DNVGL-ST-F101 App.C E600.

8.7.3
It is recommended in [6.6] that no welding of anodes to linepipe or pressure containing pipeline component in CRA materials (type 13Cr or 22Cr/25Cr duplex stainless steel) shall be performed. If ordinary welding is still to be applied for fastening of anodes on CRA, the WPQ shall demonstrate that the maximum hardness in the heat affected zone does not exceed 300 HV or 350 HV for ferritic/martensitic and ferritic-austenitic (duplex) linepipe materials, respectively. For duplex linepipe material the microstructure shall be examined to confirm the ferrite content in the range 35 - 65% in the weld metal and HAZ. The weld material shall also be essentially free from grain boundary carbides, nitrides and intermetallic phases. Essentially free implies that occasional strings of detrimental phases along the centerline of the base material is acceptable given that the phase content within one field of vision (at 400X magnification) is < 1.0% (max. 0.5% intermetallic phases).

8.7.4
Inspection of anode installation shall include visual examination of each weld or brazed connection. The integrity of each thermite welded or brazed electrical connection shall be tested by a sharp blow with a 1 kg hard rubber headed hammer.
8.7.5
For anodes to be installed on concrete coated pipes, it shall be verified during production that there is no electric contact between the anodes and the steel reinforcement.

8.7.6
For inspection of any linepipe coating repairs, reference is made to DNVGL-RP-F102. Any spillage of infill on the anode surface shall be removed.

8.8 Documentation

8.8.1
For documentation to be provided prior to start of production, see [8.2.1], [8.3.4] and [8.4.2] above.

8.8.2
Purchaser may specify special requirements to final documentation; e.g. format and schedule.

8.8.3
Unless otherwise agreed, contractor shall issue final documentation containing the following:

- pre-production test (PPT) report (see [8.3.4])
- installation procedure specification (IPS) for production (see [8.2.1])
- inspection and testing plan (ITP) for production (if applicable, see [8.4.2])
- certificates for installation materials (including welding and/or brazing consumables)
- complete inspection and testing data (see [8.7])
- any accepted CR's
- any nonconformity reports.
## APPENDIX A RECOMMENDATIONS FOR COATING BREAKDOWN FACTORS

Table A-1 Recommendations for constants a and b to be used for calculation of coating breakdown factors associated with specific linepipe coating systems as defined in DNVGL-RP-F106

Maximum temperatures refer to continuous operation and are indicative only. Coating manufacturer’s recommendations shall always apply. For coatings with an inner layer of FBE and operating temperatures above 90°C, adequate FBE layer properties shall be documented by pre-qualification and/or PQT. The same applies for polychloroprene based coatings at operating temperatures above 90°C. Use of higher max. temperature than 70°C for PU is subject to specification or acceptance by owner.

<table>
<thead>
<tr>
<th>Linepipe coating type</th>
<th>DNVGL-RP-F106 CDS</th>
<th>Concrete weight coating</th>
<th>Max. temperature [°C]</th>
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<th>b</th>
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<td>Glass fibre reinforced asphalt enamel</td>
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<td>0.0003</td>
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<td></td>
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<td></td>
<td>0.030</td>
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<td>3-layer FBE/PE</td>
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<td>0.001</td>
<td>0.00003</td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
<td></td>
<td>0.001</td>
<td>0.00003</td>
</tr>
<tr>
<td>3-layer FBE/PP</td>
<td>No. 3</td>
<td>yes</td>
<td>110</td>
<td>0.001</td>
<td>0.00003</td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
<td></td>
<td>0.001</td>
<td>0.00003</td>
</tr>
<tr>
<td>FBE/PP thermally insulating coating (innermost 3LPP layer)</td>
<td>No. 3</td>
<td>no</td>
<td>140</td>
<td>0.0003</td>
<td>0.00001</td>
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<tr>
<td>FBE/PU thermally insulating coating (innermost FBE layer)</td>
<td>No. 1</td>
<td>no</td>
<td>70</td>
<td>0.01</td>
<td>0.003</td>
</tr>
<tr>
<td>Polychloroprene</td>
<td>No. 5</td>
<td>no</td>
<td>90</td>
<td>0.010</td>
<td>0.001</td>
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</table>
Table A-2  Recommendations for constants a and b to be used for calculation of coating breakdown factors associated with specific field joint coating systems, with and without infill, as defined in DNVGL-RP-F102

Maximum temperatures refer to continuous operation and are indicative only. Coating manufacturer’s recommendations shall always apply. For coatings with an inner layer of FBE and operating temperatures above 90°C, adequate FBE layer properties shall be documented by pre-qualification and/or PQT. The same applies for polychloroprene based coatings at operating temperatures above 90°C. Use of higher max. temperature than 70°C for PU is subject to specification or acceptance by owner. Any concrete coating shall meet minimum requirements of ISO 21809-5.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>none</td>
<td>4E(1) moulded PU on top bare steel (with primer)</td>
<td>70</td>
<td>FBE (CDS 1), 3LPE (CDS 2), AE (CDS 4), all with concrete</td>
<td>0.30</td>
<td>0.030</td>
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<tr>
<td>1D Adhesive Tape or 2A(1)/2A-(2) HSS (PE/PP backing) with mastic adhesive</td>
<td>4E(2) moulded PU on top 1D or 2A(1)/2A(2)</td>
<td>70</td>
<td>3LPE (CDS 2), AE (CDS 4), all with concrete</td>
<td>0.10</td>
<td>0.010</td>
</tr>
<tr>
<td>2B(1) HSS (backing + adhesive in PE with LE primer)</td>
<td>None</td>
<td>70</td>
<td>3LPE (CDS 2)</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>2B(1) HSS (backing + adhesive in PE with LE primer)</td>
<td>4E(2) moulded PU on top 2B(1)</td>
<td>70</td>
<td>3LPE (CDS 2) with concrete</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>2C (1) HSS (backing + adhesive in PP with LE primer)</td>
<td>None</td>
<td>110</td>
<td>3LPP (CDS 3) or FBE (CDS 1)</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>2C (1) HSS (backing + adhesive in PP with LE primer)</td>
<td>4E(2) moulded PU on top 2B(1)</td>
<td>110</td>
<td>3LPP (CDS 3) or FBE (CDS 1) with concrete</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>3A FBE</td>
<td>none</td>
<td>90</td>
<td>FBE (CDS 1), 3LPE (CDS 2) and 3LPP (CDS 3)</td>
<td>0.10</td>
<td>0.010</td>
</tr>
<tr>
<td>3A FBE</td>
<td>4E(2) moulded PU on top</td>
<td>90</td>
<td>FBE (CDS 1), 3LPE (CDS 2) and 3LPP (CDS 3) with concrete</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>2B(2) FBE with PE HSS</td>
<td>none</td>
<td>70</td>
<td>FBE (CDS 1) and 3LPE (CDS 2)</td>
<td>0.1</td>
<td>0.0003</td>
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<tr>
<td>2B(2) FBE with PE HSS</td>
<td>4E(2) moulded PU on top FBE + PE HSS</td>
<td>70</td>
<td>FBE (CDS 1) and 3LPE (CDS 2) with concrete</td>
<td>0.1</td>
<td>0.0003</td>
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<tr>
<td>5D(1) and 5E FBE with PE applied as flame spraying or tape, respectively</td>
<td>none</td>
<td>70</td>
<td>3LPE (CDS 2)</td>
<td>0.01</td>
<td>0.0003</td>
</tr>
<tr>
<td>2C(2) FBE with PP HSS</td>
<td>none</td>
<td>140</td>
<td>3LPP (CDS 3) and FBE/PP thermal insulation coating</td>
<td>0.01</td>
<td>0.0003</td>
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<tr>
<td>5A/B/C(1) FBE, PP adhesive and PP (wrapped, flame sprayed or moulded)</td>
<td>none</td>
<td>140</td>
<td>3LPP (CDS3) and FBE/PP thermal insulation coating</td>
<td>0.01</td>
<td>0.0003</td>
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<tr>
<td>NA</td>
<td>5C(1) Moulded PE on top FBE with PE adhesive</td>
<td>70</td>
<td>FBE/PU based thermally insulating coating</td>
<td>0.01</td>
<td>0.0003</td>
</tr>
<tr>
<td>NA</td>
<td>5C(2) Moulded PP on top FBE with PP adhesive</td>
<td>140</td>
<td>FBE/PP thermal insulation coating</td>
<td>0.01</td>
<td>0.0003</td>
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<tr>
<td>8A polychloroprene</td>
<td>none</td>
<td>90</td>
<td>polychloroprene (CDS 5)</td>
<td>0.03</td>
<td>0.001</td>
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APPENDIX B  SEAWATER RESISTIVITY AS A FUNCTION OF SALINITY AND TEMPERATURE

Figure B-1  Resistivity vs. temperature for salinity 5 - 20‰

Figure B-2  Resistivity vs. temperature for salinity 25 - 40‰
### APPENDIX C INSPECTION AND TESTING PLAN FORMAT (APPLICABLE TO PROCEDURE QUALIFICATION TRIAL/PRE-PRODUCTION TEST AND PRODUCTION)

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<th>Activity number</th>
<th>General description</th>
<th>Ref. to spec.</th>
<th>Ref. to procedure or method/tool</th>
<th>Test frequency</th>
<th>Acceptance criteria</th>
<th>Reporting document</th>
<th>Inspection code*</th>
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<td>Anode cables (if applicable)</td>
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<td><strong>2 Preparation of inserts</strong></td>
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<td>Visual inspection of welds</td>
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<td>Blasting of inserts</td>
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<td><strong>4 Marking</strong></td>
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<tr>
<td><strong>5 Inspection and testing</strong></td>
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<td>5.2</td>
<td>Anode visual inspection – surface irregularities</td>
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</tbody>
</table>
### Reference documents:

**Activity number** | **General description** | **Ref. to spec.** | **Ref. to procedure or method/tool** | **Test frequency** | **Acceptance criteria** | **Reporting document** | **Inspection code**
--- | --- | --- | --- | --- | --- | --- | ---
5.3 | Anode visual inspection – cracks |  |  |  |  |  | Applicator | Purchaser | 3rd party
5.4 | Anode weight |  |  |  |  |  |  |  | 
5.5 | Anode dimensions and straightness |  |  |  |  |  |  |  | 
5.6 | Electrochemical test |  |  |  |  |  |  |  | 
5.7 | Destructive test – internal defects |  |  |  |  |  |  |  | 
5.8 | Destructive test – insert position |  |  |  |  |  |  |  | 
5.9 | Fit-up test |  |  |  |  |  |  |  | 
5.10 | Calibration of equipment |  |  |  |  |  |  |  | 

### 6 Coating (if applicable)

6.1 | Application of coating |  |  |  |  |  |  |  | 
6.2 | Recording of coating thickness |  |  |  |  |  |  |  | 

### 7 Preparations and attachment of anode cables (if applicable)

7.1 | Assembly of cables |  |  |  |  |  |  |  | 
7.2 | Crimping and brazing of cable to cable lug |  |  |  |  |  |  |  | 
7.3 | Welding/brazing of cable lug to anode insert |  |  |  |  |  |  |  | 
7.4 | Electrical resistance test |  |  |  |  |  |  |  | 
7.5 | Hammer test |  |  |  |  |  |  |  | 

### 8 Dispatch

8.1 | Packing/transportation details |  |  |  |  |  |  |  | 

### 9 Final documentation

9.1 | Content of final documentation |  |  |  |  |  |  |  | 

* R = Review, I = Inspection, M = Monitoring, W = Witness, H = Hold
APPENDIX D  PROCEDURE FOR EXECUTION AND DOCUMENTATION OF CATHODIC PROTECTION DESIGN

D.1  General

D.1.1
This appendix gives recommendations, advice and guidance for the execution and documentation of a pipeline galvanic anode CP detailed design, meeting the requirements in DNVGL-RP-F103. It is to be considered as a complement to Sec.6 of this RP and can only be used in context with this section. All equations and numerical values for design parameter to be used are contained in Sec.6 and in App.A. In this appendix, emphasis is laid on the documentation of design input and calculations to be contained in a CP design report (see [6.8]).

D.1.2
The calculation procedure is applicable also with use of design parameters specified in ISO 15589-2 and differing from those recommended in this RP. However, it is strongly advised that no calculations of CP current demands or anode net mass/current output requirements shall be performed by mixing design parameters from the two standards. The terminology and units of design parameters in [4.2] of the RP should be used consistently.

D.1.3
For compliance with this RP, inclusion of spread sheet out-puts in the CP design report (see [6.8]) shall not replace the documentation of design data inputs and calculation outputs as required in this appendix.

Guidance note:
It is encouraged to include any spread sheet out-puts as an annex to the CP design report; however, all relevant design parameters and results of calculations shall be contained in the applicable sections of the report.

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D.1.4
This appendix is also applicable to the verification of CP design calculations performed according to this RP.

D.1.5
Unless otherwise stated, section and paragraph numbers referenced in this appendix refer to sections or paragraphs in the main part of this RP. For definition of parties involved, special terms and implications of "shall", "should" and "may", see Sec.3.

D.2  Identification of cathodic protection design data

D.2.1
All design data shall be given in a dedicated section of the CP design report (see [6.8]) with reference to the actual standard, project document and/or communication with purchaser/owner (see Sec.3).

D.2.2
Based on the design basis of the project, purchase order and any other project document referred to by Purchaser, the following design premises and design parameters shall be identified for inclusion in the CP design report (see [6.8]):

— design life
— pipe material/grade, OD and wall thickness (including tolerances)
— pipeline length, and type of any burial/coverage along routing
— type and thickness (max./min., including tolerances) of factory applied coating, field joint coating, any concrete coating and infill. (Reference should preferably be made to pipeline coating types specified in DNVGL-RP-F106 and DNVGL-RP-F102)
— cutback length of linepipe coating
— type of structures and components at the pipeline terminations and possibly along its length (e.g. riser bases, tie-in structures, isolation valves) including information on coatings and any dedicated CP systems for such structures/components
— type of internal fluid, max. operating inlet and outlet temperatures
— any information on temperature profile along the length of the pipeline and increase/decrease of inlet/outlet temperature over time
— any information on seawater temperature, seawater and soil resistivity along the length of the pipeline
— any special requirements to anode materials, anode design and/or anode installation specified by owner/purchaser
— any provisions to be made to electrically insulate the CP systems of adjacent structures from the pipeline CP system
— any special requirements to CP design contingency specified by owner/purchaser (see [5.2]).

D.2.3
Any extra contingency for the CP design should preferably be defined as a design factor to be used in calculating the required net anode mass or anode current output (see [6.1.5]).

Guidance note:
Any contingency to be included in the CP design is primarily a concern of owner but may be proposed and justified by contractor for owner’s consent.

D.2.4
When owner has specified compliance with DNVGL-RP-F103, any deviations from this document specified or accepted by owner or by purchaser on his behalf shall be highlighted and documented by making reference to the applicable document (e.g. design basis, purchase order or technical query).

D.2.5
Contractor shall ensure that the information from purchaser affecting CP design is complete and clear. Any lack of data or unclear issues affecting the overall CP design shall be brought to the attention of purchaser through a formal query.

D.2.6
Any assumptions made by contractor due to lack of information from purchaser shall be highlighted in the CP design report (see [6.8]). The selection of design parameters based on such assumptions shall further be explained and justified in the report.

D.3 References

D.3.1
All standards, project documents and communications with purchaser containing information on CP design parameters, or affecting the CP design otherwise, shall be contained in a dedicated section of the CP design report (see [6.8]). For reference to project specific documents, the actual revision number shall be included.

D.3.2
When coating breakdown factors according to App.A are to be used, the applicable project specifications for factory applied pipeline coating and field joint coating shall be referenced.

D.3.3
Reference should be made to any CP design reports for installations at the pipeline terminations and any installations along the route of the pipeline having self-supporting CP systems.
D.4 Calculation of current demands (see [6.2] and [6.3])

D.4.1
According to this RP, the CP current demand for pipelines is determined by the design of coatings (factory applied coating and field joint coating), burial/coverage and sometimes also by fluid temperature in addition to the pipeline OD and length. In case the resulting current demand per unit length varies significantly along the pipeline, it shall be divided into sections with identical or similar parameters affecting current demand (see [6.2.1]). Pipelines may also be divided in sections based on differences in thickness of concrete coating or installation conditions affecting the size/type of anodes to be used for that specific section.

Guidance note:
Variations in seawater temperature along the pipeline does not affect the CP current demand according to this RP whilst the anode current output may be affected. For pipeline systems with constant inner diameter, variations in current demand as a result of variations of wall thickness (due to variations in depth or design factor) are normally not significant and may be disregarded.

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D.4.2
For each pipeline section, the applicable design current density shall be defined according to [6.2.4] in this RP, being applicable to calculations of both mean and final current demands. If owner/purchaser has specified design current densities according to ISO 15589-2, the applicable value shall be selected from Sec.7.4 of that standard.

Guidance note:
Fig.2 of ISO 15589-2 defines upper and lower limit for design current densities at ambient seawater temperatures up to 25°C. Owner/purchaser has to define the values to be used e.g. by referring to either the upper or lower curve in Fig.2 or any intermediate values.

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D.4.3
The surface area of each pipeline section shall be calculated based on its length and the linepipe nominal OD. Surface areas of any pipeline components of the actual section (e.g. spools, tie-in units, isolation valves) with coatings other than those defined in App.A shall be calculated separately (see [6.2.8]). For any pipeline components to be designed with self-providing CP systems (e.g. riser bases, tie-in structures) reference is made to DNVGL-RP-B401.

D.4.4
For each pipeline section, the mean and final coating breakdown factors shall be calculated as described in [6.2.6] and [6.3.2], respectively. Recommended values for the constants a and b for factory applied coating and FJC are defined in Table A-1 and Table A-2, respectively. Use of other constants shall be specified or accepted by owner.

D.4.5
For use of the recommended values in App.A, contractor shall verify that all major requirements in DNVGL-RP-F106 and DNVGL-RP-F102 for coating design, procedure qualifications and quality control of coating materials and their application are defined in the applicable specifications for factory applied coating and field joint coating, respectively. If owner/purchaser has specified use of the recommended parameters for calculation of coating breakdown factors in ISO 15589-2 (Table 3 and Table 4), contractor should verify that the requirements to coating in that standard will apply (Sec.7.5 of ISO 15589-2): "coating quality being in accordance with the various parts of ISO 21809 or other commonly applied industry standards specifying an equal level of quality coatings".

Guidance note:
DNVGL-RP-F106 and DNVGL-RP-F102 include more stringent requirements and detailed recommendations to coating design, documentation of procedures and quality control of coating applications than ISO 21809.

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D.4.6
According to this RP, coating breakdown factors shall be calculated separately for factory applied coating and field joint coating, taking into account differences in coating design, the length of the pipe joints to be welded and the length of the cut-back (see guidance note to [6.7.4]).

**Guidance note:**
Regarding philosophy for definition of coating breakdown factors in DNVGL-RP-F103 vs. ISO 15589-2, see guidance notes to [6.2.7].

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D.4.7
Based on the surface area of the pipeline section, coating breakdown factors and design current density, the mean and final current demands are calculated according to [6.2.1] and [6.3.1], respectively, adding the current demands of any pipeline components being uncoated or with other types of coating.

D.4.8
Current demand calculations shall be documented in the CP design report (see [6.8]); e.g. in a table where the current demand for each pipeline section is given together with surface areas, design coating breakdown factors and design current densities. Any CP current demands of pipeline components for the actual section shall also be included.

**D.5 Calculation of net anode mass (see [6.4])**

D.5.1
Based on the calculated current demands, the required net anode mass for each section of the pipeline shall be calculated according to [6.4.1]. The selection of anode utilisation factor and anode material electrochemical capacity is addressed in [6.4.2] and in [6.4.3] - [6.4.4], respectively.

D.5.2
Use of electrochemical capacities or anode utilisation factors higher than the default values in this RP, and specified or accepted by owner, shall be justified by reference to the applicable document where the use of such modified design parameters is specified or accepted. The same applies to use of an anode material of other type than Al-Zn-In and/or with composition deviating from that recommended in Table 6-1.

D.5.3
For pipeline sections with internal fluid temperature exceeding 30°C and with buried/covered anodes, the design electrochemical capacity of the anode material shall be selected according to Table 6-3. However, for any buried pipeline sections with a length smaller than the specified minimum anode distance, the anodes to sustain the current demand should be installed on adjacent unburied sections and the required net anode mass is then to be calculated using electrochemical capacities for ambient seawater temperature.

D.5.4
The calculated required net anode mass for each section shall be documented in the CP design report (see [6.8]) together with the relevant design parameters, e.g. in the table referred to in [D.4.8] of this appendix.

**D.6 Tentative selection of type/size and calculations of number of anodes to meet anode net mass requirements ([6.5], [6.6])**

D.6.1
For compliance with Sec.8.1 of ISO 15589-2, this RP uses a default maximum distance between pipeline anodes of 300 m (see [6.7.1]). A larger distance shall be specified or accepted by owner. (Owner may also specify a minimum distance smaller than 300 m). Any specification or acceptance of minimum/maximum anode distance by owner shall be documented in the CP design report (see [6.8]) making reference to the applicable document.
D.6.2

Unless otherwise specified or accepted by owner/purchaser, pipeline anodes shall be of bracelet type consisting of two half shells per anode assembly.

**Guidance note:**
Pipeline anodes are typically purchased by the pipeline installation contractor. There are two basic types of pipeline bracelet anodes: square end and tapered end anodes. The former are used on concrete coated pipelines on which the half-shells are attached to each other by welding or bolting of the protruding anode inserts and any lateral displacement during installation is prevented by the concrete coating subsequently applied to pipe joints with anodes pre-installed. Tapered anodes are used on pipelines which are not concrete coated and are then placed on top of the corrosion preventing coating prior to or during pipeline installation. Special provisions are required to avoid slippage of anodes during installation using either compression of anode half shells followed by welding or bolting them together, or by direct welding of anode tabs to the pipeline (see [6.6] and Sec.8).

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D.6.3

The minimum number of anodes to be installed is calculated by dividing the length of the pipeline section with the maximum distance between the anodes (e.g. 300 m) and rounding up to a whole number. The minimum net anode mass per anode is then calculated by dividing the required minimum net anode mass (see [D.5.1] in this appendix) by the number of anodes.

**Guidance note:**
The tentative calculations according to this paragraph do not need to be documented in the CP design report unless they will also apply for the final design, see [6.5].

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D.6.4

If square end bracelet anodes are to be used (i.e. for concrete coated pipeline sections), a tentative anode length can be calculated using the minimum net anode mass per anode (see [D.6.3]), nominal OD of the pipe including corrosion protective coating, the thickness of the concrete coating, a tentative gap between the half shells (typically about 50 mm on each side) and the specific density of the anode material (specific densities for pure Al and Zn are applicable), possibly also making some allowance for the volume of the anode steel inserts. For tapered anodes, it is pertinent to consult the pipeline installation contractor for suitable anode dimensions. Finally, one or more anode manufacturers should be consulted to ensure that the tentative anode dimensions are suitable for casting of anodes.

**Guidance note:**
For pipelines with relatively low mean current demands per unit length, the anode dimensions (minimum length and/or thickness) and hence net mass as dictated by casting practice will typically be substantially larger than required by the calculations described in [D.6.4]. Hence, to ensure an anode utilisation factor of 0.80 the minimum thickness may be 50 mm. An anode length much less than 50% of the outer pipe diameter may complicate casting. On the other hand, for pipelines with relatively high current demand per unit length, anode casting and handling restrictions may dictate that the required net anode mass is divided on two or more anodes. (At least for concrete coated pipes, installation of one or more anodes on one pipe joint is then normally most convenient; a conservative approach taking into account the interference between the anodes is then to consider adjacent anodes as one long anode when calculating the anode resistance).

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D.7 Calculation of anode current output for specific anode dimensions and tentative number of anodes to meet anode current output requirements (see [6.5])

D.7.1

Based on the tentative anode dimensions, the final anode current output shall be calculated according to [6.5.1] using the applicable design closed circuit anode potential according to Table 6-3, the design protective potential (see [6.7.11]) and the final anode resistance (see [6.5.2]).

D.7.2

The required number of anodes based on the total final current demand of the actual pipeline section shall be calculated according to [6.5.3]. If the number of anodes required based on the tentative anode
dimensions is larger than the number dictated by the total net anode mass requirement, then two options apply:

1) The number of anodes as required by [6.5.3] is chosen for the final design, accepting an excess capacity in terms of net anode mass which is considered as reasonable by contractor.

2) The size of the anodes is decreased and the number increased until re-iterative calculations show that the requirements of both minimum net anode mass (see [6.4]) and minimum anode final current output (see [6.5]) are met. The latter approach may reduce or eliminate an excess anode net mass as required from the tentative calculations.

D.7.3
In case a maximum anode distance has been specified in the design premises (e.g. one anode every 12 pipe joints) a default anode shape/size may be selected and calculations are subsequently performed to confirm that the net anode mass and final current output meet the requirements for mean and final current demands.

D.8 Final anode sizing and distribution of anodes (see [6.7])

D.8.1
The results of final calculations according to the procedures in [D.5] to [D.7] shall be documented in the CP design report (see [6.8]) with specification of all relevant design parameters used.

Guidance note:
The final sizing of a pipeline CP system will need some engineering judgement by contractor, taking into account the potential benefits of any contingency installed (see [D.7.2]). For an offshore pipeline, the total cost of a CP system is more affected by the number of anodes installed than their individual net mass so that squeezing the anode size to barely meet the calculated minimum net anode mass requirement may not be cost effective to owner. If practical, it is recommended that before the anode sizing of the actual pipeline sections is finalised, the pipeline installation contractor should be consulted to assess 1) the proposed anode dimensions and 2) the spacing/distribution of anodes if less than 300 m or some lower maximum distance specified by owner/purchaser. Any changes requested will then result into re-iterative calculations as in [D.6] and [D.7].

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D.8.2
In case a distance between bracelet anodes exceeds 300 m (i.e. as specified or accepted by owner, see [D.6.1]) calculations according to [6.7.9] shall be performed to verify that this distance does not exceed the maximum protective length dictated by the voltage drop induced in the pipe wall by the CP current returning to the anode.

D.8.3
The number of anodes and the applicable size/type to be installed for each pipeline section shall be documented in the CP design report (see [6.8]), including the calculations of a) total net anode mass and total final current demand as required by the input parameters applied and b) total net anode mass and final anode current output as installed. If a deliberate contingency has been included in the design (e.g. by use of a design factor, see [D.2.3]), the minimum requirements for a) and b) according to this RP should also be calculated (i.e. excluding the design factor) to visualise the contingency of the design in relation to the requirements of both purchaser and this RP. The data above should be presented in a tabular form.

Guidance note:
For pipelines installed in seawater of ordinary salinity (about 35‰) or higher, the current output from bracelet anodes of a typical dimension needed to meet the net anode mass requirement will normally exceed the final current demand. However, in seawater of lower resistivity the anode current output may become decisive which means that an excess net anode mass will have to be installed.

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D.8.4
The CP design report (see [6.8]) shall include an outline drawing of the bracelet anode assembly to be used (see [6.6]), including nominal length, thickness, inner diameter, gap between half-shells and any tapering dimensions. Locations of anode tabs and other provisions for fastening and electrical connection of anodes shall also be indicated with tentative tolerances.
**D.8.5**

In accordance with ISO 15589-2 and this RP, owner/purchaser may specify, or contractor may propose for acceptance by owner, that the entire pipeline or parts of the pipeline shall receive CP from existing anodes on adjacent structures or by anodes to be installed on such structures. This approach may also include the use of so-called anode banks located along the pipeline and with a distance exceeding the limit of 300 m between anodes specified in the ISO standard and this RP.

**D.8.6**

The total mean current demand of pipeline sections to be protected by anodes on other structures (including any anode bank) shall be calculated as in [D.4]. For calculation of the required net mass of anodes other than bracelet type, reference is made to DNVGL-RP-B401 containing resistance formulas for the actual types of anodes. For new structures with CP systems to be installed, the required amount of anodes for protection of the pipeline shall then be added to that required for the structure. For an existing structure with a CP system that was not designed for protection of the actual pipeline, the capacity of the existing system shall be assessed based on the CP design documentation and any results from inspection of CP (e.g. potential recordings or visual inspection of anode consumption). In case the capacity of the existing CP system is deemed to be marginal, the concept in [D.8.5] should be rejected.

**Guidance note 1:**

Most CP systems are designed with an inherent contingency in the design code (e.g. DNVGL-RP-B401) accounting for some additional current demand of items not included in the design calculations. For a recently installed structure with galvanic anode CP, an additional mean/final current demand of a pipeline section by 5% should readily be acceptable. For older CP systems any assessment of spare capacity is primarily to be based on inspection data including anode consumption and protection potential. For structures with marginal capacity, fitting of new anodes to the structure itself or as an anode bank close to the structure is only efficient if the overall capacity of the CP system is significantly increased. (A marginally protected structure will otherwise drain most of the current from the new anodes added).

---end of guidance note---

**Guidance note 2:**

If owner/purchaser has specified that the protective range shall be calculated according to the B.2 procedure of ISO 15589-2, the governing design parameter “pipe-to-electrolyte electrical resistance” is subject to specification or acceptance by owner/purchaser.

---end of guidance note---

**D.8.7**

The protective range of an anode bank located at each end of the pipeline and at a distance where it is not affected by an adjacent structure (i.e. other than the pipeline itself), may be calculated according to [6.7.9]. \( L \) is then calculated from equation (20) and the maximum length between the two subsequent anode banks (if applicable) is \( 2L \). Equation (20) is also applicable for calculations of maximum distance between bracelet anodes (i.e. other than the default value of 300 m). It is recommended to take into account the loss of one anode in the attenuation calculations along the pipeline; i.e. the maximum anode distance then becomes \( L \).

**Guidance note:**

\( L \) (equation (20)) should be considered as an absolute maximum distance between bracelet anodes (i.e. if the default value of 300 m is to be exceeded). The net anode mass requirement shall further be met and it is recommended to include some contingency. Any excess anode mass installed can be utilised as a contingency in case the calculated current demand was underestimated due to e.g. pipeline components not included in the current demand calculations, or unforeseen mechanical damage to the coating during installation and/or operation, or if the design life of the pipeline is eventually extended.

---end of guidance note---

**D.8.8**

To calculate the protective range of anodes located at one end of the pipeline e.g. on a secondary structure, or by an anode bank significantly affected by an adjacent structure, the equations in [6.7.6] and [6.7.7] are applicable. For coated subsea structures freely exposed to seawater, a design global protection potential \( (E'_{c}) \) of −0.95 V is recommended. For platform sub-structures or other major areas in predominantly bare steel, a design global protection potential \( (E'_{c}) \) of −0.90 V is recommended as a default value and −0.80 V is recommended as protection potential criterion \( (E_{p}) \), see [6.7.11].
D.8.9
For anode banks connected to the pipeline by means of a cable, the voltage drop in the cable needs to be included in the calculation. The calculated voltage drop at maximum anode current output should then not exceed 10% of the design driving voltage.

D.8.10
Calculation of current demands, anode net mass requirements and protective lengths according to [D.8.5] to [D.8.9] shall be detailed in the CP design report (see [6.8]). All design parameters shall be identified. Any assessment and assumptions regarding the capacity of existing CP systems to be utilised for a CP of pipeline section shall be described and justified.
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