

ENGINEERING STANDARD
FOR
ELECTROCHEMICAL PROTECTION

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1. SCOPE

This Engineering Standard provides the design requirements for electrochemical protection of metals against corrosion. The electrochemical methods of preventing corrosion consist of cathodic and anodic protection. Anodic protection at this stage of development is applicable to limited combinations of metal and corrosive environment so there has been found little applications for it in industries so far. Economics and difficulty in application has also limited its application to metal structures. For this reason the standard has emphasized on cathodic protection which had been used widely and effectively in different industries as well as in oil, gas and petrochemical industries.

Design requirements for cathodic protection systems (impressed and galvanic) for buried and immersed metal structures such as buried pipelines, distribution pipelines, in plant facilities, vessels and tanks and marine structures, are described in this engineering standard.

The standard also provides general guidelines for applying cathodic and anodic protection to metal structures.

Appendices A, B and C are included in this standard with the following topics as guides to the design engineer:

Appendix A Considerations for cathodic protection design.

Appendix B Design principles of cathodic protection for buried pipeline.

Appendix C Design principles of cathodic protection for marine structures.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor/Consultant/Contractor.

BSI (BRITISH STANDARD INSTITUTE)

BS 4683 Part 2 (1971)	"The Construction and Testing of Flameproof Enclosures of Electrical Apparatus"
BS 6651 (1985)	"The Protection of Structures Against Lightning"
CP 1003	"Electrical Apparatus and Associated Equipment for Use in Explosive Atmospheres of Gas or Vapor other than Mining Applications"
BS 7361 (1991)	"Cathodic Protection"
BS 7430 (1991)	"Code of Practice for Earthing"

DIN (DEUTSCHES INSTITUT FÜR NORMUNG)

DIN 30676	"Design and Application of Cathodic Protection of External Surfaces"
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IP (INSTITUTE OF PETROLEUM)

Model code of safe practice in petroleum industry.

IPS (IRANIAN PETROLEUM STANDARD)

IPS-C-TP-274	"Construction Standard for Coatings"
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IPS-C-TP-820	"Construction Standard for Cathodic Protection"
IPS-E-TP-100	"Engineering Standard for Paints"
IPS-E-TP-270	"Engineering Standard for Coatings"
IPS-E-EL-100	"Engineering Standard for Electrical System Design"
IPS-E-EL-110	"Engineering Standard for Electrical Area Classification and Extent"
IPS-M-EL-155	"Material and Equipment Standard for Transformer-Rectifier"
IPS-M-TP-750	"Material and Equipment Standard for Cathodic Protection"
IPS-I-EL-215	"Inspection Standard for Initial and Periodical Inspection of Electrical Installation in Potentially Explosive Gas Atmospheres"
IPS-I-TP-820	"Inspection Standard for Monitoring Cathodic Protection"

NACE (NATIONAL ASSOCIATION OF CORROSION ENGINEERS)

RPO1 (69) 83	"Recommended Practice-Control of External Corrosion on Under ground or Submerged Metallic Piping Systems"
	"Fundamentals, Section 410, Cathodic Protection, Corrosion Prevention" Manual-Volume II NACE
RP 0388-88	"Recommended Practice-Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks"
Sudbuy, J.D., O.L., Shock, D.A.	"Anodic Passivation Studies" Corrosion, 16, 47 t (1960) Feb. NACE

3. DEFINITIONS AND TERMINOLOGY

See also DIN 30676.

Acidity

The presence of an excess of hydrogen ions (H^+) over hydroxyl ions.

Aerobic

Presence of oxygen, in this Engineering Standard, this refers to the state of electrolyte adjacent to the metal structure, for instance sea bottom mud.

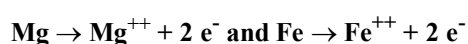
Alkalinity

The presence of an excess of hydroxyl ions (OH^-) over hydrogen ions.

Anaerobic

Lacking free oxygen. In this Engineering Standard, this refers to the state of electrolyte adjacent to the metal structure. For instance normal sea water. Anode

The electrode of an electrolyte cell at where oxidation occurs. Common anode reactions are:



Anode cap

An electrical insulating system placed over the lead wire connection of an anode preferably consisting of an epoxy resin encapsulation surrounded by a heat-shrinkable outer covering.

Anode depolarization

Removal of protective layers and complexing ions resulting in increased corrosion current and corrosion rate. Contrary to cathode depolarization, the increased corrosion is accompanied by a negative (-) shift in anode-to-electrolyte potential.

Anode polarization

Build-up of protective layers and complexing ions on anodic electrode. Polarization of the anode results in decreased corrosion and positive (+) shift in anode-to-electrolyte potential.

Anodic area

That part of metal surface which acts as anode.

Anodic protection

Anodic protection is the use of an impressed current to induce passivity on the surface of the metal by making the metal an anode. The potential of the anode must be controlled within a very narrow range to retain the passive surface condition, anodic protection is applicable to only limited combinations of metal and corrosive environment.

Attenuation

The decrease in a potential and current density along buried or immersed pipeline from the drainage point.

Attenuation constant "a"

The magnitude of the attenuation constant is directly affected by the longitudinal resistance of the pipe and inversely affected by the resistance across the coating. The attenuation constant describes how much the potential change or current flow decreases with increasing distance from the drain point.

Backfill

A low resistance moisture holding material immediately surrounding buried anode for the purpose of increasing the effective area of contact with soil. In impressed current anode bed this refers to coke breeze.

Blistering

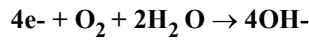
The formation of swellings on the surface of an unbroken paint film by moisture, gases or the development of corrosion products between the metal and the paint film.

Bond resistance

The ohmic resistance of a bond including the contact resistance at the points of attachment of its extremities.

Cathode (opposite of anode)

The electrode where reduction occurs. A typical cathodic reaction.

**Cathode depolarization**

Removal of protective layers and complexing ions, often caused by high acidity, high oxygen content, accidental shorts to other structures, results in increased corrosion current and corrosion rate. Cathode depolarization is indicated by a positive (+) shift in cathode-to-electrolyte potential.

Cathode polarization

Build up of protective layers and complexing ions on the cathode electrode. Polarization of the cathode results in decreased corrosion and negative (-) shift in cathode-to-electrolyte potential.

Cathodic area

That part of the metal surface which acts as a cathode.

Cathodic protection (CP)

A means of rendering a metal immune from corrosive attack by causing direct current to flow from its electrolytic environment into the metal.

Characteristic resistance

The characteristic resistance of the pipe is the electrical resistance between the pipe and remote earth in one direction only from the drain point in ohms.

Concentration cell

A cell involving an electrolyte and two identical electrodes, with potential resulting from differences in the chemistry of the environments adjacent to the two electrodes.

Continuity bond

A metallic connection that provides electrical continuity. Mechanical fasteners are not reliable continuity bonds. Exothermal weld process or brazing is required.

Copper/copper sulfate reference electrode

A reference electrode consisting of copper in a saturated copper sulfate solution.

Corrosion

The chemical or electrochemical reaction of a metal with its environment, resulting in its progressive degradation or destruction.

Corrosion product

The chemical compound or compounds produced by the reaction of a corroding metal with its environment.

Current density

The direct current per unit area, generally expressed as milli amp. Per sq.m. Current density required to achieve cathodic protection varies depending on environment and metal being protected.

Deep anode bed

Type of ground bed using a drilled vertical hole to contain impressed current anodes. Construction techniques vary widely but objectives are low ground bed resistance, uniform current distribution, less interference and permanent moisture. Presently current output is up to 150 amperes per hole.

Typical depth range from 30-400 meters to reach moist low resistivity strata.

Dielectric union

Similar to insulated flange but typically threaded to pipeline and used on pipe diameters 2-inch and below and pressures less than

Drainage (current requirement) tests

Tests with current applied for a short period, usually with temporary anodes and power sources in order to determine the current needed to achieve cathodic protection.

Driving E.M.F. (galvanic anode system)

The difference between the structure / electrolyte potential and the anode \ electrolyte potential.

Electrical grounding

Provides a low resistance path to ground for fault currents in electrical equipment and distribution networks. Since bare copper is commonly used, current requirement calculations must include the copper as a substantial sink for cathodic protection current to adequately size for cathodic protection system.

Electrical isolation

The condition of being electrically insulated from other metallic structures. Continuity bonds eliminate electrical isolation while insulating devices establish isolation.

Electrochemical cell

A circuit consisting of an anode and a cathode in electrical contact with a solid or liquid electrolyte. Corrosion generally occurs at anodic areas.

Electrolyte

A chemical substance or mixture, usually liquid or soil. Containing ions that migrate in an electric field refers to the soil or liquid adjacent. For the purpose of this Standard, the term "electrolyte" refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic structure, including moisture, salts and other chemicals contained there in.

Electronegative

A qualification applied to a metallic electrode to indicate that its potential is negative with respect to another metallic electrode in the system.

Electropositive

A qualification applied to a metallic electrode to indicate that its potential is positive with respect to another metallic electrode in the system.

Electrosmosis

The passage of a liquid through a porous medium under the influence of a potential difference.

Environment

The surroundings or conditions (physical, chemical and mechanical) in which a material exists. Usually liquid component or soils containing ions that migrate in electric field.

Exothermal (cadweld/thermit) weld

Process of insuring electrical connection of cable to piping or steel structures incendiary mixture of fine aluminum powder with a metallic oxide of iron or chromium which when ignited yields an intense heat.

Finite line

If the line terminates in an insulated flange or dead ends, it is called a finite line.

Flow line

Pipeline carrying product from wellhead to Gas-Oil-Separator-Plant (GOSP), typically 100-250 DN, coated or uncoated usually above ground on pipe supports with periodic road crossings.

Foreign structure

A buried or immersed electrically isolated structure that may be subjected to corrosion interference arising from the cathodic protection of another structure.

Galvanic anode or sacrificial

A metal which because of its relative position in the electromotive force (e.m.f) series, provides sacrificial protection to metals that are less negative (lower) in the series, when the two are electrically coupled in an electrolyte. The voltage difference between the anode and the structure causes a current flow in the structure that opposes the corrosion current. The common types of galvanic anodes are rod, bracelet and ribbon.

Galvanic corrosion

Corrosion caused by the electrical coupling of dissimilar metals in an electrolyte or similar or dissimilar metals in dissimilar electrolytes.

Gosp

Acronym for GAS-OIL-SEPARATOR-PLANT. Usually located geographically central to a group of oil wells and fed by flowline from each wellhead, typically incoming and outgoing pipelines electrically isolated from in-plant (on-plant) facilities at the GOSP perimeter.

On-plot cathodic protection is separately installed and operated from off-plot cathodic protection.

Ground (anode) bed

Commonly a group of manufactured electrodes or scrap steel which serves as the anode for the cathodic protection of pipelines, tanks or other buried metallic structures. Types of ground beds are surface and deep anode configurations.

Holiday

A discontinuity (pinhole or flaw) in a coated surface that exposes the metal substrate to the environment.

Impressed current

Direct current supplied by a power source external to the anode system. Typical power sources are rectifiers solar modules and engine-generators.

Infinite line

It is relatively long finite line or a line directly connected to a structure of quite different electrical characteristics such as bare line or a tank farm.

Insulated flange

A flanged joint in which flange faces and securing bolts are electrically insulated from each other by insulating sleeves, washers and gaskets. Pipe size and pressure rating must be specified. Insulated flanges are used to electrically isolate pipelines and systems.

Insulated joint

Performs similar function to an insulating but does not incorporate flange gaskets or bolts. Provides electrical isolation via epoxy sealed gap in a section of pipe.

Insulated spool

It is similar to insulated joint but incorporates internal non-conductive lining where electrically conductive pipeline products are involved.

Interference bond

A welded metallic connection between two sections of a structure or two or more different structures to carry electrical current. Often used to by pass current.

In known locations to avoid corrosive current discharge (interference) in unknown or, undesirable locations. Then resistance bonds are used, the resistance value must be less than the parallel structure -to- structure soil resistance.

Interference test

A structure-to-electrolyte test to determine the existence of corrosion interaction between two buried or immersed structures where one or both are cathodically protected.

Ion

Ion of an atom, or group of atoms, carrying a charge of positive or negative electricity.

Ir drop (or voltage drop)

Significant structure-to-electrolyte potential component due to flow of current through the electrolyte. Parameters are high resistance conditions, e.g. soil resistivity and contact resistance, large cathodic protection current levels, proximity to structure and coating and wire resistance. Often the IR drop component is negligible but must always be considered for each environment.

Leakage or coating resistance

Leakage resistance of pipe or resistance of pipe radially to remote earth. This resistance includes the resistance of the coating (if any) and is affected by the resistivity of the environment. Unit is Ohm-Kilometer.

Linear pipe resistance

The longitudinal pipe resistance of the pipe is the pipe resistance in Ohms per unit length, which can be calculated from the specific resistivity of steel or iron and by regarding the pipeline as an annular cylinder.

The specific resistivity of steel pipe will normally vary from 15 to 23 micro-ohm-cm depending on its chemistry. In absence of specific test results it is normal to use a value of 18 microhm-cm.

Open-circuit (off) potential

The difference in voltage between a structure and a reference electrode under a condition of no current flow to the structure.

Note:

Interference current flow may exist and is often detected by open circuit potential measurement.

Oxygen concentration cell

A galvanic corrosion cell caused by a difference in oxygen concentration at two points on a metal surface. Areas of lower oxygen are commonly anodic to areas of greater oxygen.

Passive

The state of metal when its behavior is more noble (resist corrosion) than its position in the "EMF" series would predict.

Protection current

The current made to flow into a metallic structure from its electrolytic environment in order to effect cathodic protection of the structure.

Protection potential

A term used in cathodic protection to define the minimum potential required to suppress corrosion. Protective potential depends on the structure metal and the environment.

Reference electrode

An electrode used for measuring the potentials of other electrodes. Examples of commonly used and installed reference electrodes are copper-copper sulfate (Cu/CuSO_4), silver-silver chloride (Ag/AgCl) and zinc (Zn). Permanent reference electrodes are often required at inaccessible locations such as long road crossing and under large diameter tank bottoms.

Remote earth

The areas in which the structure-to-electrolyte potential change is negligible with change in reference electrode position away from the structure.

Reverse current switch

The reverse current switch is installed in series with interference bonds where stray current is known to reverse direction. Prevents serious corrosion, where reversed current can discharge to the electrolyte, by interrupting the reversed current. A failed switch becomes an open circuit or a solid bond.

Silver/silver chloride electrode (Ag/AgCl)

A reference electrode consisting of silver, coated with silver chloride in an electrolyte containing chloride ions.

Stray current corrosion

Corrosion resulting from direct current (usually man-made) flow, through other than the intended circuit. May be internal or external. Corrosion occurs where current leaves a metal surface.

Splash zone

That part of external structure between a level 2 meters above Mean High Water Springs (M.H.W.S) and a level 3 meters below the Lowest Astronomical Tide (L.A.T).

Structure-to-electrolyte potential

The potential difference between a metallic structure and the electrolyte surrounding it, measured with a reference electrolyte. Typical examples are pipe-to-seawater potentials.

Sulfate reducing bacteria (S.R.B.)

A group of bacteria found in most soils and natural waters, but active only in anaerobic conditions of near neutral pH. They reduce sulfates in their environment, with the production of sulfides. SRB increase cathodic protection current requirements as a result of cathodic depolarization by sulfides.

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Submerged zone

That part of external structure below the splash zone.

Surface anode bed

Type of ground bed using impressed current or galvanic anodes. This type of ground bed is used in relatively low resistivity soils like marl (low resistivity limestone and clay) with water retaining capability.

Test access hole

Provides a means of contacting soil through concrete or asphalt for measuring structure-to-soil potentials. Contains no wires and is usually capped but easily accessible.

Test station

Permanent wires attached to the structure and led to a convenient location for electrical measurements. Used at points where the structure or soil is otherwise inaccessible for electrical testing (underground or underwater).

Weight-coat

Steel-Mesh reinforced concrete layer applied over a primary coating system. Provides negative buoyancy for submarine pipelines.

Zinc reference electrode

A 99.9% metallic zinc rod, with an iron content not exceeding 0.0014%, which contact directly with the electrolyte around the structure for potential measurement purposes. Some of the zinc alloys used for galvanic anodes are also suitable. The metallic electrode can be made in any convenient form.

Point of minimum protection

Since voltage varies with distance along a pipeline due to attenuation, the point of minimum protection (least negative potential) must be adequately protected to assure complete protection of a pipeline.

With a uniformly coated line protected from a single drain point, the point of minimum protection will be the end (most remote from the drain point). With a multiple-drain point system, points of minimum protection will exist between drain points. To ensure complete cathodic protection of the line the locations of points of minimum protection shall be determined and the system shall be adjusted to achieve adequate protection at these points.

4. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

5. PURPOSE OF CATHODIC PROTECTION

Cathodic protection provides an effective method of mitigating the corrosion damage to metal surfaces exposed to a conducting (corrosive) electrolyte (see Appendix A).

6. GENERAL APPLICATION OF CATHODIC PROTECTION

6.1 Cathodic protection shall be applied to metal structures where they are in contact with corrosive soils or water, whenever economically justified (see also clause A.2.1). Materials other than steel or iron shall be considered as separate cases. The metal structures shall be coated whenever practical for maximum cathodic protection efficiency.

6.2 Impressed current cathodic protection shall be applicable to but not necessarily limited to:

- a) Buried land pipes.
- b) Submarine pipelines within the area of influence of shore or offshore platforms where ac power is available.
- c) Offshore structures (where power is available).
- d) Piers.
- e) Storage tank bottoms (where exposed to soil).
- f) Water tank interiors.
- g) Ship hulls (unless galvanic protection is used, (see 6.3).
- h) Well casings.
- i) Buried plant piping.
- j) Seawater intake systems.
- k) Desalination plants.

6.3 Galvanic cathodic protection shall be applied to but not necessarily limited to:

- a) Submarine pipelines (beyond the influence of impressed current schemes).
- b) Short sections of buried land pipes in areas where soil resistivities are less than 5000 ohms-cms and ac power is not available or in special cases such as road crossings.
- c) Offshore structures and piers where power sources are not available also for all offshore structures for temporary protection during construction and for achieving rapid polarization and maintaining protection in conjunction with impressed current systems.
- d) Special electrical grounding facilities on land pipelines.
- e) Heat exchanger water boxes.
- f) Water tank interiors.
- g) Ship hulls.
- h) Small boat piers where impressed current systems are not economical.
- i) Process vessel interiors.

6.4 All buried land pipes and sea pipelines shall be provided with an anticorrosive, dielectric coating in accordance with IPS-E-TP-270 and IPS-C-TP-274.

6.5 Cathodic protection systems shall be so located to prevent the possibility of disturbance or damage to other structures.

7. CRITERIA FOR CATHODIC PROTECTION

7.1 General

Criteria for cathodic protection is in general agreement with the current revision of NACE RP-01-69-83 and in specific agreement with paragraphs 6.2.2 and 6.2.1 which state that "the selection of a particular criterion for achieving the objective of using cathodic protection is to control the corrosion of metallic surfaces in contact with electrolytes, depends, in part, upon past experience with similar structures and environments where in the criterion has been used successfully".

Because the conditions and environments make it impractical to comply with Paragraph 6.2.4 of NACE RP-01-69 which states that "the voltage measurements on all buried structures are to be made with reference electrode positioned as close as feasible to the structure surface being investigated" and "the corrosion engineer shall consider voltage (IR) drops other than those across the structure-electrolyte boundary, (IR) drops the presence of dissimilar metals, and the influence of other structures for valid interpretation of his voltage measurements ", specific standard criterion incorporates allowances for the intrinsic inaccuracies of structure-to-electrolyte potential measurements, the standard criterion for steel structures in different environments is stated in the following paragraphs (see also Clause 3.2 of DIN 30676, 1985).

7.2 Buried Pipes

The criterion most widely used on buried pipes is based on the measurement of potential differences between the pipe and its environment.

Coated buried pipelines shall have a minimum pipe-to-soil polarized potential of -1.0 (off) Volts (see Clause 3.2 of DIN 30676, 1985) with reference to copper/copper sulfate half cell. The potential shall be measured immediately after interrupting all the cathodic protection systems influencing the pipeline structure, where it is not practical to measure the interrupted or polarized potential on a pipe, the general guideline for the protection criteria shall be as follows:

7.2.1 For buried pipelines in low resistivity soils (less than 2000 ohmcm), the protection criteria shall be -1.3 (on) volts measured at the 1 km test stations or -1.1 (on) volts measured at close interval spacing (15 meters or less) with the cathodic protection currents applied.

7.2.2 For buried pipelines on high resistivity soils, (greater than 2000 ohm-cm), the protection criteria shall be -1.5 (on) volts measured at the 1 km test stations or -1.2 (on) volts measured at close interval spacing (15 meters or less) with the cathodic protection currents applied.

7.2.3 Buried facilities in plant areas shall be considered protected at a minimum of -0.85 (on) volt, measured at test holes over the metallic structure with the current flowing.

Another criterion in use is potential change from natural value to the value obtained after application of cathodic protection. In this method potential change is used as criterion rather than an absolute value (say - 0.85 volts to copper/copper sulfate electrode). In this system, the intent is to change the pipe potential by 0.25 or 0.3 volt in the negative direction when the cathodic protection is applied.

Note:

Special conditions (e.g. backfill, pipecoating characteristics or other parameters) may require further interpretation of voltage readings), (see NACE RP 01-69-83 Paragraph 6.5).

7.3 Tanks Exteriors

Tank undersides may be considered partially coated due to contact with sand asphalt padding. However, contact with the soil will vary with flexing of the base. The potential recorded at the periphery of the underside shall be -1.10 -1.20 (on), volt with reference to a copper/copper sulfate half cell; where permanent reference electrodes have been installed under the tank bottom, a minimum potential of +0.25 (on) volt zinc to steel indicates adequate protection.

7.4 Submerged Pipelines

Offshore submerged pipelines shall have a minimum Pipe-to-water potential of -0.90 (on) volt with reference to a silver/silver chloride half cell.

7.5 Offshore Structures and Ship Hulls

Steel structures, other than pipelines, shall have a minimum structure -to-water potential of -0.90 (on) volt with reference to a silver/silver chloride half cell.

7.6 Tank, Pipe and Water Box Interiors

Structures storing or transporting conductive waters or other conductive liquids shall have a minimum electrolyte to internal surface potential of -0.90 (on) volt with reference to silver / silver chloride reference cell or +0.15 (on) volt with reference to an internal zinc reference electrode.

7.7 Well Casings

In general, onshore well casings shall be considered adequately protected when a polarized casing -to- soil potential of -1.0 (off) volt to a copper/copper sulfate reference cell is measured with the cell located close to the casing and the cathodic current momentarily interrupted. Alternatively, the potential measured with the cathodic current shall be -1.2 (on) volts to the copper/copper sulfate reference cell with the cell located remotely a minimum of 75 meters from the well and preferably 180 away from the anode bed. Where it is impractical to obtain valid casing-to-soil potential measurements, current requirement and polarization test data may be used in interpreting the protected status of well casings. Offshore well casings shall be considered protected when the casing-to-water potential is -.90 (on) volt to a silver chloride reference cell placed close to the casing. Table 1 lists the observed protection potentials i.e. potential without allowances for (IR) drop error for full protection of various metals, measured against difference standard electrodes.

TABLE 1 - MINIMUM AND MAXIMUM POTENTIALS FOR CATHODIC PROTECTION OF BARE METALS (VOLTS, WITHOUT IR DROP)

Metal or alloy	CONDITION	REFERENCE ELECTRODE							
		Copper/copper sulfate		Silver/silver chloride sea-water**		Silver/silver chloride saturated KCl		Zinc/(clean) sea-water	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Unalloyed and low alloy ferrous materials	At temp. below 40°C	- 0.85	N.A*	- 0.80	N.A	- 0.75	N.A	+ 0.25	N.A
	At temp. higher than 60°C	- 0.95	N.A	- 0.90	N.A	- 0.85	N.A	+ 0.15	N.A
	In anaerobic media with high activity of sulfate reducing bacteria and sulfate	- 0.95	N.A	- 0.90	N.A	- 0.85	N.A	+ 0.15	N.A
	In aerobic and in anaerobic media with low activity of sulfate reducing bacteria and sulfates	- 0.85	N.A	- 0.80	N.A	- 0.75	N.A	+ 0.25	N.A
	In sandy soils with resistivities greater than 50000 ohm.cm	- 0.75	N.A	- 0.70	N.A	- 0.65	N.A	+ 0.35	N.A
Stainless steels with a chromium of at least 16% by weight, for use in soil and fresh water	At temp. below 40°C	- 0.10	N.A	- 0.50	N.A	- 0.00	N.A	+ 1.00	N.A
	At temp. higher than 60°C	- 0.30	N.A	- 0.25	N.A	- 0.20	N.A	+ 0.80	N.A
Stainless steels with a chromium content of at least 16% by weight, for use in salt water	—	- 0.30	N.A	- 0.25	N.A	- 0.20	N.A	+ 0.80	N.A
Copper; copper/nickel alloys	—	- 0.20	N.A	- 0.15	N.A	- 0.10	N.A	+ 0.90	N.A
Lead	—	- 0.65	- 1.70	- 0.60	- 1.65	- 0.55	- 1.60	+ 0.45	- 0.60
Aluminum	In fresh water	- 0.80	- 1.10	- 0.75	- 1.05	- 0.70	- 1.00	+ 0.30	- 0.00
Aluminum	In salt water	- 0.90	- 1.10	- 0.85	- 1.05	- 0.80	- 1.00	+ 0.20	- 0.00
Aluminum	In soil	- 0.95	- 1.20	- 0.90	- 1.15	- 0.85	- 1.10	+ 0.15	- 0.10
Steel in contact with concrete	—	- 0.75	- 1.30	- 0.70	- 1.25	- 0.65	- 1.20	+ 0.35	- 0.20
Galvanized steel	—	- 1.20	N.A	- 1.15	N.A	- 1.1	N.A	+ 0.10	N.A
<p>* Not applicable</p> <p>** Silver/silver chloride/sea water (salinity 32-38%) in brackish water (salinity < 32%), the potential reading from an open electrolyte reference electrode must be corrected for the lower chloride concentration. For measurements in such water a closed electrolyte reference electrode is advantageous.</p>									

Notes:

- 1) All potentials have been rounded to the nearest multiple of 0.05 V. The figures for electrodes in which sea-water is the electrolyte are valid only if the sea-water is clean, undiluted and aerated.
- 2) Aluminum. It is not at present possible to make firm recommendations for the protection of aluminum since this metal may corrode if made too strongly negative. There are indications that corrosion can be prevented if the potential is maintained

between the limits shown in the Table. Alternatively, it has been recommended in the case of pipelines to make the metal electrolyte potential more negative than its original value by 0.15 V.

3) Lead. In alkaline environments lead may occasionally be corroded at strongly negative potentials.

4) Stainless steels. In many environments, stainless steels will not require any form of protection. In some cases anodic protection is used.

Stainless steels are however, often susceptible to crevice corrosion. A crevice may be encountered between two metals, e.g. at a riveted or bolted seam, or between a metal and non-metal or at a gasketed joint. Crevice attack is a particular form of differential aeration corrosion and is most often encountered in a marine environment. It has been found that cathodic protection will significantly reduce the incidence and severity of this form of corrosion; polarization to potentials given in Table 1 is necessary.

Difficulty can, however, arise if the crevice can seal itself off from the environment; the protective current cannot flow to the seat of the attack which may proceed unabated.

Polarization of stainless steels to excessively negative potentials may result in hydrogen evolution which can cause blistering and loss of mechanical strength.

Experience has shown that random pitting of stainless steel may not be influenced by cathodic protection, despite the evidence from certain laboratory studies.

5) Steel in concrete. If steel, whether buried or immersed, is only partially enclosed in concrete, the protection potential is determined by the exposed metal and is as indicated in Table 1. Iron or steel fully enclosed in sound concrete free from chlorides would not normally require cathodic protection because of the alkaline environment. For circumstances where cathodic protection needs to be applied, for example because there is doubt as to adequacy of the concrete cover or to provide very high reliability, it has been suggested that potentials less negative than are normally required for the protection of steel may be suitable.

8. TYPES OF CATHODIC PROTECTION SYSTEMS

8.1 Impressed Current Systems

In this type of system, an external source of dc power, usually an ac/dc transformer-rectifier, is used to provide the driving voltage between the anode and the structure to be protected. The negative terminal of the dc source is connected to the structure by a suitable cable and the positive terminal similarly connected to the anode. The dc power source shall be adjustable so that variations in cathodic protection current and voltage are available.

Rectifiers are especially applicable where electric power is available and current requirements are large or soil resistivity is too high for sacrificial anodes. They are a very flexible source since practically any combination of current and voltage ratings is available and the voltage of a rectifier is normally adjustable over a wide range.

8.2 Galvanic Anode Systems

In a galvanic anode system, the driving voltage between the structure to be protected and the anodes is provided directly by the potential difference between the materials involved. If the galvanic anode is subject to possible wetting by oil, Aluminum alloy or magnesium anodes shall be used.

Galvanic anodes, either singly or in groups or ribbon, are connected directly to the structure to be protected and are consumed at a rate proportional to the current output. Because of the limited driving voltage their use is generally in soil or water conditions of electrical resistivity less than 5000 ohm-cm.

This system is applicable where the soil resistivity and current requirements are low and also where a power supply does not exist or can be provided only at uneconomical costs.

The use of magnesium anodes is usually not feasible where the soil resistivity is above 5000 ohm-cm (although magnesium ribbon may be used in soils of higher resistivity). A general rule-of-thumb suggests that zinc anodes are better used in the lower soil resistivities (below 1500 ohm-cm).

The construction of galvanic anode systems shall be according to IPS-C-TP-820.

8.3 Galvanic versus Impressed Current System

In cases where either galvanic anode or Impressed Current System can be used successfully, the choice is dictated by economics. A cost study is required to determine which type of system is more economical. (See also A.2.4).

9. EQUIPMENT AND FACILITIES FOR IMPRESSED CURRENT SYSTEMS

9.1 Cathodic Protection Transformer-Rectifiers

A transformer-rectifier in conjunction with an anode system offers the most reliable and effective means for supplying cathodic protection when an ac power supply is available. Transformer-rectifiers for cathodic protection use are generally rated in the range of 10 to 400 amperes and from 10 to 100 volts.

Transformer rectifier construction may use either air cooling or oil immersion. In the latter, all current carrying circuits are immersed in oil filled tanks. Oil immersed units are preferred for installation in severe corrosive environments (see IPS-E-TP-100 for definition). However, air cooled units may be acceptable in less corrosive atmosphere or non-classified areas (see IPS-M-EL-155). The air cooled units are used in ambient temperature below 40°C.

9.2 Alternative Cathodic Protection Power Sources

Where there is no access to ac supplies, any of other sources of power, as listed below which technically and economically is justified may be considered:

- a) Diesel-alternator-rectifier set.
- b) Gas engine-alternator-rectifier set.
- c) Thermo-electric generator (gas operated).
- d) Closed circuit vapor turbine (gas or kerosene operated).
- e) Solar powered generator with battery storage.
- f) Wind generators with battery storage.
- g) Alternating current turbine operating from by pass pipeline flow.
- h) Fuel cells consisting of two conducting plates and electrolyte.
- i) Petrol engine-alternator.

In case of Gas trunkline, gas from the pipeline is used to power the gas engine. If the trunkline carries a petroleum product which is suitable for engine fuel, it may be taken directly from the line as well. Otherwise, fuel like gas, oil or petrol, depending on type of engine selected, must be brought to the generator station periodically to fill fuel storage tank at site.

9.3 Impressed Current Anodes

9.3.1 Ferro Silicon (an iron alloy with a silicon content of approximately about 14 W% and a carbon content of approximately 1 W%), graphite, scrap iron and magnetite (Fe_3O_4 plus additives) is to be considered a suitable material for anodes in contact with soil.

9.3.2 Ferro silicon anode with 4W% chromium is recommended for use in soils containing chloride ions. For anodes in contact with salt water, inert anodes of platinized titanium, tantalum or niobium or lead/silver anodes are commonly used.

9.3.3 Polymeric anodes are used for cathodic protection of reinforcing steel in salt contaminated concrete and can also be used for cathodic protection of inplant facilities. The system consists of a mesh of wirelike anodes, which are made of a conductive polymer electrode material coated onto copper conductors. The conductive polymer not only serves as an active anode material but also shields the conductors from chemical attack. These mesh anodes are designed and optimally spaced to provide long term uniform protection at low current densities. In case of protecting steel in concrete, the anode mesh is placed on the surface of a reinforced concrete structure, covered with an overlay of portland cement or polymer modified concrete and then connected to a low voltage dc power source.

9.3.4 Ceramic anodes are the newest materials available for cathodic protection anodes. These anodes are supplied either as oxide coatings on transition metal substrates or as bulk ceramics. Their use as cathodic protection anodes for protecting reinforcing steel in concrete is new but the oxide coated transition metal anodes have been used since the late 1960 in the chlor-alkali industry as anodes for chlorine production and seawater electrolysis, and cathodic protection of water tanks and bund steel structures, among other industrial processes. These anodes are produced in sheet, mesh and wire form.

9.3.5 Following considerations shall be considered when selecting the anode for an impressed current system:

- The relative importance of cost and consumption rate varies according to conditions. Thus, if the electrolyte resistivity is high, an extensive anode installation will be needed. Cheap material is therefore normally chosen and it will not be excessively costly to provide an additional amount to allow for its higher consumption. For anodes in a low resistivity environment, such as sea-water, a large mass of material is not generally required so that a compact anode of material capable of working at high current density may be more economical. Compactness may often be essential, for example to minimize interference with water flow. In such applications, the mechanical properties of the material and ability to withstand abrasion by suspended matter may also be important.
 - Graphite used as an anode material can be operated at a current density of 2.5 A m^2 to 10 A m^2 . It is normally impregnated with wax or a synthetic resin to fill the pores and the consumption rate can then be appreciably lower than that of iron and steel. Chlorine which can be generated electrolytically in saline waters is particularly aggressive towards graphite anodes.
 - High silicon cast iron will operate at current densities in the range 5 A/m^2 to 50 A/m^2 with consumption rates in the range 0.2 kg/A year to 1 kg/A year , according to anode shape and conditions. It is suitable for buried or immersed conditions.
 - Magnetite (Fe_3O_4) is a natural mineral which can be made into a cathodic protection anode by proprietary methods. Such anodes are available in the form of cast hollow cylinders with an internal metallic lining to which a cable is connected and sealed. Magnetite has a low consumption rate of less than 5 g/A year and may be used in soils, fresh-water and sea-water. This material is brittle and requires careful handling.
 - Lead alloys of various compositions are used in sea-water applications but are unsuitable for installations where deposits may form. These anodes rely on the formation of a lead dioxide (PbO_2) surface film which constitutes a conducting medium that does not deteriorate rapidly and is selfrepairing. For example, lead alloyed with antimony and silver can operate at current densities up to 300 A/m^2 . In another type, the lead is alloyed with silver and tellurium. The performance may be affected adversely in deep water or waters of low oxygen content.
- Thin platinum wire may be inserted into the lead alloy surface to form a bi-electrode which can be beneficial in the initial formation of a film of lead dioxide. This mechanism operates at a current density greater than 250 A/m^2 . Such anodes can be operated at current densities up to 2000 A/m^2 . Other lead alloys are available and the operating conditions may be affected by the type of alloy.
- Platinum and platinum alloys e.g. platinum/iridium are too expensive for use as anodes except in special applications. They are, however, frequently used in the form of a thin layer of platinum or platinum alloy about 0.0025 mm thick on a titanium, niobium or tantalum substrate.

These metals are used as the substrate because they are protected under anodic conditions by an adherent, inert, non-conducting surface oxide film, and therefore resist corrosion at any gap in the platinum. The application of platinum or platinum alloy (platinizing) can be confined to those areas where current transfer is required.

Anodes using these materials can operate satisfactorily at current densities up to 1000 A/m² of platinized surface but operating voltages dictate that a lower figure is used as a basis for design. In electrolytes containing chlorides, the oxide film on titanium may break down if the voltage exceeds 8V; with niobium and tantalum 40 V is permissible. Higher voltages may be permissible with fully platinized anodes or in non-saline environments. The life of the platinum film may be affected by the magnitude and frequency of the ripple present in the dc supply. Ripple frequencies less than 100 Hz should be avoided. Therefore, anode/electrolyte potential needs to be suitably limited and full-wave, rather than half-wave, rectification is preferable. The life of the platinum film may also be affected by the electrolyte resistivity, the consumption rate increasing with resistivity.

Recent developments have included the use of oxides of precious metals (e.g. ruthenium and iridium), mixed with other oxides, on a titanium substrate. These have operating conditions similar to the platinized anodes described above and are said to withstand current reversal. Another material available is a conducting polymer extruded onto a copper conductor.

Characteristics of the principal anode materials are summarized in Table 2. These are arranged in order of cost consumption rate and are given only as examples. For standard specification see IPS-M-TP-750 Part 5.

9.4 Cables

Cable conductors shall be sized such that the conductor be capable of carrying maximum designed current for the circuit without excessive voltage drops except that bonding cables shall be 16 mm² minimum. The cables shall meet the requirements of IPS-M-TP-750 Part 7.

Anode cable insulation shall be compatible with the anode environment which will include generated chlorine gas. (See IPS-M-TP-750 Part 7 for Chlorine resistant cable).

9.5 Insulating Devices

The structure to be protected shall be isolated from other structures or facilities by means of applicable insulating devices such as insulating flanges, insulating joints and insulating spools.

In the case of pipelines, these include, for example, pressure raising or reducing systems, transfer systems and domestic service installations.

In areas where there is a risk of explosion, insulating devices shall be fitted with explosion-proof spark gaps and shall be equipped to prevent sparking such as may occur by bridging caused, for example, by contact with tools.

Insulating flange sets shall not be buried. Insulating joints and spools may be installed below grade and buried, provided they have a suitable bond station. They shall be properly identified by marker posts.

TABLE 2 - CHARACTERISTICS OF PRINCIPAL ANODE MATERIALS

MATERIAL	DENSITY	MAXIMUM OPERATING CURRENT DENSITY	CONSUMPTIO N RATE	MAXIMUM OPERATING VOLTAGE	PROBABLE UTILIZATION FACTOR	REMARKS
Steel	g/cm ³ 7.85	A/m ² 5	Mass/A year 9 kg	V 50	% 30 to 50	Used with carbonaceous backfill
Impregnated graphite	1.1	10	0.5 kg	50	50	Higher consumption occurs in chloride containing environment unless chromium or molybdenum is added.
High-silicon iron	7.0	50	0.2 to 1.0 kg	50	50 to 90	
Carbonaceous backfill	0.7 to 1.1	5	1 to 2 kg	50	50	Only used in conjunction with other anode materials
Magnetite	5.8	100	< 5 g	50	60	Cannot withstand current reversal. Operating current density under oxygen evolution conditions should not exceed 200 A/m ² . Wear rates of platinized (and platinum/iridium) anodes increase with decreasing chloride levels
Lead alloys	11.3	300	25 g	25	80	
Platinum on titanium, niobium or tantalum	21.5	1000	10 mg ¹⁾	8 ¹⁾ 40 ²⁾	90	

1) Platinum on titanium.

2) Platinum on niobium and platinum on tantalum.

9.6 Anode Beds

In order to minimize the anode to earth resistance, anode beds shall be constructed with a number of anodes connected in parallel to a common positive dc source.

The construction of anode beds shall be of the following forms:

- a) Horizontal trench, with carbonaceous backfill and multiple inert anodes laid horizontally in the center of the backfill.
- b) Vertical augered or excavated holes each with a single anode surrounded with carbonaceous backfill.
- c) Deep anode beds, constructed vertically to depths which may approach 150 meters. These beds may or may not contain carbonaceous backfill and casing along with the selected anode material as specified in IPS-M-TP-750 Part 5.

The anode beds shall be constructed according to IPS-C-TP-820.

9.7 Electrical Bonding Station

Where one system may affect another, the structures involved shall be bonded together. Minimum 16 mm² size cable shall be used. Resistors if required shall be of the fixed (soldered) tap type or Nickel-chrome wire.

Bonding stations shall also be installed across each insulating device in easily accessible locations as required to mitigate interference. Bonding wires from both sides of an insulating device shall be terminated in common bond box. Installation shall be in accordance with IPS-C-TP-820.

9.8 Test Stations

Stations providing facilities for cathodic protection measurements shall be installed. Bonding stations which include bond current regulating resistors and ammeter shunts shall be connected between main and secondary cathodically protected structures so that the currents may be regulated and measured. Installation shall be in accordance with IPS-C-TP-820.

9.9 Connections

All negative drain or bonding cable connections to steel shall be permit welded, or brazed (see IPS-C-TP-820).

9.10 Electrical Continuity

It may be necessary to install continuity bonds between different sections of the structure or plant before cathodic protection is applied (see A.2.3.1).

9.11 Protective Coatings

The function of a coating is to reduce the area of metal exposed to the electrolyte (see A.2.3.2).

9.12 Insulation

It often happens that a well-coated structure, to which cathodic protection could be applied economically, is connected to an extensive and poorly coated metallic structure the protection of which is not required or would be uneconomical (see also A.2.3.3). In such a case the well coated structure shall be isolated before applying cathodic protection to it.

9.13 Safety

Sparking hazards may occur when opening or connecting in-service cathodically protected pipelines.

9.14 Site Survey

A corrosion survey of the location of the proposed facility to be cathodically protected shall be made. Information gathered shall include ac power sources, electrolyte resistivities, possible anode bed and rectifier locations and lay out of existing facilities which may be interfered with by the new installation.

9.15 Provision for Testing

A cathodic protection installation is unlikely to remain effective unless it is adequately maintained. Details of tests that are necessary are given in IPS-C-TP-820 and IPS-I-TP-820. It is important that the necessary facilities be considered at the design stage so that testing can be carried out conveniently from the time of commissioning the installation. Recommendations relating to the provision of testing facilities for different types of structure or plant are given in each section.

10. CATHODIC PROTECTION OF BURIED STEEL PIPES

Buried steel pipes are defined as cross country pipelines and distribution net works, for design calculation of pipeline see Appendix B.

10.1 Application

This Section defines the design requirements for Cathodic Protection (CP) of buried steel pipes such as gas or water pipelines and distribution lines.

10.2 General

10.2.1 Buried steel pipes shall be cathodically protected with impressed current systems except as noted in Par. 6.3.b.

10.2.2 All buried steel pipes shall be coated prior to installation (see IPS-E-TP-270 and IPS-C-TP-274).

10.2.3 Short buried lengths of above-ground pipelines such as road crossings shall be coated and insulated from the rest of pipeline and protected by galvanic anodes, if such crossings are not an integral part of an impressed current system. An exclusive galvanic anode system is deemed necessary for road crossings only when the soil resistivities are less than 5000 ohm-cm and the pipelines do not have impressed current system. In cases where the road crossings are located in soil resistivities of 5000 ohm-cm or higher and the impressed current system is not economical, galvanic anodes shall be used as an insurance against corrosion.

10.2.4 As far as possible, the design shall utilize existing equipment and available power.

10.2.5 A site survey shall be made to determine soil resistivities and suitable locations for anode beds unless the information is available from existing systems or previous surveys made by the owner corrosion Control Department.

10.2.6 The level of protection for buried pipes shall be in accordance with Section 6. In general, the pipe-to-soil potential shall be limited to values specified in Table 2, without the cathodic protection current flowing (off) (see clause 3.2 of DIN 30676, 1985).

10.2.7 The minimum design current density of the cathodic protection system for coated buried pipes shall be in accordance with Table 1 of IPS-E-TP-270.

In cases where coated buried pipes with high quality coatings such as epoxy are electrically continuous with buried pipes with lower quality coating such as plastic tape the cathodic protection design current capacity for the worst case shall be used.

The real amount of current required to attain protection is determined by the current requirement test (see IPS-C-TP-820). Results of a soil resistivity test (see IPS-C-TP-820) and a current requirement test will provide the information necessary to design a ground bed. Soil resistivity tests are also necessary to locate the ground bed in an area of low soil resistivity and also to determine the type of anode bed.

10.2.8 Cathodically protected pipes shall be electrically continuous. They shall be insulated from other buried metallic structures, except where stray current interference bonds are required.

10.2.9 Facilities for pipe-to-soil potential measurements shall be installed at intervals not more than 1 km markers for pipelines and at 250 to 300 meters for distribution lines according to IPS-C-TP-820.

10.2.10 On Pipelines longer than 19 Km, in-line current measurement facilities shall be available at intervals of not more than 10 km. In addition, these facilities shall be installed at all branches or intersections with other pipework. The current measurement facilities shall consist of two pairs of cables, each pair connected to the pipeline 60 meters apart.

10.2.11 All equipment, including the anodes and power source, shall be designed for the life of the pipeline, or 25 years whichever is lesser.

10.2.12 There shall be direct access to rectifiers from the GOSP or plant areas. If located within an electrical substation, the rectifier shall be separately fenced, with a separate entry from the plant area or a separate gate if in a remote area.

10.2.13 All pipeline anchors and all pipeline supports except above grade concrete pads shall be electrically (metallically) separated from the pipeline.

10.2.14 At a plant or gosp the rectifier negative connection shall be made to the pipeline side of the insulating device. The insulating device shall be installed immediately after the pipe becomes exposed.

10.2.15 All buried pipes in a corridor will have an integrated cathodic protection system irrespective of the type of coating on the new and existing pipes.

10.2.16 The pipe should, whenever possible, be surrounded with a backfill that is free from stones and carbonaceous material such as coke. If this is impracticable, an additional wrapping of heavy bituminized felt or other suitable material such as rock shield shall be provided. Where pipes cross streams or rivers, additional protection, in the form of concrete encasement over the pipe coating, may be required.

As the coating deteriorates, an appreciably higher current density is likely to be required to maintain protection and this shall be allowed for in the design of the cathodic protection system. Factors contributing to coating deterioration include soil bacteria, soil stress, pipe movement, effects of pipeline product temperature, water absorption, etc.

TABLE 3 - POTENTIAL LIMITS FOR CATHODIC PROTECTION OF COATED BURIED PIPES

COATING SYSTEM	OFF POTENTIALS, VOLT (Ref. Cu/CuSo₄)
Epoxy powder fusion-bonded	- 1.5
Asphalt and coal tar enamel	- 2.0
Tape wrap (laminated tape system)	- 1.5
Epoxy coal tar	- 1.5
Polyethylene (2 layers)	- 1.0
Polyethylene (3 layers)	- 1.5

10.3 Types of Cathodic Protection Systems

10.3.1 Impressed current system

An impressed current system shall consist of one or more stations comprising a dc power source, anode bed, and connecting cables. The location of these stations for pipeline will be influenced by the availability of ac power and the attenuation of potential. The attenuation of protection along a pipeline from a single cathodic protection installation will depend on both the linear resistance of the pipeline and the coating conductance. It may be calculated using the formulas given in Appendix B. The attenuation formulas are not applicable to distribution lines, the current requirements and availability of land for station will influence on location of the station in this case.

10.3.1.1 Surface anode beds

Horizontal or vertical anode beds shall be constructed in accordance with IPS-C-TP-820. The choice between horizontal or vertical anode beds shall be made after field survey results. Anode beds shall be rated for the maximum output of the power source. The minimum anode bed distance from the buried pipe or adjacent structure shall be 100 m, unless field data show interference is not a problem. Preferred criteria for this minimum distance is 50 meters for 30 amperes rated output, 100 meters for 50 amperes output and 200 meters for 100 amperes output and 300 meters for 150 amperes output. Multiple rectifier anode bed installations in the same general area shall have anode beds separated by a minimum distance of 300 m.

Multiple anode beds to be separated by a minimum distance of 100 meters. The anode bed (ground bed) shall be installed at right angles or parallel to pipeline.

To achieve the desired objective, careful consideration shall be given to selection of installation site for anode bed. The most important consideration is determination of effective soil resistivity which is prerequisite for the site selection, the consideration must also be taken into account when selecting a site for anode bed. One point to be considered in this respect is to ensure that no other underground metallic structure exists within the area of influence surrounding the anode bed, since such metallic structure will pick up current from the anode bed and create a stray current interference problem that will require corrective measures. It is essential that interaction effects be taken fully into account and suitable precautions adopted (see A.3.3).

In planning impressed current system consideration shall also be given to availability of power before final decision is made on selection of site for anode bed.

Coverage of each bed and optimum spacing between the beds are other points of consideration in selecting site for anode bed.

10.3.1.2 Deep anode beds

Deep anode beds are generally employed where top soil strata have a high resistivity and/or where the horizontal or vertical anode bed is impractical like in gas distribution systems. Resistivity generally decreases considerably with depth, especially into the water table. Such anode beds shall be constructed in accordance with IPS-C-TP-820. If more than one deep anode is to be connected to a single rectifier they shall be spaced at a minimum distance of 30 m from each other unless closer distances are justified. Deep anode beds installation shall be in accordance with standard drawings IPS-D-TP-707 and IPS-D-TP-713.

10.3.1.3 Cables

Conductor sizes shall be sufficient to carry the maximum designed current load of the circuit without excessive (5%) voltage drop (see also 9.4). All cables and wires shall be in accordance with IPS-M-TP-750 Part 7.

10.3.1.4 Connections

All positive anode cables from rectifiers to anode beds shall be run in continuous lengths to a maximum length of 150 m. An above grade test box (bond box) shall be used for every 150 m cable run exceeding this length. Only in exceptional cases buried splices shall be used in epoxy filled splice case. Generally, buried splices shall be restricted to header to anode cable connection(s) and negative cable splices.

Negative drain or bonding cable connections to steel shall be termite welded or brazed.

10.3.1.5 Anode materials

The type of anode materials which may be considered for use in impressed current ground beds shall be in accordance with IPS-M-TP-750 Part 1.

10.4 Galvanic Anode Systems

In cases where galvanic protection is required, i.e. where relatively small increments of current are required in area with low soil resistivity (listed below) it shall consist of block or prepackaged anodes installed along the buried pipe, or ribbon anode installed in the same trench along the pipeline according to installation of anodes shall be in accordance to IPS-C-TP-820 with standard drawings IPS-D-TP-711 and 714.

- a) On bare or very poorly coated systems where complete cathodic protection may not be feasible from a cost standpoint.
- b) On well coated pipes having overall impressed current cathodic protection systems, where additional small amounts of current are needed.
- c) To correct stray current interference.
- d) On short increments of well coated pipe such as distribution and service lines.

The weight of the anodes required and the current output can be calculated using formulas given in Appendix B.

- e) Galvanic anodes are also placed at specific points on a pipeline (often termed "hot spots") and may be expected to protect only a few feet of pipe.
- f) Galvanic anodes may be used to provide temporary protection of sections of buried pipes where particularly corrosive condition exist, e.g. at river estuary crossings, pending commissioning of an overall impressed current system.

10.4.1 Magnesium

High potential magnesium 1.70 V (Cu/CuSO₄) will be used as galvanic anode material as per material specification (see IPS-M-TP-750 Part 3). Magnesium anode may be used in soil resistivities less than 5000 ohm-cm. For soil resistivities less than 700 ohm-cm zinc anodes can be used.

10.5 Isolation of Buried Pipes (see also NACE Standard RP 0288-86 item No. 53060)

In design of ground bed for gas or oil transmission pipeline it is a common practice to locate ground beds at compressor or pumping stations, where power source is available. This is a sound practice from technical and economical standpoint provided that following consequence are taken into consideration and the relevant remedial actions are implemented:

- If station pipings, equipment and machineries are not insulated from mainline, most of the protective current for mainline will be drained from poorly coated buried pipes and valves. This would inevitably reduce the protection span of mainline.
- Lack of isolation of mainline from station piping and facilities would cause protective current to flow preferentially through low resistance copper grounding of the station; the apparent result is reduction in length of the mainline being protected .
- To obviate the above-mentioned undesirable consequences, it is essential to isolate station facilities and piping from mainline using insulating joints or flanges. This isolation could in turn create stray current problem on station buried piping and accelerate corrosion. Resistor bonding and test for stray current interference shall be made to ensure that effect of stray current is reduced to the acceptable limit before separate cathodic protection system is installed for station piping.

This risk of corrosion acceleration can be reduced by paying special attention to the coating of the pipeline near such equipment and by locating the groundbed as distant as possible from such equipment. It is essential that the decision is based on an assessment of the relative costs of providing complete or partial protection and an assessment of the likelihood and consequences of corrosion of the various parts of the isolated equipment.

Once the cathodic protection is commissioned, procedures described in Section A.3 enable any effects of interaction to be assessed and overcome.

If the pipe contains an electrolyte, there is danger of corrosion being stimulated at the inner surface of the pipe. With weak electrolytes, for example potable waters, it may suffice to coat the pipe internally for at least two diameters either side of the isolating joint. Replacement of a length of pipe by a length of nonmetallic piping, if practicable, may be a more economical method.

In the case of highly conducting electrolytes such as sea water, or brine, it will probably not be feasible to coat or replace a sufficient length of pipe to eliminate the danger of corrosion occurring internally near the flange. The tests to determine the length of pipe that shall be treated would be complicated (see A.3.6). Where the provision of an isolating joint is considered to be essential and conditions allow, it may be considered best to install extra heavy walled pipe on either side of the joint and to accept the need for periodic inspection and replacement.

10.5.1 Insulating devices

10.5.1.1 Cathodically protected pipelines shall be electrically isolated from plant piping, wellheads, etc., by the installation of insulating devices. Insulating devices shall also be installed at transitions between cathodically protected buried pipes and noncathodically protected aboveground pipes, where economically justified, and also between submarine pipelines and land pipelines where current control and distribution justify their use. Pipes of different metals shall be insulated from each other. Insulating devices shall conform to IPS-M-TP-750 Part 8 or 9 as required as appropriate.

10.5.1.2 Insulating flange sets shall not be installed in buried portions of pipes. Insulating joints may be installed below grade and buried. Insulating joints that are buried shall be provided with a protective coating equal to or better than that applied to the pipeline.

10.5.1.3 Insulating devices shall not be used to electrically isolate gas operated valves and new and existing pipelines installed in a pipeline corridor.

10.5.1.4 Bounding stations shall be installed across each insulating device in easily accessible locations as required to mitigate interference.

10.5.1.5 Bond wires from both sides of insulating device shall be terminated in a common bond box in the way to allow the electric continuity of the pipelines to be opened when necessary.

10.5.1.6 Distribution networks require insulating devices to be fitted to all domestic service pipes and sometimes also to individual sections since it may be convenient to subdivide the area to be protected into smaller zones.

10.5.1.7 Distribution networks also require insulating devices to limit the zone of influence of the impressed current stations. They shall also be installed at pipeline nodes so as to prevent signals emitted anywhere on the network from returning to their send out point.

10.5.1.8 Isolating joints for pipelines need to be adequate for the maximum pressure and temperature conditions encountered on the particular installation. The usual method of insulating flanged joints is to employ insulating sleeves on the studs or bolts and insulating washers under the nuts and/or the heads of the bolts, bright mild steel washers being provided to prevent damage to the insulating washers when being tightened. The insulating sleeves and washers are usually of synthetic resin bonded fabric; the insulating gaskets may be of compressed nongraphited asbestos or other suitable materials. Wire reinforced gaskets or electrically conducting gaskets are unsuitable. The insulating gasket shall comply with IPS-M-TP-750 Part 9.

10.5.1.9 The internal bore and centralizing of the insulating gasket shall ensure that no recess is formed internally, between flanges, in which material that would bridge the insulating gap might accumulate.

10.5.1.10 Under dry conditions and before connection to other structures on either side, an electrical resistance greater than 1 MΩ shall be attainable for pipes of 500 mm diameter or less. Care shall be taken to ensure that the testing voltage is appropriate to the intended service conditions. The gap between the flanges shall be filled with compound and the outer faces of the flange taped to minimize the possibility of accidental short circuit. Exposed isolating devices shall be painted a distinctive color for identification.

10.5.1.11 It is preferable to assemble isolating joints and test them both hydrostatically and electrically before they are installed in the pipeline, the isolating joint being supplied with short lengths of pipe so that the joint can be welded into the pipeline without being dismantled. If insulation is being introduced at a pair of flanges already provided in the pipeline, care shall be taken to ensure that it is not damaged. In either case, final testing of the isolating device after assembly will be required. This can usually most conveniently be carried out on commissioning the cathodic protection system by measuring the change of potential across the flange.

10.5.2 Pipe supports

Cathodically protected pipelines installed above ground and supported, with steel supports, shall be insulated from the supports by means of a minimum 3 mm thickness of insulating material (not wood) placed between the cradle and the pipe. Insulating material shall extend at least 25 mm beyond all support edges. Buried pipe supports have diminished the effectiveness of cathodic protection systems and have caused pipeline leaks. Pipe supports shall not be buried at the support pipeline interface.

Insulating devices shall be considered at the termination points of above grade piping run when electrical insulation of large quantities of pipeline supports becomes economically impractical. The buried sections of pipe shall then be appropriately bonded together if necessary to maintain continuity within the cathodic protection system.

10.5.3 Electrical ground isolation

For maximum effective electrical isolation, insulating flange kits, spools, or joints shall be located on the pipeline side of motor operated valves, instrumentation (electrical or pneumatic), and corrosion monitoring devices. Grounding cables, electrical neutrals, feed back lines etc., act as low resistance shunt paths, thereby "shorting" the insulating flange kits and joints. Where isolation is not practicable, the equipment shall be electrically isolated from the pipeline or alternatively separate grounding for the equipment shall be installed and isolated from the general grounding system for the power supply. Polarization cells can also be used to isolate pipelines from grounding systems. Cathodic protection junction boxes and conduit runs shall have a separate ground rod and not be tied into the general grounding system of a plant.

10.6 Test and Bonding Stations

10.6.1 Potential measurement

Test stations for potential measurement shall be installed at intervals not more than 1 Km markers for pipelines and at 300-500 meters of distribution lines and when required at valve boxes, bonding stations, road crossings and other appropriate locations dictated by operational needs. The cable conductor size shall be 16 mm² for pipelines and 10 mm² for distribution lines. Test stations shall be installed in accordance with IPS-C-TP-820.

10.6.2 Bonding stations

Bonding stations shall be in accordance with IPS-C-TP-820. Minimum 16 mm² cables shall be connected to the structures and brought into the bonding stations. Bonding and test stations may be combined where feasible.

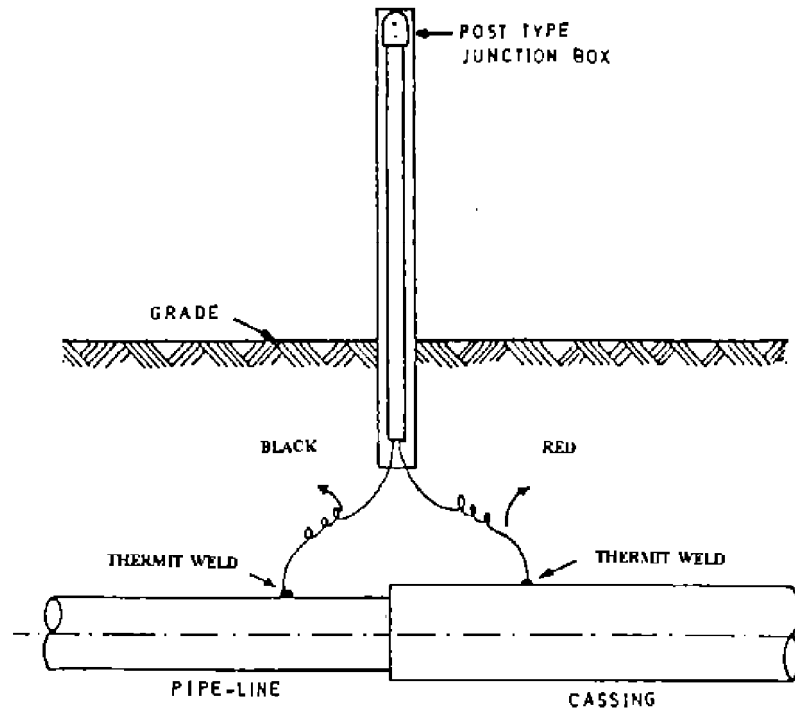
Fixed tap resistances or nichrome wire are required and a shunt included to enable current measurements. Construction shall be carried out in accordance with IPS-C-TP-820.

10.6.3 Line current measurement

Two test leads separated by a fixed distance (usually 30 to 60 meters) are required for measurement of current flow in the line. The current flow is calculated from the voltage drop measured in the span of pipe between the two test leads. In impressed current system, as a minimum, facilities for measurement of current flow shall be installed in both direction of each drain point and the midpoints between drain points. Installation shall be in accordance with IPS-C-TP-820.

10.7 Cased Crossing Test Station

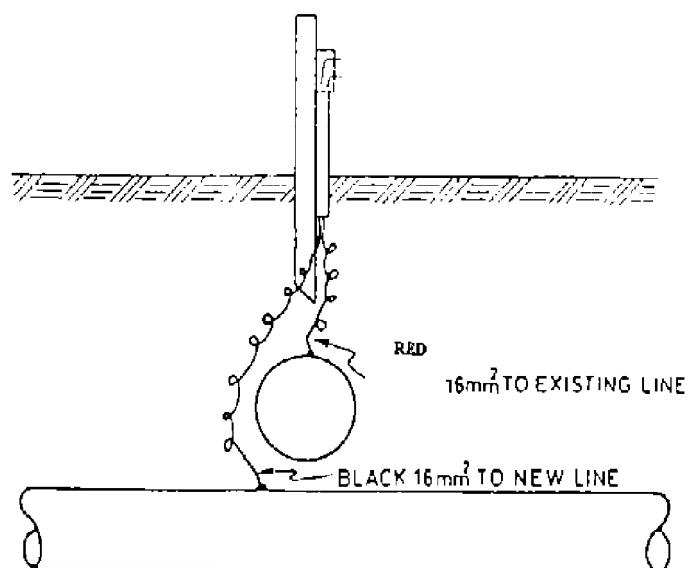
Casing pipe used at road and railroad crossings must have test stations installed to allow a periodic check for shorts between the carrier pipe and the casing or the vent pipe (see Fig. 1). Installation shall be in accordance with IPS-C-TP-820.



TYPICAL CASSED CROSSING STATION
Fig. 1

10.8 Line Crossing Test Station

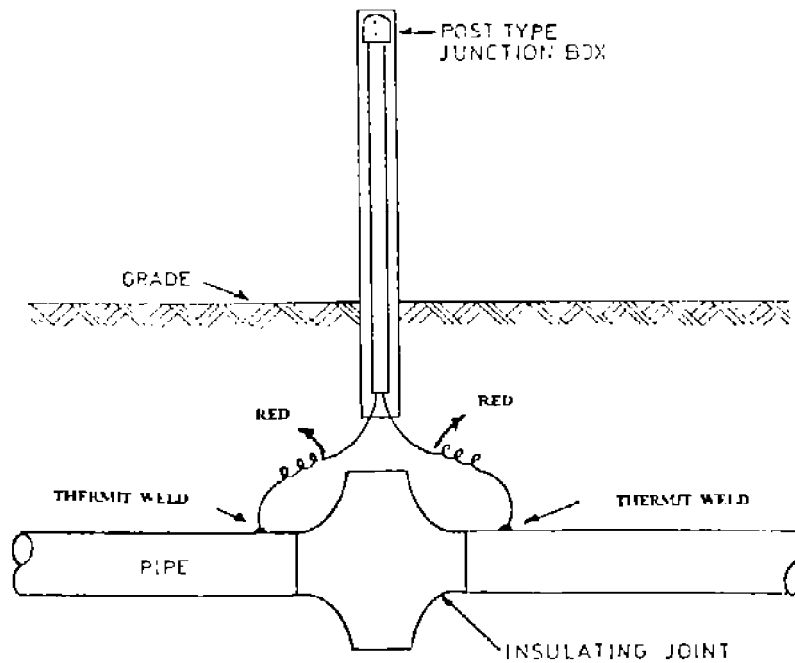
The pipeline crossing test station shall be installed at locations where the possibility of interference problems may exist (see Fig. 2). If stray current is found, a resistance bond wire can be installed. Installation shall be in accordance with IPS-C-TP-820.



TYPICAL LINE CROSSING TEST STATION
Fig. 2

10.9 Insulated Fitting Test Station

All underground insulated joints must have test stations installed to allow a periodic check of the effectiveness of the insulator (see Fig. 3). Installation shall be in accordance with IPS-C-TP-820.



TYPICAL INSULATING JOINT TEST STATION

Fig. 3

10.10 System Design

Design principles of cathodic protection for buried pipelines are given in Appendix B.

10.11 Measurement and Tests

All necessary measurements and tests shall be fully in accordance with IPS-C-TP-820 and IPS-I-TP-820.

10.12 Particular Considerations

10.12.1 Casings

Pipe sleeves (casings) may act as a shield preventing the flow of cathodic protection current to the carrier pipes inside them; their use shall therefore, be avoided where possible. If, however, their use is mandatory, measures as indicated below shall be taken:

a) Protection of carrier pipe

Any section of pipe installed inside concrete or steel pipe sleeves shall be coated to at least the same standard as the remainder of the pipeline. If it is feasible to keep the pipe inside the sleeve dry by means of suitable end seals, this will ensure freedom from corrosion. If, however, it is impossible to exclude water, consideration may be given to installing galvanic anodes in the form of magnesium or zinc strip attached to the carrier pipe. The

carrier pipe shall be supported by insulating centralizers in order to prevent coating damage during installation and, where steel sleeves are used, to prevent electrical contact between pipe and sleeve. Such contact is to be avoided since, unless protection has been provided by galvanic anodes inside the sleeve, the carrier pipe will be left without protection because of the shielding effect of the sleeve. If the sleeve is poorly coated it will also cause a marked increase in the current required for cathodic protection. If insulation is provided, it shall be checked before backfilling.

b) Protection of sleeve casing

If a steel sleeve is used and is insulated from the carrier pipe, corrosion will be accelerated, particularly at the inner surface if moisture has not been excluded from the space between the sleeve and the pipe. If the sleeve is to be cathodically protected, it shall, be coated to the same standard as the pipeline. The sleeve can be cathodically protected by connecting it to the pipeline through a surface connection box or by means of galvanic anodes. If the sleeve is cathodically protected, it is particularly desirable to safeguard the carrier pipe inside the sleeve either by complete exclusion of moisture or by use of galvanic anodes.

It may be possible to seal the pipe sleeve to the pipe by welding at each end and to fill the annular space with an inert gas, e.g. Nitrogen. The sleeve shall then be coated externally to reduce the cathodic protection current demand but it would be unnecessary to coat the pipe inside the sleeve.

Note:

The installation of pipe sleeves (casings) shall be in accordance with IPS-C-TP-820.

10.12.2 Concrete encased pipe

Pipe to be encased in concrete, as at river crossing, valve boxes, etc. shall first be coated to the same standard as the rest of the pipeline.

10.12.3 Protecting existing pipelines

Cathodic protection, usually by impressed current, may often be applied to old pipelines, even though they are bare or have badly deteriorated coatings, in order to prolong their life. It is rarely economical to lift and recoat such pipelines except possibly at selected points where interaction may be expected (see A.3). High current densities will therefore be necessary. The current initially required can be determined by means of a drainage test carried out after isolating the pipeline as far as possible from other structures in contact with the soil. The final current requirement will usually be much less due to long term polarization effects.

10.12.4 Scale detachment

After a cathodic protection system has been put into operation it may be found that there is a temporary increase in the number of leaks due to scale detachment at heavily corroded areas where the pipe wall has been seriously weakened or perforated. The majority of such leaks become manifest in the first one or two years operation of the cathodic protection system (see also h of A.2.5.1).

11. CATHODIC PROTECTION IN PLANT FACILITIES

11.1 Application

11.1.1 This Section of engineering standard applies to in-plant facilities such as: tank bottoms, metallic pipelines and other metal structures buried or in contact with soil or water.

11.1.2 The design of new plants shall provide an integrated cathodic protection system for all buried metallic pipelines and where required for electrical grounding grids if they are electrically connected to the buried metallic pipelines or other protected facilities.

11.1.3 The design of additional facilities in existing plants shall provide an integrated cathodic protection system. If economically justified, the new cathodic protection system shall incorporate protection for the existing plant buried facilities as specified in Paragraph 11.1.2 where required to minimize interference or ensure operation of the system.

11.1.4 If steel Groundbed is selected for temporary protection, the consumption of steel at design output rate shall be taken into consideration. One ampere of direct current discharging into the usual soil can remove approximately 9 kg (20 pounds) of steel in one year.

11.2 General

11.2.1 Cathodic protection of the in-plant facilities may be provided by impressed current or galvanic systems or a combination of both.

11.2.2 The choice between impressed current or galvanic systems shall be based on economic analysis the availability of electric power and the effectiveness of either system.

11.2.3 As far as possible, the design shall utilize existing equipment and power available.

11.2.4 A site survey shall be made to determine soil resistivities and suitable locations for anodes unless the right information is available from existing systems or previous surveys made by company corrosion control department or other departments.

11.2.5 The level of protection shall be in accordance with Section 7 of this Standard.

11.2.6 The design current density for plant cathodic protection system shall be determined by current requirement test (see IPS-C-TP-820).

11.2.7 The cathodic protected facilities shall be electrically continuous.

11.2.8 All equipment, including the anodes and power source(s) shall be designed for the life of the in-plant facilities or 25 years whichever is lesser.

11.2.9 There shall be direct access across to the transformer/rectifier(s) from the plant areas. If located within an electrical substation, the transformer/rectifier shall be separately fenced, with separate entry from the plant area or a separate gate if in a remote area.

11.2.10 All above grade facilities such as transformer/rectifier(s), junction boxes, ac step down transformers, etc. should be located in the lowest electrically classified area (see IPS-E-EL-110 for classified area).

11.3 Types of Cathodic Protection Systems

11.3.1 Integral impressed current systems

The following design guidelines determine the outline and definition of integral impressed current system:

11.3.1.1 All metallic buried sections within the plot limits shall be electrically bonded together by means of accessible cables. The cable connections shall be made by means of over ground test boxes. No significant section shall be left out to minimize the rise of interference. The primary reason for bonding is electrical safety during ground fault conditions.

11.3.1.2 Distributed anode configurations and/or polymeric anodes are preferred for new construction sites and where demolition of concrete and asphalt is minimal. Deep well anode designs may be used where justified by structure complexity and installation economics.

11.3.1.3 Insulating flanges, joints or spools shall be specified only where needed to limit protective current flow between the on-plot and off-plot pipeline sections.

11.3.1.4 Bonding stations shall be provided across insulating flanges, joints and spools.

11.3.1.5 All installations which have limited accessibility for accurate potential readings, such as tank bottoms, shall be provided with permanent packaged reference electrodes.

11.3.1.6 Current density to be applied shall be selected from the results of cathodic protection tests.

11.3.1.7 Tank undersides may be considered partially coated due to contact with sand asphalt padding. However, contact with soil will vary with flexing of the base. The potential recorded at the periphery of the underside shall be -1.10 volt minimum with reference to a copper/copper sulfate half cell. Where permanent reference electrodes have been installed under the tank bottom, a potential of -0.85 volts versus to copper/copper sulfate half cell indicates adequate protection. (see also 11.8)

11.3.2 Galvanic anode system

11.3.2.1 Galvanic anode systems may be used in conjunction with segregated impressed current systems to protect small buried metal structures such as road crossings. Where conditions indicate cathodic protection can not be fully achieved with packaged magnesium anodes, a helically wrapped magnesium ribbon and plastic envelope system shall be used at road crossings.

11.3.2.2 When ac power for permanent impressed current will be delayed after plant construction, temporary galvanic anodes shall be installed in soil less than 5000 ohm-cm.

11.4 Impressed Current System Details

An impressed current system shall consist of one or more stations comprising ac power source, anodes, connecting cables and necessary test facilities. The location of the transformer/rectifier(s) will be influenced by the availability of ac power and the anode locations.

11.4.1 Anode beds

Horizontal or vertical anode beds shall be installed in accordance with details specified in IPS-C-TP-820.

The choice between horizontal or vertical anode beds shall be made after field survey results and evaluation of local conditions. Anode beds shall be rated for the maximum output of the power source.

Design of ground bed is based mainly on the following points:

- Current requirement for section of pipeline to be protected by the particular ground bed .
- Soil resistivity of site selected for ground bed.
- Type of anode material and its dimensions.
- Type of anode installation (vertical, horizontal, spacings between anodes, backfill material surrounding anodes).
- Life expectancy of ground bed, based on the consumption of anode and backfill resulting from current discharge.
- Cables used in cathodic protection circuit (material and size).

11.4.2 Cables

Conductor sizes shall be sufficient to carry the maximum designed current rate of the circuit. Power loss in cables should not exceed 8% of total dc power. All cables and wires shall be in accordance with (IPS-M-TP-750 Part 7). Cable run design shall use loops or multiple returns to minimize (IR) drop and increase security of the anode system.

11.4.3 Connections

Splices shall be made in above-ground boxes except for splices of the header cable to anode cable connections. Underground splices shall be made with split bolt connectors (line taps). All underground splices shall be waterproof type and insulated with epoxy kits and standard rubber tape or vinyl tape according to IPS-M-TP-750 Parts 11, 12 and 13.

11.4.4 Anode materials

For the various types of standard anodes which may be considered for use in impressed current groundbeds see IPS-M-TP-750 Part 1.

11.5 Galvanic Anode System Details

11.5.1 In special cases where sacrificial anode protection is required, it shall consist of anodes distributed around in-plant facilities.

11.5.2 The weight of the anodes required and the current output can be calculated, using formulas given in Appendix B.

11.5.3 Magnesium may be used as sacrificial anode material in soil resistivities less than 5000 ohm-cm.

11.5.4 Zinc anodes may be used in soil resistivity less than 700 ohm-cm.

11.6 Test and Bonding Stations

11.6.1 Potential test stations

To allow for a systematic inspection scheme a number of test points with marker plates shall be installed at predetermined locations. The marker plate shall identify the protected buried structure and include the CP test station number.

The cable from this station shall be connected to the buried structure. In cemented and asphalted areas, test stations shall be installed in accordance with IPS-D-TP-718.

11.6.2 Reference electrodes

Where testing with a portable test electrode is inaccurate i.e. under tank bottoms and foundations, permanent reference electrodes shall be used. These electrodes shall be installed prior to the construction of the protected structure. Reference electrodes used for this purpose are the prepackaged high purity zinc electrodes or permanent Cu/CuSO₄ electrodes.

11.6.3 Current monitoring stations

Four point test stations may be required in the case that the designer can foresee that a high electrical current may occur in one of the multiple legs of the system.

11.6.4 Bonding stations

All bonding stations shall provide for measuring the current by means of a shunt and space to install a resistor if required.

11.7 Hazardous Locations

Transformer rectifier specifications must follow the rules and regulations concerning area classification for electrical equipment, (see IPS-E-EL-110). Other electrical equipment such as above-ground splice boxes, bond boxes or test stations are generally non-explosion proof and require a hot work permit for opening and test work.

11.8 Oil Storage Tank Bottoms

Large oil storage tanks are often erected on earth foundation mounds. The top of the foundation mound may be provided with a bit-sand carpet or some form of coating may be applied to the underside of the tank bottom. During operation, the bottom of the tank is subject to flexure and settlement. The bit-sand carpet is therefore liable to be damaged, thus allowing parts of the tank bottom to come into contact with the soil of the foundation mound. Any coating applied to the tank bottom plates is also likely to be partially destroyed by the heat of welding of the lap joints, with the same result.

Hence if the environment is corrosive, cathodic protection may be applied to supplement the protection provided by carpeting or tank bottom coating.

The above general considerations also apply to similarly constructed tankage for use with liquids other than petroleum or its products.

11.8.1 Structure preparation

The tank foundation mound should as far as possible be constructed so that it will distribute protection current uniformly to the whole of the underside of the tank. This means that the use of rubble, rock fill etc., should be avoided and the mound should consist of fine-grained and well compacted material.

Oil storage tank bottoms are constructed by lap welding individual plates and are therefore electrically continuous. Where groups of tanks are to be cathodically protected, provision will need to be made for bounding between individual tanks.

If it is desired to confine the protection current to the tanks, isolating joints will be required in all pipelines connected to the tanks.

If flammable liquids are being stored, such joints should be located outside the tank bund (see 11.6.2).

11.8.2 Application to oil storage tank bottom

Current density figures of the order of 10 mA/m² are normally required for uncoated tank bottoms resting on bit-sand carpets and, owing to the large areas involved, impressed current is usually preferred. Galvanic anodes may, however, be worth consideration for small isolated tanks on soil with low resistivity.

Groundbeds should as far as possible, be symmetrically arranged around the tank or group of tanks and a distance of not less than one tank diameter from the tank periphery is desirable. Ground beds should not be located inside tank bunds if flammable liquids are being stored. Where space is restricted, consideration may be given to installing anodes at considerable depths.

11.8.3 Particular considerations

Structure soil potentials vary across the underside of a cathodically protected tank bottom and rim potentials usually need to be more negative than -0.85V in order to ensure protection at the center. The main factors concerned are the insulation provided by the tank bottom coating in relation to soil resistivity, and variations in soil resistivity with depth at the tank site.

On new constructions it may be possible to install two or three permanent reference electrodes in the foundation mound prior to tank erection so that the least negative rim potential necessary to secure full protection of the tank bottom can be assessed suitable mechanical protection will be required.

Where measurement is impracticable, an arbitrary value of rim potential has to be adopted. Potentials in the range of -1.10V to -1.20V (copper/copper) sulfate reference electrode have been found to be satisfactory.

Tanks which remain empty for prolonged periods are therefore, unlikely to receive complete protection because upward flexure of the tank bottom when the tank is emptied leads to loss of contact with the foundation.

Cases may arise where an old tank on a granular bed, e.g. granite chips, is lifted for rebottoming and the subsequent application of cathodic protection. Under these circumstances, the spaces between the granite chippings should be filled with suitable fine grained material to enable protection current to flow to the whole of the underside surface of the new bottom.

12. CATHODIC PROTECTION VESSELS AND TANK INTERNALS

(See also NACE Standard RP 0388-88, Item No. 53069).

12.1 Application

12.1.1 This Section of standard applies to all types of water storage tanks, consider water boxes, salt water strainers, produced oil field brine handling and treating vessels and other vessels in which water may be in contact with the interior surfaces.

12.1.2 Due to the varied nature of vessel and tank design, this Standard contains specific designs for only the most common types and is intended to be a general guide for all vessel and tank design used.

12.1.3 The need for providing cathodic protection to tanks containing high resistivity (low dissolved solid content) waters shall be dependent on the severity of existing or anticipated corrosion and also the end use of the water itself.

12.2 General

12.2.1 Internal cathodic protection may be provided by galvanic or impressed current systems.

12.2.2 Internal coatings shall be used in conjunction with cathodic protection to protect internals of vessels containing moderately corrosive waters e.g. aquifer or process raw water (see IPS-E-TP-100 and IPS-E-TP-350).

12.2.3 For vessels containing severely corrosive waters such as produced oil field brines, all corrosion control methods should be considered including chemical inhibition, internal coatings and cathodic protection.

12.2.4 For waters whose end use precludes the possibility of contamination due to cathodic protection anode material, such as demineralized or treated boiler feed water, inert platinized anodes shall be used, if cathodic protection is required.

12.2.5 The level of protection shall be in accordance with Section 7 of this Standard. Potentials of coated vessels should be maintained as near the minimum protective potential as possible to prevent coating disbondment and excessive scale build-up.

12.2.6 The minimum design current density requirement is dependent on the oxygen content, temperature, resistivity and velocity of electrolyte. In general, a minimum criteria of 100 mA/m² of bare steel surface shall be used for relatively clean saline or raw waters. Vessels handling water containing depolarizers such as hydrogen sulfide and oxygen or operating at high flow rate usually require higher current densities to maintain protective potentials.

Internal coatings decrease the area of bare steel in contact with water and thus reduce the current required for protection.

12.2.7 The design life of a period galvanic anode system shall be for the testing and inspection period. Impressed current systems shall be designed for the life of the vessel or 25 years.

12.3 Types of Cathodic Protection Systems

12.3.1 Impressed current systems

12.3.1.1 Impressed current systems are generally used in applications with high power demands, such as for large water storage tanks or where current requirements may change.

12.3.1.2 Automatic potential control rectifiers can be considered for use in applications where varying conditions, as mentioned in 11.2.6, combine to create a changing current density requirement to maintain protective potentials. These decrease the likelihood of underprotection or coating disbondment due to overprotection.

12.3.1.3 High silicon-cast iron or platinized titanium anodes are the most common types of impressed current anodes used. Specifications for these anodes are detailed in IPS-M-TP-750 Part 1.

12.3.1.4 Installation details for impressed current systems for water storage tank internals shall be in accordance with applicable Iranian Petroleum Standard Drawings.

12.3.1.5 Separate transformer rectifier for impressed current systems shall be installed for each tank or vessel to be protected.

12.3.1.6 Where cathodic protection is applied internally to plant, corrosion interaction affecting neighboring structures is unlikely appreciable current flows only through and inside the protection plant.

12.3.2 Galvanic anode systems

12.3.2.1 Galvanic anodes are considered for use in applications where water resistivity and power requirements are low, or electrical power is not available or if their use is economically feasible, or in cases where sufficient impressed current anodes cannot be provided or placed for proper current distribution, as would be in the case of a compartmented vessel.

12.3.2.2 Zinc, magnesium and aluminum alloys are the common galvanic anode materials used. Their properties and specifications are given in IPS-M-TP-750 Part 3. Design calculations are given in Appendix B.

12.3.2.3 Zinc anodes are commonly used in low resistivity brines due to their longer life. Zinc may show decrease in driving potential and possible polarity reversal above 65°C and passivation in the presence of phosphates, chromates and sulfides. The use of zinc anodes shall not be specified for electrolytes in which these conditions may exist.

12.3.2.4 Magnesium anodes are generally specified for high resistivity waters. In low resistivity brines, current output shall be controlled by resistors in the external circuits or by partially coating anodes to control exposure of active metal.

12.3.2.5 Aluminum alloy anodes have a lower driving potential compared with magnesium, providing a longer life in low resistivity electrolyte. Like zinc, they are self regulating and do not need resistors for external current control.

12.3.2.6 Installation details for galvanic anodes in water tanks and also for other types of vessels or tanks, anodes may be internally supported or mounted horizontally through the vessel sides. Care shall be taken in anode placement design to ensure proper current distribution to all internal surfaces in contact with the electrolyte. Vessel redesign or internal modification should be considered, if necessary, for providing effective cathodic protection throughout.

12.3.2.7 Where large stand of anodes are used for the protection of tanks then the resistance should be determined using the formula:

$$R = \frac{\rho h}{27L} \ln \frac{8L}{D} \quad i$$

Where:

- R = anode-to-electrolyte resistance of single vertical anode to remote reference (ohms).
 ρ = electrolyte resistivity in (ohm-cm).
 L = length of anode in cm (including backfill, if used).
 D = diameter of anode in cm (including backfill, if used).

12.3.2.8 Where flat plate anodes are used their resistance is to be determined from the following formula:

$$R = \frac{\rho}{2S}$$

However if the flat plate anodes are close to the structure or painted on the lower face then the resistance is to be determined using:

$$R = \frac{\rho}{4S}$$

Where:

- R = anode-to-electrolyte resistance of a single flat plate anode.
 ρ = the resistivity of electrolyte in ohm-cm.
 S = mean length of anode sides, in cm.

12.4 Current Density

12.4.1 Uncoated tanks used as permanent water ballast are to have a minimum current density of 110 mA/m² but this may have to be increased to at least 130 mA/m² if hot oil is stored on the opposite side of the bulkhead.

12.4.2 Uncoated tanks used for the storage of crude oil at ambient temperature alternating with water ballast are to have a minimum current density of 90 mA/m² however this should be increased for higher temperatures.

12.4.3 Unless shown otherwise the resistivity of the water should be assumed to be 25 ohm-cm.

12.5 Anode Distribution

12.5.1 Having determined the number and size of anodes, they are to be distributed as follows:

- a) Ballast only tanks; evenly over all the uncoated steel work.
- b) Crude oil/ballast tanks; evenly but with some emphasis on horizontal surfaces in proportion of the area of these surfaces.

12.5.2 Anodes shall be arranged in the tank so that protection can be provided to all surfaces without exceeding potentials (in the vicinity of the anodes) that will be detrimental to coating.

12.5.3 Where freezing occurs, provisions should be made for periodic replacement or for an anode installation unaffected by either freezing or falling ice. Alternatively the tank may be operated so that ice accumulation anodes does not occur on the anodes or in a solid mass across the tank which could damage the anodes when collapsing.

12.6 Reference Electrode Position

12.6.1 In vertical cylindrical vessels equipped with roof hatches, electrodes may be inserted through these hatches. If this is anticipated, the anodes shall be at the maximum distance from these hatches.

12.6.2 In compartmented vessels, reference electrodes shall be installed as far as possible from the anodes in order to obtain potential representative of the steel surface.

12.6.3 Zinc reference electrical shall not be installed in tanks containing high temperature brine (65°C and above).

12.7 Protection of Specific Installations

12.7.1 Storage tanks

12.7.1.1 Impressed current cathodic protection is the method normally used for large tanks such as overhead water towers, oil refinery sea water storage tanks, boiler feed water tanks and river water tanks in power stations. In the case of open topped tanks, anodes of silicon iron or platinized titanium, or lead anodes, if possible toxicity is not a consideration, may be suspended from adequate supports.

Alternatively, it may be preferable to drill the tank and insert anodes and reference electrodes through the wall. Anodes shall be so distributed that they are in the best position to ensure even current distribution, i.e. at points roughly equidistant from the bottom and the sides, and so placed as to ensure adequate penetration of current into the corners.

When the water resistivity is exceptionally high, as for example in boiler feed-water tanks, copper-cored platinized titanium continuous anodes may be used; the high resistivity of the water necessitates considerable anode lengths being used to achieve adequate current distribution.

12.7.1.2 Where galvanic anodes are used, they are normally attached directly to the metal surface to be protected.

Corrosion is most probable near the waterline where differential aeration effects are greatest; anodes will normally need to be distributed up to about 600 mm below the minimum water level.

For domestic water tanks, sufficient current may be obtained from a single magnesium anode.

12.7.1.3 Tanks for storage of chemicals

Among the types of plant that have been protected are brine storage tanks, acid storage facilities, and electrolytic resistance tanks.

The methods of applying cathodic protection to tanks containing chemicals are similar to those for water storage tanks. Care needs to be taken in selecting anode material to ensure that it does not react with the chemicals involved. Galvanic anodes are seldom suitable and it is normal to use impressed current with platinized titanium anodes.

An alternative system, used to protect certain types of chemical plant, is that of anodic protection (see 14).

12.7.2 Water circulating systems

Circulating water systems are often constructed from cast-iron* or mild steel, and where the metal is not subject to onerous conditions such as mechanical erosion, high temperature or chemically aggressive coolants, a moderate increase of thickness will generally ensure a reasonable life. With cast iron, mechanical considerations in casting and handling often result in an adequate wall thickness. There is, therefore, generally little economic incentive to protect, for example, runs of iron or steel pipe work particularly as this requires anodes to be mounted about every four pipe diameters along the length of the run and there has been insufficient experience of such applications for detailed guidance to be given.

The corrosion rate may be locally high due to galvanic action between the various combinations of metal and alloys in the system. Generally, the ferrous component acts as an anode and so corrodes. This process is more important if the oxygen content of the water and the water velocity are high. In such circumstances, the protection of large heat exchangers or coolers becomes economical and details are given in 12.7.2.1 and 12.7.3. Difficulties of application have prevented the benefits of cathodic protection going extended to the inside of other items of plant, even where the combination of materials can give rise to corrosion at appreciable rates. The basic principles of sound design practice have not, therefore, emerged. Thus, in the case of pumps, even with the impressed current system, it is difficult to position sufficient anode material to provide the relatively large protection current densities that are needed, particularly at points where galvanic action may occur, without interfering with water flow.

*** With cast iron, graphitic corrosion occurs in which metal is removed, leaving the graphite. This does not materially alter the application of cathodic protection except that, the graphite being electropositive, the current density required may be increased.**

Similarly with valves, care must be taken to position the anodes, according to the proportions of the service life during which the valve will be in the open and closed positions, in such a way as to ensure that the current reaches those parts of the exposed surface which are subject to severe corrosion. If the water is stagnant for long periods it may be necessary to take measures to prevent the accumulation at parts of the system of chlorine developed at the anodes.

12.7.2.1 Heat exchangers (tube and shell)

Typical plant has cast iron water boxes with tube plate and tubes of copper-based alloys. Where this is the case, the cast iron corrodes, the effect falling off with increasing distance from the components in copper-based alloy. Severe local attack with deep penetration may thus occur on cast iron adjacent to tube plates.

Non-ferrous tube plates and tube ends may also be attacked, principally due to water turbulence and impingement, and cathodic protection may help to reduce the rate of attack. It has been observed that the coating of a ferrous water box or its replacement by a non-metallic type has been accompanied by accelerated tube end attack due to the removal of the cathodic protection previously afforded by the corroding water box.

In such a case, provision should be made for alternative means of protecting the tube plate and tube ends, for example, by installing galvanic anodes (see 12.7.1.1.2).

In circulating water systems, the flow velocity is usually much higher than is encountered with immersed structures and this, together with the presence of metals that are more electropositive than iron, increases the current density required for protection. A rough guide to the amount of current required for cathodic protection of condensers and coolers has been found by experience to be 2.5 A/M^2 , estimated on the area of the tube plate without deducting the cross sections of the tubes. The figure relates to power station condensers using sea-water as coolant and without internal coating of water box or tube sheet. The protective current may be provided by either galvanic anodes or impressed current, the factors determining the methods to be used being largely those outlined in A.2.4 including current requirements, power availability, possible hazards and the accessibility of the components for maintenance. Impressed current has advantages in that the current may be manually or automatically varied to maintain full protection at all times irrespective of changes of flow rate or composition of the cooling water.

Galvanic anodes cannot normally be so adjusted and also require comparatively frequent renewal. On large power station condensers, galvanic anode renewals may not only be costly but also involve considerable effort. Galvanic anodes are generally more suitable for smaller units, Particularly if periodic shut-downs provide regular opportunities for inspection and anode renewal. They may also be of advantage in plant where hazardous atmospheres exist since the use of flameproof electrical equipment, which would be necessary with an impressed current system, can be avoided.

Cathodic protection is not usually applied to condensers or coolers below about 500 mm diameter.

12.7.2.1.1 Water box coatings

The use of coatings in conjunction with cathodic protection does not generally lead to economy because, even with a well-coated box, the current that will flow to the heat exchanger surface, which cannot be coated, will still be considerable. Suitable coatings include one or more coats of epoxy resin paint (minimum thickness 0.25 mm) or of epoxy resin mastic, applied after abrasive grit blasting to a high standard. Coatings should not be used that are adversely affected by the alkaline environment produced near anodes; coatings which may come off as sheets, causing tube blockage, should be avoided.

12.7.2.1.2 Galvanic anode systems

The anodes are usually of either zinc alloy or magnesium, Zinc anodes are generally more suitable where the cooling water, magnesium anodes are generally more suitable because their higher driving potential enables them to provide a greater current output than would be the case with zinc anodes. In certain cases, e.g. where the water box is very well coated or of non-ferrous material, soft iron anodes may be fitted to provide cathodic protection of the tube plate and tube ends.*

* Iron corrosion products are beneficial in assisting film formation on non-ferrous metals; ferrous sulfate is sometimes injected to produce inhibiting films.

In any particular installation, anode wastage rates will be mainly determined by the mean temperature, flow velocity and resistivity of the cooling water. In view of these variable factors, it is often advisable to determine anode wastage rates by trial. If cathodic protection is being applied to an existing design of water box, the maximum amount of anode material which can be installed will be limited by the physical dimensions of the water box; anodes should not cause excessive water velocity or turbulence.

In many industrial plants, regular opportunities for opening-up condensers for anode inspection and renewal occur during plant shutdowns. In the case of oil refinery units, this may be every 2 to 3 years and it may be possible to install sufficient anode material to provide continuous protection over this interval. In some cases, this will entail modification to the water box, for example, dished floating head covers can be made deeper to allow space for the anodes and to maintain sufficient crossover area to avoid undue turbulence.

For zinc alloy anodes in sea-water-cooled condensers, the minimum anode weight to be installed on the cover of a coated water box for a five-year life in a temperate region can be estimated from the formula:

$$W = 80D^2$$

Where:

W = weight of zinc anodes in kilograms.

D = nominal diameter of the wetted part of the tube plate in meters.

In tropical regions the anode life will be about half that stated above.

12.7.2.1.3 Impressed current

High quality coatings are not normally used in conjunction with impressed current. Cantilever or continuous platinized titanium anodes are generally installed. In the latter case, the anode should be located approximately one third of the depth of the water box from the tube plate up to a maximum separation of 300 mm. Where water boxes have depths appreciably greater than 1 m, additional anodes may be needed to protect remote parts of the water box.

Where long lengths of continuous anode, it may be preferable to use copper-cored platinized titanium to reduce voltage drop along the length of the anode. The electrical input to the anode can be at any technically suitable and convenient point along it, or it can be fed from two points to reduce voltage drop.

If cantilever anodes are used, they need to be distributed about the water box to ensure adequate distribution of current.

Reference electrodes will be required so that the effectiveness of the cathodic protection can be measured and these should be mounted near the point of maximum galvanic influence and remote from anodes. If adequate levels of protection are reached at such points, it can be assumed that all parts of the box are adequately protected.

It is not general practice to protect coolers of less than 500 mm diameter. If, however, this needs to be done for special reasons, the factors relating to large condensers also apply, except for the location of anodes, which can be of the cantilever type mounted centrally in the end covers.

12.7.2.2 Box coolers

"Coil in box" coolers comprise a series of pipe coils, of from 75 mm to 150 mm diameter in a steel box through which a flow of cooling water is maintained. The coils, which usually carry hot oil, are generally arranged in vertical banks and the necessary anodes can be installed only in the restricted space between these banks of tubes.

In order to obtain an adequate spread of protection current both along the tubes and also vertically down the bank of tubes, either a series of vertical or horizontal anodes are required, or a combination of both.

Depending on conditions, impressed current with either lead alloy or platinized titanium anodes can be used. It is usually impossible to accommodate sufficient galvanic anode material to maintain protection over a useful life.

It should be noted that a significant temperature gradient may exist from top to bottom of the box that will cause an appreciably higher output current density from anodes located near the water surface. Under certain circumstances, this

can lead to overprotection near the water surface at the expense of underprotection in the bottom corners of the box. This tendency should be taken into account in determining the configuration of the anode system.

Because of the higher output of anodes near the water surface, vertical anodes that are suspended from above the water level are subject to wastage in the form of necking. This problem may be overcome by a suitable anode shape, e.g. a tapered anode, or by sleeving the anode at the water line.

13. CATHODIC PROTECTION OF MARINE STRUCTURES

13.1 Application

13.1.1 This Section of standard specifies the general design requirements for cathodic protection of the submerged zones of marine structures and the buried parts of integral onshore/offshore structures (see also Appendix C).

13.1.2 The specifications are applicable to all types of marine structures and pipelines. Although detailed requirements are given only for the most common types of structures, the system elements are basic to the protection of all types of structures.

13.2 General

13.2.1 Sea water is an excellent medium for the application of cathodic protection. Because of its homogeneity and uniform low electrical resistivity, an even current distribution over the protected surface of the structure is readily obtained. Bare steel in sea water is polarized without difficulty if an adequate current density is maintained.

13.2.2 Galvanic anode may be placed very close to, or in contact with the structure to be protected. Impressed current anodes, however, must be well insulated from the protected structure if they are mounted on it.

13.2.3 Where it is necessary to place impressed current anodes very close to the structure, dielectric shielding between the anode and the structure shall also be provided.

13.2.4 Impressed current cathodic protection is preferred for all installations where power is available. Silicon cast iron, lead alloy and graphite anodes may be used for the buried sections of integral onshore/offshore structures. Lead silver alloy anodes and platinized titanium anodes may be used for the submerged zones of marine structures and the buried parts of the integral offshore structure.

13.2.5 Provisions shall be made for readily accessible dc measurements using shunts or clamp-on ammeters.

13.2.6 Galvanic anode systems shall be designed for the life of the facility or 25 years, whichever is lesser.

Impressed current anode systems shall be designed for 10 years life on offshore structures.

13.2.7 The level of protection shall be as specified in Section 6 Paragraphs 7.4 and 7.5, which indicate the minimum potential required.

13.2.8 The size and design of the cathodic protection scheme is based on the current density necessary to bring the structure up to level of protection required, sea water velocity and oxygen content affect the current density requirements and shall be considered in the design.

13.2.9 For remote offshore bare steel structures an initial 216 milliamperes per square meter current density seems to be sufficient to achieve rapid polarization. In order to maintain the required cathodic protection level, 54 to 86 milliamperes per square meter is usually sufficient.

13.2.10 Current density

Current densities to be used for bare and coated steel work (buried or in sea water) with galvanic or impressed current systems are given in Tables 3 and 4.

13.2.10.1 Current densities for offshore structures:

TABLE 4 - CURRENT DENSITIES IN MILLIAMPERES PER SQ.METER FOR OFFSHORE (PLATFORMS, GOSPS, ETC.) AND PIERS

*C.P. SYSTEM	REQUIRED CURRENT (mA/SQm)
Steel environment	Milliampere
Below mud line (see Fig. 4)	22
In water velocity up to 0.60 meter per second	110
In water velocity over 0.60 meter per second	220

* C.P. = cathodic protection

13.2.10.2 Current densities for shore-side structures:

TABLE 5 - CURRENT DENSITIES IN MILLIAMPERES PER SQ. METER FOR SHORE-SIDE STRUCTURES (WHARVES, SHEET PILING)

*C.P. SYSTEM	REQUIRED CURRENT (mA/SQm)	
Steel environment	Bare	Coated
Back-filled or below mud line (see Fig. 4)	22	11
In water	54	27

Note:

For more details of current density refer to NACE PR-01-76 (1988 revision) corrosion control of steel fixed offshore platforms associated with petroleum production.

13.2.10.3 For all coated pipelines, current density shall be 2.5 milliamperes per square meter submerged surface.

13.2.11 Each rectifier and/or generator shall be provided with its own anode system.

13.2.12 Negative drain or bonding cable connections to steel shall be thermit welded or brazed.

13.2.13 Drain or bonding cable connections shall be made outside classified areas wherever possible, see IPS-E-EL-110 for classified areas. Where cable-to-steel connections must be made in classified areas, two parallel cables shall be installed with separate connections to the steel. All equipment, including connection boxes, rectifiers, test points, etc. shall be suitable for the area classification.

13.2.14 The minimum size of bonding cables shall be 16 mm² copper. Permanent test lead connections shall be insulated copper conductor, minimum size 10 mm² and colored coded as needed.

13.2.15 Resistor bonding station shall be installed outside classified areas wherever possible (see IPS-E-EL-110 classified area).

13.2.16 Electrical components such as anodes, drain cables, anode cables, exothermal weld connections, etc. for impressed current circuits shall be rated for the maximum loading possible on each component of the circuit.

13.2.17 Conductors shall be selected and sized so that voltage drop does not exceed 5%.

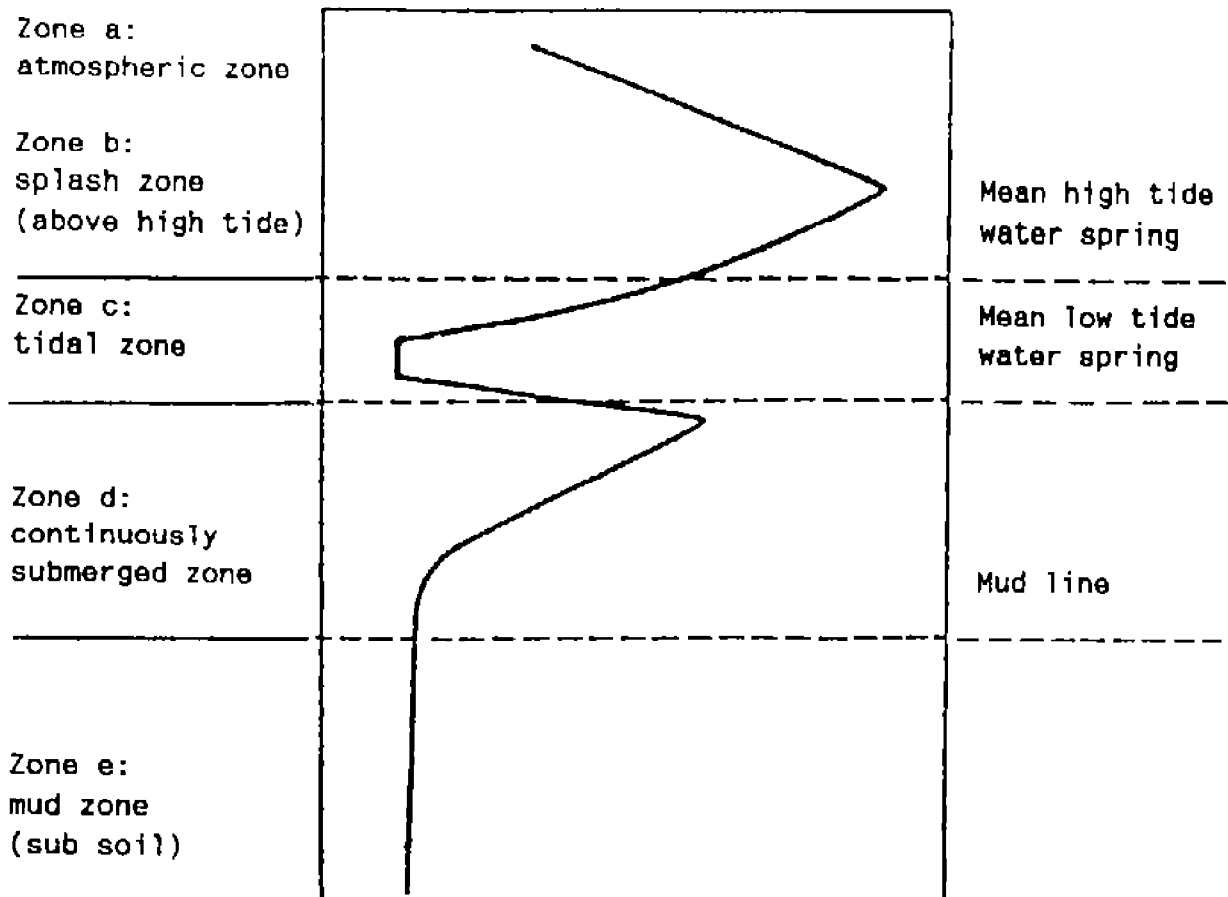
13.2.18 All bonding stations, test cable terminations, etc. shall be clearly identified.

13.2.19 In certain cases, it may be advantageous to provide a flexible bond connection to vessel which lie alongside a cathodically protected structure for long period in order to protect their hulls and to prevent interaction effects (see A.3.7). Account should be taken of the additional current required when designing the cathodic protection installation. It should be borne in mind that alterations in berthing will affect the current requirement and care should be taken that removal of a vessel does not lead to overprotection and consequent damage to paint protection of the piling (see a of A.2.5.1).

13.3 Marine Structural Zones

Corrosion on offshore structures may be divided into four zones of attack. These zones, which are shown in the generalized diagram of Fig. 4 overlap somewhat, and some differences in the corrosion rate may be expected within the same zone. The four zones are as follows:

- a) The atmospheric (spray zone) where the metal appears to be dry most of the time.
- b) The splash zone, above the water line, where the wave action usually keeps the metal wet (sometimes subject to scour from ice).
- c) Tidal zone, the portion of the structure between mean high tide and mean low tide; it is alternately immersed in sea water and exposed to a marine atmosphere.
- d) The submerged or underwater zone, where the metal is always covered by water (low oxygen below 8 m, high oxygen above 8 m).
- e) The mud zone, or subsoil zone the portion of the structure laying below the sea bed (below the mud line), where the structure has been driven into the ocean bottom.



**ZONE OF CORROSION FOR STEEL PILING IN SEA WATER AND RELATIVE
LOSS OF METAL THICKNESS IN EACH ZONE**

Fig. 4

13.4 Zone Protection

All structural steel work, is to be suitably protected against loss of integrity due to the effects of corrosion. Suitable protective systems may include coatings, metallic claddings, cathodic protection, corrosion allowances or other approved methods.

Combination of methods may be used. Consideration should be paid to the design life and maintainability of the surfaces in the design of the protective systems. Special consideration will be given to the corrosion protection of floating fixed installations.

13.4.1 Atmospheric zone

Steelwork in atmospheric zone is to be protected by suitable coatings. (see IPS-E-TP-100).

13.4.2 Splash zone

Steelwork in the splash zone is to be protected by one or more of the following:

13.4.2.1 Wear plates

- a) Wear plates should compensate for the anticipated corrosion and wear during the life of the platform. Wear plates are usually 13 to 19 mm thick.
- b) Wear plates are needed because damage can occur to coatings or sheathings used in the splash zone. Repair of coatings of or near the water line is extremely difficult and costly.
- c) In addition to providing a corrosion allowance, wear plates add stiffness and strength, thereby providing greater impact resistance.
- d) Wear plates are usually coated or sheathed for additional corrosion protection.

13.4.2.2 Alternative corrosion control Measures for steel in the splash zone are as follows:

13.4.2.2.1 70/30 nickel-copper alloy (UNS N04400*) or 90/10 copper-nickel alloy (UNS C70600) sheathing.

- a) This sheathing {UNS N04400, typically 1 to 5 mm (18 to 4 AWG gage) thick, UNS C70600, typically 4 to 5 mm thick} is attached to tubular members in the splash zone either by banding or welding. Welding is preferred because the annulus between the steel member and the sheathing is sealed.
- b) The metal sheathing should be protected from impact damage. Alloy clad steel plate may aid in preventing damage.

13.4.2.2.2 Vulcanized chloroprene

(See IPS-E-TP-350 and IPS-C-TP-352).

- a) Vulcanized chloroprene is typically applied in thickness of 6 to 13 mm.
- b) Since this coating cannot be applied in the fabrication yard, it is normally restricted to straight runs of tubular members.
- c) A minimum of 51 mm should be left uncoated at each end of a tubular member to prevent damage to the chloroprene during the welding operations.

* Unified Numbering System (UNS) for Metals and Alloy, Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA15096.

13.4.2.2.3 High-build organic coatings

(See IPS-E-TP-350 and IPS-C-TP-352).

- a) These coatings are usually filled with Silica glass-flake, or fiberglass.
- b) These coatings are typically applied to thickness of 1 to 5 mm over an abrasive blast cleaned surface.
- c) Since these coatings may be applied in the fabrication yard after assembly, joints may be protected as well as straight tubular runs.

13.4.3 Submerged zone

13.4.3.1 The submerged zone shall be considered as extending from the base of the structure, including all steel below the mud line, up to and including tidal zone, hereafter (see Fig. 4).

13.4.3.2 Steel in the submerged zone is to be protected by an approved means of cathodic protection. Using sacrificial anodes with or without an impressed current system. High duty coatings may be used in conjunction with cathodic protection system. For design purposes, the upper limit of the submerged zones shall be Mean High Tide Water Spring (M.H.W.S) Level.

13.4.3.3 Calcareous coating

In the case of cathodic protection of steel in sea water, the creation of alkaline environment adjacent to steel structure (cathode) has an especially beneficial effect. When the pH of an electrolyte such as sea water containing calcium and magnesium salts is increased, there will be a gradual precipitation of these salts.

Therefore, when the pH of sea water adjacent to a metal surface increases as a result of applying cathodic protection, there will be precipitations on the surface of the metal, the precipitations are calcareous coatings which consist of calcium and magnesium hydroxides and carbonates. The composition of these coatings will depend on the composition of the sea water, the temperature of the water and the current density on the surface of the metal. The more dense coatings are formed initially at relatively high current densities.

When such coatings have been formed, the current requirements to maintain adequate cathodic protection on the surface of the bare metal will be drastically decreased. In the light of this, after formation of calcareous film it is quite possible to cut down the number of rectifiers in operation.

13.5 Protection of Specific Installations Including Vessels

13.5.1 Marine sheet piling and wharves

13.5.1.1 Marine sheet steel piling and wharves shall be cathodically protected on both sides, including all anchor piles, anchor ties, bracing, etc. the joints between anchor piles, anchor ties and the walking beam, shall be bonded to ensure good electrical continuity. Bonds shall be insulated copper conductors not less than 35 mm² and shall be brazed or thermit welded to the steel.

13.5.1.2 The overall electrical continuity of sheet piling must be insured by a continuous walking beam or some other means, sized to pass the maximum cathodic protection current output of the system without excessive voltage drop.

13.5.1.3 In general, two separate anode systems, one offshore and one onshore, shall be installed to deal with the land side and water side faces (where only one transformer-rectifier is utilized, adjustments to the current distribution will be accomplished by installing variable resistors in the anode circuits).

The ideal anode location is remote and behind the wharf structure with the cable routes above high water mark on the shore. Where this is not practicable, a remote sea bed installation may be used for the water side face of the wharf.

The lateral spread of current along the wharf from distributed anodes, will be improved by increasing the distance between wharf and anodes. Provisions shall be made for boosting polarization on the water side face (see 13.8).

13.5.2 Piers

13.5.2.1 Small piers and jetties may require separate offshore and onshore anode systems. The selection of a remote distributed anode systems or remote sea bed installation depends upon the shape and continuity of the structure, the number and type of anodes required and the availability of a location for remote anode systems, safe from mechanical damage. More uniform current spread will be obtained from anodes located approximately 30 meters from the structure.

13.5.2.2 Large piers shall in general be protected by multiple rectifier impressed current systems. Each rectifier shall have a separate negative connection to the structure and a separate anode system so that each anode system is energized by only one rectifier. Cathodic connections shall thus be distributed over the structure. Platinized titanium or other inert anode located and mounted in such a way as to be free from the risk of mechanical or wave damage are preferred. Systems which are either distributed and rigidly fixed below low water level or a sea bed installation remote from the structure are also preferred. Electrical continuity between separate structural parts of large piers and between individual piles shall be provided by means of bonding cables (see 13.2.14).

13.5.3 Offshore wellhead and tie-in platforms

13.5.3.1 Each platform shall be considered as a separate unit for cathodic protection. All pipeline risers shall be provided with insulation flanges at platform elevation. Test stations shall be installed on all insulating flanges in a position accessible for inspection and testing.

13.5.3.2 Where power is available, impressed current cathodic protection shall be applied generally as for piers (see 13.5.2). In all other cases, platform structures shall be protected by means of galvanic anodes mounted in positions where they will not be subject to damage by platform operation procedures.

13.5.3.3 Pipe supports on the seaward side of all insulating flanges shall be electrically insulated from the pipe.

13.5.3.4 In the case of wellhead platforms, for design purposes, an allowance of 20 amperes per well casing shall be added when calculating current requirements of platform structure.

13.5.4 Offshore goshes and sea islands

13.5.4.1 Multiple interconnected structures, such as offshore goshes or sea islands shall in general be protected by multiple rectifier impressed current systems. Each rectifier shall have a separate anode system and separate negative connections distributed over the structures. Platinized titanium or lead silver alloy anodes are preferred. They should be rigidly mounted below water level and distributed on the structures where they are not likely to be subjected to mechanical damage. Alternatively, one or, more separate remote anode systems could be constructed and connected to the rectifier by means of submarine cables.

13.5.4.2 Where structures are interconnected by walkways, bridges or other steel structures, these shall not be used to provide continuity of the whole structure. Bonds shall be provided at all junctions between these adjacent structures, bridges or walkways to avoid any possible sparking hazard. These bonds shall be sufficiently flexible to allow relative movement between the sections and must be sized to the maximum output of the cathodic protection system.

13.5.4.3 Insulating flanges shall be provided at deck level for all pipe risers. Bonding stations shall be provided on all insulating flanges. Pipe supports shall also be electrically insulated from the pipe.

13.5.5 Submarine pipelines

13.5.5.1 Submarine pipelines shall include all lines installed on the sea bed. This includes lines laid from land to land and offshore structure to land and offshore structure to offshore structure.

These pipelines will generally be coated with a dielectric coating and concrete weighted. For design purposes, conductance of the coating shall be 5300 micromhos per square meter (500 micromhos / ft²).

Many of the considerations outlined in Section 10 are applicable to submarine pipelines.

13.5.5.2 All submarine pipelines shall be cathodically protected. Where power is available, coated submarine pipelines shall be protected by impressed current systems up to point where attenuation reduces the potential to unacceptable level, (see 7.4). Where power is unavailable or beyond the point where the potential is unacceptable, a galvanic anode system shall be installed.

13.5.5.3 Submarine pipelines shall be isolated at their extremities by means of insulating flanges with bonding stations.

13.5.5.4 Submarine trunklines and tielines shall be isolated at the shore end by means of insulating devices.

13.5.5.5 The galvanic anode system to be used will be aluminum alloy bracelet anode system or zinc bracelet anode system (see Fig. 5). Specifications of which are given in IPS-M-TP-750 Part 5.

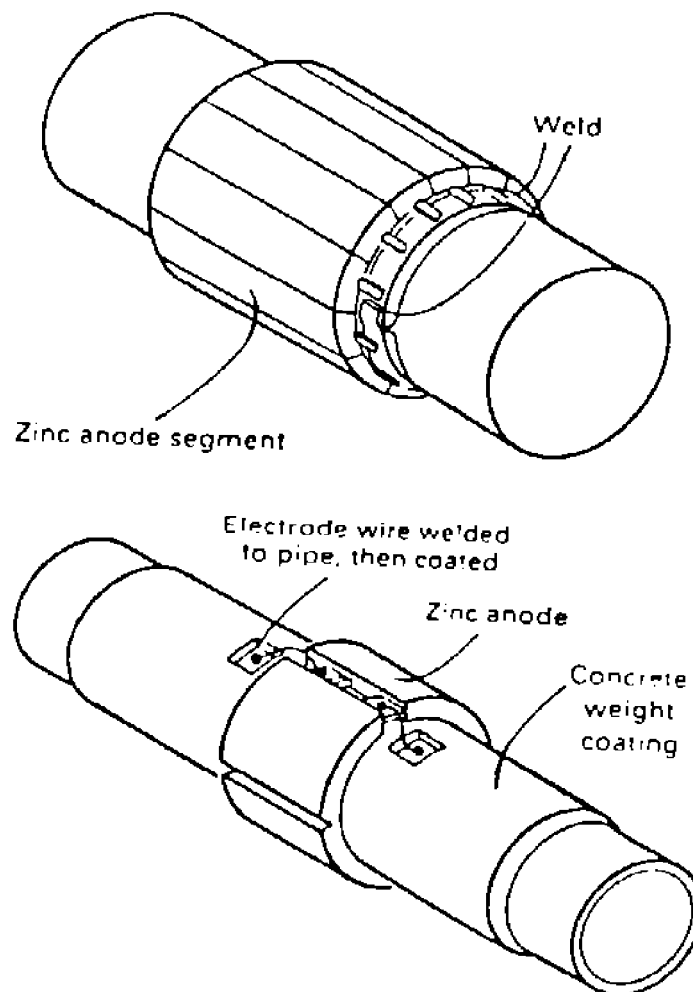
13.5.6 Vessels

13.5.6.1 Steel hulls of tankers, barges, launches and other vessels can be protected from external corrosion by means of cathodic protection. Both impressed current and galvanic anode systems have been successfully employed. Graphite or high-silicon cast iron anodes are usually used for impressed-current systems, although platinum anodes have been used. Magnesium is normally used for galvanic anode systems. Special anodes of the various materials are available for ship bottom protection, and special anode mounting methods are required for either type of system. With either type of system, the anodes must be distributed over the bottom to provide relatively uniform current distribution on the submerged portion of the hull.

13.5.6.2 For the design of a ship-bottom cathodic protection system the following factors shall be taken into account:

- a)** Variation of current requirement with speed of ship.
- b)** Variation of circuit resistance if the vessel moves from sea water to brackish or fresh water.
- c)** Susceptibility of some paint coatings to damage by cathodic protection.
- d)** Possibility of damage to and removal of the anodes by striking objects in the water.
- e)** Possibility of losing protection by electrical connection of a protected vessel to an unprotected vessel or pier.

More information regarding cathodic protection of ships internal and external are given in Appendix C.



TYPICAL PIPELINE BRACELET ANODES

Fig. 5

13.6 Anodes for Impressed Current Systems (See IPS-M-TP-750 Part 1 for Specification)

13.6.1 High silicon iron

13.6.1.1 High silicon cast iron is a material which corrodes relatively slowly. In sea water, where chlorine is produced at anode surface, the addition of chromium to the iron improves the performance.

13.6.1.2 The resistance of a single anode in free flowing sea water, is less than the anode in silt, mud or soil. It is common to install groups of anodes, sometimes mounted on wood or concrete frame work to reduce silting or covering.

13.6.1.3 The effect of anything rubbing or scraping the active anode surface is to accelerate dissolution at that position. Suspension or stabilizing cables, therefore, must not be attached around the active anode surface. Suspension by the anode cable is prohibited.

13.6.1.4 The number of anodes is determined by the allowable current density (see 12.6.1.6), the life, and the circuit resistance of the system. Design life shall be 10 years.

13.6.1.5 For onshore installations, where the anode is placed directly in ground not permanently salt water saturated, the anode surface actually in contact with the soil is inevitably something less than the whole area. Furthermore, as the anodic reaction proceeds, the oxygen or chlorine gas evolved must be able to escape, otherwise these two factors reduce the active anode area so that the recommended operating current density is exceeded and rapid but localized dissolution occurs. For this reason, it is usual to install a low resistance carbonaceous (coke) backfill around the anodes in accordance with applicable Iranian Petroleum Standard Drawing.

13.6.1.6 Anode life is influenced by the current density of operation and the total current emitted. In free flowing sea water, a maximum output of 10 A/m² is allowed and the total anode weight requirement shall be based on a consumption rate of 0.4 kg per ampere per year. This rate reduces to 0.2 kg per ampere per year when the anode is placed in coke backfill. For anodes buried directly in the soil or which become silted over on the sea bed the applicable figures are 10 A/m² maximum output and 0.8 kg per ampere per year.

13.6.2 Platinized anodes

13.6.2.1 Platinized anodes are generally constructed from solid or copper cored or titanium cored rod approximately 12 mm diameter and approximately 1500 mm long onto which is deposited, a layer of platinum 0.005 mm thick. Other shapes and configurations are also available. Platinized anodes are limited in use to free flowing sea water in marine designs.

13.6.2.2 The anodes may be mounted on supports cantilevered off the structures but electrically insulated from them. Alternatively, they may be mounted remote from the structure or supported on immersed non-metallic frames raised over the sea bed above the level of silt deposition.

13.6.2.3 Anode to cable connections may be made to one or to both ends of anode rod. The connection must be completely encapsulated in a suitably sealed plastic assembly filled with epoxy resin. When securing the anode to its mounting, contact with the platinized section of anode rod should be avoided and nothing should touch or rub the platinized active surface.

Platinized titanium anodes should not be used under the following conditions:

- a)** Where solids such as silt may accumulate on the anode rod.
- b)** Where electrolyte resistivities, or the dc power source voltage is of such a value that the voltage between anode and electrolyte exceeds 7 Volts exclusive of anode and cathode reaction voltages. (The design should thus ensure a terminal voltage not exceeding 7 Volts).
- c)** Where the frequency of the ac ripple content of the dc power source currents is below 100 Hz (three phase rectification must therefore be used).
- d)** Where the dc power source is intermittent and does not provide a constant anodic reaction at the anode. (Inert anodes installed in an electrolyte, particularly prior to commissioning, are possibly subject to loss of anode material and to deposit by marine growths which could detach the platinum).
- e)** Where the anode is not totally immersed at all states of the tide.
- f)** Where the electrolyte is stagnant and does not allow diffusion of anode-produced chlorine gas away from anode assembly.

13.6.2.4 Location of anodes on structures

Multiple anode assemblies should be mounted on the structure under cathodic protection. It will be necessary to distribute the anodes over the members of complex structures such as piers to provide cathodic protection to all the immersed structural members.

13.6.2.5 Platinized titanium anodes shall be designed for operational current densities not exceeding 700 A/m² of platinized area. The 0.005 mm thick platinizing dissolves at the rate of about 10 milligrams per ampere year. Although abrasion by suspended solids reduces platinum life, a 0.005 mm platinized surface may be regarded as providing a permanent inert anode with a life in the order of 15 years.

13.6.2.6 In determining the length of anode rod to be installed, consideration must be given to the effect of linear voltage drop resulting in non-linear current dissipation over longer anode lengths. Copper-cored anodes may be used to overcome this problem. The physical flexing of long rods in flowing sea water may result in fatigue fractures so that a larger section is to be preferred if anode movement is likely.

13.6.2.7 Platinized niobium anodes are also available in various shapes and configurations. One type of these anodes is available under the trade name "Morganode". These anodes may be used in higher or low resistivity waters and driven at up to 100 Volts dc.

13.6.3 Lead silver alloy

Lead will normally dissolve under anodic polarization. It becomes a stable anode material only when used in conditions where the anodic reaction produces a lead peroxide film over the anode surface. The alloying of lead with 2% silver is conducive to the production and retention of the desired lead peroxide film. Lead-silver anodes are suitable for use in sea water. They should be operated at about 215 A/m² (20A/FT²). If operated at this current output they are regarded as permanent inert anodes also with a life in the order of 20 years. These anodes are the pile mounting type and are the least expensive of the precious metal anodes. They may be used in a skid mounted configuration on the sea floor. This anode is available under the trade name "Morganode".

13.6.4 Graphite

13.6.4.1 Graphite is a material which corrodes relatively slowly. Graphite anodes are not suitable for freely suspended installation. They may be installed onshore, preferably in carbonaceous backfill (coke). The general consideration of Paragraph 13.6.1 shall apply.

13.6.4.2 Graphite anodes buried in carbonaceous (coke) backfill or directly in salt water saturated low resistivity soils, may be operated at a current density of 4 amps per square meter. The consumption rate of anode material is 0.135 kg per ampere year at this current density. See IPS-M-TP-750 Part 1 for Specification.

13.7 Anodes for Galvanic Anode Systems

13.7.1 Galvanic anodes may be alloys of such active metals as magnesium, zinc or aluminum. These alloys can be obtained in a variety of shapes and sizes to deliver protective current to a specific offshore platform with optimum current distribution. The method used to attach the anodes to the platform will be governed by their type and application, but low resistance electrical contact must be maintained throughout operating life of the anodes.

13.7.2 The performance of galvanic anodes in sea water depends critically on the composition of the alloy, particularly in the cases of zinc and aluminum (see Appendix B of NACE Standard, RP-01-76, 1983 Revision).

13.7.3 Magnesium anode

Magnesium anodes are very active and furnish high current outputs. For this reason, they can provide cathodic protection with a minimum number of anodes. Because of their properties they usually are not used for long life designs.

For marine structures, the use of magnesium is confined to providing boosted polarization current (see 13.8). For offshore structures, the design life of this material is three months.

For the protection of small structures or short buried pipeline sections onshore, magnesium anodes are buried in the soil adjacent to the structure and directly connected. These anodes require moist soils with resistivities less than 5000 ohm-

centimeters for satisfactory operation. In cases where the soil is occasionally dry, moisture can be retained around the anode by providing a chemical backfill. Pre-packaged anodes are installed in a cotton bag surrounded with gypsum-bentonite-sodium sulfate backfill. This anode is suitable for land installation.

Standard bare magnesium anodes may be used for immersed, silted, or onshore burial installations. Magnesium is available in a variety of purities with different performances. Efficiency is 50% for all grades and consumption rate is 1230 ampere hours per kg. The design potential is normally -1.70 Volts referred to Ag/AgCl. See IPS-M-TP-750 Part 4 for Specification.

13.7.4 Zinc anode

Zinc anodes are mainly used in sea water for protection of marine craft. Due to their lower current capacity and higher cost, zinc anodes are not normally recommended for submarine pipeline or offshore structures.

13.7.5 Aluminum alloy anodes

This type of anodes are generally suitable for use on submarine pipelines as well as offshore structures and continues to give satisfactory performance in sea bottom environments.

Its chief use will be as bracelet anodes on submarine pipelines, where its use represents an initial cost saving of up to 60% over zinc bracelet anodes due to its higher current capacity. (See IPS-M-TP-750 Part 5 and Part 6).

13.8 Boosted Polarization

13.8.1 As cathodic protection commences to operate, a layer of alkaline material is produced on the protected surface by the cathodic electrode reaction. This material persists unless removed by unusual physical conditions and its presence reduces the amount of current necessary to maintain the cathodic protection.

13.8.2 For on shore based installations, the difference in cost between providing permanent capacity to polarize rapidly and capacity to maintain the cathodic protection may be significant. This is particularly so in the case of large surface area structures such as sheet piled walls, etc., and in these cases, temporary current sources are provided for the initial polarization. This boosted polarization may be provided by using welding generators connected with the negative output to the structure and the positive output to temporary anode systems.

13.8.3 For offshore structures provided with galvanic anode systems, boosted polarization shall be by 9 mm × 18 mm ($\frac{3}{8}$ inch × $\frac{3}{4}$ inch) magnesium ribbon connected to the structure in addition to the designed cathodic protection.

13.9 Cathodic Protection Design for Marine Structures (for Design Calculation see Appendix C)

13.9.1 Plans and information

The following plans and information are to be submitted:

- a)** A surface area breakdown for all areas to be protected (seawater immersed and buried) including secondary steelwork and details of temporary appurtenances.
- b)** The resistivity of the seawater.
- c)** All Current densities used for design purposes.
- d)** The type and location of any reference electrodes, their methods of attachment and the method for transmitting the potential data.
- e)** Full details of any coatings used and the areas to which they are to be applied.
- f)** Details of any electrical bonding. Piles to piles sleeve jacket legs, or insulation.

13.9.2 Galvanic anode systems

In addition to the information given by Paragraph 13.9.1, the following plans and information are to be submitted:

- a) The design life of the system, in years,
- b) anode material and minimum design capacity of anode material in Ampere hour/kg,
- c) the dimensions of anodes, including details of the insert and its location,
- d) the net and gross weight of the anodes in kg,
- e) the means of attachment,
- f) location plans of the anodes,
- g) calculation of anodic resistance, as installed and when consumed to their design utilization factor, in ohms,
- h) closed circuit potential of the anode materials, in Volts,
- i) details of any computer modeling,
- j) the anode design utilization factor.

13.9.3 Impressed current systems

In addition to the information required in Paragraph 13.9.1, the following plans and information are to be submitted:

- a) The anode composition and where applicable, the thickness of the plated surface, consumption and life data,
- b) anode resistance, limiting potential and current output,
- c) details of construction and attachment of anodes and reference electrodes,
- d) size, shape and composition of any dielectric shields,
- e) diagram of the wiring system used for impressed current and monitoring systems, including details of cable sizes, underwater joints, type of insulation and normal working current in the circuits, the capacity, type and make of protective devices,
- f) details of glands and size of steel conduits,
- g) plans showing the location of anodes and reference electrodes,
- h) if the system is to be used in association with coating system then a statement is to be supplied by the coating manufacturer that the coating is compatible with the impressed current cathodic protection system.

13.10 Fixed Potential Monitoring Systems

Cathodic protection systems should be monitored. For a permanent monitoring fixed electrodes are to be utilized to measure steel/sea water potential and possibly anode current output and/or cathode current density.

These reference electrodes, may be high purity zinc or zinc alloy and silver/silver chloride electrode.

The signals from these fixed reference points should be transmitted to the surface indicator, and preferably recorder by either hard wire or an acoustic link.

The intervals between measurements should accommodate all conditions of weather, tide and operating conditions and should indicate trends in the cathodic protection performance.

13.11 Potential Survey

13.11.1 Potential surveys are to be carried out at agreed intervals.

13.11.2 Should the results of any potential survey measured with respect to a silver/silver chloride reference electrode indicate values more positive than minus 0.8 volts for aerobic conditions or minus 0.9 volt for anaerobic conditions, then remedial action is to be carried out at the earliest opportunity.

13.12 Retrofits

13.12.1 Where bracelet anodes are proposed for retrofits then the tightens of the units are not to rely on the anode material being indirect contact with the platform bracing or pipework. Due to the possible effects of hydrogen, high tensile steel belting materials should be avoided and the hardness for all such bolting materials should be limited to a maximum Vickers Diamond Pyramid Number of 300.

13.12.2 Where it is necessary to weld anodes to the structure then only approved welding procedures are to be used.

13.12.3 The welding procedure is to be qualified under fully representative conditions.

14. ANODIC PROTECTION

14.1 General

This Section is included in this electrochemical protection standard to provide background on the principles of anodic protection and to suggest possible applications that should be considered for this method of corrosion control. It is hoped that the information provided in this Section will assist the users in evaluating the current literature on the subject and in recognizing possible applications of anodic protection.

14.2 Principles of Anodic Protection

14.2.1 The phenomenon of anodic passivity can be illustrated by the simplified experiment shown in Figure 6. The equipment consists of an electrolyte in which are immersed the metal sample to be protected (the anode), the inert cathode, and the reference electrode. The anode, cathode, and reference electrode are connected to a potential controller ("potentiostat") which is capable of providing a wide range of current while holding the potential of the anode within very narrow limits.

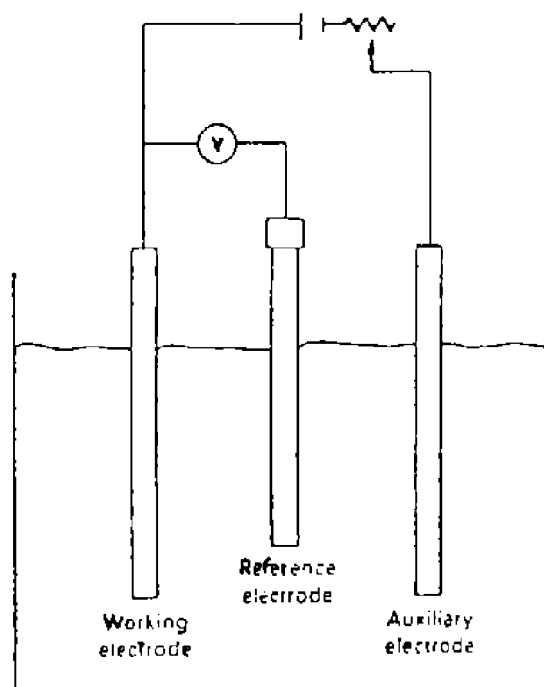


Fig. 6

Schematic of experimental apparatus used for anodic polarization studies. Current flow between the working electrode and the auxiliary electrode forces a shift in potential between the working electrode and the reference electrode. V, volt-meter.

In this example, the anode to be protected is assumed to be iron. The inert cathode is usually platinum and the reference electrode is a calomel half cell. The potential of the anode with respect to the reference electrode is first measured to ensure that the metal surface is in the active condition and that no films or corrosive products that might inhibit the passivation reaction are present. Current is then applied to the anode. Polarization curves are obtained by plotting the potential between the anode and the reference electrode corresponding to each value of the applied current.

A typical polarization curve obtained in this manner is shown in Fig. 7. Point " E_{corr} ", obtained before current is applied, represents the initial condition of the system typified by the reaction of the corroding anode:

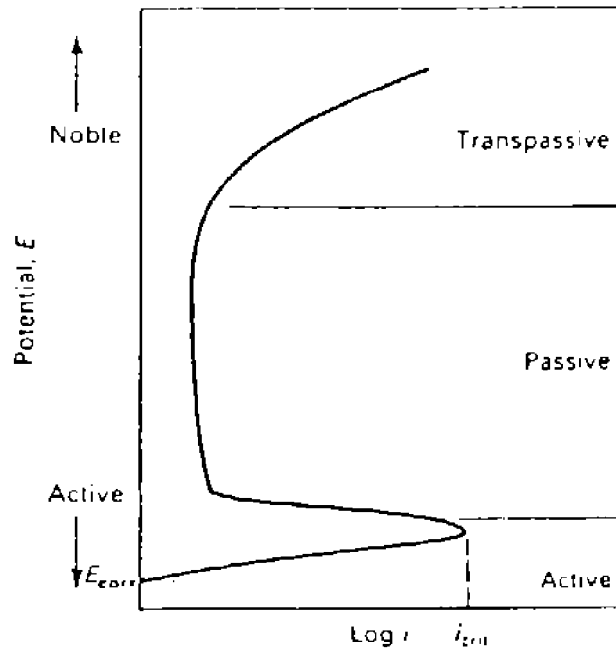
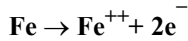
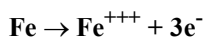


Fig. 7

Schematic anodic polarization curve. Metal environment systems that have this type of anodic polarization behavior are termed activepassive and can be anodically protected.

As current is applied to the anode (and returned to the external circuit through the cathode), the potential shifts in the direction of greater passivity. However, loss of metal at the anode also increases as a result of the greater current discharged by the anode to the solution. The current is further increased until there is an abrupt change in the plotted potential-current relationship. This point, designated as " E_c ", is shown as the Flade potential. Further increase in the potential applied by the controller results in a decrease in current flow.

As the potential and current approach point " E_p ", the system is in the passive state. The anode reaction has become:



In order to retain the system in the passive state, the potential of the anode with respect to the reference electrode must be controlled closely within the narrow region shown by the nearly vertical portion of the curve near point " E_p ". If the potential is allowed to increase beyond point " E_A ", the current will again increase and will indicate a corresponding increase in the rate of corrosion. The section of the curve beyond point " E_A " is known as the transpassive region.

It is generally agreed that the following conditions must be true for anodic passivity of iron and sulfuric acid to occur:

- a) A protective film must be at least 100Å (Angstrom) thick.
- b) No more than 10^{-2} coulombs/cm² must be required for the film to form.
- c) The film must be an electronic conductor.

- d) The E-VS-I characteristics defined by Fig. 7 must be satisfied.
- e) The film must be formed very rapidly.
- f) The passivated metal must be oxidized.
- g) The film must be hydrophobic.
- h) The passive film must be relatively acid-insoluble.

14.2.2 The exact nature of the passive film is not completely understood. Three possible theories have been suggested:

14.2.2.1 Oxide film theory: The iron dissolves in the electrolyte and reacts with oxygen to form protective precipitates of iron oxide. These precipitates form a film which presents a chemical and physical barrier to the corrosive medium.

14.2.2.2 Absorption theory: Oxygen is absorbed on the surface to form a barrier layer.

14.2.2.3 Sequence model theory: Oxygen is initially absorbed on the surface and is followed by a slow formation of an amorphous iron-oxygen structure. This occurs by the diffusion of iron from the base metal into the absorbed oxygen film.

The sequence Model theory has received considerable support in recent papers.

14.3 Contrast with Cathodic Protection

It is important to distinguish clearly between the phenomenon on anodic protection described in this Section and the well established practice of cathodic protection described previously in this Standard.

In cathodic protection, the metal to be protected against corrosion is made the "cathode" of an electrolytic cell. This condition is achieved by impressing current into the cell by means of an anode. Cathodic protection is much simpler to achieve and is less subject to operating difficulties because the potential control is less critical. However, in contrast to anodic protection, cathodic protection is not effective in strong acid solutions.

14.4 Effects of Variable Factors on Anodic Protection

Variable factors affecting the tendency of a system to become passive by the application of anodic protection are as follows:

14.4.1 Solution concentration

Electrolyte concentration affects the current density required to establish passivity in a given metal-electrolyte system. In a case of iron and sulfuric acid, the current density required for passivity decreases as the concentration of sulfuric acid increases. This is in contrast to corrosivity of sulfuric acid, which is at its maximum at 55% concentration and decreases towards zero at 0% and 100% acid concentrations.

14.4.2 Surface area of the anode

The current density required to establish passivation is constant for any given combination of metal and electrolyte under a given set of conditions; this value is usually determined by laboratory experiment. Therefore, as the surface area increases, the total current required will increase but the voltage requirement will remain the same. Hence, the experimental results for the current requirements can be extrapolated to cover process situations under similar conditions.

14.4.3 Different metals

Passivation studies* have been made on a number of materials in 67 weight percent sulfuric acid. Those materials which were successfully passivated are shown below, with the current densities required to maintain passivity and with some examples of the very much higher currents required to establish passivity:

TABLE 6 - CURRENT DENSITY REQUIRED FOR ANODIC PROTECTION OF VARIOUS METALS IN 67 WEIGHT PERCENT SULFURIC ACID:

METAL	ESTABLISH PASSIVITY		MAINTAIN PASSIVITY	
	amp/cm ²	amp/ft ²	amp/cm ²	amp/ft ²
Type 302	512×10^{-6}	0.475	2.2×10^{-6}	2.04×10^{-3}
Type 304			3.8×10^{-6}	3.53×10^{-3}
Type 310			0.5×10^{-6}	4.7×10^{-3}
Type 316	580×10^{-6}	0.539	0.1×10^{-6}	0.093×10^{-3}
Type 405			2.7×10^{-6}	2.51×10^{-3}
Type 410			10.9×10^{-6}	10.2×10^{-3}
Type 446			0.7×10^{-6}	0.65×10^{-3}
Mild Steel (SAE1020)			15.0×10^{-6}	13.9×10^{-3}
Titanium			0.08×10^{-6}	0.075×10^{-3}
Hastelloy			0.5×10^{-6}	0.47×10^{-3}
Carpenter 20			0.03×10^{-6}	0.027×10^{-3}

These variations in current density requirements should be noted. Carpenter 20 has the lowest current density rating and, therefore, requires only a small current density to retain passivity under these conditions. Variations in solution pH, temperature, concentration or other physical test conditions will cause a shift in the values given above.

For this reason it is important to conduct careful laboratory analyses under the precise conditions to be encountered by the metal on process plants to determine the current density required both to initially obtain passivity and to hold the system in the passive state.

From the studies which have been made, it appears that any ferrous metal can be passivated successfully, although the current density requirements to retain passivity will vary depending on the metal and the electrolyte. Experimental studies have shown that it is not possible to passivate the copper-based alloys such as brasses and bronzes, some of the rare metals such as titanium, hafnium, zirconium, and niobium, which are used to promote corrosion resistance in special alloy systems can be successfully passivated.

14.4.4 Temperature effect

As the temperature of the solution is increased, the current density required to maintain passivity increases. For example, the current density required to maintain the passivity on 304 SS and 67 weight percent sulfuric acid is more than three times as great at 85°C as at 52°C. The cause of this radical increase is probably related to the increased solubility of the passive layer at an elevated temperature.

14.4.5 Chemical environment

On the basis of developmental work which has been conducted**, it appears that passivity can be established in a broad range of oxidizing chemical environments including sulfuric acid, phosphoric acid, nitric acid, sodium hydroxide, lithium hydroxide, ammonium nitrate, and aluminum sulfate. It is not possible to attain passivity in reducing systems such as hydrochloric acid, ferrous chloride, stannous chloride, hydroiodic acid and sodium chloride. Although these reducing systems cannot be passivated, it is possible to passivate oxidizing systems which contain small amounts of these reducing agents. However, the addition of these agents will increase the current density required to attain passivity and will also increase the current density required to maintain the system in the passive state.

Agitation of the electrolyte does not adversely affect the ability to passivate the system. In some systems that have been tested, agitation has increased the rate at which the passive state was formed as well as decreased the current density required for passivity.

* Fundamentals, Section 410, Cathodic Protection, Corrosion Prevention Manual-volume II NACE.

** Sudbury, J.D., rigs, O.L., shock, D.A., "Anodic Passivation Studies", Corrosion, 16,47t (1960) Feb. NACE.

14.5 Applications to Process Plants

Any proposed application of anodic protection should be evaluated by users' experienced technical personnel. Following are some of the factors that should be considered in determining whether anodic protection may have promise for a specific application:

14.5.1 Services

Services that have been investigated to determine their suitability for anodic protection include:

14.5.1.1 Sulfuric acid: The use of stainless steel in the storage of sulfuric acid up to concentrations of 85% is practical when anodic protection is applied. For concentrations higher than 85% sulfuric acid, it is probably more economical to use mild steel. The storage of 100% sulfuric acid (oleum) in carbon steel tanks under anodic protection will give complete protection with no contamination of the oleum through reaction with the iron.

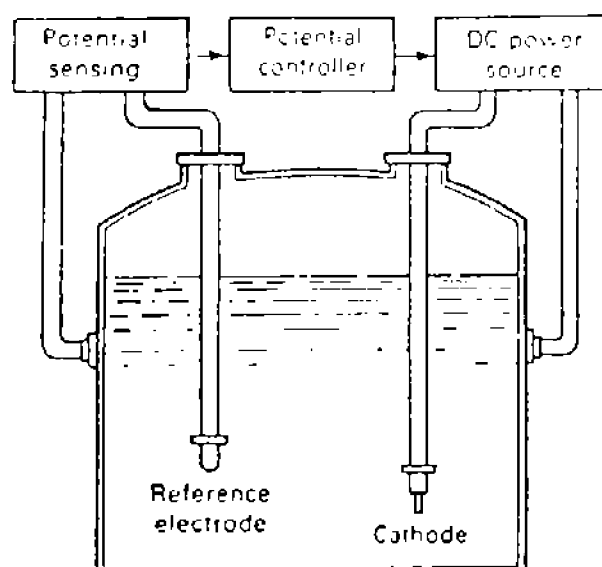
14.5.1.2 Phosphoric acid: Stainless steel is attacked by phosphoric acid over a wide range of concentrations. The anodic protection is feasible for pure phosphoric acid. The current density requirements for initiation and maintenance are comparatively low, so that the current required to passivate an average process vessel will not be unduly large.

14.5.1.3 Alkalies: Passivation in alkaline solutions results in the formation of a film which is different from that associated with oxidation systems. The notable features of the passivation of alkaline solutions are the length of time necessary for passivation to occur and the higher current densities required. The maximum pH limit for passivity of 304 stainless steel in lithium hydroxide is about 9.5.

14.5.1.4 Salt system: There would be little difficulty in applying anodic protection to systems containing 304 stainless steel in solutions of aluminum sulfate and of ammonium nitrate.

14.5.1.5 Nitric acid: The systems containing nitric acid are easily passivated. For a combination of halogen acid and nitric acid the maximum allowable halogen content is about three percent HCl, with 304 stainless steel. This halogen acid-nitric acid system does not seem to be feasible for anodic protection.

Fig. 8 shows a schematic of an anodic protection system for a storage vessel.



SCHEMATIC OF AN ANODIC PROTECTION SYSTEM FOR A STORAGE VESSEL

Fig. 8

One or more cathodes, a reference electrode, a potential sensing and controlling circuit, and a d.c. power supply are required for each anodic protection system. The vessel wall is made the anode of the circuit by current forced between the cathode and the tank wall. The currents are controlled so that the potential of the wall with respect to the reference electrode is shifted and maintained in the passive region (see Fig. 7).

APPENDICES

APPENDIX A

CONSIDERATIONS ON CATHODIC PROTECTION DESIGN

A.1 General Principle of Electrochemical Corrosion and Cathodic Protection

A.1.1 Behavior of buried or immersed metals in the absence of cathodic protection

A.1.1.1 The nature of metallic corrosion

When a metal corrodes in contact with an electrolyte, natural atoms pass into solution by forming positively charged ions. Excess negative electrons are left behind. For example, in the case of iron:



Thus corrosion is accompanied by the flow of an electric current from metal to electrolyte due to the movement of positive ions into the electrolyte and of negatively charged electrons into the metal. Any area at which current flows in this direction is referred to as an anodic area. The metallic ions may react with negative ions in the solution to give insoluble corrosion products (e.g. rust in the case of steel). Such reactions do not materially affect the argument which follows except in cases when the corrosion product is such as to stifle further attack. The electric circuit is completed by the passage of current from solution to metal at other areas known as cathodes. Various reactions occur at cathodes; these do not, in general, cause corrosion (see A.1.1.5).

Because the same number of electrons are related for each atom of the metal going into solution, the current is proportional to the corrosion rate. For example, in the case of iron or steel, two electrons flow for each atom going into solution, as shown in Equation 1.A, and a corrosion current of one ampere corresponds to loss of about 9 kg per year.

A.1.1.2 Polarization

The potential difference between any metal and the surrounding electrolyte varies with the density and direction of any current crossing the interface. This variation is referred to as polarization. The relationship between potential and current may be determined by an arrangement as shown in Fig. 9a.

It is not necessarily linear (see Fig. 9b). The section Z-A of the curve corresponds to corrosion and the more positive the potential the greater the corrosion rate. In practice it is difficult to draw firm conclusions as to the corrosion rate from measurement of the potential difference between metal and solution or soil because the shape of the curve and the potential corresponding to zero current flow both vary according to the properties of the surrounding electrolyte. However, it will be seen that any current flow which makes the potential more positive, normally increases the probability that corrosion will occur. Conversely, changing the potential in the negative direction reduces the corrosion rate and may prevent corrosion entirely.

The way in which the potential difference between a metal and the surrounding electrolyte is measured should be specified. If a metal electrode in direct contact with the electrolyte is used, the result will depend, to some extent, on the effect of the electrolyte on the particular metal chosen. For this reason a reference electrode, e.g. one of several types described in section 3 (definitions), should be used and the type of reference electrode should be stated when any results are quoted.

A.1.1.3 Formation of cells

Suppose that potentials of two different metals with respect to a solution are measured with the arrangement shown in Fig. 2, the switch S being open, and the metal marked A found to be more negative,. When the switch is closed, current will flow in the direction shown by the arrows. Metal A will therefore be the anode, and will be corroded, while C acts as cathode. Metals and conducting materials commonly used are listed below in such order that each normally acts as anode with respect to all the materials which follow it:

- Magnesium (most electronegative of the materials listed), Zinc,
- Aluminum (certain aluminum alloys may be more electronegative),
- Iron and Steel,
- Lead,
- Brass,
- Copper,
- Graphite, Coke, etc. (most electropositive of the materials listed).

Thus the connection of magnesium to iron results in a cell in which the magnesium acts as anode and the iron as cathode.

Cells may also arise due to differing properties of the electrolyte in contact with different parts of the same metal surface. Thus, increased concentration of oxygen tends to make the potential of a metal more positive so that variation of soil density and porosity is a common cause of corrosion cells.

Arrangements giving rise to such cells are shown in Fig. 11. The size of the cells may vary greatly. In Fig. 11c, for example, the anodic area may be small, the resultant pitting can, however, lead to rapid penetration.

For simplicity let anodic and cathodic areas be shown separately as in Fig. 10. It will be recalled that the anode was the electrode which, with the switch open, had the more negative potential with respect to the solution. If there is resistance in circuit this will still be true, even with the switch closed although the difference in potential will be smaller. This will also be true in cases such as in Fig. 11a in which anode and cathode are parts of the same metal surface in contact with different environments. If the total resistance in the circuit is low there will be little difference in the metal/electrolyte potential at the anodic and cathodic areas but corrosion will occur at the former, the potential at the anodic area being more positive than it otherwise would be due to the current flowing in the cell. This illustration has been included to emphasize the difficulty of determining whether corrosion is occurring by measuring the metal/soil potential without having other information.

A.1.1.4 Passivity

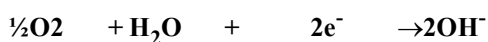
If the corrosion product forms an adherent film on the surface of the metal, further attack may be prevented. The corrosion resistance of stainless steel, for example, is due to protection by films. The metals titanium and tantalum form highly resistant and adherent films and can therefore withstand strongly positive potentials without corroding.

A.1.1.5 Reactions at cathodic areas

The following are among the most common reactions that occur at cathodes:



Hydrogen ions + Electrons → Hydrogen gas (Eq. 2.A)



Oxygen + Water + Electrons → Hydroxyl ions (Eq. 3.A)

The first of these reactions is favored by acidity (excess of hydrogen ions) while the second is favored by presence of dissolved oxygen. Both tend to make the solution near the cathode alkaline (excess of hydroxyl ions over hydrogen ions); In contrast to the anodic reaction (e.g. Equation 1.A), cathodic reactions do not involve the passage of metal into solution; hence in general, corrosion does not occur at cathodic areas.

In practice the rate of corrosion is often determined by the rate at which the cathodic reaction can be maintained. For example, if the relevant reaction is that given by Equation 3.A, replenishment of oxygen may be the controlling factor.

In near-neutral anaerobic soils, sulphate-reducing bacteria give rise to a further type of cathodic reaction and soils of this kind are often particularly aggressive to iron and steel. It is possible, by determining pH and redox potential, to assess whether conditions are such that sulphate-reducing bacteria are likely to be active.

Although, as previously indicated, the reactions occurring at cathodes do not directly result in corrosion, it should be noted that the environment of the metal is altered, for example it becomes more alkaline. In the case of aluminum and, occasionally, lead, corrosion may result. Alkalinity may also cause deterioration of paints and other coatings by saponification. Effects of the cathodic reactions that arise when cathodic protection is applied are listed in A.2.5.1.

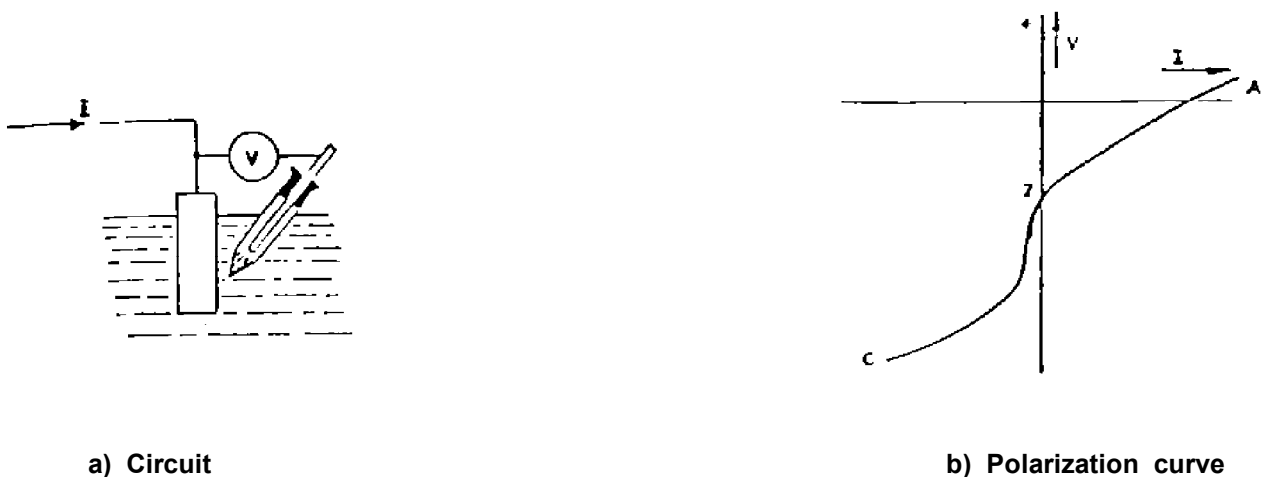
A.1.2 Cathodic protection

A.1.2.1 Basis of cathodic protection

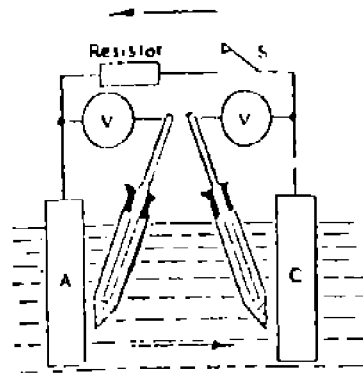
Corrosion implies the existence of anodic and cathodic areas (see Fig. 12a). In applying cathodic protection, a current (I in Fig. 12b) is superimposed in such a direction that the structure to be protected acts as a cathode. If the current is sufficient, no part of the structure acts as anode. This entails the use of an auxiliary anode. If this anode is of a material such as magnesium, the protection current will flow due to the e.m.f.* arising from the cell formed (Galvanic anode system). Alternatively, the e.m.f.* may be derived from a separate direct-current source, giving a wide choice of materials for the auxiliary anode including some which are not consumed (Impressed current system).

In Fig. 12b, the anodic area (A) has been shown separated from the cathodic area (C) in order that the currents to the two areas can be seen. The criterion for cathodic protection is that the current flowing in the anode circuit is reduced to zero or reversed. However, anodes and cathodes are often parts of the same metallic surface (as shown in Fig. 11) and the individual anodic areas may be small. It is thus impossible, in most cases, to confirm that cathodic protection has been achieved by measuring the relevant current. For most of the metals commonly encountered, however, it is possible to state values of metal/electrolyte potential at which corrosion does not occur in environments such as soil or natural waters.

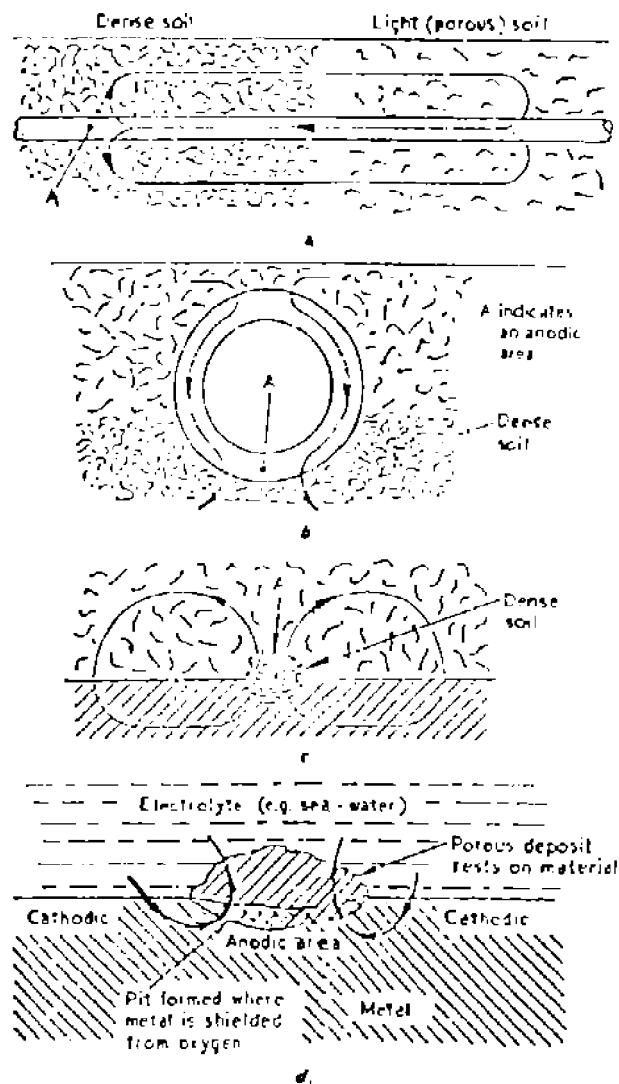
* Electromotive force.



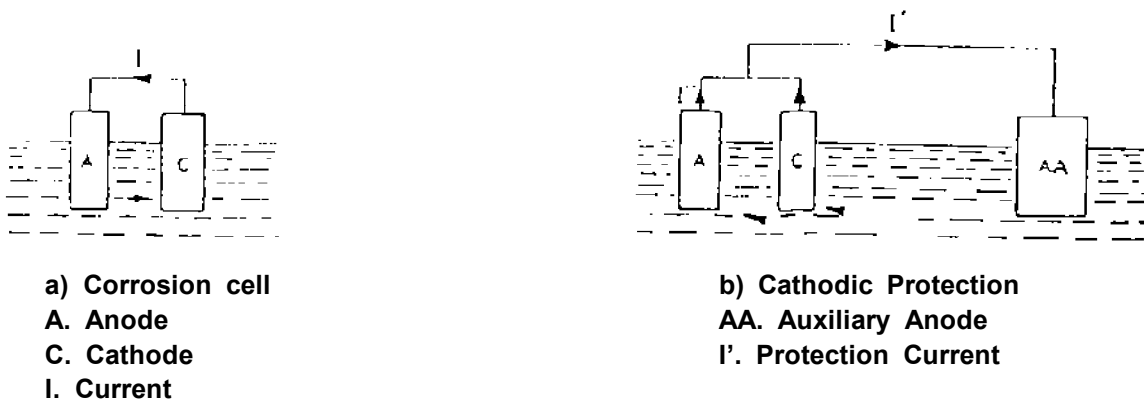
MEASUREMENT OF POLARIZATION
Fig. 9



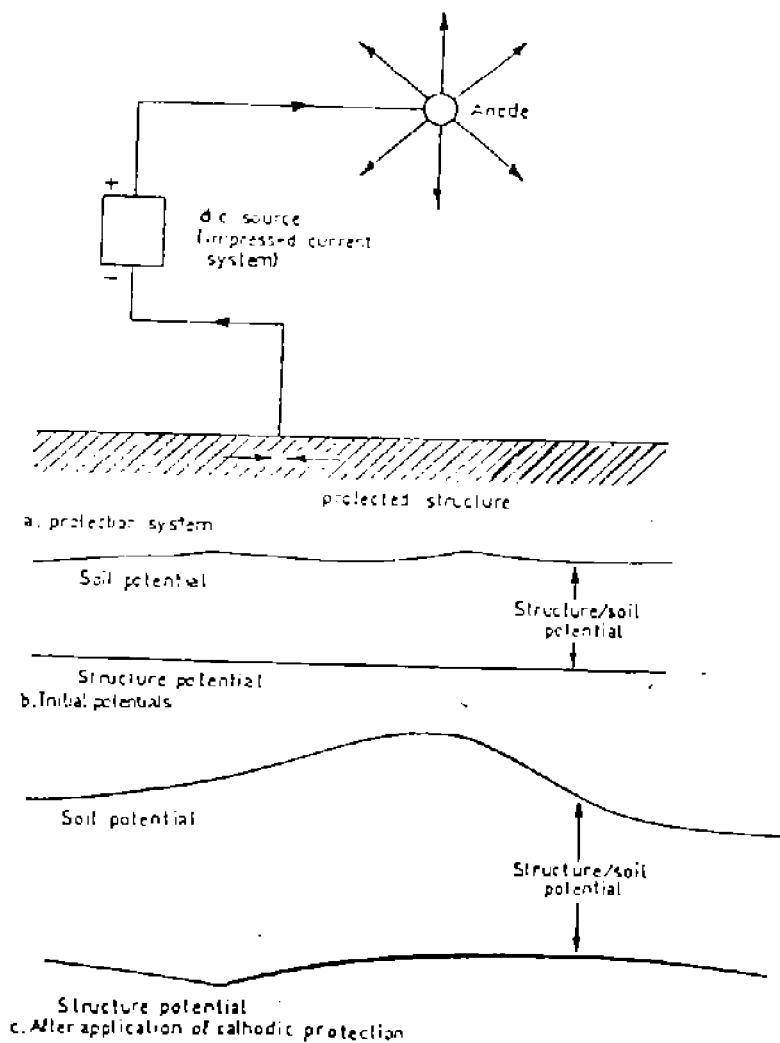
CELL
Fig. 10



CELLS DUE THE DIFFERENTIAL AERATION
Fig. 11



THE BASIS OF CATHODIC PROTECTION
Fig. 12



CATHODIC PROTECTION SYSTEM AND DISTRIBUTION OF
STRUCTURAL/ELECTROLYTE POTENTIAL
Fig. 13

A.2 Considerations Applicable to Most Types of Structures

A.2.1 Range of application

Cathodic protection can, in principle, be applied to any metallic structure or plant that is in contact with mass of soil or water. The application of cathodic protection to metal surfaces that are intermittently immersed for example due to the action of tides, may also be beneficial.

However, economic considerations sometimes restrict the range of application. It may, for example, be uneconomical to protect certain types of existing structure because the cost of making them suitable for cathodic protection is excessive.

The function of the structure or plant under consideration will determine the benefit to be expected by suppressing corrosion. Thus, a certain amount of attack in the form of pitting may be tolerable on some structural members while the same severity of attack would cause failure of a pipe. If the consequences of penetration by corrosion are important, for example hazards due to leakage of a flammable gas or liquid, or interruption of the operation of a large plant or the failure of a ship's plate, the need to ensure complete reliability will become overriding and cathodic protection would be regarded as economical even under otherwise unfavorable circumstances.

A.2.2 Basis of design

It has been shown in section 1 of this Appendix that cathodic protection is achieved by causing current to flow from the surrounding electrolyte into the structure at all points, the criterion being that the structure/electrolyte potential is, at all positions, more negative than the appropriate protective potential given in Section 7 of this Standard. Fig. 13 represents, in outline, the system required, which consists of a buried or immersed anode, a connection to the structure to be protected and (in the case of impressed current systems only) a source of e.m.f.

Current flows in the metallic parts of the circuit in the directions indicated by the arrows and returns through the electrolyte (soil or water) to the protected structure. When the potential drop through the electrolyte and/or the structure is appreciable, the potential change due to the cathodic protection is non-uniform as shown in the lower parts of the Figure 13. The following factors tend to increase the non-uniformity of the cathodic protection:

- a) Small separation between the anode and the structure (particularly if the electrolyte resistivity is high).
- b) High resistivity of soil or water (particularly if anodes are close to the structure).
- c) High current density required to protect the structure (the current density will be governed by the quality of the coating, if any, and the availability of oxygen at the surface of the metal or the activity of anaerobic bacteria (see A.1.1.5).
- d) High electrical resistance between different parts of the structure.

The tendency for the current density to be highest at points nearest the anode may occasionally be an advantage since it is possible to concentrate the effect at a point where it is most needed. For example, when corrosion of iron or steel occurs due to proximity of a more electropositive metal, the attack is often local; only a small proportion of the surface may require protection.

Normally, however, the whole of the metal surface is to be protected and non-uniformity, as shown in Fig. 13, is uneconomical because some parts of the surface receive more current than is required to attain the protection potential. Moreover, since the potential should, generally, not be made too strongly negative for the reasons given in A.2.5.1 it may be impossible to compensate for poor initial design by increasing the current and thereby making the potential more negative. Additional anodes will therefore be needed and, in the case of protection by impressed current on extensive structures, this will also entail the provision of additional sources of e.m.f. Thus, if the use of cathodic protection is envisaged, a first step is to consider whether the structure or plant can be designed, or modified if it already exists, in such a way as to make the installation of cathodic protection more economical. These aspects are discussed further in A.2.3. Consideration should also be given to the correct placing of anodes both as regards separation from the structure and their distribution over the surface. When structures such as pipelines are being protected with impressed current, considerations such as the availability of power supplies may, however, have an important bearing on the design.

The characteristic of two systems, i.e. galvanic anodes and impressed current, are compared in A.2.4.

Economical design of structure or plant and its associated cathodic protection system entails striking the best possible balance between factors which affect the initial cost (effectiveness of structure coating, electrical conductance between sections of the structure or plant, extent and position of the anode system, number of separate units, etc.) and factors which affect the running cost, notably the power required and frequency of replacement of anodes. There are, in addition, certain considerations which relate only to particular types of structure. For example, in the cathodic protection of ships' hulls or of pumps, consideration should be given to the hydraulic drag arising from the installation of the anodes. In the case of buried structures, possible effects of the direct current flowing in the soil on other structures in the vicinity may also have an important effect on the economics of the scheme (see A.3). There are also some secondary effects of cathodic protection (see A.2.5.1) which need to be taken into account.

A.2.3 Design or modification of structures to be protected

A.2.3.1 Electrical continuity

It may be necessary to install continuity bonds between different sections of the structure or plant before cathodic protection is applied. The resistance of these bonds should be sufficiently low to ensure that the potential drop due to the passage of the protective current through the structure is small (see A.2.2). In the case of impressed current installations, it may be economical to improve connections between different parts of the structure, even though metallic connections already exist, in order to reduce the total resistance.

It should be noted that if the structure is not metallically continuous, part of the protection current flowing in the electrolyte towards a protected section may pass through isolated sections of the structure. Corrosion may be accelerated where such currents are discharged from the structure and return to the electrolyte (see A.3). This accelerated corrosion could be internal where conducting fluids are being conveyed in pipelines.

A.2.3.2 Protective coating (see IPS-E-TP-270)

The function of a coating is to reduce the area of metal exposed to the electrolyte (soil or water). By this means it is possible to reduce greatly the current density required for cathodic protection. As indicated in A.2.2., the fact that the current is spread more uniformly may reduce the number of points at which cathodic protection need to be applied.

A coating should, ideally, have a high electrical resistance and be continuous, i.e., there should be few holidays. It should be resistant to any chemical or bacterial action to which it might be exposed, and should withstand all temperature variations to which it may be subjected; no blisters should exist and the coating should adhere strongly to the surface to be protected; it should have satisfactory aging characteristics and adequate mechanical strength. Ability to resist abrasion may be important in some applications.

Coatings may take the form of paints, or materials such as bitumen and coal tar which are often reinforced with glass fiber or other fibrous material. Plastics sheet or tapes may also be used for certain structures. The most suitable form of coating depends on the type of structure and its environment; more particular information is given in IPS-E-TP-100 and IPS-E-TP-270. In deciding upon the type of coating to be used, the aim should be to achieve overall economy in the combined cost of the protected structure and of the initial and running costs of the protection schemes. Due regard should be paid to the life expected of the structure and to the economics of preparing the coating should this become necessary.

In the case of buried structures, a secondary but important function of the coating is to reduce the potential gradients in the surrounding soil thereby decreasing interaction with neighboring buried structures (see A.3).

The protection current, particularly if strongly negative potentials are used, may produce sufficient alkali (see A.1.1.5) to affect the coating adversely. The extent to which coatings are alkali resistant is therefore important in some applications. This is further discussed in A.2.5.1. It is, however, possible to give only general information in respect of coatings. If, in a particular case, the coating performance was critical, it would be desirable to determine the properties by test beforehand.

Concrete cannot be considered to be a substitute for an insulating coating and such a coating should be provided in addition wherever possible.

Metal spraying is not treated as a coating for the purposes of this Standard; its use in conjunction with cathodic protection is unlikely.

The adverse effect of a non-adherent coating shall not be oversimplified.

A non-adherent coating is a barrier that will prevent from a pipeline, the flow of cathodic protection current from soil. In other words cathodic protection current could not flow to the pipe metal through the soil or water between the non-adherent coating and pipe metal.

However, if the disbonded or non-adherent coating (which acts as a cathodic shield) is sufficiently porous to absorb enough soil moisture to become conductive, the moisture may pass enough current to protect the pipe metal (which is in contact with soil or water) under the non-adherent or disbonded coating. Such a disbonded coating would not then act as a complete shield or barrier. This phenomenon has been proved beyond doubt on a number of gas transmission pipeline running through marshy land or terrain with low water levels.

A.2.3.3 Isolation

It often happens that a well-coated structure, to which cathodic protection could be applied economically, is connected to an extensive and poorly coated metallic structure the protection of which is not required or would be uneconomical. In such a case, the well-coated structure shall be isolated before applying cathodic protection to it. In the case of coated pipelines for example, the inclusion of isolating joints and terminal installations is normally considered to be essential.

A further application is the isolation of a section of a structure to prevent or reduce excessive effects on neighboring structures due to interaction (see A.3). If the isolated section is so placed that the required continuity of the structure is interrupted, this should be restored using insulated cable. It may, on occasion, be desirable to shunt an isolating device by means of a resistor. For example by choosing an appropriate value for the resistor, it might be possible to adjust the current so that it is sufficient to protect the relevant section of the structure but is insufficient to cause unacceptable interaction on nearby structures.

Isolating joints are sometimes required part of the safety precautions at oil terminal jetties (see A.4.4.2 (e)). They should not be installed in above-ground situations where concentrations of flammable gas or vapor occur (see A.4.4.2 (d)).

The protection of only part of a structure may accelerate the corrosion of nearby isolated sections of the structure as explained in A.2.1 and A.3. For this reason it may be advisable to apply a coating with a particularly high insulation resistance to the protected section of the structure where it is near unprotected equipment or to take the other measures described in A.3.2.2 to prevent possible damage.

With equipment containing electrolytes, corrosion could similarly occur on the inner surface of the unprotected section. With highly conducting fluids, for example brine, such corrosion could well be rapid. For this reason the inclusion of isolating devices, for example, pipelines containing seawater or strong brine is inadvisable (see also A.3.6).

A.2.4 Comparison of the various systems

The advantages and disadvantages of the galvanic anode and impressed current methods are set out in Table 1.A. A further method known as electric drainage which is applicable only to structures affected by stray currents flowing in the soil, and may have advantages in suitable cases.

TABLE A.1 - A COMPARISON OF GALVANIC ANODE AND IMPRESSED CURRENT SYSTEMS

GALVANIC ANODES	IMPRESSED CURRENT
1- They are independent of any source of electrical power.	1- Requires a mains supply or other source of electric power.
2- Their usefulness is generally restricted to the protection of well-coated structures or the provision of local protection, because of the limited current that is economically available.	2- Can be applied to a wide range of structures including, if necessary, large, uncoated structures.
3- Their use may be impracticable except with soils or waters with low resistivity.	3- Use is less restricted by the resistivity of the soil or water.
4- They are relatively simple to install; additions may be made until the desired effect is obtained.	4- Needs careful design although the ease with which output may be adjusted allows unforeseen changing conditions to be catered for.
5- Inspection involves testing, with portable instruments, at each anode or between adjacent pairs of anodes.	5- Needs inspection at relatively few positions; instrumentation at points of supply can generally be placed where it is easily reached.
6- They may be required at a large number of positions. Their life varies with conditions so that replacements may be required at different intervals of time at different parts of a system.	6- Requires generally a small total number of anodes.
7- They are less likely to affect any nearby neighboring structures because the output at any one point is low.	7- Requires the effects on other structures that are near the groundbed of protected structures to be assessed but interaction is often easily corrected, if necessary.
8- Their output cannot be controlled but there is a tendency for their current to be self-adjusting because if conditions change such that the metal to be protected becomes less negative, driving e.m.f., and hence current, increases. It is possible, by selection of material, to ensure that the metal cannot reach a potential that is sufficiently negative to damage paint.	8- Requires relatively simple controls and can be made automatic to maintain potentials within close limits despite wide variations of conditions. Since the e.m.f. used is generally higher than with galvanic anodes the possible effects of ineffective control or incorrect adjustment, for example damage to paintwork or coatings, are greater.
9- Their bulkiness may restrict flow and/or cause turbulence and restrict access in circulating water systems. They introduce drag in the case of ships' hulls.	9- Allows of more compact anodes by the use of suitable materials; drag is negligible.
10- They may be bolted or welded directly to the surface to be protected thus avoiding the need to perforate the metal of ships' hulls, plant to be protected internally, etc.	10- Requires perforation in all cases on ships' hulls, plant to enable an insulated connection to be provided.
11- Their connections are protected cathodically.	11- Requires high integrity of insulation on connection to the positive side of the rectifier which are in contact with soil or water: otherwise they will be severely corroded.
12- They cannot be misconnected so that polarity is reversed.	12- Requires the polarity to be checked during commissioning because misconnection, so that polarity is reversed, can accelerate corrosion.

A.2.5 Special considerations

A.2.5.1 Secondary effects of cathodic protection

It will have been noted from A.1.1.5 that the application of cathodic protection may give rise to secondary effects such as the development of alkalinity or the evolution of hydrogen at the protected surface. The effects that may occur are described in the following paragraphs.

- a) Alkalinity may cause the deterioration of paints. The effect can be minimized by avoiding the use of very negative potentials and by using paints that are less susceptible to such damage.
- b) Alkalinity causes, in the case of seawater or similar solutions, a white calcareous deposit (chalking). This is beneficial since the current density needed to maintain cathodic protection is reduced. If, however, formation of the deposit is excessive, water passages may be obstructed or moving parts impeded.
- c) Aluminum is corroded in alkaline environments and can therefore be cathodically protected only if the potential is maintained within certain limits (see Table 1 Note 2).

Since Aluminum is an amphoteric metal and sensitive to Alkali, cathodic protection of aluminum pipe is a special problem. The reaction in a cathodic protection circuit generates alkali at the cathodic surface. If too much cathodic protection is applied, the alkalinity at the surface of an aluminum pipe may become strongly enough to consume the aluminum chemically. The danger is that a buried aluminum pipeline under strong cathodic protection actually may corrode faster than it would if not cathodically protected at all.

- d) exceptionally, lead can be corroded when protected cathodically in an alkaline environment (e.g. cables installed in asbestos-cement pipes).
- e) Hydrogen evolved at strongly negative potentials may create an explosion hazard in enclosed spaces (see A.4.3 and A.4.4).
- f) Hydrogen embrittlement of high tensile steel is a possible danger.
- g) Hydrogen produced at flaws in a coating may progressively detach the coating from the surface of the metal.
- h) Rust and scale is sometimes detached from a surface during the initial period of operation of cathodic protection and may block water passages or cause other difficulties during a short period. If iron or steel has been seriously corroded, removal of rust that is plugging holes may cause a number of leaks to become apparent during this period.
- i) Chlorine may be evolved at the anodes of an impressed current cathodic protection installation if the electrolyte contains chloride. This may cause nuisance or create a hazard (see A.4.4.3)

A.2.5.2 Effects of stray currents from protection installations

Where a protected structure, or the anode(s) or ground-bed(s), lies near to other buried or immersed metallic structures that are not fully insulated from earth, the latter (secondary) structures may, at certain points, pick up a proportion of the protective current due to potential gradients in the soil or water and return it to earth at others. The secondary structures may corrode at these latter points (see A.3).

A.2.5.3 The avoidance of damage or hazard due to overvoltages (see also IPS-E-EL-215)

Overvoltages due to faults on power equipment or to lightning may cause serious damage to equipment installed to provide cathodic protection. If isolating joints have been inserted in a protected structure, there is risk of flashover and explosion if the structure contains low flash-point material. The following recommendations shall be read in conjunction with any other relevant standards or Regulations.

A.2.5.3.1 Damage to cathodic protection equipment by overvoltages

The groundbed of a cathodic protection system will often be the best available connection to earth in a particular locality and this may result in the associated equipment being subjected to overvoltages or excessive current that originate either from faults on power equipment or lightning as follows:

a) Faults on power equipment via the protective earthing of equipment

In high resistance areas, where it is difficult to obtain a good connection to earth, a system of protective earthing is often employed. This involves the bonding together of all the earth and/or neutral terminals of plant and equipment so that they are at the same potential, although this potential may be appreciably higher than true earth potential.

b) Lightning

Any currents due to strikes to the protected or associated structures are liable to flow to earth via the groundbed. This could damage the meters of the transformer/rectifier equipment and may also damage the rectifier stack. In either case overvoltages can arise across the terminals of the equipment, and a suitable surge diverter or protective spark gap should be installed across the output terminals of all transformer/rectifier equipment. Further advice on lightning considerations is given in BS 6651 (1985) (see also IPS-E-EL-215).

A.2.5.3.2 Isolation of buried structures that are associated with a lightning protection system

Care is needed if isolating joints are to be installed in buried structures where lightning protection has been installed in accordance with BS 6651 (1985). That standard requires, that metal cable sheaths, metal pipes and the like entering a building or similar installation should be bonded as directly as possible to the earth termination of the lightning protection system, at the point of entry to the building. This bonding is necessary in order to avoid break down through the soil as a result of a lightning discharge with consequent risk of damage to the pipes, cables, etc.

The installation of isolating joints for cathodic protection purposes where buried structures approach terminal or other installations clearly runs counter to these requirements since the deliberate electrical separation of the metallic services from other earthed components, including the earth termination of the lightning protection system, could, in the event of a lightning storm, result in a breakdown through the soil or flashover of the isolating joint, with consequent risk of damage or explosion.

To satisfy the opposing requirements, the isolating joints should be bridged by discharge gaps to effect adequate connection between the two earthed systems during the discharge of lightning current. The impulse breakdown voltage of these gaps should lie below that of the isolating joints. The gaps should be capable of discharging lightning currents without sustaining damage and should be encapsulated to provide complete protection from moisture.

A.2.5.3.3 Buried structures in the vicinity of a lightning protection system

Where the structures to be cathodically protected pass close to, but are not already incorporated in, a lightning protection system installed to protect some other structure or installation, the question may arise as to the minimum distance between a lightning protection earth and other buried metalwork, for example the groundbed of a cathodic protection system, beyond which the need for bonding as mentioned in A.2.5.3.2 can be discounted.

This distance, S , can be estimated from the relationship $S = IR/E$ where I is the crest value of the lightning current discharged through an earth termination of resistance, R , and E is the impulse break down strength of the soil.

Although no systematic tests have been carried out, tests on a variety of soil specimens have indicated values of E to be from 0.2 kV/mm to 0.5 kV/mm. Assuming the lower of these, together with a current of 200 kA (an exceptionally severe lightning current), separation, S , (in meters) is given by $S = R$ where R is the resistance of the earth electrodes before any bonding to other structures has been carried out. BS 6651 (1985) requires that the resistance to earth of the whole lightning protection system should be not more than 10 ohms (see also IPS-E-EL-215).

A.2.6 Factors affecting design

The following factors affect the application of the principles outlined previously in this Section.

A.2.6.1 Variations of conditions affecting the cathodic protection of buried structures are generally slow. Manually adjusted control equipment is therefore usually sufficient. Automatic control may, however, be required if the structure to be protected is affected by stray currents from electric traction systems; the control system has to be quick acting. Suitable equipment is available. The position of the sensing electrode should be carefully chosen.

A.2.6.2 The nature of the coating and the method of application will determine the most negative potential that can be applied without likelihood of coating damage. Conventional limits of structure/soil potential for coal tar and asphaltic pipeline enamels are -2.0 V (off) with an absolute minimum of -2.5 V (off) (copper/copper sulfate reference electrode). Other coatings may be more susceptible to overprotection and the structure/soil potential may need to be limited to less negative values (see A.2.5.1).

A.2.6.3 For steel structures, the usual criterion of protection is -0.85 V (without allowance for IR drop error) relative to a copper/copper sulfate reference electrode. Where anaerobic conditions occur and sulfate-reducing bacteria may be present, a more negative value of -0.95 V (without allowance for IR drop error) should be adopted.

A.2.6.4 Special backfills can be used to assist in obtaining a low resistance between anodes and the soil.

A.2.6.5 Special care is needed to avoid accelerating the corrosion of other buried structures by interaction (see A.3).

A.2.6.6 For buried structures near electric traction systems, electric drainage can be used (see A.2.6.7).

The application of cathodic protection to a buried or immersed structure (referred to as the primary structure) causes direct current to flow in the earth or water in its vicinity. Part of the protection current traverses nearby buried or immersed pipes, or cables, jetties or similar structures, or ships alongside (termed secondary structures), which may be unprotected and the corrosion rate on these structures may, therefore, increase at points where the current leaves them to return to the primary structure. This effect is described as "corrosion interaction".

A.2.6.7 Electric drainage

In dc traction systems, the negative of the d.c. supply is usually connected to the running rails which are in electrical contact with the soil. Thus the soil will provide an additional path, in parallel with the track, for current flowing from the traction unit towards the point of supply particularly in the case of extensive structures such as pipelines or cables, part of the current flowing in the soil may be picked up in one area and discharged in another, leading to accelerated corrosion.

This can be prevented by bonding the pipeline or cable sheath and armoring to a return rail at the most negative portions of the track, i.e. near sub-stations or where negative feeders are connected to the rails. The bonding cable will then carry most of the return traction current back to the point of supply thus ensuring that the structure receives partial, or sometimes complete cathodic protection. This form of cathodic protection is known as 'electric draining' or 'drainage'.

Under no circumstances should any connection or bonding be made to railway running rails or structures without consultation with, and subsequent written permission from, the railway authorities.

The electric drainage method can be applied in all circumstances because of the likelihood of current reversals in the drainage bond; a rectifier (or other unidirectional device) is therefore usually provided as illustrated in Fig. 14a. This is referred to as "polarized electric drainage".

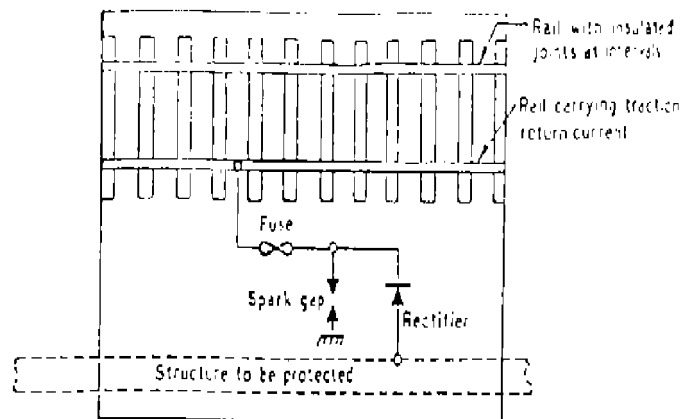
The track voltage may attain relatively high values and it may be necessary to protect the rectifier and bond against excessive currents by means of suitable series resistors and/or inductors and overload circuit breakers or fuses and by providing more than one drainage connection (see Fig. 14b).

For railway signaling purposes, a relay and power supply are usually connected between the two rails of a railway track so as to provide remote indication that a train is in the section. This arrangement is known as a track circuit and there are "single rail" track circuits and 'double rail' track circuits. In the first type there are insulated joints in one rail at each end of each signaling section and the traction return current is confined to the other rail. In the second type there is an impedance bond at each end of each track circuit and the traction return current flows in both rails as it does also when there are no track circuits.

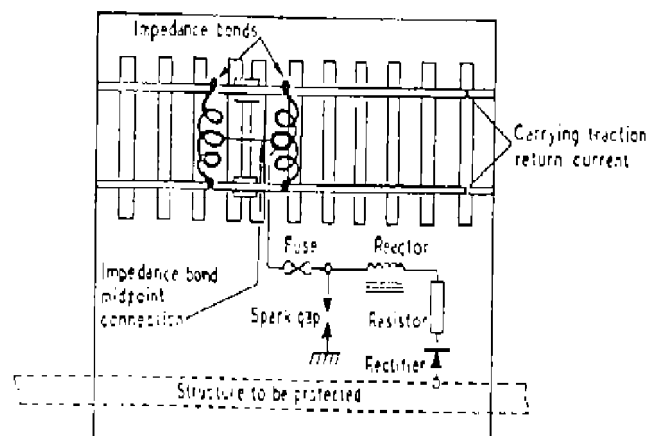
Irrespective of the type of drainage system used, the connection to the rail is made to both rails where there are no track circuits, to the traction return rail only where there are single rail track circuits, and to the mid-point of an impedance bond where there are double-rail track circuits.

Fig. 14a shows the case with single-rail track circuits, Fig. 14b the case with double-rail track circuits and Fig. 14.c the case with no track circuits.

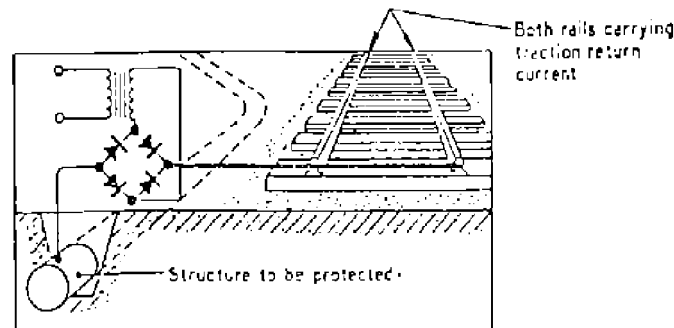
The amount of cathodic protection applied to nearby buried structures by means of drainage bonds may be increased by the use of 'forced electric drainage' which entails the insertion in the drainage connection of an independent mains-operated cathodic protection rectifier as shown in Fig. 14.c. It may be necessary to limit the output from the rectifier by means of saturable reactors or transformers or similar devices.



**a) Polarized drainage without resistor
(on an electrified line with single-rail track circuits)**



**b) Polarized drainage with resistor and reactor
(on an electrified line with double-rail track circuits)**



c) Forced drainage on an electrified line without track circuits
(drainage supplemented by rectified ac)

TYPICAL ELECTRIC DRAINAGE SYSTEMS

Fig. 14

A.3 Measures to Safeguard Neighboring Structures

The application of cathodic protection to a buried or immersed structure (referred to as the primary structure) causes direct current to flow in the earth or water in its vicinity. Part of the protection current traverses nearby buried or immersed pipes, or cables, jetties or similar structures, or ships alongside (termed secondary structures), which may be unprotected and the corrosion rate on these structures may, therefore, increase at points where the current leaves them to return to the primary structure. This effect is described as 'corrosion interaction'.

Corrosion interaction can be minimized by care during the design stage, as discussed in A.3.2 can be assessed by interaction testing (see IPS-C-TP-820) tests and criteria for corrosion interaction (see A.3.1) and can be corrected, if necessary, by measures described in A.3.2. One method is to bond the secondary structure to the primary structure so that the former is also cathodically protected. When this method is proposed, consideration should be given to safety aspects discussed in A.4.2.

Corrosion interaction affecting neighboring structures is unlikely to occur as a result of applying cathodic protection to plant internally because appreciable currents flow only through and inside the protected plant.

A.3.1 Criteria for corrosion interaction

Any current flow that makes the potential of a metal surface with respect of its surroundings more positive is liable to accelerate corrosion. The structure/electrolyte potential is therefore used as the basis of assessment. Positive structure/electrolyte potential changes are the more important. Steel surrounded by concrete needs special consideration for reasons explained in A.3.1.2. Occasionally, negative changes have to be limited (see A.3.1.3).

A.3.1.1 Limit of positive structure/electrolyte potential changes

All structures except steel in concrete. The maximum positive potential change at any part of a secondary structure, resulting from interaction, should not exceed 20 mV. The adoption of a single criterion for all types of structure, irrespective of the value of the structure/electrolyte potential, is over-simplification. It is, however, believed to be reasonable on the basis of evidence at present available. Where, however, there is definite reason to suppose that the secondary structure is already corroding at an appreciable rate, even a small potential change will reduce the life of the structure and no change of the structure/electrolyte potential should be permitted.

A.3.1.2 Positive structure/electrolyte potential changes steel in concrete

The foregoing criterion is inapplicable to steel that is completely covered by concrete. Under such conditions, steel becomes passive so that corrosion is prevented. The governing consideration may, therefore, be the disruptive effect of the evolution of oxygen which occurs when the steel is more positive than about +0.5V (copper/copper sulfate reference electrode). However, the behavior of the steel may be affected by the presence of chlorides (whether introduced initially or due to a saline environment) which may prevent passivation, so that it is impossible to make firm recommendations. Another complication is that it is not a simple matter to evaluate the structure/electrolyte potential or to measure changes in it across the steel/concrete interface. Changes in the steel/soil potential measured simply by placing the reference electrode in the soil close to the concrete (as distinct from close to the steel) may need to be referred to a criterion other than the 20 mV given in A.3.1.1. However, until another criterion more appropriate to these circumstances is approved, it may be convenient to use the 20 mV criterion as a basis for decision as to whether or not corrective measures should be undertaken.

These considerations apply only to steel fully enclosed in sound concrete. If the steel is only partially encased, the provisions of A.3.1.1 apply to any area of the surface in direct contact with the soil. It may be noted that in these conditions a cell may be formed in which the steel in contact with soil acts as an anode. The structure/soil potential is likely, therefore, to be more positive at positions near the concrete and there may be corrosion quite apart from any effect of interaction.

A.3.1.3 Negative changes of structure/electrolyte potential

If the recommendations made in A.3.2 are followed, excessive negative changes of structure/electrolyte potential on the secondary structure will normally be avoided. Large negative changes may, however, occur if the groundbed of an impressed current cathodic protection scheme is unduly close to a secondary structure. Except in the case of aluminum (and, exceptionally, lead in alkaline environment), corrosion is unlikely to result from making the structure/electrolyte potential more negative. The considerations are, therefore, the secondary effects described in A.2.5.1 particularly the disruption of coatings. In the absence of any special considerations, structure/electrolyte potentials more negative than -2.5 V (copper/copper sulfate reference electrode) should be avoided on buried structures. In the case of immersed structures, in areas with potentials more negative than -0.9V (silver/ silver chloride/ seawater electrode) high duty coatings must be used. These are based on epoxy resin, chlorinated rubber, vinyl or other alkali resistant materials (see IPS-E-TP-100). Economic considerations will determine whether these should be applied overall or only to area near anodes. Some paints e.g. coal-tar epoxy, can withstand potentials more negative than -1.1V (silver/silver chloride/seawater electrode).

Success depends on an adequately prepared surface which ideally should be freshly blast cleaned and free from weathered or unsuitable shop primer.

Where the potentials foreseen are more negative than can be withstood by a paint coating. An insulating shield as described in A.3.1.4 must be applied near the anode. The boot-top area should be coated with a high duty coating such as chlorinated rubber or epoxy paint in preference to oleoresinous types.

A.3.1.4 Insulating shields for impressed current systems. The high current densities at which impressed current anodes may be required to operate result in very negative potentials immediately adjacent to the anodes. As most hull paints are unable to withstand these potentials, it is important that the surface around each anode be covered by a robust protective shield, extending well beyond the anode mount itself.

The shape and size of the anode shields will be determined by the shape of, and maximum current anticipated from, the anodes. A diskshaped anode, for example, will require a circular shield, whereas a long strip anode will require a rectangular shield of smaller width but greater total area. The dimensions of a shield should be large enough to ensure that the structure/electrolyte potential around its edge is unlikely to cause breakdown of the adjacent hull paint.

The potential, E , at a distance, r , (in meters) from the center of a disk-shaped anode may be calculated approximately from the formula:

$$E = E_o - \frac{\rho I}{2\pi r}$$

Where:

- E_o is the general hull potential when protected (V)
 ρ is the water resistivity (Ωm)
 I is the current (A)

The value of E_o is normally about -0.80 V (silver/silver chloride/seawater reference electrode).

In the case of a linear anode, the most negative potential occurs on either side of the center of the anode and the corresponding approximate formula for this potential, at distance d from an anode of length L (meters), is:

$$E = E_o - \frac{\rho I}{\pi L} \left(\ln \frac{2L}{d} - 1 \right)$$

Where:

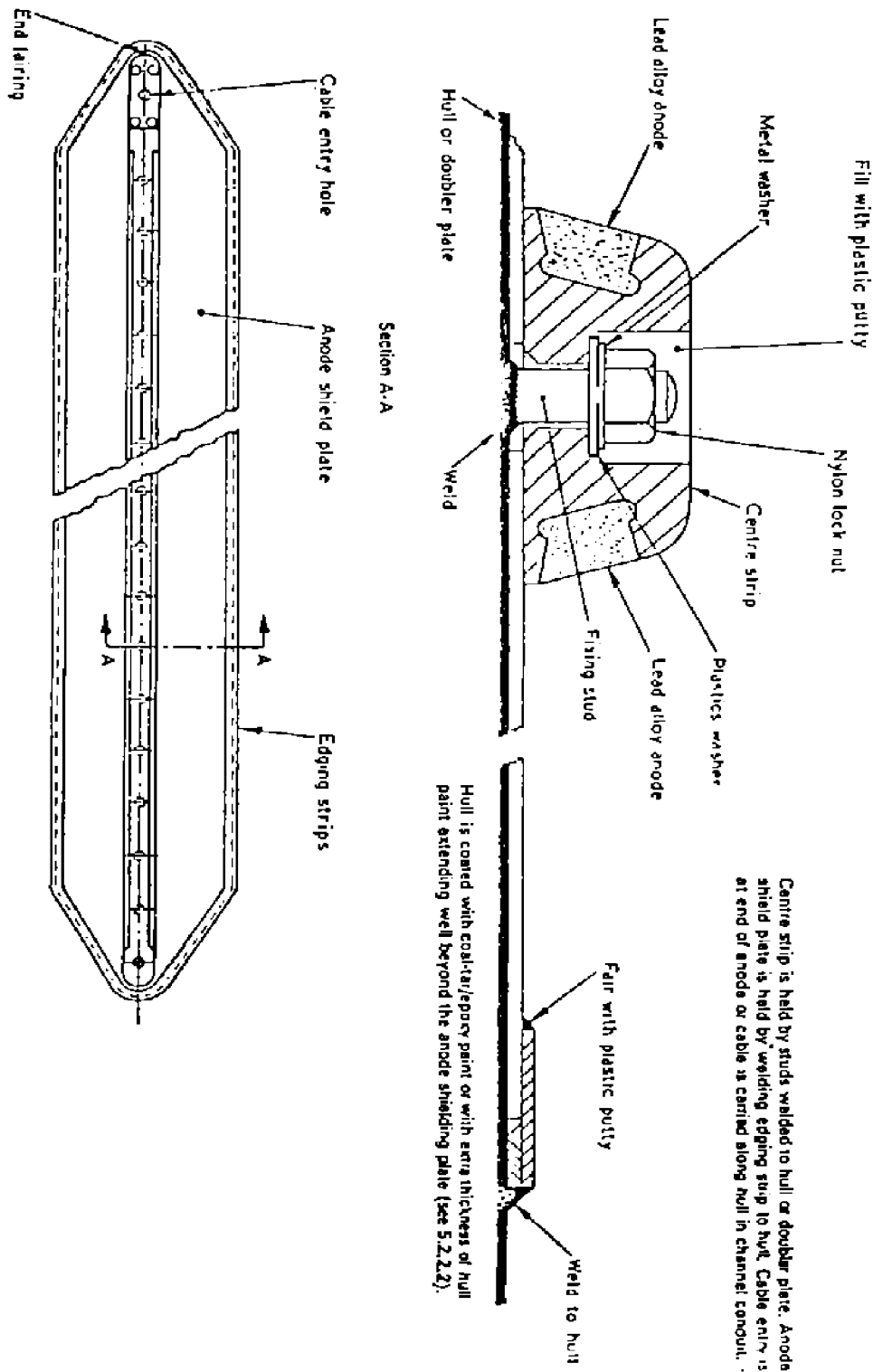
E_o , ρ and L are as above and \ln is the natural logarithm.

The size of the shield should be such that the potential E at its edge is not more negative than can be withstood by the paint that will be applied to the surrounding area of the hull.

The shield may consist of either a high duty coating, e.g. epoxy or glass-reinforced polyester resin of about 1.0 mm thickness built up on the hull steel, or a prefabricated shield usually made as an integral part of the anode mount. The latter form is more durable and resistant to mechanical damage but its size may be limited by difficulties of mounting and cost of fabrication. Where necessary, therefore, this type should be supplemented by an appropriately sized surround of a suitable high duty coating.

Care should be taken to see that the hull plating beneath performed shields is adequately protected and, in those cases where it is applicable, the shields are firmly bonded to the plating. It is also recommended that such shields be secured at their outer edges by welded steel fillets or other suitable means to prevent lifting or stripping. Examples of typical anodes and shields are shown in Fig. 15.

As a rule, anti-fouling paint will be applied to the anode shield but it is imperative that no paint be applied to the working surface of the anode.

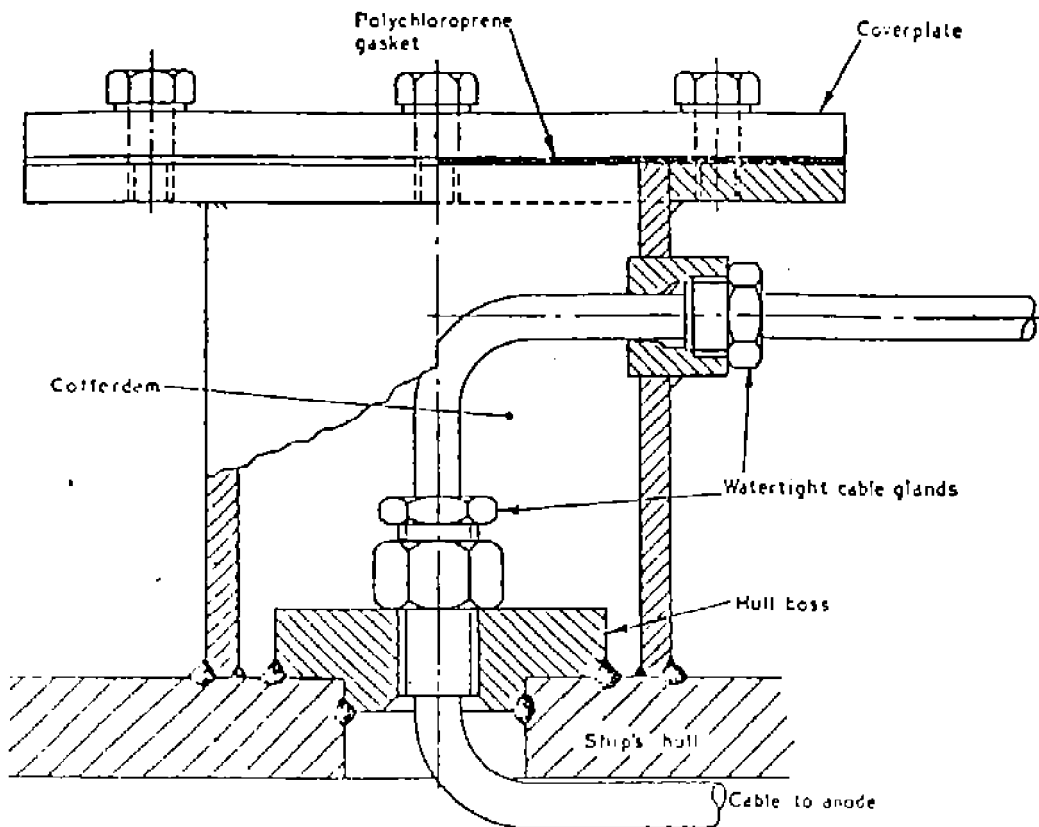


a) Lead alloy hull anode with prefabricated shield

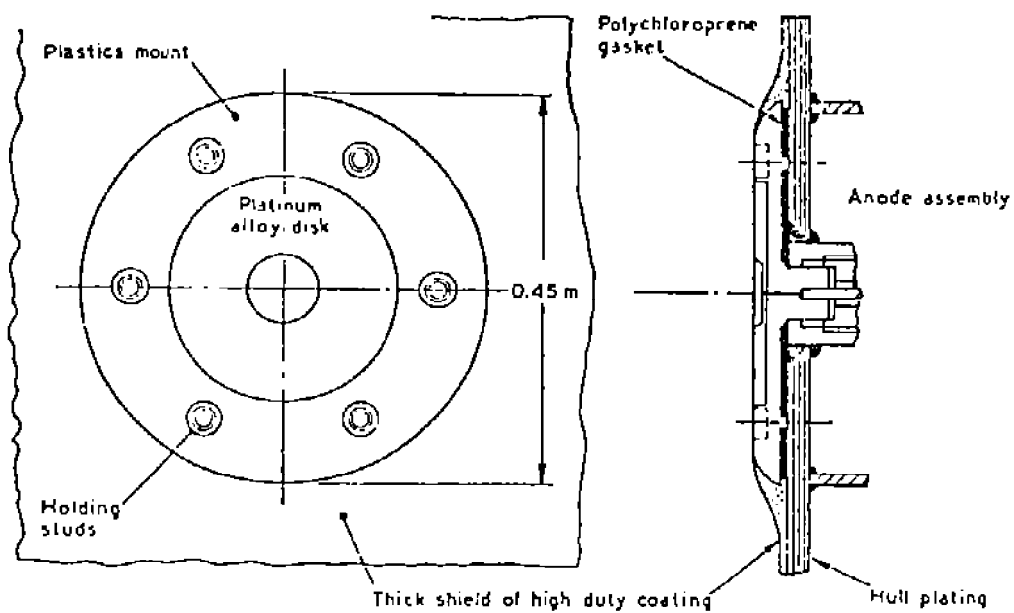
HULL ANODES FOR IMPRESSED CURRENT

Fig. 15

(to be continued)

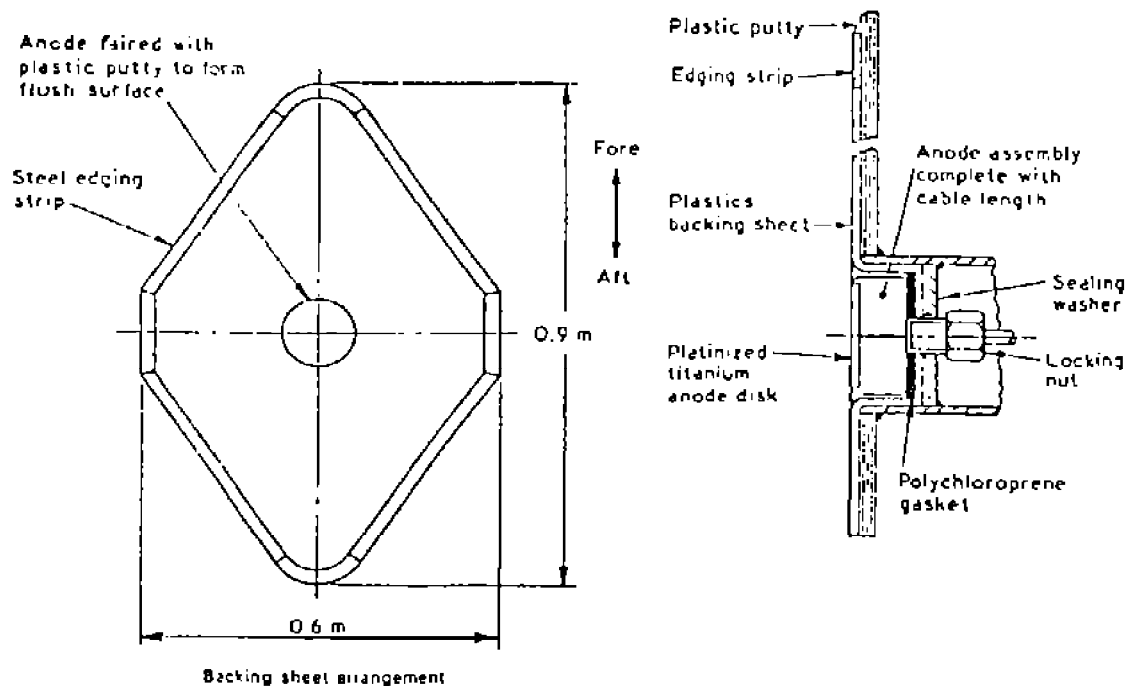


b) Example of hull penetration gland



c) Platinum alloy disk anode mounted on ship's hull

(to be continued)



d) Platinized titanium disk anode recessed into ship's hull
Fig. 15 (continued)

A.3.2 Design of cathodic protection installations to minimize corrosion interaction

It is impossible to estimate precisely the amount of corrosion interaction likely to be caused by a cathodic protection scheme. The magnitude of any positive changes of structure/electrolyte potential on neighboring secondary structures will depend mainly on the following:

a) The quality of the coating on the primary structure

The better the coating the smaller will be the current required for protection and the interaction effects will be reduced accordingly.

b) The quality of the coating on the secondary structure

A coating on the secondary structure tends to increase the measured positive changes of structure/electrolyte potential. The greater part of the increased change of potential difference occurs across the coating and may be regarded as a measurement error that arises because it is impracticable to place the measuring electrode sufficiently close to the surface of the metal. However, high positive changes of structure/soil potential across a resistive coating indicate a possibility of enhanced corrosion should local coating defects exist or develop later.

c) The magnitude of the structure/electrolyte potential change on the primary structure in the vicinity of the secondary structure

Because interaction effects are roughly proportional to this structure/electrolyte potential change, it should be kept to the minimum required to provide protection at positions remote from the point of application. A larger structure/electrolyte potential change is necessary at the points of application if the length of structure protected from any one point is increased. Thus, interaction can be reduced by applying the protection at a larger number

of points so that the structure/electrolyte potential change on the primary structure is more uniform and by ensuring, as far as other considerations allow, that the points of application and associated larger structure/electrolyte potential changes are remote from other structures.

d) The spacing between the primary and secondary structures

Interaction will be greatest at a crossing point or other proximity. The greater the separation of the structures, the less the effect will be.

e) The distance between the groundbeds or anodes and the secondary structure

Structures close to the anode system may be affected by the potential gradient around the anode.

Anodes or groundbeds should not, therefore, be placed close to other structures.

f) Soil or water resistivity

The potential gradient at any point in the soil is the product of current density and resistivity. Thus, in general, interaction is minimized by siting groundbeds in low resistivity areas.

A.3.2.1 Galvanic anodes

The current available from a single galvanic anode of typical size in most soils is generally of the order of tens of milli-amperes compared with impressed current installation where tens of amperes may be produced. If the total current is less than 100 mA, interaction testing may be omitted. Even if the current exceeds 100 mA, corrosion interaction is unlikely, particularly if anodes are placed at least 2 m away from any secondary buried structure and so that the secondary structure does not lie between anode and primary structure.

If anode outputs in excess of 100 mA are used, or groups of anodes installed together are used, or if anodes are sited so that another underground metallic structure lies between the anode and the primary structure, interaction testing may be required.

It may be important to reach agreement at an early stage as to whether testing is necessary for a particular anode system, as connecting links to facilitate disconnection for testing purposes may be necessary. Links may, of course, be required for testing the output of anodes, whether interaction testing is considered necessary or not.

A.3.2.2 Impressed current-installations

The following precautions should be taken:

- a)** Structure/electrolyte potentials on the primary structure kept to the minimum consistent with the required level of protection being obtained.
- b)** High quality coatings provided to minimize protection current on a new buried or immersed structure that is to be protected cathodically.
- c)** The new structure sited as far from neighboring structures as is practicable and the spacing at all crossing points ascertained as being the maximum which conditions permit.
- d)** The longitudinal resistance of the structure to be cathodically protected made as low as is practicable by means of continuity bonds, welded joints, or other means.
- e)** The groundbed sited as far from neighboring structures as practicable.
- f)** Consideration given to installing anodes at a considerable depth, e.g. 15 m to 30 m.
- g)** The total current to be applied distributed from a sufficient number of units to ensure a reasonably uniform distribution of structure/electrolyte potential on the primary structure.

A.3.3 Measures to reduce corrosion interaction

A.3.3.1 Choice of method

In addition to reconsidering the precautions taken during the installation of the cathodic protection scheme, and to ensuring that the current is the minimum necessary to provide an acceptable level of protection, one or more of the following methods should be considered by the parties concerned as a means of reducing corrosion interaction at the points on the secondary structure where positive changes in excess of the recommended maximum have been measured.

The method adopted should aim at restoring the structure/soil potential of the secondary structure to the original value, or preferably making it more negative than the original value. Bonding between structures may be precluded by safety considerations referred to in A.4.2. For example, the bonding together of electric transmission towers and pipelines containing flammable liquids or gases is generally to be avoided. In such cases the other measures for eliminating the effects of interaction, suggested in A.3.2.2 and below in items c to e, are to be preferred.

The following techniques are available:

- a)** A joint cathodic protection scheme so that full protection is given to both structures.
- b)** Connection together of the two structures by means of one or more remedial bonds, which may include suitable resistors to limit the current to the minimum necessary to correct the interaction. This is one of the most effective methods of reducing possible corrosion interaction. The remedial bond should preferably be connected to the secondary structure at or near the point where the maximum positive structure/electrolyte potential change was measured, but if the structures are some distance apart at this point, and it is more convenient, the installation of a remedial bond at a point not too far distant, where the structures are closer together, may be satisfactory. For reasons referred to in A.2.3.1, it is essential that any structure to be so bonded be electrically continuous. If it is suspected that the secondary structure may be discontinuous, joints should be tested (see IPS-I-TP-820) and continuity bonds installed as necessary. The bond, the connections to the two structures, and any resistors, should be constructed to specifications satisfactory to both parties. The bond should be an insulated copper conductor and of adequate size to carry any fault current that may flow (see A.4.2) but should be not less than 16 mm² cross-sectional area. The bond should be installed inside a suitable housing or building where it can be regularly inspected. When a buried bond is required, mechanical protection against digging operations may be necessary; it is desirable that suitable identification markings be provided. In circumstances where it is clear that corrosion interaction will occur, much testing time will be saved if bonds are installed at suitable positions before interaction tests are made. It is always necessary to measure the current flowing in the bond, but if a regular check of the current is required, for example, where resistance bonds have been provided to control the current, a suitable enclosure and a removable link or other bolted connection may be installed at a point accessible to both parties.
- c)** A galvanic anode connected to the secondary structure if the positive changes are small and localized, e.g. a meter or so each side of a point where two structures are close to each other.
- d)** Increasing resistance between the two structure, at a point where a positive change is measured, by applying locally an additional good quality coating or warping to the primary and/or secondary structure. If the secondary structure is coated, it is essential that it be free from holidays.
- e)** Isolation, in the case of a pipeline, of a section of pipe adjacent to secondary structures by means of isolating joints. The isolated section can then be bridged by means of an insulated cable of appropriate size to maintain continuity along the main section of the pipeline. The isolated section can be generally protected by means of galvanic anodes. Alternatively, one of the isolating joints can be shunted by a resistor of such value that the pipe between the isolating joints is protected without causing excessive interaction. This method is particularly applicable at parts of the route near groundbeds where the primary structure/electrolyte potentials are strongly negative, creating possible severe interaction on secondary structures. The method can be applied at road crossings where there may be a number of secondary structures, or at railway crossing, to limit interaction with signaling and other equipment. A section of pipe can also be isolated at crossings with electrified railways to reduce the effects of stray traction of pipeline.

It is very important to ensure that methods that entail extending the cathodic protection to further structures are not used in such a way that consequent negative changes on such structures, in turn, cause corrosion interaction on a third structure.

A.3.3.2 Temporary operation of an installation

If it is urgently required to operate a cathodic protection installation which is completed except for arrangements necessary to reduce structure/electrolyte potential changes on neighboring plant, it is recommended that, wherever it seems unlikely that material damage will be caused to the secondary structure, the parties concerned should agree to a limited period of operation without remedial measures, this is to enable the protection to be maintained while the necessary additional work, which should be put in hand as soon as possible, is carried out.

The period during which such temporary operation may be permitted depends on the amount by which the measured structure/electrolyte potential changes exceed the agreed limit, and on any available evidence as to the existing state of the two structures, and on the period, if any, during which the protection has already been operated prior to testing. If there is no history of corrosion on the secondary structure it is suggested that, where it is expected that the remedial measures will eventually eliminate the adverse changes entirely, temporary operation may be permitted for periods of not exceeding three months with structure/electrolyte potential changes of up to +50 mV.

A.3.4 Cathodic protection systems installed adjacent to telecommunication services

Electrical interference. If a telecommunication cable is boned to, or is close to, a cathodic protection system energized from a source of alternating current through rectifiers, or if the groundbed of the cathodic protection system is sited close to the earth electrodes of a telecommunication system, there may be interference to telecommunication circuits. This is due to harmonic currents of the fundamental frequency of the alternating current supply feeding the rectifier unit inducing unwanted noise voltages into the telecommunication circuits.

With rectifier output currents of the order of 5 A or less, interference is unlikely. With greater currents, or if interference occurs, consideration should be given to the provision of smoothing for the rectifier.

A.3.5 Cathodic protection systems adjacent to railway signal and protection circuits

It is imperative that the use of cathodic protection on, or adjacent to, railway property be so planned and operated as to ensure that it cannot cause false operation of railway signaling plant.

Railway authorities should be advised of any preliminary planning tests proposed to be carried out in the vicinity of railway running lines. Possible causes of such false operation include the following:

- a) Current from the cathodic protection system interfering with the operation of the track relays of railway track circuits of the direct current type.
- b) Alternating current components in the rectified current of the cathodic protection system interfering with the operation of the track relays of railway track circuits of the alternating current type.
- c) Induction in cable or line wires from the harmonics in the rectified current of the cathodic protection system interfering with remote control transmission associated with signaling installations.

If the railway authorities agree to the bonding of the protected structure to the running rails, or to structures which are themselves connected to the running rails, special precautions may be required to safeguard the railway signaling equipment (see also A.2.6.7).

A.3.6 Interaction at discontinuities in cathodically protected structures

As already indicated in A.2.3.1 and A.2.3.2, if cathodic protection is applied to a pipeline containing a conducting electrolyte, interaction across any discontinuities can cause corrosion of the internal surfaces. Testing to ensure that the pipeline is electrically continuous (see IPS-I-TP-820), and bonding between sections; if necessary, is, therefore, particularly important. Similarly, if isolating joints are inserted in pipes containing weak electrolytes, remedial measures should be taken (see 10.5).

Insertion of isolating joints in pipes containing highly conducting electrolytes is inadvisable.

A.3.7 Jetties and ships: corrosion interaction at sea and river terminals

Corrosion interaction may arise due to cathodic protection of a ship if it is moored alongside an unprotected vessel or jetty, or due to cathodic protection on jetties which may cause interaction while unprotected ships are alongside.

In either case, the interaction may be reduced by bonding the unprotected ship to the protected ship or jetty. This will be effective only if the resistance of the bond is low compared with that of the current path through the water. Bonding is sometimes dispensed with in the case of small vessels, notably tugs, that are alongside a protected jetty for short periods. Fortuitous contact may provide some alleviation.

Bonding is sometimes required for other purposes (see A.4.4).

Interaction can be minimized in designing cathodic protection for jetties, by locating anodes on the landward side or within the peripheral boundary of the outer piling. The bonding of ships moored alongside a cathodically-protected jetty will increase the current required for protection and the installation should be designed accordingly.

A.4 Safety Aspects

A.4.1 Danger of electric shock

A.4.1.1 The current normally used for impressed current cathodic protection is rectified ac, taken from a step-down transformer and a rectifier.

The transformer should comply with the requirements of IPS-M-EL-155. The core of the transformer, unless double-insulated, and all the exposed metalwork should be effectively earthed (see also A.2.5.3).

It is not generally practicable to earth the output circuit of the equipment other than by means of the combined effect of the groundbed or immersed anode and the natural earthing of the structure to be protected. Therefore, unless the transformer is a double-insulated isolating type or is a type having an earthed metallic screen between the windings, or windings on separate limbs of the core, then steps should be taken to ensure that the combined resistance to earth of the groundbed and the protected structures is low enough to permit operation of the protective fuses or switchgear in the event of a fault between the input or high voltage windings of the transformer (i.e. mains voltage) and the dc output of the associated rectifier.

A.4.1.2 Installations on buried structures

In the case of buried groundbeds, attention should be paid to the danger of possible harm to persons and cattle due to the voltage gradient at the surface of the soil. This will depend on the depth and geometry of the groundbed, the soil resistivity and the current flowing into the soil, and should at no point be such that the voltage occurring between the feet of persons or animals having access to the site could be dangerous.

The voltage gradient on the surface of the soil will not, however, be dangerous to persons and animals if,

- a) The dc, output voltage of the cathodic protection rectifier does not exceed 50 V dc.
- b) The anodes and the upper surface of the backfill surrounding the anodes are buried at least 300 mm below ground level, thus ensuring that only proportion of the output voltage appears across the surface of the earth, and,
- c) The leads are fully insulated and protected against mechanical damage between the anode connections and a point well above the surface of the ground.

The danger might be enhanced if, for example, a wire fence on wooden supports passed close to the groundbed. If the wire were earthed at some distance from the groundbed, the voltage between the wire and the soil near the groundbed would be a substantial proportion of the total voltage drop through the soil. These matters should be considered at the design stage, any necessary confirmatory tests being carried out during commissioning.

A similar danger would occur if a wire fence on wooden supports were altered in order to install a groundbed, and a wooden support replaced by a metal support buried close to the groundbed.

A.4.1.3 Installations on immersed structures

When groundbeds are placed in open water, possible dangers to bathers or fish should be considered. The risk is greater in fresh water than in seawater.

There is a possibility of danger from electric shock to divers if they approach to within one to two meters of impressed current anodes which are in operation: this is particularly important when the underwater scrubbing of a ship's hull is in operation. Ships' impressed current systems should be switched off before divers commence submerged work of any kind.

A.4.1.4 Installations for the internal protection of plant

Voltages in excess of 50 V dc. are seldom used for cathodic protection, thus the danger of electric shock would appear to be small, but safety procedures should be adopted that make it impossible for personnel to enter tanks or pipes that normally contain water, whilst the supply to the anodes is switched on.

A.4.2 Fault conditions in electricity power systems in relation to remedial and/or unintentional bonds

There is a possible risk in bonding a cathodic protection system to any metalwork associated with the earthing system of an electricity supply network, whether by intention or not. This is particularly important in the vicinity of high-voltage sub-stations.

Bonds between metalwork associated with an electricity power system (e.g. cable sheaths) and cathodically protected structures, can contribute an element of danger when abnormal conditions occur on the power network. The principal danger arises from the possibility of current flow, through the bonds, to the protected structure, due to either earth-fault conditions or out-of-balance load currents from the system neutral (see also A.3.3.1).

The current, together with the associated voltage rise, may result in electric shock, explosion, fire or overheating and also risk of electrical breakdown of coatings on buried structures. Such hazards should be recognized by the parties installing the bond and any necessary precautions taken to minimize the possible consequences. The rise in temperature of conductors is proportional to i^2t , where i is the fault current and t its duration. Conductors, joints and terminations should be sufficiently robust, and of such construction, as to withstand, without deterioration, the highest value of i^2t expected under fault conditions. For extreme conditions, duplicate bonding is recommended. Precautions should also be taken against danger arising from the high electro-mechanical forces which may accompany short-circuit currents (see A.2.5.3 and also BS 6651 last edition).

It is difficult to ensure that current-limiting resistances comply with the foregoing requirements; their insertion in bonds through which heavy fault current might flow should therefore be avoided as far as possible. If they are used, it is essential that they be carefully designed for the expected conditions.

Bonds and any associated connections should be adequately protected from damage or deterioration.

A.4.3 Hydrogen evolution

A.4.3.1 In impressed current systems, and sometimes with magnesium anodes, excessive polarization can cause evolution of hydrogen on the protected structure. Thus, in situations such as closed tanks where hydrogen can collect, an explosion hazard can arise.

Where hydrogen evolution could produce an explosion hazard, the structure/electrolyte potential should be carefully monitored: hydrogen evolution is not significant at structure/electrolyte potentials less negative than -1.0V with reference to silver/silver chloride for steel in seawater.

A.4.3.2 Special precautions for ships

Hydrogen gas forms an explosive mixture with air and for this reason all protected tanks that contain ballast water or have just been deballasted cannot be regarded as gas-free spaces until tested and found safe. It should be borne in mind that the highest concentrations of hydrogen in a tank will be in the upper part of the tank, i.e. immediately below the deckhead or within the hatch coating. It is essential, therefore, that an escape route to the atmosphere for this gas be ensured at all times.

No dangerous accumulation of gas is likely if the tank hatch lids are in the raised position but if, for any reason, they have to be lowered and fastened, it is essential that the gas be able to find its way through suitable venting pipe. In the event of such a pipe being fitted with a pressure/vacuum valve, this should be set in the 'open' position, giving completely free access to the atmosphere.

During dry-docking it may be necessary, for trim or other reasons, to ballast or partly ballast one or more tanks that are cathodically protected by magnesium. To ensure that hydrogen gas is readily dispersed, the tank lids should be secured in the open position throughout the period the vessel is in dry-dock.

A.4.4 Installation in hazardous atmospheres

A.4.4.1 Explosion hazards (see IPS-E-EL-110)

Cathodic protection can introduce danger in areas in which a flammable mixture of gas, vapor* or dust (i.e. a hazardous atmosphere) may be present which could be ignited by an electric arc or spark.

Typical examples of such installations are tanks, pipelines**, manifolds, jetty piles, floating craft, etc. Incendive sparking might arise, due to cathodic protection, from:

- a) Intentional or unintentional disconnection of bonds across pipeline joints or any other associated equipment under protection or fortuitously bonded to protected equipment.
- b) Intentional or unintentional short-circuit of isolating devices e.g. by tools or break down due to voltage surges on the pipeline induced by lightning or electrical power faults.
- c) Unintentional short-circuits by fortuitous bridging of points of different potential, e.g. by metal scraps, odd lengths of wire, mobile plant.
- d) Connection or disconnection of loading lines to tankers, barges, and rail car gantry structures and associated pipelines.
- e) Disconnection or breakage of cables carrying cathodic protection current.
- f) Unintentional short-circuiting of impressed current anodes when the liquid level is lowered in plant under internal cathodic protection.
- g) Connection or disconnection of instruments employed for measuring and testing of cathodic protection systems.

In locations where any of the above hazards may arise, operating personnel should be suitably instructed and durable warning notices should be authoritatively displayed as appropriate.

It should be noted that the likelihood of incendive sparking may be greater in the case of impressed current systems than with systems using galvanic anodes. However, there is danger if a suspended or supported galvanic anode, or portion of an anode, becomes detached and falls on to a steel member beneath; the risk, however, is not present with zinc anodes.

* See also CP 1003 and the Institute of Petroleum Model Code of safe Practice in the Petroleum Industry.

** See Part VI of the Institute of Petroleum Model Code of safe Practice in the Petroleum Industry. (With special reference to 8.5.5).

A.4.4.2 Measures to avoid the explosion hazard

Cathodic protection systems that are to operate where flammable concentrations of gas or vapor occur should conform to the statutory and other safety regulations applicable to the particular installation and industry concerned, e.g. the Ship Classification Societies have laid down requirements governing the use and inspection of anodes within the tanks of ships classified by them (see Appendix C paragraph C.2.1.2.1), and approval should be obtained in each individual case as appropriate.

The following safety measures should be adopted where applicable:

- a) Flameproof enclosure (see BS 4683: part 2 and CP 1003) of transformer/rectifiers or other apparatus when it is impossible to site it outside the area of risk.
- b) Flameproof enclosure (see BS 4683: part 2 and CP 1003) of resistive bonds.
- c) The provision of a temporary continuity bond across any intended break, before any break is made in protected pipelines or other structures or equipment included in the cathodic protection scheme.

Note:

It is essential that these bonds be securely clamped to each side of the intended break and remain connected until the work is completed and normal continuity restored.

- d) Siting outside the area of risk any isolating devices in above-ground pipelines.

Note:

Where this is not practicable, measures to avoid arcing or sparking, due to the reasons given in A.4.4.1(b) should be adopted. These would include the use of resistive bonds or zinc earth electrodes connected to each side of the insulating device.

- e) Insertion of an isolating device and, if necessary, an encapsulated spark gap (see A.2.5.3.2), in each of the loading lines, at oil terminal jetties, as referred to in A.4.4.1(d).

Note:

This is to ensure that the line is electrically discontinuous as a precaution against the dangers associated with incendive sparking. An independent ship/shore bonding cable does not eliminate the hazard. It is essential that any other cable brought on board is connected and disconnected outside the area of risk, or equivalent measures are taken to avoid incendive sparking upon connection and disconnection, e.g. by the use of appropriate flameproof techniques (see BS 4683: part 2 and CP 1003).

Where the loading line is wholly flexible, the isolating device (flange) should be fitted to the jetty manifold.

Where the line is partly flexible and partly a metal loading boom, the insulating device should be inserted between the flexible hose and the loading boom.

An isolating device should be incorporated in an all-metal flowboom, care always being taken to ensure that the flowbooms are not fortuitously earthed to the ship by tools or loads suspended from the ship's gear.

Similar considerations apply to ship-to-ship transfers if either or both vessels are cathodically protected and certain low flashpoint cargoes are being handled. An isolating device should be fitted at the manifold of one vessel and the line securely earthed to the manifold of the other vessel. Alternatively, electrically discontinuous hoses may be used i.e. hoses specially made with the bonding wire omitted. For tankers at submarine line berths, at least two hoses that are electrically discontinuous should be inserted into the string of flexible hoses, at the end of the rigid line.

These should preferably be the second and third hoses from the tanker manifold. These precautions are not normally considered necessary in the case of single-buoy moorings.

f) If the circumstances envisaged in A.4.4.1(f) could arise, arrangements should be made to ensure that the circuit is automatically or manually isolated when the anodes are not submerged.

g) Protection devices (surge diverters) should be installed to safeguard the rectifier and associated equipment, e.g. instruments, against over-voltages due to lightning or to other external cause (see A.2.5.3, also BS 6651 and BS 7430).

Note:

This applies particularly to rectifiers that are supplied from overhead lines.

h) Double-pole switches should be provided in each dc circuit entering an area in which flammable concentrations of gas or vapor might occur, to ensure that both poles are isolated during maintenance, etc.

A.4.4.3 Chlorine evolution

For an impressed current cathodic protection installation in a marine environment, the anode reactions result in the electrolytic formation of chlorine. Seawater is normally slightly alkaline and the chlorine will form sodium hypochlorite; other side reactions, such as the oxidation of hypochlorite to chlorate and the formation of bromine from bromides are possible. Under stagnant conditions, the chlorine will be evolved as a gas and will presents hazard to inspection and maintenance personnel.

It is sometimes impossible with internal protection of enclosed vessels or plant to drain completely a vessel before entering for maintenance. If it happens that anodes remain energized and immersed, the chlorine level in the remaining water will increase. Disturbing the water, e.g. by walking through it, will release enough chlorine in the restricted air space to cause acute discomfort; the cathodic protection should, therefore, always be switched off before a vessel is entered.

The formation of hypochlorite and gaseous chlorine will be minimized by the incorporation of a system of two level or automatic control into the cathodic protection installation.

APPENDIX B

DESIGN PRINCIPLES OF CATHODIC PROTECTION FOR BURIED PIPELINES

B.1 Impressed Current System

B.1.1 Current-voltage relationships

B.1.1.1 Attenuation

When current is drained from a buried pipeline, the potential of the line to its surroundings is changed and current is picked up from the soil and flows in the pipe toward the drain point. The current flow in the line and the potential change are maximum at the drain point. At any point other than the drain point, the current flow in the pipe is less because of the current picked up between that point and the drain point is less. Likewise, the voltage change is less because of the voltage drop caused by the flow of current in the pipe between that point and the drain point is less. This decrease of voltage and current flow with distance from the drain point is called attenuation. The rate, of attenuation is influenced by pipe resistance, coating conductivity, polarization, length of line, and method of termination (insulating device or metallic connection to other facilities). In the case of bare or poorly coated lines soil resistivity also has a large effect.

B.1.1.2 Attenuation formulas

Formulas have been derived to express the relationship between current and potential along a uniform pipeline when current is drained from a single point. The most commonly used forms of these attenuation formulas are given bellow. These formulas apply specifically to coated lines; they are based on the assumption that the pipe is of uniform section and resistivity, and that coating conductivity is uniform. The effect of soil resistivity and polarization are neglected. The voltage as used in the attenuation formulas for coated lines is the voltage change across the coated line, this is the voltage change between the pipe and adjacent soil and is the significant voltage change in cathodic protection.

The attenuation formulas are sometimes applied to bare lines. In this case soil resistivity is assumed to be uniform and the resistance per unit length of the line to remote earth is usually substituted for the coating resistance. The voltage in the formulas then becomes the voltage change with respect to remote earth. This voltage does not necessarily indicate the adequacy of cathodic protection. In addition, polarization has a profound effect on attenuation in the case of bare lines, and wide variations in soil resistivity further tend to invalidate calculated results. For these reasons, extreme caution should be used in applying the attenuation formulas to bare lines.

B.1.1.3 Calculations

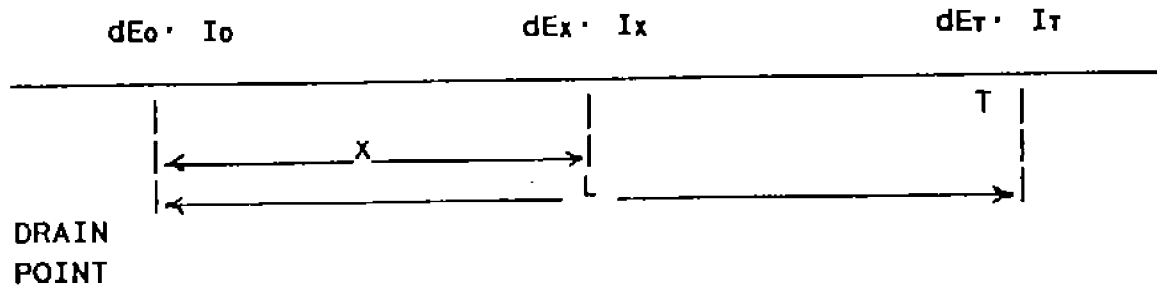
The calculations in this Section are intended to be a guide only. They should not be considered as absolute or the only method of calculation. Cathodic protection design procedures are empirical at best or based on empirically modified theory.

B.1.1.3.1 Symbols

SYMBOL	QUANTITY	UNITS
R_s	Linear pipe resistance	ohms m
R_L	Leakage (coating resistance)	ohms per m
α	Attenuation constant	per kilometer
R_O	Characteristic resistance	ohms
ρ	Soil resistivity	micro-ohm cm
ρ'	Steel resistivity	micro-ohm cm

g	Coating conductivity	micro mhos per m ²
D	Pipe diameter	mm
L	Pipe length	kilometer
t	Pipe wall thickness	mm
a	Pipe cross sectional area	square cm
A	Surface area of pipe	m ² per m
W	Weight of pipe	kg per m
dE _O	Change in potential at drain point	volts
dE _X	Change in potential at point ×	volts
dE _T	Change in potential at end of line	volts
I _O	Current at drain point	amps
I _X	Current at point × on line	amps
I _T	Current at end of line	amps

B.1.1.3.2 Formulas



a) General case

$$dE_X = dE_O \cdot \cosh \alpha X - I_A \cdot R_O \cdot \sinh \alpha X \quad \text{Volts}$$

$$I_X = I_O \cdot \cosh \alpha X - \frac{dE_O}{R_O} \cdot \sinh \alpha X \quad \text{Amps.}$$

Or:

$$dE_O = dE_X \cdot \cosh \alpha X + R_O \cdot I_X \cdot \sinh \alpha X \quad \text{Volts}$$

$$I_A = I_X \cdot \cosh \alpha X - \frac{dE_X}{R_O} \cdot \sinh \alpha X \quad \text{Amps.}$$

b) Finite lines

$$dE_O = dE_T \cosh \alpha L \quad \text{Volts}$$

$$I_O = \frac{dE_T}{R_O} \cdot \sinh \alpha L \quad \text{Amps.}$$

$$dE_X = dE_T \cosh \alpha (L - X) \quad \text{Volts}$$

$$I_X = I_O \frac{\sinh \alpha (L - X)}{\sinh \alpha L} \quad \text{Amps.}$$

c) Infinite lines*

$$\begin{aligned} dE_X &= dE_O e^{-\alpha X} && \text{Volts} \\ I_X &= I_O e^{-\alpha X} && \text{Amps.} \\ I_O &= \frac{dE_O}{\alpha R_L} = \frac{dE_O}{R_O} && \text{Amps.} \\ \ln dE_O &= \ln dE_X + \alpha x \\ \ln I_O &= \ln I_X + \alpha x \end{aligned}$$

d) Linear pipe resistance

$$R_s = \frac{\rho' L}{a}$$

Note:

Steel resistivity varies from 16 to 23 micro -ohm cm.

An average value is 18 micro-ohm cm.

e) Leakage (coating resistance)

$$R_L = \frac{I}{g A L} \text{ (ohms per km) }^*$$

f) Characteristic resistance

$$R_O = \sqrt{R_S \cdot R_L} \text{ ohms}$$

g) Attenuation constant

$$a = \sqrt{\frac{R_S}{R_L}} \text{ per km}$$

$$\alpha = \frac{R_O}{R_L}$$

$$\alpha = \frac{R_S}{R_O} = \frac{R_S I}{2 E_A I}$$

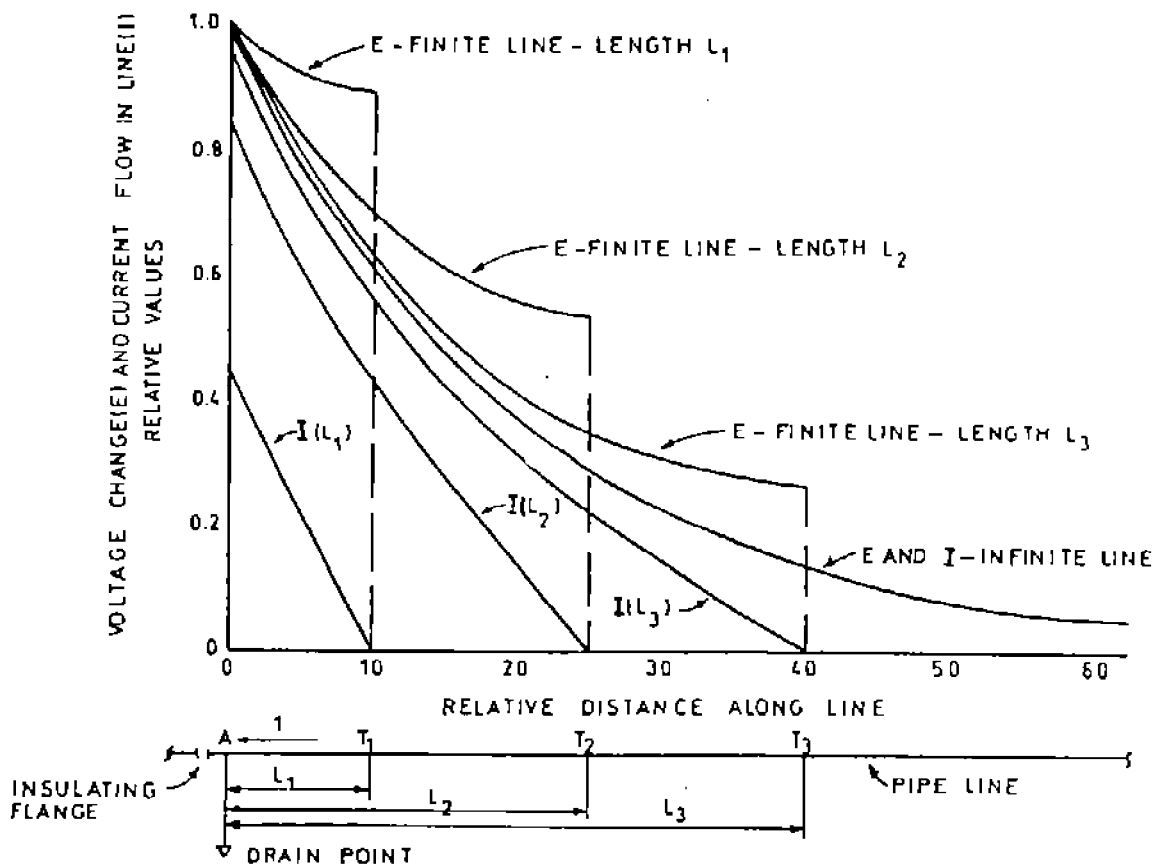
* In almost all cathodic protection systems, there are no infinite lines.

** For design purposes, the coating conductivity of buried, non-fusion bonded epoxy coated landlines may be taken as 2000 micromhos per m². Fusion bonded epoxy coated lines shall be considered to have a coating conductivity of 400 micromhos per m².

B.1.1.4 Single drain point

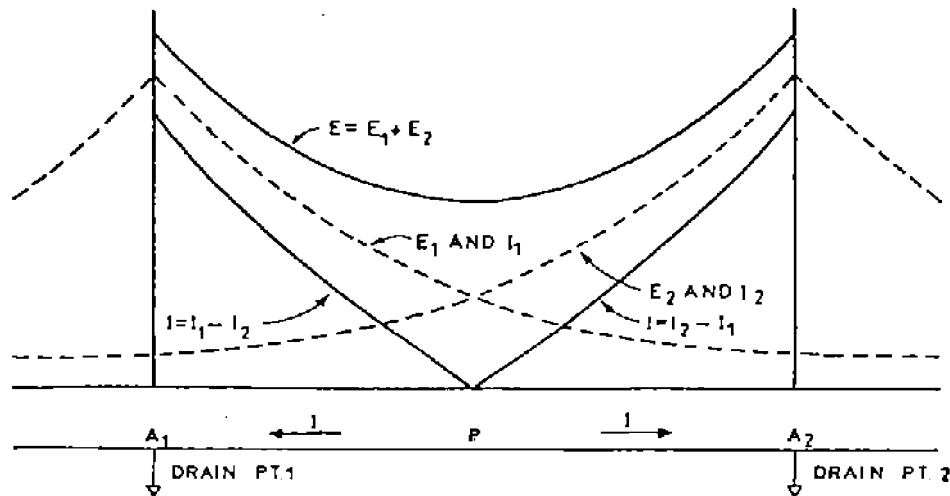
Fig. 16 shows a schematic layout of a pipeline with current drained at a single point at one end, together with typical attenuation curves. If the line is infinitely long, the current flow and voltage change vary exponentially with distance along the line as shown by the curve labeled, "E and I - Infinite Line". If the line terminates in an insulated flange or dead ends, it is called a finite line. Attenuation curves for finite lines of three different lengths, with the voltage at the drain point the same as in the case of the infinite line are also shown in Fig. 16. The current flowing at the far end of a finite line is, of course, zero, and the potential is substantially higher than the potential at the same distance on an infinite line. Length L_1 corresponds to a short finite line; in this case, the current drained is substantially less than that for the infinite line. Length L_3 corresponds to a moderately long finite line; in this case the current drained is nearly as great as the current drained from the infinite line, but the potential at the far end is nearly twice as great as the potential at the corresponding distance on the infinite line.

In the above examples, the current drained at the drain point is equal to the current flowing in the line at the drain point because current flows to the drain point from one direction only. In the usual case, the line extends in both directions from the drain point and current flow to the drain point from both sides. Under these conditions, assuming a symmetrical, uniform system, the total current drained is twice the current flowing in the line at the drain point from either direction.



TYPICAL ATTENUATION CURVES-SINGLE DRAIN POINT

Fig. 16



TYPICAL ATTENUATION CURVES-MULTIPLE DRAIN POINTS
Fig. 17

B.1.1.5 Multiple drain points

When a long pipeline is placed under cathodic protection, it is usually necessary to drain current at numerous points. A portion of a long uniform pipeline with current drained at two points is illustrated in Fig. 17. The attenuation curves for drain points 1 and 2, considering each drain point independently, are shown as dashed curves. These correspond to the infinite line curve of Fig. 16. The potential change at any point between the two drain points, with current drained at both drain points, can be obtained by adding the potential changes produced by the individual current drains; this is shown as the upper solid curve in Fig. 17. Since the currents induced by the two current drains flow in opposite directions between the two drain points, the resultant current flowing in the line at any point between the two drain points is equal to the difference in the currents resulting from the two current drains. At the midpoint P, the two currents are equal and opposite and the resultant current is zero. Since there is no resultant current flow in the line at this point, the current and potential distribution will not be disturbed if the line is cut at this point and an insulating flange is inserted. From this it follows that the resultant current and voltage distribution between a drain point and the electrical midpoint between two drain points is the same as for a finite line of the same length. This can be seen by comparing the curves in Fig. 17 with those in Fig. 16.

B.1.1.6 Effect of coating

The coating on the pipe line has a great effect on the current required to protect the line and the rate of attenuation of current and voltage along the line. With well coated lines, the current requirements are modest and attenuation is slight, and drain points may be spaced at wide intervals. With bare or poorly coated lines, current requirements are large, attenuation is rapid, and drain points must be spaced at close intervals.

B.1.1.7 Point of minimum protection

Since voltage varies with distance along a pipeline due to attenuation, the point of minimum protection (least negative potential) must be adequately protected to assure complete protection of a pipe line. With a uniformly coated line protected from a single drain point, the point of minimum protection will be the end most remote from the drain point. With a multiple-drain-point system, points of minimum protection will exist between drain points. One of the main problems encountered in field teets on pipe lines is to determine the locations of these points of minimum protection. Once these points have been located, it is normally a relatively simple matter to adjust the system (assuming it is adequately designed) to achieve adequate protection at these points and thus complete protection of the line.

B.1.1.8 Bare and poorly coated lines

The above discussion is strictly applicable only to uniformly coated pipelines. This is not always the case in practice; bare lines, lines partly wrapped and partly bare, or coated lines with the quality of the coating varying widely from point to point are frequently encountered. In the case of a coated line with variable coating quality, the line will pick up relatively more current from the soil in the areas of poor coating. This will result in larger potential drops in the soil adjacent to the poorly coated sections, and the pipe-to-soil potentials in these areas will be lower (the line will be less negative with respect to adjacent soil) than in nearby areas of good coating. Where lines are partly coated and partly bare, this effect is even more pronounced; the pipe-to-soil potential at a bare area will normally be much lower than that at an adjacent coated area, even though the coated area may be more remote from the drain point.

Where a bare pipeline is buried in soil of uniform resistivity, the potential along the line will vary in the same manner as for a uniformly coated line. However, if a bare line passes through soil where the resistivity varies widely from point to point, current pick-up will be largely concentrated in the areas of low soil resistivity with resulting large potential drops in the soil and low pipe-to-soil potentials in these areas.

B.1.1.9 Voltage limitations

B.1.1.9.1 Coating deterioration

An excessive potential applied to a coated line has a detrimental effect on the coating; the bond between the coating and the pipe may be destroyed and the coating conductance will increase many times. The rate of coating deterioration increases rapidly as the potential is increased. For this reason, the maximum potential applied to a coated pipe line should not exceed approximately 2.0 volts (off) to copper/copper sulfate electrode, or the potential change should not exceed about 1.0 to 1.5 volts (off) with respect to the initial potential (see Table 3). The lower values should be observed whenever possible. The minimum potential change should be 0.3 volt with respect to initial potential.

B.1.1.9.2 Maximum rectifier spacing

The potential and current at the drain point required to protect a finite line (or the section between minimum points in the case of a multiple-drain-point system) increase rapidly as the length is increased. Since the potential change at the drain point should not exceed approximately 1.0 to 1.5 volts, this limits the length of coated line that can be protected from a single drain point and thus determines the maximum spacing between units in a multiple-drain-point system (see B.1.1.3.2 Formulas).

Spacings between drain points (or rectifiers) depend on pipeline coating and diameter of pipeline as well as soil resistivities of the terrain.

It is possible to protect 75 kilometer of well coated large diameter cross country pipeline from one station; whereas it is not practical to protect such distance of small diameter pipe from a single station.

B.1.1.9.3 Depolarization effect

Any depolarizing parameter will result in increasing current requirement for cathodic protection. The most effective mechanism for depolarization and removal of hydrogen polarization film is sulfate reducing bacteria. The bacteria is active when conditions are anaerobic. Under this condition, the active sulfate reducing bacteria reduces sulfates to sulfide and removes hydrogen polarization film by oxidation and forming water.

By maintaining the minimum potential value at -0.95 (with reference to copper/copper sulfate electrode), soil pH will be kept around 9 and sulfate reducing bacteria would be rendered inactive. Therefore minimum potential value of -0.95 is essential to eliminate depolarizing effect of sulfate reducing bacteria in soils where this bacteria is present.

B.1.1.9.4 Bare lines

The maximum voltage that can be applied to a bare line is limited only by economics. An excessive potential will not damage bare steel pipe, but it will result in an excessive current pick-up and inefficient utilization of the applied power.

B.1.2 Current requirements

For pipeline design requirements shall be based on the following minimum current density value for total coated and uncoated pipeline surface:

<u>PIPELINE SURFACE</u>	<u>CURRENT DENSITY (ma/sq.m)</u>
Uncoated	20.0
Tape or coal tar/bitumen	1.25
Fusion bonded epoxy or 3-layer polyethylene	0.25

B.1.2.2 Two 32 pound magnesium anodes shall be installed on all buried valves, on the pipeline at gas reservoir and pipeline anchor locations.

B.1.2.3 An additional current capacity of 50 amperes shall be provided at plant terminations where insulating devices are bonded to control interference.

B.1.2.4 Measurements (see IPS-C-TP-820)**B.1.2.4.1 Coated lines**

On existing pipelines, it is desirable to make field tests to determine the current required for cathodic protection. For coated pipelines, the usual procedure is to conduct preliminary tests to determine the coating conductivity of representative sections of the line. From these tests, it is possible to calculate or to determine from the charts the approximate current required for protection, as discussed in the sub-section on calculations (see B.1.4). After this preliminary determination of current requirements is made, the type of system to be installed impressed current or galvanic anode can be selected. If a galvanic anode system is to be installed, no further tests are required until installation of the anodes is commenced.

If an impressed current system is to be installed, the maximum distance between drain points (limited by voltage across the coating) can be determined once the coating conductivity is known. This is also covered in the sub-section on calculations (B.1.4). The actual drain point spacing will be influenced by several other factors; it will normally be considerably less than the theoretical maximum spacing.

B.1.2.4.2 Bare lines

In the case of bare lines, the initial drain tests will normally consist of determining by direct field measurement the distance that can be protected with a given current drain. In these tests, it should be remembered that, assuming uniform conditions along the pipeline, the potential change at the mid-point between two rectifiers draining equal currents will be twice the voltage change produced by one rectifier alone. Consequently, if tests are conducted using a single drain point, the distance each rectifier can protect if multiple units are installed will be the distance at which one-half the desired final voltage can be obtained during drain tests with a single drain point.

B.1.3 Sizing of rectifiers

After rectifier sites have been selected and the anodes and test leads have been installed, it is usually desirable to conduct drain tests to determine by direct measurement the current and voltage required at each drain point. These data determine the output rating of the rectifier at each location. The tests are made with batteries or welding generators as sources of direct current, utilizing the permanent anodes and permanent test leads.

B.1.4 Calculations

B.1.4.1 If the approximate coatings conductivity is known, the current required to protect a coated line and the maximum distance between drain points may be estimated using the "Attenuation" formulas (B.1.1.3.2).

B.1.4.2 Circuit resistance

The total resistance in the cathodic protection circuit is as follows:

$$R_T = R_C + R_G + R_L + R_S$$

Where:

- R_T is total circuit resistance at rectifier terminal.
- R_C is cable resistance, both positive and negative cables.
- R_G is resistance of anode bed to earth.
- R_L is resistance of coating (see e of B.1.1.3.2).
- R_S is resistance of structure to be protected (may be ignored).

B.1.4.2.1 Cable resistance

Cable resistance is that from the pipeline via the power source to the first anode of the anode bed, plus effective resistance of the header cable along the line of anodes.

It is practical to use the resistance of one half of the ground bed header cable as the effective header cable resistance.

Table B.1: Includes data on resistance of copper conductors in the sizes commonly used in pipeline corrosion engineering work.

Table B.2: Gives the correction factors for conductor resistance at temperatures other than 25°C.

Table B.3: Provides some design data on cables.

**TABLE B.1
RESISTANCE OF COPPER CONDUCTORS**

GENERAL USE	RESISTANCE OF STRANDED COPPER CONDUCTORS IN OHMS PER METER TIMES 10 ⁻³ AT 25°C		
	Conductor size mm ²	(AWG)	
Impressed Current	107.20 mm ²	(4.0)	0.16695
	85.03 mm ²	(3.0)	0.21058
Ground-bed	67.43 mm ²	(2.0)	0.26601
	53.48 mm ²	(1.0)	0.33456
	42.41 mm ²	(1)	0.42312
	33.63 mm ²	(2)	0.53136
	21.15 mm ²	(4)	0.84952
Galvanic anode Installations	13.30 mm ²	(6)	1.35136
	21.15 mm ²	(4)	0.84952
Pipeline test points	16.77 mm ²	(5)	1.07140
	10.55 mm ²	(7)	1.70361
Instrument Test Leads	1.31 mm ²	(16)	13.71
	0.823 mm ²	(18)	21.84
		(20)	34.77
		(22)	55.76

TABLE B.2 CORRECTION FACTORS FOR OTHER TEMPERATURES FOLLOW

TEMPERATURE C = F		MULTIPLY RESISTANCE AT 25°C BY:
-10	14	0.862
-5	23	0.882
0	32	0.901
5	41	0.921
10	50	0.941
15	59	0.961
20	68	0.980
30	86	1.020
35	95	1.040
40	104	1.059

B.1.4.2.2 Anode to electrolyte resistance calculations

B.1.4.2.2.1 Single cylindrical anode (H.B. Dwight)

The following formulas give the anode to earth resistance of a single cylindrical anode:

$$R_v = \frac{\rho}{2\pi L} \left(\ln \frac{8L}{d} - 1 \right)$$

$$R_h = \frac{\rho}{2\pi L} \left(\ln \frac{4L^2 + 4L^p \overline{S^2 + L^2}}{dS} + \frac{S}{L} \sqrt{\frac{S^2 + L^2}{L}} - 1 \right)$$

- R_v = resistance to earth of a single vertical anode (ohms).
 R_h = resistance to earth of a single horizontal anode (ohms).
 L = Length of anode including backfill (cm).
 d = Diameter of anode including backfill (cm).
 ρ = Electrolyte resistivity (ohm-cm).
 S = Twice the depth of anode (cm).

For a single vertical anode, the following simplified expression can be used:

$$R_v = \frac{\rho K}{L/d}$$

Where:

- R_v = Resistance to earth of a single vertical anode (ohms).
 ρ = Effective soil resistivity (ohm-cm).
 L = Length of anode (cm).
 K = Shape function, representing ratio of anode Length/Anode diameter (from Table B.4).
 L/d = Ratio of length to diameter of anode.

TABLE B.3 - CABLE DESIGN DATA

Copper conductor	Number of strands	Diameter of strands		Cross sectional area of conductor (calculated)		Single conductor weight per km run	Single conductor resistance per metre run at 20 °C	Typical DC current ratings (conductor temp. max 70 °C)
metric		inch	mm	sq in	sq mm	kg	microhm	amp
2.5	1		1.78		2.49	22.2	7280	18
	1	0.0808		0.00513	3.31		5315	20
4.0	7		0.85		3.972	36.1	4610	24
	1	0.1019		0.00816	5.26		3340	30
6.0	7		1.04		5.95	54.0	3080	31
	1	0.1285		0.013	8.37		2101	40
10	7		1.35		10.02	90.8	1830	42
	7	0.0612		0.0206	13.3		1345	55
16	7		1.70		15.89	145	1150	56
	7	0.0772		0.033	21.14		850	70
25	7		2.14		25.18	229	727	73
	7	0.0867		0.041	26.66		673	80
	7	0.0974		0.052	33.65		532	95
35	19		1.53		34.93	317	524	90
	19	0.0664		0.066	42.45		423	110
50	19		1.78		47.28	429	387	145
	19	0.0745		0.083	53.43		335	125
	19	0.0837		0.1045	67.45		266	145
70	19		2.14		68.34	620	268	185
	19	0.0940		0.132	85.07		211	165
95	19		2.52		94.76	860	193	230
	19	0.1055		0.166	107.16		167	195
120	19		2.03		119.75	1086	153	260
	37	0.0822		0.196	126.68		141.4	270
150	37		2.25		147.11	1334	124.0	355
	37	0.0900		0.235	151.86		118.1	300
	37	0.0973		0.275	177.50		101.1	325
185	37		2.52		184.54	1673	99.1	405
	37	0.1040		0.314	202.78		88.6	360
240	61		2.25		242.54	2199	75.4	480
	37	0.1162		0.392	253.15		70.9	405
300	61		2.52		304.2	2759	60.1	560
	61	0.0992		0.471	304.2		59.1	455
	61	0.1071		0.550	354.5		50.5	490
	61	0.1109		0.589	380.1		47.2	500
400	61		2.85		389.1	3528	47.0	680
	61	0.1145		0.628	405.2		44.3	515
	61	0.1215		0.709	456.3		39.4	555
500	61		3.20		490.6	4448	36.6	800
	61	0.1280		0.785	506.4		35.4	585
630	127		2.52		633.4	5744	28.3	910

Note:

Typical current ratings are given as a guide only-always check manufacturer's rating for the particular site operating conditions, including all relevant derating factors.

TABLE B.4 - THE SHAPE FUNCTION

L/D	K
5	0.0140
6	0.0150
7	0.0158
8	0.0165
9	0.0171
10	0.0177
12	0.0186
14	0.0194
16	0.0201
18	0.0207
20	0.0213
25	0.0224
30	0.0234
35	0.0242
40	0.0249
45	0.0255
50	0.0261
55	0.0266
60	0.0270

B.1.4.2.2.2 Single row vertical anode group

The total anode to earth resistance of a group of vertical anodes in parallel and equally spaced in one row is given by:

$$R_n = \frac{I}{n} R_v + \frac{\rho}{S} \rho'$$

Where:

- R_n = Total anode to earth resistance of vertical anodes in parallel (ohms).
- R_v = Anode to earth resistance of a single vertical anode, from B.1.4.2.2.1 (ohms).
- n = Number of vertical anodes in parallel.
- ρ = Soil resistivity, measured with pin spacing equal to S. (ohm-cm).
- ρ' = Paralleling factor, from Table 5.B.
- S = Spacing between adjacent anodes (cm).

TABLE B.5 PARALLELING FACTOR

n	ρ'
2	0.00261
3	0.00289
4	0.00283
5	0.00268
6	0.00252
7	0.00237
8	0.00224
9	0.00212
10	0.00201
12	0.00182
14	0.00168
16	0.00155
18	0.00145
20	0.00135
22	0.00128
24	0.00121
26	0.00114
28	0.00109
30	0.00104

B.1.4.2.2.3 More than one row vertical anode group

An anode group composed of two or more rows of vertical anodes, separated by a distance substantially larger than that between the anodes within a single row, has a total resistance approximately equal to the total parallel resistance of all the rows. The usual formula for paralleling resistance is used.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

B.1.4.2.2.4 Vertical and horizontal anode groups-simplified

If anodes are assumed to be installed vertically (3 to 5 cm diameter and 3 m long) or horizontally (0.1m², 3m long and 1.8m deep) the following two simplified formulas may be used:

$$R_v = \frac{\rho F}{537} \quad R_h = \frac{\rho F}{483}$$

- R_v = Anode to earth resistance any number of vertical anodes (ohms).
 R_h = Anode to earth resistance, any number of horizontal anodes (ohms).
 ρ = Effective soil resistivity (ohm-cm).
 F = Adjusting Factor for group of anodes, from Table B.6.

Note:

For $n = 1$, $F = 1.0$.

TABLE B.6 - ADJUSTING FACTORS FOR PARALLEL ANODES

No. OF ANODES IN PARALLEL	ADJUSTING FACTORS		ANODE SPACING IN METERS (FEET)		
	1.5 m (5')	3 m (10')	4.5 m (15')	6 m (20')	7.5 m (25')
2	0.652	0.576	0.551	0.538	0.530
3	0.586	0.460	0.418	0.397	0.384
4	0.520	0.385	0.340	0.318	0.304
5	0.466	0.333	0.289	0.267	0.253
6	0.423	0.295	0.252	0.231	0.218
7	0.387	0.265	0.224	0.204	0.192
8	0.361	0.243	0.204	0.184	0.172
9	0.332	0.222	0.185	0.166	0.155
10	0.311	0.205	0.170	0.153	0.142
11	0.292	0.192	0.158	0.141	0.131
12	0.276	0.180	0.143	0.132	0.122
13	0.262	0.169	0.139	0.123	0.114
14	0.249	0.160	0.131	0.116	0.107
15	0.238	0.152	0.124	0.109	0.101
16	0.226	0.144	0.117	0.103	0.095
17	0.218	0.138	0.112	0.099	0.091
18	0.209	0.132	0.107	0.094	0.086
19	0.202	0.127	0.102	0.090	0.082
20	0.194	0.122	0.098	0.086	0.079
22	0.182	0.114	0.091	0.079	0.073
24	0.171	0.106	0.085	0.074	0.067
26	0.161	0.100	0.079	0.069	0.063
28	0.152	0.094	0.075	0.065	0.059
30	0.145	0.089	0.070	0.061	0.056

B.1.4.3 Rectifier choice

Having determined the current requirement and circuit resistance (B.1.4.2), the necessary driving voltage can be calculated using the ohm's law, then the proper rectifier size will be chosen.

B.2 Galvanic Anodes System

B.2.1 Symbols

SYMBOL	QUANTITY	UNIT
I_a	Anode Current Output	milliamperes
R_a	Anode Resistance to Earth	ohms
R_c	Cathode resistance to Earth	ohms
E_a	Open-Circuit Potential between Anode and Reference Electrode	Volts
E_c	Open-Circuit Potential between Cathode and Reference Electrode	Volts
E_o	Open-circuit Potential between Anode and Cathode = $E_a - E_c$	Volts
E_{cu}	Closed Circuit Potential between Cathode and Reference Electrode	Volts
E_d	Driving voltage between Anode and Cathode for Protected System = $E_a - E_{cu}$	Volts
W	Weight per Anode	Kg
n	Number of anodes	
Q	Weight of anode Material consumed per unit Current	Kg per amp. year
$I_{c.d.}$	Design current density for protection	ma.per m ²
Y	Design life of system	years
L	Length of Anode	cm
D	Diameter of anode	cm
W_m	Weight of anode Material required	kg
A	Surface area of structure to be Protected	m ²
ρ	Soil resistivity	ohm-cm

B.2.2 Current output

$$I_a = \frac{E_o}{R_a + R_c} = \frac{E_a - E_c}{R_a + R_c} \text{milliamps}$$

For Negligible Cathode resistance:

$$I_a = \frac{E_d}{R_a} = \frac{E_a - E_{cu}}{R_a} \text{milliamps}$$

Where:

$$R_a = \frac{Q}{2\pi L} \ln \frac{8L}{D}$$

B.2.3 Anode life*

For zinc anodes:

$$Life = \frac{71.4 W}{I_a} \text{m years}$$

* Assumes anode will be replaced when it is 85% dissolved.

For magnesium anodes

$$Life = \frac{108.7 W_m}{I_a} \text{ years}$$

B.2.4 Weight of anode material required

$$W_m = \frac{A \cdot I_{cd}}{1000} \cdot Q \cdot Y, \text{ kg}$$

Where:

I_{cd} = Required current density (ma/m²).
 Y = Design life in years.

B.2.5 Number of anode requires

$$n = \frac{W_m}{\text{Weight of individual anode}}$$

APPENDIX C

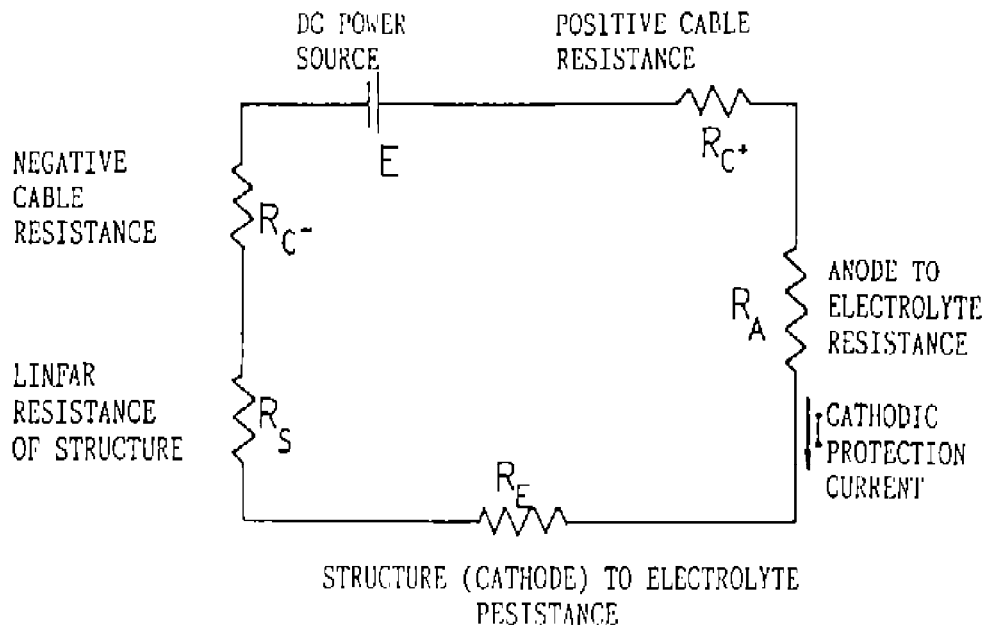
DESIGN PRINCIPLE OF CATHODIC PROTECTION FOR MARINE STRUCTURES

C.1 Design Calculations

The calculations in this Appendix are intended to be guide to the design engineer. They should not be considered as absolute or the only method of calculation. Cathodic Protection design procedures are empirical, or at best, based upon empirically modified theory.

C.1.1 Impressed current systems

C.1.1.1 Impressed current cathodic protection circuits may be represented by the following simplified equivalent circuit:



In order to size the system, it is first necessary to know the current to be impressed on the structure to achieve cathodic protection. The requirements are detailed in paragraph 13.2.10 for different environments. In determining the total current required, all metal surfaces submerged in the electrolyte at mean high water shall be included in the calculation:

$$\text{Total current (Amps)} = \frac{\text{Surface area (m}^2\text{)} \times \text{milliamperes per square meter}}{1000}$$

Having determined the total current requirement, the individual elements in the total load resistance are then adjusted to match the total dc output of the available power source.

From the above diagram, it will be seen that to establish the total circuit resistance, 5 resistances in series have to be considered as follows:

$R_{c+} + R_{c-}$: The resistance of the positive and negative cables will be dependent on the length and cross sectional area of the conductor.

R_E : The cathode to electrolyte resistance may be calculated using ohms law:

$$R = \frac{E}{I}$$

Where:

E is the change of the structure-to-electrolyte potential to achieve cathodic protection (usually 1/3 to 1 Volt) and I is the total current requirement in amperes.

R_A : The anode-to-electrolyte resistance will be dependent on the shape, number, and spacing of the anodes used, and the electrolyte resistivity. Design calculations are given below.

R_S : The resistance of structures such as platforms may be ignored. In the case of pipelines and piers, where length is extensive in comparison to cross-section or where continuity bonds are installed, this factor should be evaluated.

Where a structure such as sheet piling or pier-approach piling has been made electrically continuous by special bonding, the resistance of these bonds must be included in the resistance of the structure.

The following formulas are offered to assist in estimating the anode-to-electrolyte resistance:

C.1.1.2 Single cylindrical vertical anode (H.B.DWIGHT)

The anode-to-electrolyte resistance, R_A , of a single vertical anode, mounted at the surface, is given by:

$$R_A = \frac{\rho h}{2L} \ln \frac{8L}{D}$$

Where:

- R_A = Anode-to-electrolyte resistance of a single vertical anode to remote reference (ohms).
- ρ = Electrolyte resistivity in (ohm-cm). (for sea water is 15 ohm-cm)
- L = Length of anode in (cm) (including backfill, if used).
- D = Diameter of anode in cm. (including backfill, if used).

C.1.1.3 Group of vertical anodes equally spaced in straight line

For a multiple anode system where n anodes are spaced at s cm and connected in parallel, the total resistance to electrolyte of the array, R_n , is given by:

$$R_n = \frac{1}{n} R_A + \frac{\rho}{\pi s} \left(\frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \dots + \frac{1}{n} \right)$$

Where:

- R_n = Total resistance in ohm.
- n = Number of anodes in parallel.
- R_A = Resistance of a single vertical anode (see C.1.1.2).
- ρ = Electrolyte resistivity in ohm-cm.
- s = Spacing between anodes in cm.

The above calculations are applicable generally for anodes in sea water or soil. For square sectional, anodes use equivalent diameter.

C.1.1.4 Vertical anodes surrounded in (coke) carbonaceous backfill

For design purposes, the diameter and length of the column of backfill, instead of the anode dimensions, apply to the calculations in C.1.1.2 and C.1.1.3.

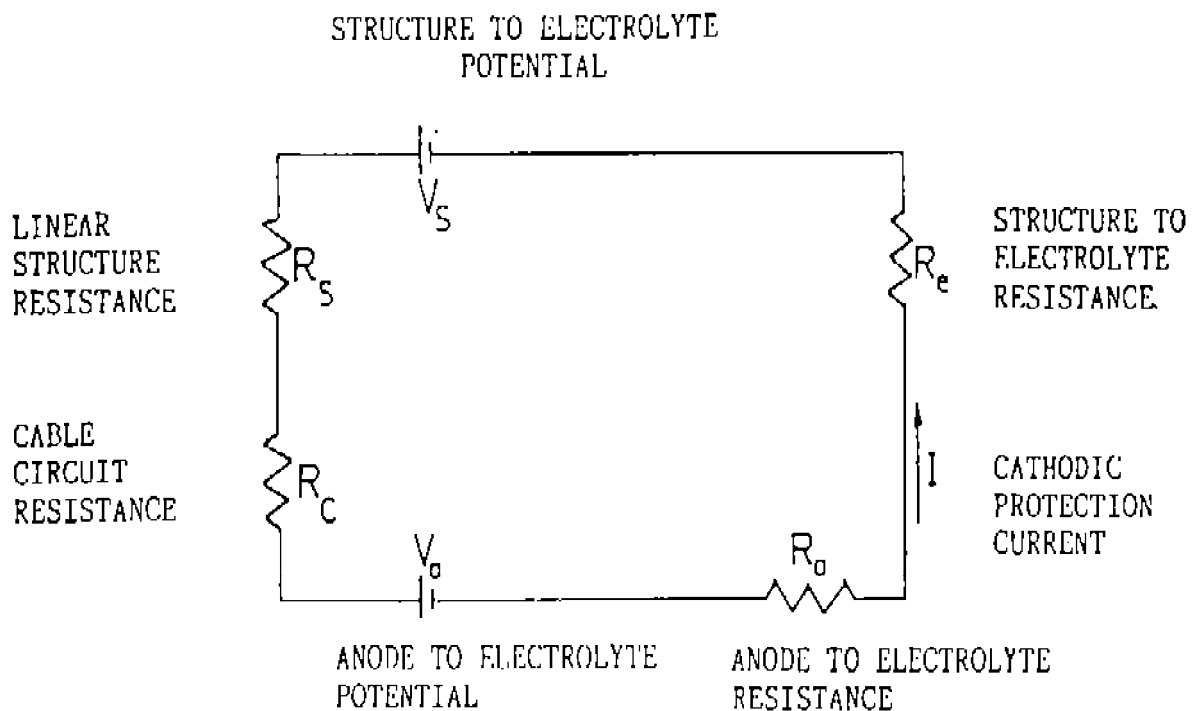
C.1.1.5 Anodes laid horizontally in free flowing sea water

The calculations in C.1.1.2 and C.1.1.3 apply, provided the depth of immersion is greater than one anode length. All other cases of horizontally laid anodes are dealt with in this Engineering Standard for cathodic protection of land systems.

C.1.2 Galvanic Anode Systems

C.1.2.1 Equivalent circuit

A galvanic cathodic protection circuit may be represented by the following simplified diagram:



Although the diagram shows two voltage cells, one at the anode interface and one at the cathode interface, each are in fact half cells.

The same resistance elements will exist as for the impressed current system; however, galvanic anodes are usually attached close to the cathode with consequent low resistance connections so that both structure and cable circuit resistance can usually be ignored. Anode-to-electrolyte resistance is usually large in comparison to structure-to-electrolyte resistance and becomes the governing factor in galvanic anode design.

The anode-to-electrolyte resistance will be dependent on electrolyte resistivity and anode size and shape. The cathod-to-electrolyte resistance, however, will increase as the cathodic reaction proceeds, and its potential will tend to approach that of the anode. With this increase in circuit resistance and reduction in potential difference between the cathode and anode, the current output from the anode will decrease, and subject to its efficiency, its life will be extended. This explains why the number of galvanic anodes can be increased without resulting in overprotection.

The outputs of galvanic anodes shall be calculated on a basis that when protected, the structure-to-electrolyte potential is not less than -0.8 Volts, approaching -0.9 Volts referred to Ag/AgCl.

C.1.2.2 Anode output formula

When the steel is polarized to protective level, I_a is given by:

$$I_a = \frac{E_d}{R_a} = \frac{E_a - E_{cu}}{R_a} \text{ amperes}$$

In these formulas, the symbols shown are as follows:

- I_a : Anode Current Output (amps).
- R_a : Anode Resistance to Electrolyte (ohms).
- E_a : Open-circuit potential, Anode to Electrolyte (Reference Electrode) (Volts).
- E_{cu} : Structure-to-Electrolyte potential when fully protected (Volts)
- E_d : Driving voltage between Anode and protected Structure
(volts) = $E_a - E_{cu} = V_S + V_A$
(from Diagram)

Note:

That E_a , open circuit potential between different types of anodes and electrolyte (Cu-CuSO₄ reference electrode) is nominally as follows:

Galvalum III*	- 1.05V
Zinc	- 1.05V
Magnesium	- 1.50V
Galvomag*	- 1.70V

C.1.2.2.1 Determination of R_a (anode resistance to electrolyte)

For a single anode freely suspended in sea water remote from the cathode, the formula applies (see C.1.1.2).

$$R_a = \frac{\rho}{2\pi L} \ln \frac{4L}{r} \pm 1$$

In the case of an anode fastened directly to the structure in sea water:

$$R_a = \frac{1.1}{L + 0.8W + 0.8D}$$

Where:

L, W and D are the length, width and depth of the anode in cm.

For bracelet anodes, the anode resistance R_a can be calculated from the following formula:**

$$R_a = \frac{0.315 \rho}{\sqrt{A_e}} \text{ ohms}$$

Where:

- ρ = Resistivity of Sea water in ohm-cm.
- A_e = The exposed surface area of the anode in cm².
- R_a = The anode resistance in ohm.

* Manufacturing name for special aluminum alloy anode.

** Mc, coy,s formula, from corrosion and protection of offshore steel structures. Final report NTNF-Project B0930.5116 Norges Teknisk Naturrviten Skapelige Forskningsrad, Os10.

In brakish water the resistivity of the water can increase to several 1000 ohm-cm (compared with open seawater resistivities of 15-35 ohm-cm).

Anode current outputs in brakish water will therefore be reduced considerably.

For plate anodes (Flush mounted Hull or Bracelet anodes)

$$R_a = \frac{\rho}{25} \text{ ohm} *$$

$$S = \frac{a+b}{2} \text{ i.e. the mean of the anode sides and } b < 2a$$

Where:

a = length of anode in cm.

b = width of anode in cm.

alternatively:

$$R_a = \frac{\rho}{0.58A^{0.727}} \text{ ohm}$$

Modified peterson formula:

A = Exposed surface area of anode (cm²)

C.1.2.2.2 The number of anodes N, required should satisfy both of the following:

$$a) N = \frac{I_r}{I_a}$$

$$b) N = \frac{W_r}{W_a}$$

Where:

I_r = Total current, required in amps.

I_a = Current output of anode, in amps.

W_r = Net weight of anodes material, in kg.

W_a = Net weight of individual anode, in kg.

$$W_r = \frac{I_r Y 8760}{C U}$$

Y = Life of structure, in years.

C = Practical electrochemical capacity of the alloy Ampere.hour/kg.

U = Utilization factor, i.e. proportion of net weight consumed at end of anode life. For fully supported tubular inserts $U = 0.9$.

In order to optimize the performance and efficiency of the anodes the values for (a) and (b) should be similar.

C.1.2.2.3 It is to be shown by appropriate calculations that the system is capable of polarizing the structure initially and also when the anodes are consumed to their design utilization factor.

* Lloyd's

C.1.2.2.4 It should be assumed that at the end of its life, the anode length has been reduced by 10 percent and that the remaining material is evenly distributed over the steel insert.

C.1.2.2.5 Pipelines and attenuation of potential

Calculations to determine the current demand and maximum pipe length protectable from a single impressed current cathodic protection station for long pipeline are dealt with in Appendix B.

C.2 Cathodic Protection of Ships (see also Section 6 of BS 7361, Part 1)

C.2.1 Galvanic anode system

C.2.1.1 Sacrificial anode materials

There are three materials currently used for the sacrificial cathodic protection of ships internal and external surfaces. These are zinc, aluminum and magnesium alloyed with small percentages of other elements to ensure adequate performance. Zinc and aluminum alloy materials are used for protection in sea water and the magnesium is used in-fresh water condition, for fresh water tanks and other specialized purposes.

C.2.1.2 The use of sacrificial anodes for internal cathodic protection

In 1962, after fairly extensive trials, the Classification Societies amended their rules to permit up to ten percent reduction in scantlings, of bulkhead plating, stiffeners and certain internal girders and webs, provided an approved system of corrosion control was fitted. A further amendment to the rules in 1964 allowed a five percent reduction in the thickness of the main longitudinal strength members.

An approved system of corrosion control can be the use of coatings, anodes or a combination of both. Listed below are the most widely used systems:

In cargo, cargo/ballast and ballast only tanks all surfaces are to be coated with an approved corrosion control coating.

In cargo/ballast and ballast only tanks the steelwork in the ullage space, with a minimum of the top 1.5 meters, is to be protected with an approved coating (see IPS-E-TP-100) and the remainder of the tank by anodes, either zinc, aluminum or magnesium, the latter two being subject to the restrictions marked* below under summary of Classification Society Rules. (See C.2.1.2.1)

A selective system using defined ballasting conditions applies only to ships intended for the transport of crude oil, using a defined ballasting condition, and is as shown in the following Table:

TANK	COATING	CATHODIC PROTECTION
Ballast only tanks	All surfaces	Anodes below normal ballast level plus coating of all surfaces above ballast level (see Note)
Cargo oil/ballast tanks	All surfaces above normal ballast or cargo level (see Note) and the upper surfaces of all horizontal members in the remainder of the tank. Also the tank bottom, longitudinals frames and girders up to a level of the top of the longitudinals	Anodes below normal ballast or cargo level plus coating of all surfaces above non ballast level (see Note)
Cargo oil only	All surfaces above the normal liquid level (see Note)	

Note:

The minimum coating is to be all the surfaces in the top 1.5 meter of the tank.

C.2.1.2.1 Summary of classification society rules concerning the use of anodes for internal cathodic protection:

In 1971 an IACS working party on tanker safety agreed certain unified interpretations relating to cathodic protection as follows:

Impressed current systems are not permitted in oil cargo tanks.

* Magnesium or magnesium alloy anodes are not permitted in oil cargo tanks or tanks adjacent to oil cargo tanks.

* Aluminum anodes are only permitted in cargo tanks of tankers where the potential energy does not exceed 28 kg m (200 ft lb). The height of the anode is to be measured from the bottom of the tank to the center of the anode and its weight is to be taken as the weight of the anode as fitted (including the fitting devices). However, where aluminum anodes are located on horizontal surfaces such as bulkhead girders and stringers not less than one meter wide and fitted with an upstanding flange or face flat projecting not less than 75 mm above the horizontal surface, the height of the anode may be measured from this surface. Aluminum anodes are not to be located under tank hatches or Butterworth openings in order to avoid any metal parts falling on the fitted anodes. Aluminum anodes containing magnesium shall not be used in cargo tanks.

There is no restriction on the positioning of zinc anodes but it is recommended practice to ensure the potential energy does not exceed 540 Kg m.

The anodes should have steel cores and these should sufficiently rigid to avoid resonance in the anode support and be designed so that they retain the anode even when it is wasted.

The steel inserts are to be attached to the structure by means of a continuous weld of adequate section. Alternatively they may be attached to separate supports by bolting, provided a minimum of two bolts with lock nuts are used. However, approved mechanical means of clamping will be accepted.

The supports at each end of an anode should not be attached to separate items which are likely to move independently.

When anode inserts or supports are welded to the structure, they should be arranged so that the welds are clear of high stress areas.

C.2.1.2.2 The application of sacrificial anodes for internal cathodic protection where reduced scantlings are applied

Although the procedure below should be followed in the design of any anode system, the effectiveness of such a system both in terms of anode life and corrosion control, can only be ensured by regular inspection.

System life should be for not less than four years using an estimated ballast factor. Provision should be made for additional anode consumption if it is expected that residual ballast water will be left in the bottom of the tank if ballast voyages are expected to be for less than five days, the recommended current densities should be increased by twenty per cent.

The resistivity of the ballast water is assumed to be 25 ohms cm. If brackish water of higher resistivity is expected to be used, the system should be designed accordingly.

The top 1.5 meters of the tank must be coated in order to give optimum protection. In peak and double bottom tanks where tanks can be pressed up, coatings are not required.

CURRENT DENSITIES	
Cargo/clean ballast tanks	86 mA/m ²
Ballast only and ballast white oil cargo tanks	108 mA/m ²
Upper wing tanks	120 mA/m ²
Forward and after peak tanks	108 mA/m ²
Coated surfaces	5 mA/m ²
Lower wing tanks	86 mA/m ²
Double bottom tanks, ballast only	86 mA/m ²
Cargo/dirty ballast tanks	Depend on trade

In large VLCC'S with permanent tank washing machines, the degree of protection given by the residual oil film is virtually non-existent and an increase in the current density to 120 mA/m² in cargo/clean ballast tanks is recommended.

For the long term protection of coated surfaces, adequate allowances must be made for coating breakdown. The above minimum recommended figure of 5mA/m² should be increased in proportion to the anticipated coating breakdown.

C.2.1.2.3 The type and number of anodes required

The total current required is:

$$\text{Current (amperes)} = \frac{\text{Protected area (m}^2\text{)} \times \text{current density (mA/m}^2\text{)}}{1000}$$

The total weight of anode material required is:

$$\text{Weight (Kg)} = \frac{\text{Current (amps)} \times \text{design life (years)} \times 8760}{\text{Capacity of material (amp hrs/kg)}}$$

(8760 = number of hours in one year)

The number and type of anodes selected must at least satisfy both the total current and total weight requirements as follows:

$$\text{Number of anodes} = \frac{\text{current required}}{\text{individual current output}}$$

$$\text{Number of anodes} = \frac{\text{weight required}}{\text{individual net weight}}$$

C.2.1.2.4 Anode location

In ballast only or cargo ballast tanks of clean oil tankers, anodes should be distributed evenly overall the uncoated structure but with some emphasis on horizontal surfaces, In cargo ballast tanks of crude carriers those anodes on horizontal surfaces should be distributed in proportion to the areas of these surfaces, that is on bottom longitudinals, horizontal bulkhead girders, face flats on bottom structural members and on horizontal stiffeners. The majority of anodes will therefore be located on the bottom structure.

In cases where residual ballast water is expected to be left in the bottom of the tank, a low location of the bottom anodes should be provided for example on the webs of bottom longitudinals, and provision should be made for the more continuous anode consumption that this will initial.

The pipelines used in the larger ships have given rise to significant corrosion problems. The control of external corrosion on pipelines can be achieved by bonding the pipelines and fitting pipeline anode bracelets.

C.2.1.3 The use of sacrificial anodes for external cathodic protection

Zinc and aluminum anodes are used for this purpose in sea water. Both zinc and aluminum anodes have a normal design life of one, two, three or four years to suit the owners' requirements.

Hull anodes are usually welded direct to the ship structures, but can be bolted if required.

The applied current density usually varies from 10 mA/m² to 20 mA/m² dependent on the paint system used. In certain instances this can be increased to 40 mA/m² to meet arduous operating conditions.

C.2.1.3.1 The type and number of anodes required (full hull protection)

To obtain the approximate wetted hull area the formula below may be used where LBP = length between perpendiculars; D = draft; BC = block coefficient ; B = breadth: $(1.8 \times LBP \times D) + (BC \times LBP \times B)$

Typical block coefficients for various vessels are:

Passenger vessels	0.6	Naval vessels	0.55
Cargo vessels	0.75	Coasters	0.75
Tankers	0.8 to 0.9	Dredgers	0.8
Tugs	0.6	Yachts	0.4 to 0.5
Trawlers	0.55	Launches	0.4

The total current required is:

$$\text{Current (amperes)} = \frac{\text{area (m}^2\text{)} \times \text{current density (mA/m}^2\text{)}}{1000}$$

The total weight of anode material required is:

$$\text{Weight (Kg)} = \frac{\text{current (amps)} \times \text{design life (years)} \times 8760}{\text{Capacity of material (amp hrs/kg)}}$$

The number of anodes must fulfill both current and weight requirements as for internal protection.

C.2.1.3.2 Anode location

a) Full hull protection

Anodes should be located equidistantly around the hull about six meters apart. Fifteen percent of the anodes should be located around the stern in a similar manner to the stern only protection described below. Anodes situated in the forward part of the vessel should be located to prevent damage or removal by anchor chains. If necessary, anodes can be fitted with cable guards.

b) Stern only protection

Anodes should be positioned on the stern area and rudder adjacent to the propeller, care being taken to minimize disturbance of the water flow to the propeller. Anodes should not be fitted within 300 mm of the line of the propeller tips and should be parallel to the flow lines of the hull. Twenty percent of the anodes required for full hull protection are required for stern only protection.

Magnesium anodes are used externally for vessels operating in fresh water.

C.2.1.4 Fitting out protection

Magnesium anodes are used to provide protection during fitting out, particularly in estuarine or polluted waters.

C.2.1.5 Tank descaling

The high cost of descaling cargo tanks by mechanical methods can be avoided by using magnesium ribbon, which gives an equally clean surface by an electrolytic process and enables descaling to be done during the ballast voyage without taking crew from normal work. In addition, noise, dust and attack on the metal is avoided.

Extruded flexible magnesium ribbon anode is usually produced as rectangular section or ribbed and has a continuous steel core. Its particular advantages are that the current output is three to seven times greater than cast anodes of the same weight. The current is also evenly distributed along the structure.

The method of use is as follows:

A current density of 1000 mA/m² is normally used in sea water. This is achieved by using one meter of ribbon for every three square meters of steel area.

The ribbon is usually supplied in coils of 150 or 300 meters. This should be cut into lengths of about 30 meters.

The wire should be bared for about 10 cm at each end of every length by hacksaw and cold chisel or torch.

The ribbon is spread around the bulkheads, attached at top and bottom so that it stands one to two meters away from the steel surface. An even spread of ribbon should be used to "cover" all areas of the tank. The tank is filled with clean sea water and left for four to six days.

Black oil tanks should be pressure washed before descaling. All tanks should be pressure washed after descaling to remove any loose pieces of scale. The white chalk deposit which appears is harmless to food cargoes and should be brushed off before painting.

This process releases some hydrogen gas and appropriate precautions should be taken.

C.2.1.6 Individual anode output determination and calculation (sacrificial anodes)

Anode output (amperes) is the difference in potential (volts) between anode material and steel polarized to protection divided by the resistance (ohms) of the anodes in the electrolyte. This is expressed as:

$$I = \frac{E}{R}$$

I: amperes E: volts R: ohms

In order to obtain high output, the anodes should have a small cross section in relation to their length.

The resistance of slender rod anodes (Tank Anodes) in an electrolyte (25 ohms cm resistivity) can be obtained from the following formulae:

$$R = \frac{\rho}{2\pi L} \log \frac{4L}{r}$$

Where:

R = The resistance of the anode in ohms.

r = The mean effective radius of the anode in cm.

Where:

$$r = \frac{\text{cross section area}}{\pi} \times \frac{60^*}{100}$$

ρ = The resistivity of water in ohm-cm.

L = The length of the anode in cm.

This procedure is traditionally used in calculating anode requirements in the marine industry as being indicative of anode output during its life.

For flat plate anodes (Hull Anodes) the following formula can be used:

$$R = \frac{\rho}{a + b}$$

Where:

a = length in cm

b = width in cm

C.2.2 Impressed current

C.2.2.1 It is usual to design on the basis of 35 mA/m² although this may be varied to suit.

- a) Coating condition e.g. epoxy or other pain systems.
- b) Operating conditions e.g. high speed operation, low temperature conditions.

C.2.2.2 Anodes are usually produced in two types:

- a) External type with current output 75 and 100 amperes. These are also supplied in pairs to give 150 and 200 amp output.
- b) Recessed type, of a circular design, for use in forward installation where mechanical damage from cables is likely to occur. The recessed anode may be produced in one size only with a maximum current output of 50 amperes.

C.2.2.3 Anodes are usually located external to the engine room or suitable void spaces to simplify hull penetrations and cable routes.

C.2.2.4 For vessels up to 150000 dwt, it has been found that satisfactory current distribution can be achieved with all anodes sited adjacent to the engine room. Larger vessels normally require additional anodes, of the recessed type, to be mounted forward.

C.2.2.5 System control and monitoring is by a minimum of two reference electrodes sited forward and after and mounted at least 3 meters from the nearest anode.

C.2.2.6 For design calculation (see C.1.1).

* The cross sectional area of the anode to be used in determining the mean effective radius is that corresponding to the anodes consumed by forty percent.