MANUAL

CATHODIC PROTECTION

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APPENDICES

1. INTRODUCTION

1.1 GENERAL

This manual, which is a revision of an earlier publication dated December 1970, describes the basic principles, advantages and limitations for the control of corrosion of immersed, submerged or buried metal by cathodic protection, and gives guidance for the design of the installations required.

It is intended for use in oil refineries, chemical plants, gas plants and, where applicable, in exploration, production and new ventures.

This manual should enable staff at locations in the absence of a specialist to decide when cathodic protection may be technically feasible and economically justifiable and also to deal effectively with specialist consultants and contractors normally called in to carry out cathodic protection work.

Although the principle of cathodic protection is simple, its practical application calls for a certain skill and experience, and in all but the most straightforward cases it is wise to employ people who have this, rather than to attempt the work with inexperienced staff.

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All publications referred to in this manual are listed in Section 19; the relevant standard drawings in Section 20.

Where cross references are made, the number of the section or subsection referred to is shown in brackets.

1.2 DEFINITIONS

For the purpose of this manual the following definitions shall hold:

Shall and **Should** - the word `shall' is to be understood as mandatory and the word `should' as strongly recommended to comply with the regulations of this manual.

1.3 RELATED DOCUMENTS

This manual is to be used for guidance, other documents such as those listed below provide useful guidelines for cathodic protection. In some countries operators are required to follow the local rules unless proof can be shown that the proposed method will be adequate under the circumstances envisaged. It should be realized, that for offshore, the assumptions made are based on the fact that no problems have ever been reported when systems were designed along the guidelines given in this manual. It is most complicated and expensive to monitor cathodic protection systems effectively in the deeper and hostile waters. It is therefore often recommendable to adopt conservative approach if authorities so require.

The related documents often referred to are:

British Standard CP 1021: latest revision: Code of Practice for cathodic protection.

NACE Standard RP-01-76: Control of corrosion on steel, fixed offshore platforms associated with petroleum production.

NACE Standard RP-06-75: Control of corrosion on offshore steel pipelines.

NACE Standard RP-01-77: Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems.

NACE Standard RP-05-75: Design, installation, operation and maintenance of internal cathodic protection systems in oil treating vessels.

NACE Standard RP-05-72: Design, installation, operation and maintenance of impressed current deep groundbeds.

NACE Standard RP-01-69: Control of external corrosion on underground of submerged metallic piping systems.

Det Norske Veritas: Rules for the design, construction and inspection of offshore structures (with appendices).

Det Norske Veritas: Rules for the design, construction and inspection of submarine pipelines and pipeline risers.

Det Norske Veritas: TN-A 702: Installation of sacrificial anodes.

Det Norske Veritas: TN-A 703: Fixed offshore installations cathodic protection evaluation.

IEC publication 529: Classification of degrees of protection provided by enclosures.

2. NATURE OF CORROSION AND PRINCIPLES OF CATHODIC PROTECTION

2.1 ELECTROCHEMICAL NATURE OF CORROSION

At atmospheric temperatures the corrosion of metals is an electrochemical process, in which the metal surface is in contact with an electrolyte. The electrolyte may be a film of moisture containing dissolved salts, e.g. as in the case of corrosion in the atmosphere, or may constitute the whole or part of the surrounding medium, e.g. when metal is immersed in fresh water, sea water or buried in the soil. In the last case the electrolyte is the soil water, containing dissolved salts.

At the surface of a metal corroding in an electrolyte there are active electrochemical cells in which current flows between anodic and cathodic areas.

The distribution of the anodic and cathodic areas depends on the metal surface (included impurities, oxide films such as millscale, variations in physical state, etc.), and also on the nature of the surrounding medium.

Owing to the potential differences existing between the anodic and cathodic areas, positively charged metal ions leave the metal surface at the anodes while electrons leave the surface at the cathodes. Thus corrosion takes place at the anodic areas where metal ions react with the electrolyte to form the typical corrosion products. At the cathodic areas dissolution of metal does not take place, but reactions occur in the electrolyte.

Although the basic principles of corrosion apply to all metals, illustration is simpler if discussion is restricted to iron and steel, which are the most commonly used metals in the petroleum industry; they are considered specifically in most of the sections which follow.

In this manual potential values will be referred to either a copper/copper sulphate half-cell or silver/silver chloride half-cell. The first is used mainly in soil, the second in sea water.

The natural surface potentials of iron and steel in contact with soil or water are always negative when referred to either of these halfcells; nevertheless different areas of the same piece of metal surface may have different potentials.

2.2 FACTORS AFFECTING CORROSION

2.2.1 Steel surface conditions

If a steel surface is partially covered with millscale, it is cathodic with respect to the surrounding areas of bare steel. Corrosion occurs, therefore, on the relatively lower-potential bare metal as shown in Fig. 2-1, and is particularly severe when the area of the millscale is large in relation to the area of the bare metal.

If impurities, which are usually anodic with respect to steel, are occluded in the metal surface, corrosion in the form of pitting may take place at these points as shown in Fig. 2-1.

When dissimilar metals are in contact and are surrounded by an electrolyte, the less noble metal tends to corrode more severely, and the nobler one less severely than they would if there was no contact. A common example of this is the deterioration of the zinc coating on a galvanized pipe when connected to a bare steel pipe, see Fig. 2-1.

2.2.2 Environment

The rate of corrosion of the common metals in soil or water is governed by the following factors:

- concentration of electrolyte
- concentration of oxygen
- temperature.

Water

In general, the severity of corrosion increases as one of these controlling factors increases, but, because all the influences are operating at the same time, their relative importance shall be assessed. Thus, steel will corrode far more rapidly in brackish water in which oxygen dissolves more readily than in normal sea water, even though the concentration of electrolyte (salt) in sea water is much greater.

Soil

The absence of oxygen, particularly in water-logged soils, may provide a corrosive environment for iron and steel through the growth of sulphate reducing bacteria which generates hydrogen sulphide.

As pipelines often pass through soils which differ greatly in their physical and chemical make-up, some effects are more pronounced in pipeline corrosion than in the corrosion of other steel structures. The most important soil properties as regards pipeline corrosion are salt content and aeration (oxygen content) both of which affect the steel-to-soil potential of the buried pipe.

The steel-to-soil potential of buried steel is more negative in soils with a high salt content than in soils with a low salt content. Pipeline corrosion tends to the heaviest, therefore, on those parts of the steel surface in contact with the soils having the highest salt concentrations, i.e. at the anodic areas, see Fig. 2-2.

A system comprising a lower-salt-content soil, steel, and a higher-salt-content soil, i.e. a conductor in contact with two electrolytes of different concentrations, constitutes a galvanic cell and is often referred to as a concentration cell. In general the magnitude of the current flowing between the anodic and cathodic regions of such a cell, i.e. the corrosion current, is a function of the difference between the ionic concentration of the two electrolytes.

Similarly, the steel-to-soil potential of buried steel is lower in poorly aerated soils (low oxygen content) than in well aerated soils (high oxygen content). In practice, good aeration and high electrical resistivity usually correspond to low moisture content, and vice versa. Thus, the soil in contact with the top of a large diameter pipeline may be relatively dry and well aerated while that in contact with the bottom of the pipe may be wet and poorly aerated. Consequently, corrosion may occur at the anodic areas along the bottom, see Fig. 2-2.

A knowledge of the pH value of the soil is not usually of much assistance in assessing its corrosivity, but such tests should be made if contamination by acid products is suspected. Narrow range test papers are sufficiently accurate for this purpose. The information so obtained may reinforce the arguments to implement cathodic protection.

In anaerobic soils, e.g. clay, sulphate-reducing bacteria may be active. These micro-organisms, which can exist in active form only in the absence of free oxygen, obtain their energy from the following reaction:

$$SO_4'' \xrightarrow{8H} H_2S + 2\,H_2O + 2\,OH'$$

Bacterial corrosion of iron and steel under damp anaerobic conditions is usually rapid and severe. This type of attack can often be recognized by the bright (unoxidized) appearance of the corroded surfaces and the presence of hydrogen sulphide, which can either be detected directly by its rotten-eggs odour or by the blackening effect on lead acetate test paper after dilute mineral acid has been added to a sample of the soil in immediate contact with the corroded area. If this sulphide test is carried out it shall be done on site on a fresh sample, as the sulphides are oxidized rapidly on exposure to air.

2.2.3 Stray currents

Another cause of corrosion is the influence of stray currents in the surrounding soil. Direct-current traction systems frequently cause appreciable electric currents to flow in the surrounding earth. With a poorly coated pipeline a stray current may enter the line at a point where the coating is defective, travel along the line where it is effective, and leave the line at another defectively coated point to return to its source, see Fig. 2-2. Corrosion is concentrated at the anodic parts of the pipeline, where the current leaves. Modern railway systems are designed in such a way that stray currents are minimized.

Similarly, the impressed current from a cathodic protection system may also affect unprotected buried steel structures in the neighbourhood. This should be considered when planning a cathodic protection system, see (8.).

2.3 CATHODIC PROTECTION

2.3.1 Principle

The principle of cathodic protection is to make the potential of the whole surface of the steel structure sufficiently negative with respect to the surrounding medium to ensure that no current flows from the metal into the medium. This is done by forcing an electric current to flow through the electrolyte towards the surface of the metal to be protected, thereby eliminating the anodic areas. The current may be obtained from any convenient external source, such as a battery, rectified alternating-current supply, direct-current generator or by galvanic action.

The principle when impressed current is used is illustrated in Fig. 2-3, in which a battery is shown connected to the structure to be protected and to an auxiliary anode buried in the electrolyte, The auxiliary anode is arranged to be at a higher potential than the metal structure to be protected, so that current will flow from the former to the latter.

Corrosion of steel in normally aerated soils and waters can be entirely prevented if the steel is maintained at a potential not more positive than minus 0.85 V (-0.85) with respect to a copper/copper sulphate half-cell. Under anaerobic conditions when sulphate-reducing bacteria are present, it is necessary to depress the potential a further hundred millivolts, to minus 0.95 V (-0.95) with respect to a copper/copper sulphate half-cell. (These values with respect to silver/silver chloride half-cell become -.8 and -.9 Volts respectively).

For the system to work properly the structure to be protected shall be electrically continuous. Therefore, before installing a cathodic protection system, this continuity shall be ensured between all parts of the structure. For example, with an existing underground pipeline fitted with victaulic or Johnson couplings, it is necessary to locate each joint and provide an electrical bond. In the case of conductors of an offshore drilling platform, the electrical continuity has to be attended to similarly.

2.3.2 Methods

The following two methods of applying cathodic protection to immersed and buried surfaces of metallic structures and pipelines are used:

a. Sacrificial anode

With the sacrificial anode method, use is made of galvanic action to provide the cathodic protection current. The surface of the structure is made cathodic by connecting it electrically to a mass of less noble metal buried or immersed in the common electrolyte, the less noble metal is then the anode. Magnesium, aluminium alloys or zinc are used for this purpose. The anodes are often referred to as sacrificial anodes because protection of the structure is accomplished by the simultaneous consumption of the anodes by electrochemical corrosion.

b. Impressed direct current

With the impressed direct-current method the structure is placed in an electric circuit with a direct-power supply and an earth system or groundbed. The groundbed may consist of graphite, high-silicon iron rods, cast iron scrap, or steel such as old pipe, rails or structural sections. These materials are also used for anode systems (in water). In addition, for the latter, lead alloy or platinized titanium anodes may be used. The groundbed materials used should show a relatively low consumption rate if they are to be used for long periods.

These two methods are considered in greater detail in (4.) and (5.).

2.3.3 Current density requirements

The following table gives an estimate of current densities required for cathodic protection of bare steel in various environments at ambient temperatures of 15-25 °C:

Environment	**Current density**

	mA/m²
Soil	5 - 30*
Fresh water	10 - 30
Moving fresh water	65**
Sea water	see separate table below
Sea-mud zone (e.g. piles)	10 to 30

* In anaerobic soil some months elapse before full polarization.

** The value depends on water velocity.

In this table the current density refers to the current per unit area of bare steel surface. For coated pipeline structures, therefore, it is necessary to estimate the total surface area over which the coating is ineffective, to arrive at the current required for effective protection of the whole coated system.

Design criteria for cathodic protection systems in the sea

Production area	Environmental factors (1)					
	Water resisitivity ohm.cm	Water temp. °C	Turbulence factor (Wave action)	Lateral water flow	Typical design current density (2)	
					mA/ft^2	mA/m^2
Gulf of Mexico	20	22	Moderate	Moderate	5-6	55-65
U.S. West Coast	24	15	Moderate	Low	7-8	75-85
Cook Inlet	50	2	Low	High	35-40	375-430
North Sea (Northern)	30	10	High	Moderate	9-10	95-110
North Sea (Southern)	30	10	Moderate	High	7-8	75-85
Arabian Gulf	15	30	Moderate	Low	7-10	75-110
Indonesia	19	24	Moderate	Moderate	5-6	55-65

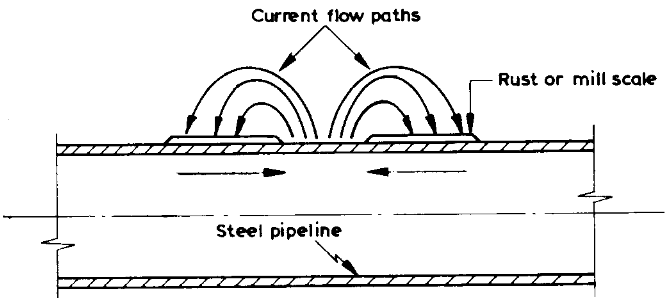
(1) Typical values and ratings, based on average conditions, remote from river discharge.

(2) All designs shall cater for the capability to deliver from 1.5 to 2 times the design current density to rapidly polarize the system after launch or after storm action. The steel potential will be more positive under these circumstances

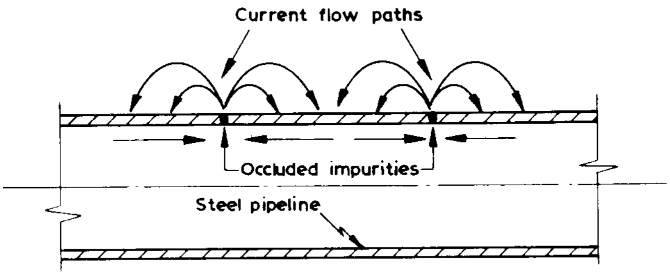
2.3.4 Protective coatings

The foregoing shows that corrosion could be prevented equally well by covering the entire underground or submarine Structure with an impervious non-conducting coating. However, this ideal condition is almost impossible to achieve at reasonable cost. Coatings are nearly always damaged to some extent either in transporting to site, erection, pipe-laying, or when backfilling after laying, and if corrosive conditions exist the corrosion at the damaged areas is likely to be severe. Consequently, the use of protective coatings and the use of cathodic protection are generally considered to be complementary. The mutual influence of these applications is considered in (6.).

Fig. 2-1 TYPICAL CAUSES OF CORROSION EFFECTS OF STEEL SURFACE CONDITIONS

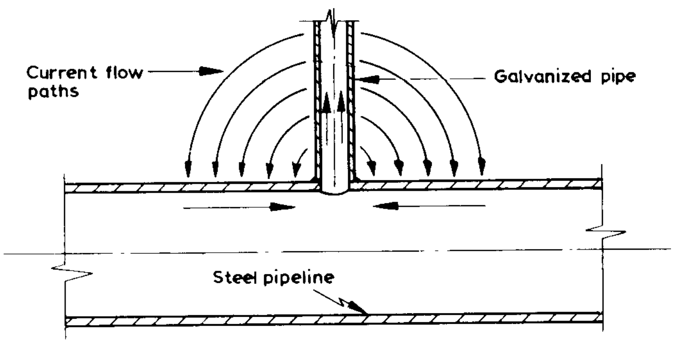


RUST OR MILL SCALE ON A METAL SURFACE



OCCLUSIONS IN A METAL SURFACE

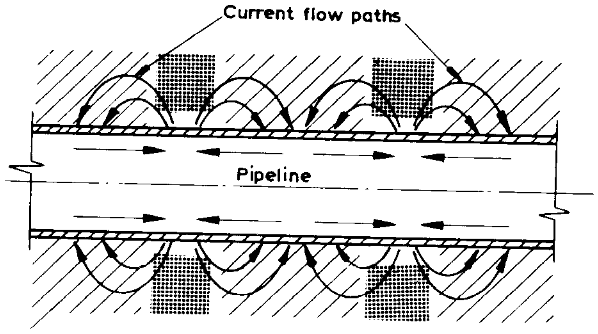
The bare metal is cathodic with respect to the impurities occluded in the surface of the metal and corrosion occurs at the anodic (occluded) areas



CONTACT BETWEEN DISSIMILAR METALS

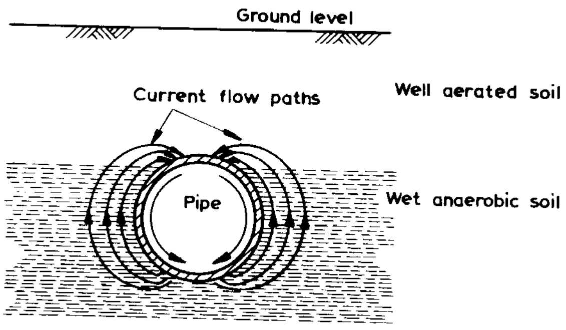
When a galvanized pipe is joined to a bare steel main, corrosion of the galvanized pipe takes place. A similar effect occurs if new steel branch pipes are connected to an old rusty steel main

Fig. 2-2 TYPICAL CAUSES OF CORROSION EFFECTS OF SOIL CONDITIONS AND STRAY CURRENTS



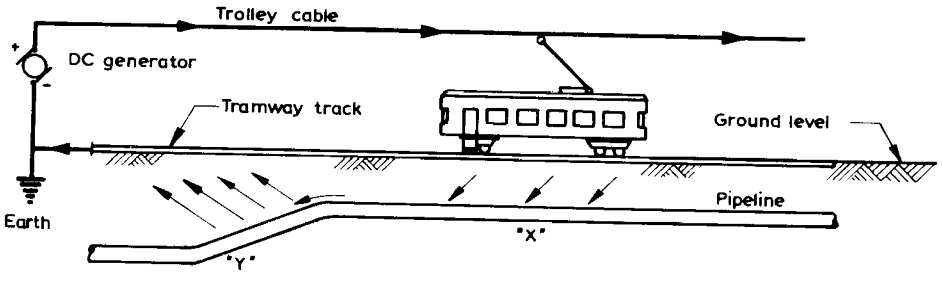
CORROSION DUE TO DIFFERENT TYPES OF SOIL AROUND PIPES

Corrosion is greatest in soil of high salt concentration, (Indicated thus : ▦) where the pipe-to-soil potential is low



CORROSION AT UNDERSIDE OF PIPE DUE TO DIFFERENTIAL AERATION OF SOIL

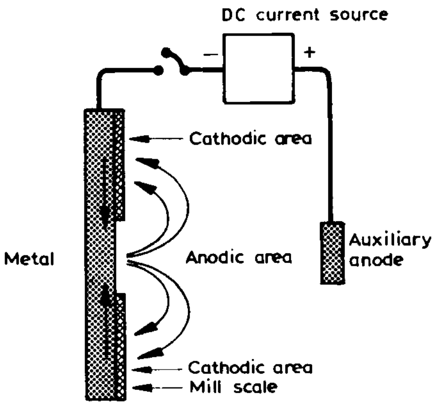
The wet soil around the underside of the pipe is less aerated than the dry soil above it



CORROSION DUE TO STRAY CURRENTS

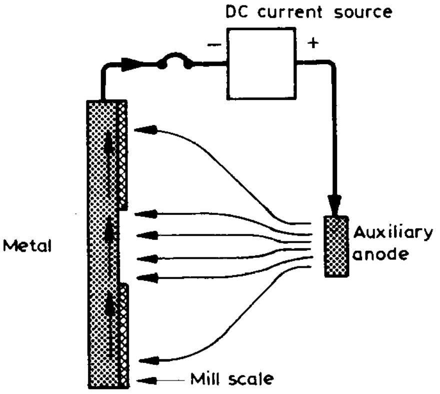
The current from the tramway track enters the pipeline at "X" and flows along it to "Y" where it leaves the line to return to its source. Severe corrosion may occur at "Y"

Fig. 2-3 GENERAL PRINCIPLE OF CATHODIC PROTECTION



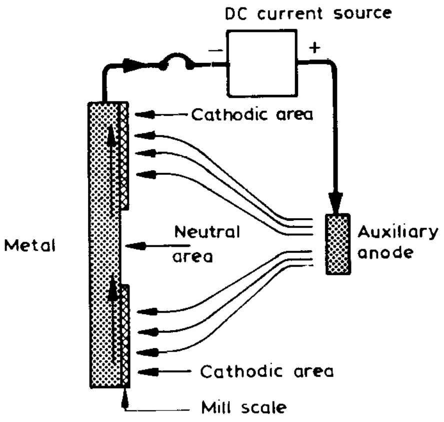
**AUXILIARY ANODE DISCONNECTED
NO PROTECTIVE CURRENT FLOWING**

Current flows from anodic to cathodic areas of structure due to local cell action. Corrosion occurs at anodic areas



AUXILIARY ANODE CONNECTED THROUGH BATTERY

Distribution of cathodic protection current impressed from auxiliary anode showing current flow to both cathodic and anodic areas (effect of local cell action ignored).
The whole structure is cathodic



AUXILIARY ANODE CONNECTED THROUGH BATTERY

Combined effect of protective current and local cell action. Resultant current distribution derived from superimposition of impressed current on local cell action, i.e. vector sum of diagrams above shows currents in and out of original anodic area to be zero

3. SURVEY METHODS AND PRELIMINARY INVESTIGATIONS

3.1 ASSESSING THE NEED FOR CATHODIC PROTECTION

The methods and instruments used for assessing whether cathodic protection is necessary for buried pipelines and other structures, and for estimating the current density and equipment required to make it effective, are described in this section. For structures in other corrosive media, e.g. box coolers, a study of corrosion history and tests with corrosion test specimens will provide the necessary data. An indication of the current densities required is given in (2.3.3).

No known soil-survey technique will predict accurately and reliably just where and to what extent corrosion of buried steelwork will occur. However, such methods provide a useful guide to the probable corrosion behaviour of a buried structure or pipeline. Any additional information which can be obtained about the corrosion history of existing underground steelwork at or near the site should also be considered.

For a pipeline, the investigation may also include chemical analyses to determine the concentrations of various salts and the pH values of soil samples taken at points along the route but, unless very little is known about the general nature of the soil, height of the water table, etc., the information obtained in this way is not usually of great value.

However, for main principles, it is now normal practice to apply cathodic protection in any case, and no soil survey is generally necessary apart from that required to find suitable groundbed locations.

Offshore facilities (pipelines, structures, etc.) shall be protected cathodically without exception.

3.2 SOIL RESISTIVITY

3.2.1 Principle

For any buried structure the most important preliminary investigation is the measurement of soil resistivity at various points, the main purpose being to locate suitable places for groundbeds. Measurements may be carried out either by the two-electrode method, using the Shepard Cane soil-resistivity meter (3.2.2), or by the two-electrode or four-electrode (single or double probe) methods using an alternating-current-type soil-resistivity meter.

The resistivity of soil can vary greatly with its water content and with the electrolyte dissolved in the water. Thus the soil resistivity at a given location may vary with the season of the year and the rainfall. However, if the soil is well drained and washed free of electrolytes by frequent heavy rain it maintains a fairly high resistivity even when moist.

3.2.2 Instruments

Instruments commonly used for measuring soil resistivity are as follows:

a. **Shepard Cane Soil-Resistivity Meter.** The Shepard Cane soil-resistivity meter, see Fig. 3-1, incorporates a low-resistance ammeter for measuring the current flowing through the soil between two buried electrodes placed 0.3 m apart, and inserted to a depth of approximately 0.3 m.
Resistivity measurements of the soil between the electrodes made in this way normally indicate conditions near the ground surface only. To measure the resistivity at greater depths, for example at the level of the proposed pipeline, test pits shall be excavated. When making tests, the electrodes shall be placed in undisturbed soil, otherwise inaccurate results will be obtained. As direct current is used to measure the soil resistivity, the push-button switch for closing the circuit shall be pushed in only momentarily, otherwise results will be affected by polarization.

b. **Four-Terminal Soil-Resistivity Meters.** The recommended method for measuring soil resistivity is the Werner or `four-pin' method in which four bare metal rods equally spaced along a straight line are driven into the ground. Alternating current is caused to flow between the outer pair of rods, and the potential difference between the inner pair is measured. If the rods are driven to only a shallow depth (approximately $^1/_{20}$ of the electrode separation `a'), the following applies:

$$\rho = 2 \pi a R$$

in which ρ = average soil resistivity, in Ω.cm up to a depth of approximately `a' cm
a = electrode separation in cm
R = measured resistance between the electrodes, in ohms.

Consequently, the average soil depth to which the resistivity readings are required shall be equal to the electrode separation to be applied. Furthermore, when seeking a low-resistance region for anode-placing, an indication of the depth at which low-resistance soil can be found, can be deduced from readings at increasing electrode spacings.

The four-pin instruments in common use are alternating-current meters making use of battery-driven vibrators.

NOTE: Examples of such meters are the Tellohm, Vibroground and Geohm meters and those made by NIEAF, see Fig 3-2. These meters are null instruments, i.e. at the balance point there is no current flowing between the measuring electrodes.

The Tellohm and Vibroground instruments can be used also in conjunction with a special type single probe in which two electrodes are mounted on a single rod so that spot readings of soil resistivity at approximately 0.3 m depth can be taken. An additional advantage of these single probe readings over Shepard Cane measurements is that an alternating current is used, thereby avoiding polarization effects.

3.2.3 Interpretation of soil-resistivity readings

Soil resistivity alone does not indicate soil corrosivity. Nevertheless, there is some relationship between the two properties, as shown by the following table:

Soil resistivity **Ω.cm**	**Soil corrosivity**
Under 1500	Very corrosive
1500 to 3500	Moderately corrosive
Over 3500	Slightly corrosive

However, some relatively high-resistivity soils may be very corrosive, e.g. acidic peaty soils and anaerobic soils containing sulphate-reducing bacteria. Corrosion can also occur in fairly high-resistivity soils if there is a considerable variation in resistivity at different points along the route of the pipeline, causing concentration-cell effects.

Deserts, although giving the impression of being dry and non-corrosive, can in most cases be considered as moderately corrosive.

3.3 POTENTIAL MEASUREMENTS

3.3.1 Principle

In measuring the potential difference between metal surfaces and the contacting electrolyte, i.e. soil, water, etc., the principle used is to form an electrochemical cell, the second half-cell being a standard reference electrode, usually a copper/copper sulphate half-cell (or silver/silver chloride). Thus, if the potential of a buried pipeline is being investigated, the electromotive force of the cell measured is as follows:

Steel/soil electrolyte/.............. /Saturated copper sulphate solution/copper.

3.3.2 Instruments

Copper/copper sulphate half-cells are the most common type of reference electrodes. A commonly available model is shown in Fig. 3-3 and the operating principle in Fig. 3-4. However, other types of reference electrodes are sometimes used, and the characteristics of these are shown in the table on page 16 and in Fig. 3-7.

Reference electrode	**Cell**	**Potential to standard hydrogen electrode at 25°C Volts**	**dE/dT V/°C**
0.1 N calomel	$Hg/Hg_2Cl_2/KCl$ (0.1 N)	0.334	-0.7×10^{-4}
1.0 N calomel	$Hg/Hg_2Cl_2/KCl$ (1.0 N)	0.280	-2.4×10^{-4}
Saturated calomel	$Hg/Hg_2Cl_2/KCl$ (saturated)	0.242	-7.6×10^{-4}
Silver chloride	Ag/AgCl/KCl (0.1 N)	0.288	-6.5×10^{-4}
Silver chloride	Ag/AgCl/sea water	0.25	-
Copper sulphate	$Cu/CuSO_4/CuSO_4$ (Saturated)	0.316	$+9.0 \times 10^{-4}$

NOTE: 0.1 N and 1.0 N in above table mean 0.1 and 1.0 `normal solution' respectively.

In measuring the electromotive force of such a cell the current flow should be restricted to the lowest practicable value, or polarization will occur, i.e. the objective is to measure the open-circuit electromotive force.

A convenient type of instrument for field use is a high-resistance voltmeter with a resistance not less than 1 megohm per volt, for field use under difficult circumstances robustness should be given consideration. The potentiometer mode shall be available. The accuracy of the 0.5 to 2.5 volt range shall be high.

3.3.3 Practical applications

The method of potential measurement is as follows:

Place the porous plug of the electrode firmly into contact with the soil, moistening the area of contact if the soil is very dry. Electrical contact then exists between the steel pipe, the soil electrolyte and the porous plug of the reference electrode. The circuit is completed by connecting the copper electrode of the half-cell via a suitable lead to the potentiometer or voltmeter, and connecting the latter to a steel probe, the sharpened point of which is in contact with the pipeline. The probe itself is plastic-sheathed except for its point. Alternatively, contact with the pipe may be made via the measuring wires inside test points erected over the pipeline, e.g. in conjunction with the kilometre markers.

The potential measured is the resultant of the potentials of all parts of the pipe surface which are `scanned' by the electrode and the reading obtained will depend therefore on the location of the electrode with respect to the pipe. The closer the electrode is placed to the pipe, the smaller is the area it will `scan', and the more likely it is that variations in potential from point to point will be detected. It is clearly impracticable to place the electrode successively close to all parts of the pipe surface and normal practice is to place it at intervals on the surface of the ground immediately above the pipe. See Fig. 3-4.

Provided that the reference electrode is not more than 0.5 m from above the centre of the pipeline, sufficiently accurate results for most purposes will be obtained. Several readings may be made at each contact of the probe with the pipeline by moving the reference electrode to different points on the soil surface along the route. To obtain accurate readings the long cable connecting the reference electrode to the voltmeter shall have a low resistance compared with the internal resistance of the voltmeter. Fig. 3-5 shows a typical series of pipe-to-soil potential measurements together with the potential differences between adjacent points along a pipeline which is not cathodically protected. Typical current-flow paths resulting from these potential differences are also shown. From these it can be seen that the point where corrosion may be expected is at `X' and `Y', where current leaves the pipeline carrying iron ions with it into the soil.

3.4 CURRENT-DRAINAGE TESTS

When it is intended to provide protection by the use of an impressed direct current, and more especially for a complicated structure, the recommended method for determining the required current and its distribution is by means of a current-drainage test.

This necessitates temporarily installing one (or more) groundbed(s) in a direct current circuit, and maximizing the output. The current is then interrupted in a sequence of e.g. 40 seconds on, 20 seconds off. The effect can be checked by measuring the steel-to-soil potential variation at various points. The location with the least `swing' determines the required minimum output of the final installation in such a way that the minimum acceptable swing is 300 millivolt negative once the final installation is activated.*

* The ratio swing observed/swing required equals test current applied/final minimum current required.

The current requirements for coated pipelines is often estimated.

Current-drainage tests, although technically reliable, are generally confined to investigations for complicated structures.

An alternative method for determining the current required for cathodic protection is the measurement of the steel-to-electrolyte potential with stepped increase of impressed current. A graph is made showing the steel-to-electrolyte potential against the logarithm of the impressed-current. The relationship is a straight line with a slight inclination at low currents; after a break point the curve continues as a straight line with a sharper rise at higher currents.

The break point indicates the current required to provide cathodic protection, see Fig. 3-6. This method is often the only feasible one when cathodic protection is being considered for structures not fully accessible, e.g. oil well casings. As the measurements are taken in a short period, full polarization does not occur and the steel-to-water or steel-to-soil potential at the break point is not a measure of the potential required to provide protection.

The location of the half-cell in such an experiment is rather critical. A remote location should be found by moving the half-cell further away during which no significant change in potential is observed. This then is the remote potential. The potential after each current step increase shall be measured whilst interrupting the current for approximately one second and reading the instant `off' potential. The time over which each current step increase is being applied shall be a constant (e.g. one or two minutes).

Fig. 3-1 SHEPARD CANE SOIL-RESISTIVITY METER

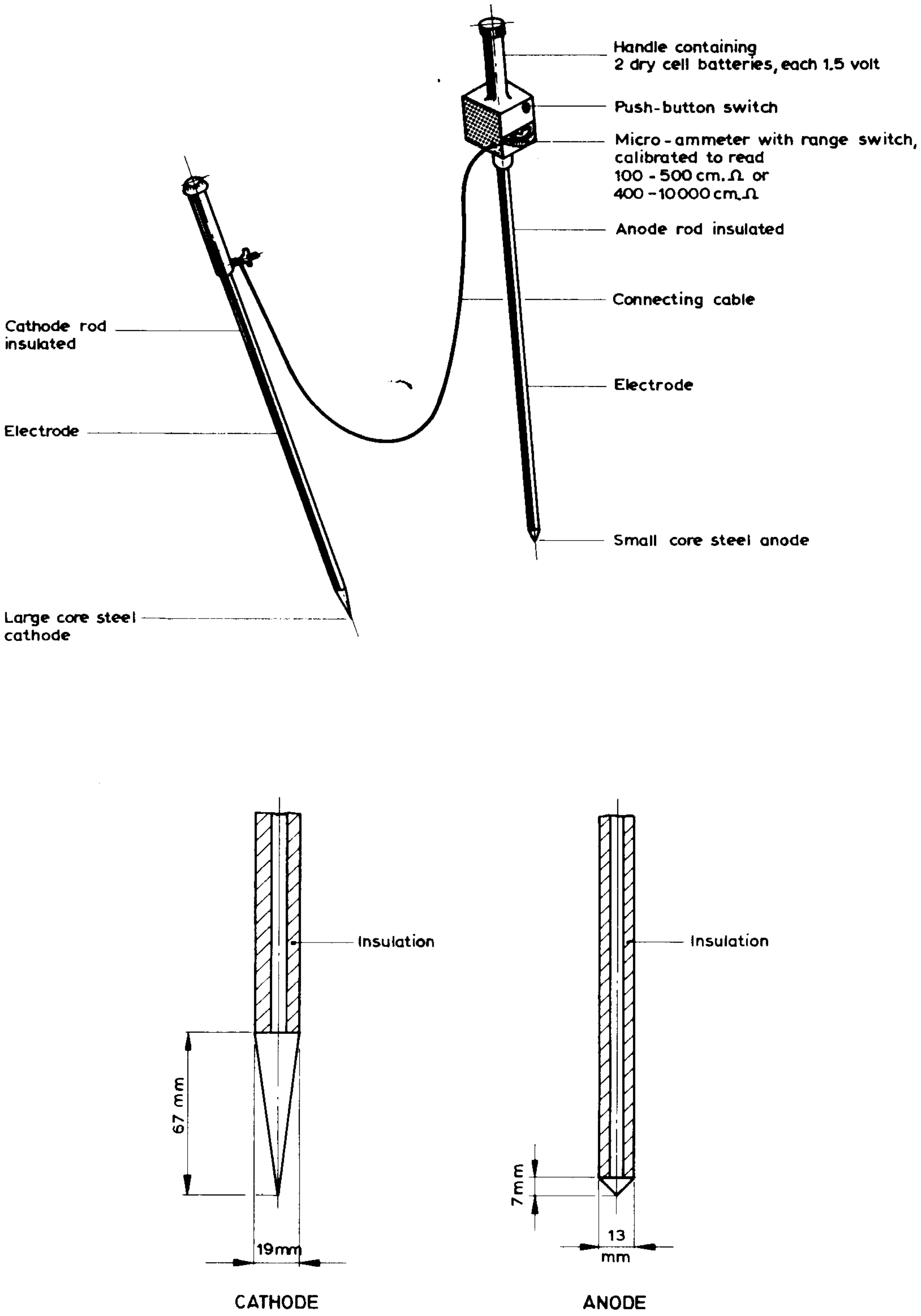
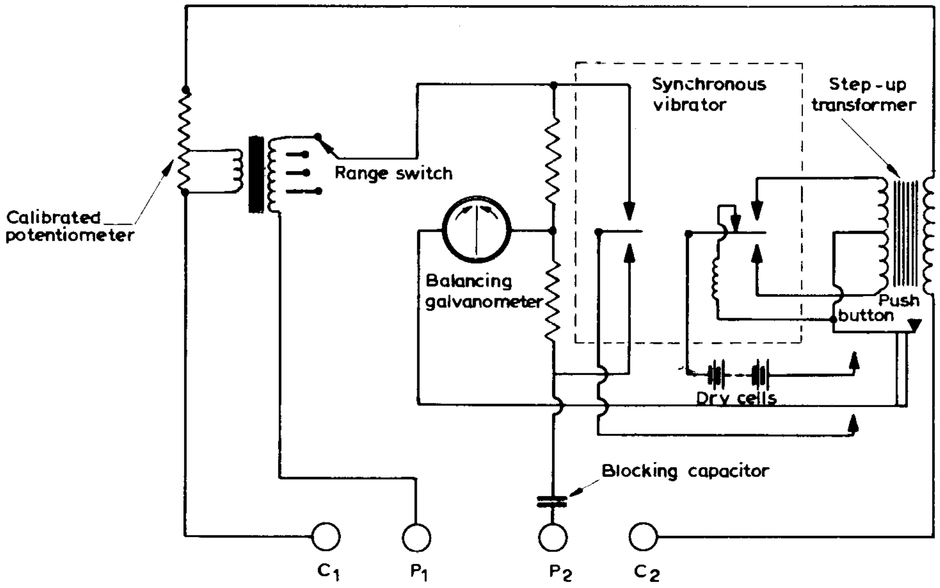
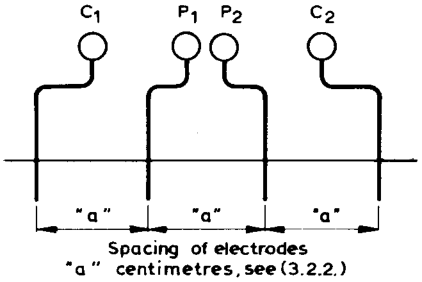


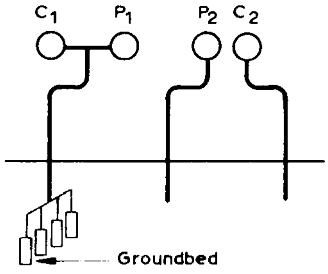
Fig. 3-2 RESISTIVITY MEASUREMENT



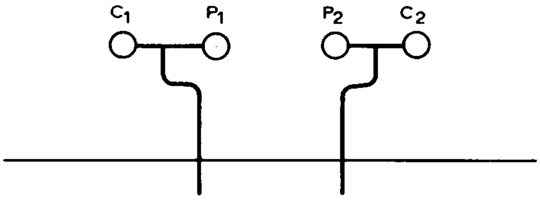
VIBROGROUND METHOD



FOUR-ELECTRODE METHOD
(SOIL RESISTANCE)

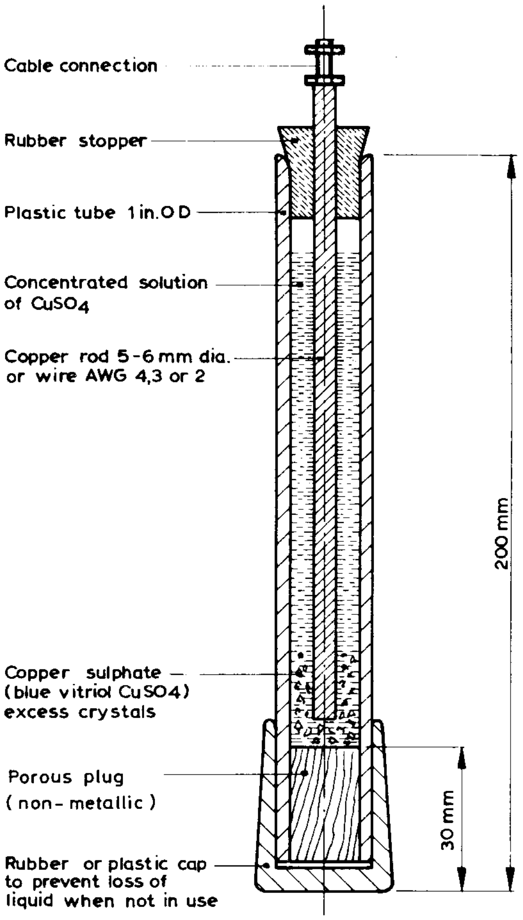


THREE-ELECTRODE METHOD
(EARTHING RESISTANCE)



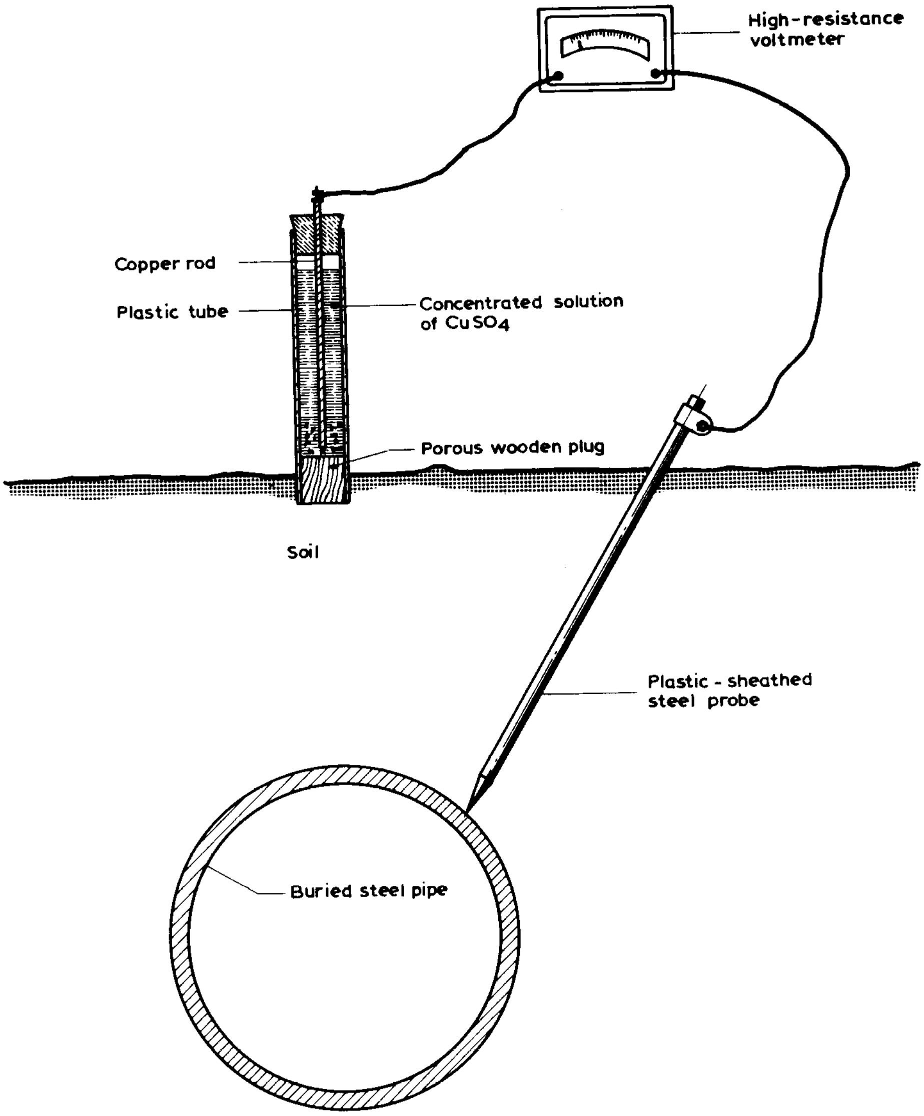
TWO-ELECTRODE METHOD
(TWO PROBES OR SINGLE PROBE)

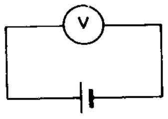
Fig. 3-3 SIMPLE MODEL OF COPPER/COPPER SULPHATE HALF-CELL (REFERENCE ELECTRODE)



Note: Contact with soil made through porous plug

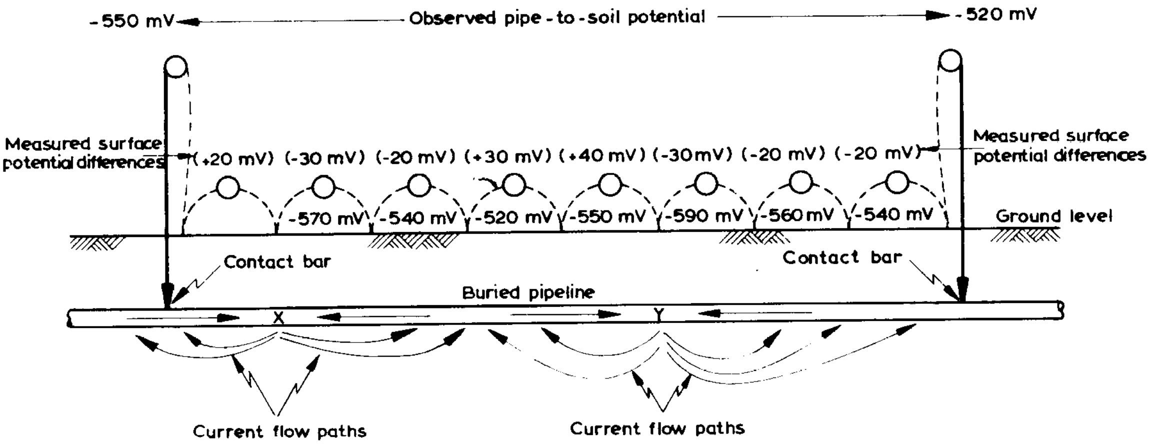
Fig. 3-4 MEASUREMENT OF PIPE-TO-SOIL POTENTIALS





EQUIVALENT CIRCUIT

Fig. 3-5 PIPE-TO-SOIL POTENTIAL SURVEY



Corrosion is most likely to occur at "X" and "Y" where potentials are most negative (anodic areas)

Fig. 3-6 RELATIONSHIP BETWEEN POTENTIAL AND IMPRESSED-CURRENT

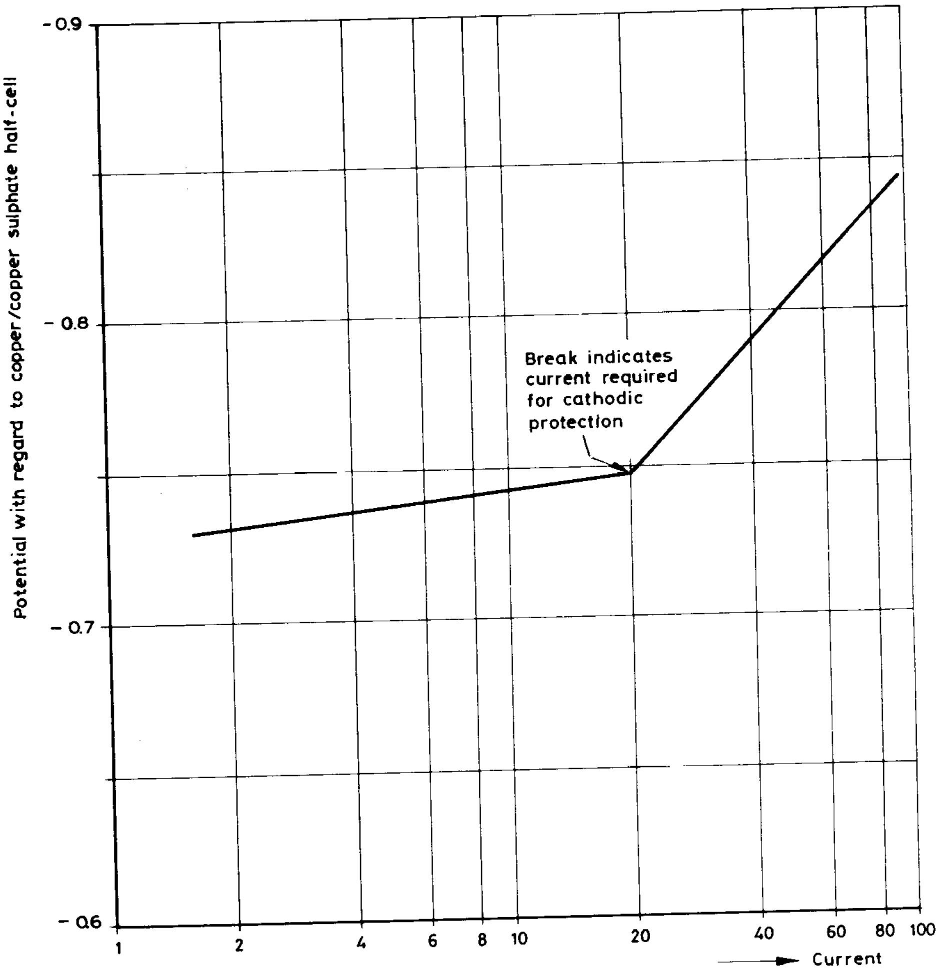
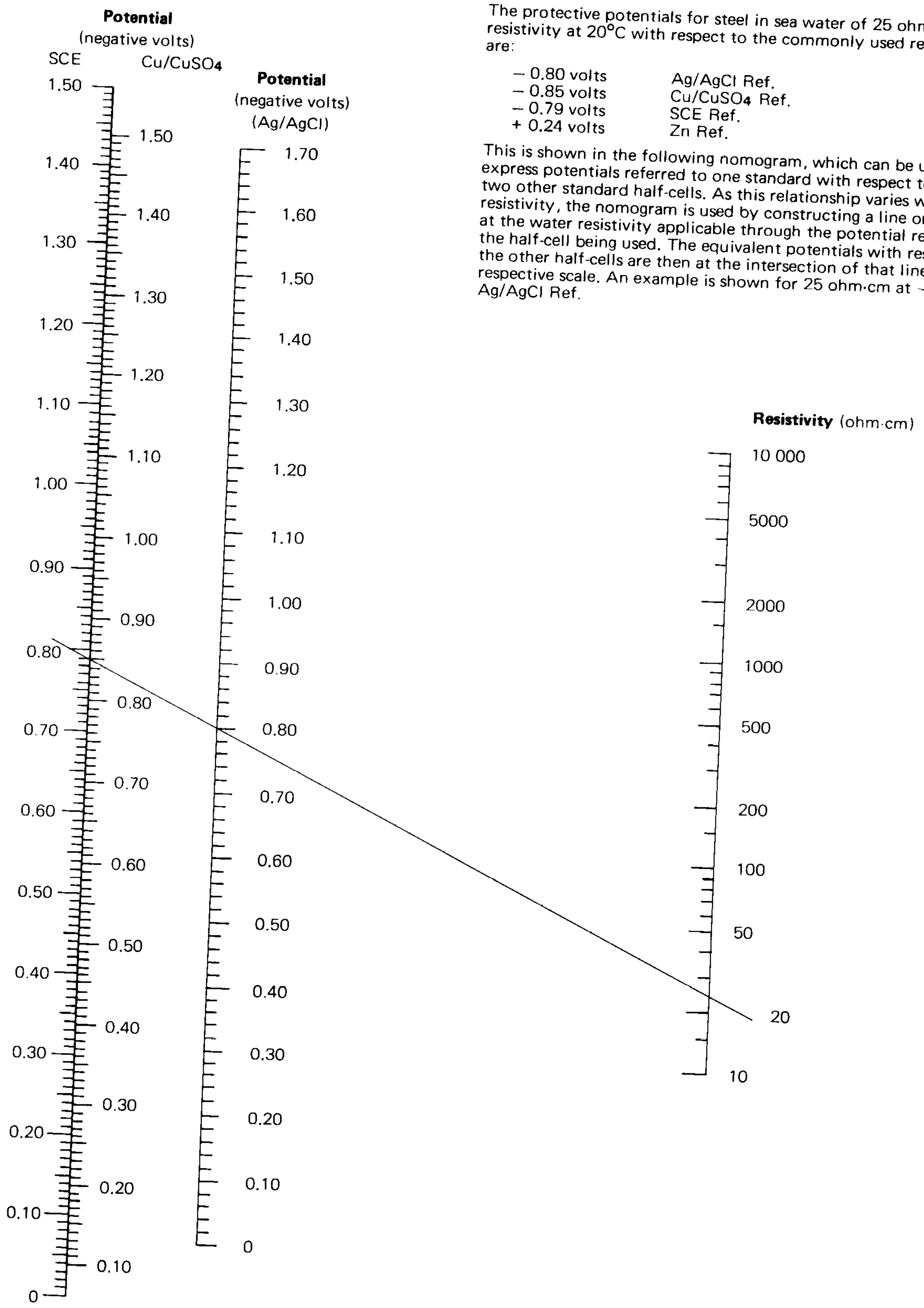


Fig. 3-7 STANDARD REFERENCE CELLS

The protective potentials for steel in sea water of 25 ohm·cm resistivity at 20°C with respect to the commonly used reference cells are:

− 0.80 volts	Ag/AgCl Ref.
− 0.85 volts	Cu/CuSO4 Ref.
− 0.79 volts	SCE Ref.
+ 0.24 volts	Zn Ref.

This is shown in the following nomogram, which can be used to express potentials referred to one standard with respect to either of two other standard half-cells. As this relationship varies with water resistivity, the nomogram is used by constructing a line originating at the water resistivity applicable through the potential referred to the half-cell being used. The equivalent potentials with respect to the other half-cells are then at the intersection of that line and the respective scale. An example is shown for 25 ohm·cm at −0.8 volts Ag/AgCl Ref.



4. PROTECTION BY SACRIFICIAL ANODES

4.1 GENERAL

When two dissimilar metals are placed in an electrolyte and joined by a conductor, an electric current tends to flow from one metal to the other. Any such current flow will increase the corrosion of the less noble (anodic) metal and reduce that of the more noble (cathodic) one. This is the basis of cathodic protection with sacrificial anodes.

Steel structures are protected by connecting to them anodes (magnesium or aluminium alloy or zinc) which are less noble than steel and are available at an economical price. In the same way, because steel is less noble than brass, steel sacrificial plates and plugs are used to prevent corrosion and de-zincification of brass, or reduce crevice attack on austenitic stainless steels and titanium.

4.2 ANODE MATERIALS

4.2.1 Capabilities and consumption rates of sacrificial anode materials

Galvanic anode alloy	**Potential $Cu/CuSO_4$ volts**	**Energy capability(1) Ah/kg**	**Consumption rate kg/Ay^2**
Aluminium-zinc-mercury	-1.1	2760-2840	3.2-3.1
Aluminium-zinc-indium	-1.15	1680-2400	5.2-3.6
Aluminium-zinc-tin	-1.1	930-2600	9.4-3.4
Zinc (MIL-A-18001H)	-1.1	820	10.7
Magnesium (HUI Alloy)	-1.55	1100	7.9

1) Based on anode loadings of 2.15-7.53 A/m^2
2) Ampere year

4.2.2 Magnesium alloy

The potential difference between magnesium alloy and steel is greater than between zinc, or aluminium, and steel and this enables magnesium to be used economically in media of higher resistivity (up to 3000Ω.cm) than where zinc or aluminium are used.

The magnesium alloy generally used for cathodic protection is of high purity. The specification is:

Cu	0.02 max.
Al	5.3-6.7
Si	0.10 max.
Fe	0.003 max.
Mn	0.15 min.
Ni	0.002 max.
Zn	2.5-3.5
Sn	-
Pb	-
Mg	remainder

4.2.3 Zinc

Zinc anodes of high-purity metal are required in order to provide a continuous protective current. Metal complying with the requirements of USA Military Spec. MIL-A-18001 H is suitable. The specification is:

Cu	0.005 max.
Al	0.10-0.50
Si	0.125 max.
Fe	0.005 max.
Cd	0.025-0.15
Pb	0.006 max.
Zn	remainder

Also acceptable is high-purity zinc (5 mg/kg Fe max., 1 mg/kg Cu max.)

Zinc of too low a purity has often failed as an anode material, because corrosion products accumulate on the metal surface and greatly decrease current output.

Zinc gives a relatively small current output, as its potential difference (driving force) with protected steel is approximately 0.25 V as compared with 0.6 V for magnesium, It is not normally economical to use it in media with a resistivity greater than 1500 Ω cm. Its main use is to provide protection in sea water or when only a small current is required and a long service life is desirable. An example of this is the use of zinc anodes as bracelets on well-coated submarine pipelines.

Zinc anodes can be used at higher water temperatures (in the range 30-60 °C); magnesium-alloy anodes will corrode too rapidly, see (4.3). The anode potential gradually deteriorates towards the temperature of 60 °C, and at approximately 70 °C in some types of water, the polarity may change from negative to positive with respect to iron, thereby promoting an attack on steel instead of preventing it.

4.2.4 Aluminium

Aluminium alloys have found wide application for cathodic protection of offshore structures.

A problem encountered a number of times was the passivation of the anode with a resulting underprotection of the system. The Royal Dutch/Shell Laboratory at Amsterdam have developed an approval test method capable of indicating which anode composition fulfills requirements. The composition of anodes is often proprietary although some typical (effective) compositions are recognized (see table). Nevertheless testing and subsequent approval of unknown suppliers' material is essential. Testing takes place at 5 °C and at ambient temperature.

Some anode compositions are claimed to be suitable in mud as well as in sea water. Also compositions for high temperatures are offered. In general the claims have not been substantiated in laboratory tests either because of severe loss of efficiency or because of a very localized attack pattern. Aluminium anodes are not recommended for other service than in sea water at this time. The indium activated type is preferred. It is the Groups' policy to discourage the use of mercury-activated anodes.

Indium-activated		**Mercury-activated**	
Fe	0.13 max.	Fe	0.08 max.
Si	0.10 max.	Si	0.11-0.21
Cu	0.01 max.	Cu	0.006 max.
Zn	0.5-5.0	Zn	0.35-0.50
In	0.005-0.05	Hg	0.035-0.048
Al	remainder	Others (each)	0.02 max.
		Al	remainder

4.3 ANODE CHARACTERISTICS

4.3.1 General

Current output (i.e. mA supplied per anode) is of primary importance in the application of sacrificial anodes as this determines the number of anodes required, and their rate of consumption, i.e. their service life. Capacity figures are given under (4.2.1).

4.3.2 Anode efficiency

In practice the theoretical A.h output of sacrificial anodes is not all available for cathodic protection, as apart from the anode material being consumed in protecting the structure, part of the material is also being consumed by the normal self-corrosion of the anode due to the action on it of the electrolyte.

The `anode efficiency' is the ratio of the ampere-hours actually supplied to the theoretical ampere-hour output per unit weight of metal consumed.

The efficiency of magnesium-alloy anodes is usually about 50%. To obtain this efficiency the magnesium alloy should be of correct composition with a low impurity content; the anodes supplied by reputable manufacturers are satisfactorily in this respect The efficiency is also influenced by the environment. In soil or water With a moderate to low salt content, the efficiency may be low because the current output is low and consequently the anode's own corrosion may be relatively high. The use of a special backfill around the anode gives a higher current output and a better anode efficiency.

At increased temperatures, e.g. in box coolers, the self-corrosion of the anodes is greater and therefore their efficiency decreases. For this reason magnesium alloy anodes should generally not be used when the temperature is higher than approximately 30 °C in brackish or salt water or higher than approximately 45 °C in fresh water. In sea water their life is too short.

Zinc anodes normally operate at an efficiency of about 90% and aluminium anodes at about 94%. The capacity figures given in (4.2.1) have been corrected and are practical consumption rates.

4.3.3 Current output of anodes

The current output of sacrificial anodes depends on the driving force available and the circuit resistance. The driving force is the difference in potential between anode and protected steel. The former depends on the type of anode used and is given in the table in (4.2.1). The potential of the protected steel is the minimum requirement as given (2.3.1).

The circuit resistance can be calculated and is the sum of cable resistance (which should be negligible) and anode-in-medium resistance. For the calculation of the latter a number of formulae is available each covering a type of medium or position of anode. The disturbance caused by mutual interference is detailed (4.3.3.4).

4.3.3.1 *Vertical anode in soil*

For a single anode placed in soil vertically, the following relationship applies:

Amended per Circular 11/84

$$R_{vert} = \frac{0.1588\rho}{L}\left(2.3 \log \frac{8L}{d} - 1\right)$$

in which R_{vert} = anode resistance in ohm

ρ = medium resistivity in ohm.cm

L = anode length in cm

d = anode diameter in cm

4.3.3.2 *Horizontal anode in soil*

For an anode single or in multiple series in a single horizontal line (trench) the following relationship applies:

Amended per Circular 11/84

$$R_{hor} = \frac{0.1588\rho}{L}\left(2.3 \log \frac{4L}{d} + 2.3 \log \frac{L}{S} - 2 + \frac{S}{0.5\ L}\right)$$

in which R, ρ, L, d as in (4.3.3.1)

S = anode depth in cm

4.3.3.3 *Anode in water*

For a stand-off anode the following relationship applies:

$$R = \frac{\rho}{2\pi L}\left(\ln\frac{4L}{r} - 1\right)$$

in which R = anode resistance in ohm

ρ = medium resistivity in ohm cm (for sea water this is 25-30 Ωcm)

L = anode length in cm

r = mean effective radius in cm = $\sqrt{(\text{cross sect. area} * /\pi)}$

For a bracelet-type anode as (e.g. used on pipelines) the following relationship applies:

$$R_{bracelet} = \frac{0.315\rho}{\sqrt{A}}$$

in which R and ρ as in (4.3.3.1) and A is the exposed surface area in cm^2.

For a flat plate anode (e.g. shiphull type) the following relationship applies:

$$R_{plate} = \frac{\rho}{2S}$$

in which R and ρ as in (4.3.3.1)
S = mean length of the 2 sides (thickness ignored) in cm

4.3.3.4 *Spacing factors*

When anodes are placed in close proximity they mutually interfere. The resistance of a group of anodes is therefore higher than the single anode resistance divided by the number of anodes.

* Some designers use only 60 percent of the cross sectional area. This represents the anode dimension halfway through its usefull life.

The spacing factor to be used for correcting the anode bed resistance is found from:

$$F_n = 1 + \frac{\rho}{\pi\, sR} \ln 0.66\, n$$

in which F_n = spacing factor (>1)

ρ = soil resistivity in Ωcm

s = distance anodes in cm

R = single anode resistance

n = number of anodes

The anode bed resistance is obtained as follows : $F_n \times \frac{\text{single anode resistance}}{\text{number of anodes } n}$

4.3.3.5 Cable resistance

The current-carrying capacity of cables used for cathodic protection (interconnection wire) is seldomly used to its maximum. More consideration is given to the maximum acceptable circuit resistance. Sometimes cable resistance can have considerable impact. The resistance of cables is given in Fig. 4-2.

4.4 PRACTICAL APPLICATION

4.4.1 Installation of sacrificial anodes

In soil

Anodes are buried along the length or perimeter of the structure. They can be installed upright or horizontally, if possible sufficiently deep to be in permanently moist soil. The distance of the anode to the structure will be relatively short, say no more than 5 metres. The anode shall always be surrounded by a low-resistance medium (backfill) in order to promote even current discharge. The backfill used for sacrificial anodes is composed of a bentonite/gypsum 50/50 mixture. Often anodes can be obtained surrounded by backfill in a linen bag and provided with a cable tail ready for installation.

In water

Anodes will be ordered with cast-in steel core. This core shall be made of readily weldable steel and can have the form of flat strip, round bar or pipe. The core is welded to the structure either directly (e.g. on offshore structures) or a * cad welded cable between core and structure is used (e.g. for bracelets around pipelines).

* Refer to (4.4 2)

The distance between anode and structure depends on the condition of the structure. For coated steel the minimum distance is zero, for a bare structure the minimum is 25 cm. The maximum distance is not critical provided the ohmic resistance of the interconnection is small compared with the anode resistance in the medium.

4.4.2 Electrical connections

A low-resistance connection is essential for the ensurance of maximum benefit from sacrificial anodes. Connections via cables or cores should preferably be by welding. The method often used for cable to steel connection is thermit welding (cad welding). Provided the size of charge is correctly chosen (manufacturers instructions), the surfaces are very clean and the atmospheric conditions acceptable (dry), the quality of a cad weld is good. Some authorities have objections against the use of thermit welding on high-strength steels because of possible copper penetration and resulting embrittlement. In such a case use can be made of a steel doubler plate onto which the cable is attached (by cad weld or brazing). Provided the doubler plate is welded by using approved welding procedures the method circumvents the copper penetration problem.

Welds made between anode cores and structural members for offshore facilities shall have the approval of the welding engineer. Procedure testing will often be required. Wet welding is not permitted.

Other methods used to connect anodes to structures are often used during retrofit exercises when welding is impossible. These are clamping, clamping plus hard-tipped bolting, flash stud welding in min habitats, stud shooting, etc. The first two methods have been successful) applications for over five years, the others are still experimental.

4.4.3 Current measurements

Some anodes should be monitored for their output to enable judgement to be made on useful life of the system. For onshore installations facilities can easily be provided by leading the wire through a test point where the cable can be interrupted and or shunted. The current can be measured via the shunt or by compensation, the latter being the most accurate. A typical arrangement is given in Fig. 4-1.

For offshore installations monitoring is complicated because cabling has to be brought to the surface or expensive gadgets have to be mounted underwater (e.g. acoustic responders). It is therefore seldomly done.

4.4.4 Electrical continuity

For any system to be protected effectively the electrical continuity has to be optimal. Any break in the current path will hamper protection and will lead to situations that are difficult to correct later on. Continuity problems can be found in pipelines with screwed or clamped connections and with conductors and casings at offshore platforms.

4.5 ANODE DISTRIBUTION

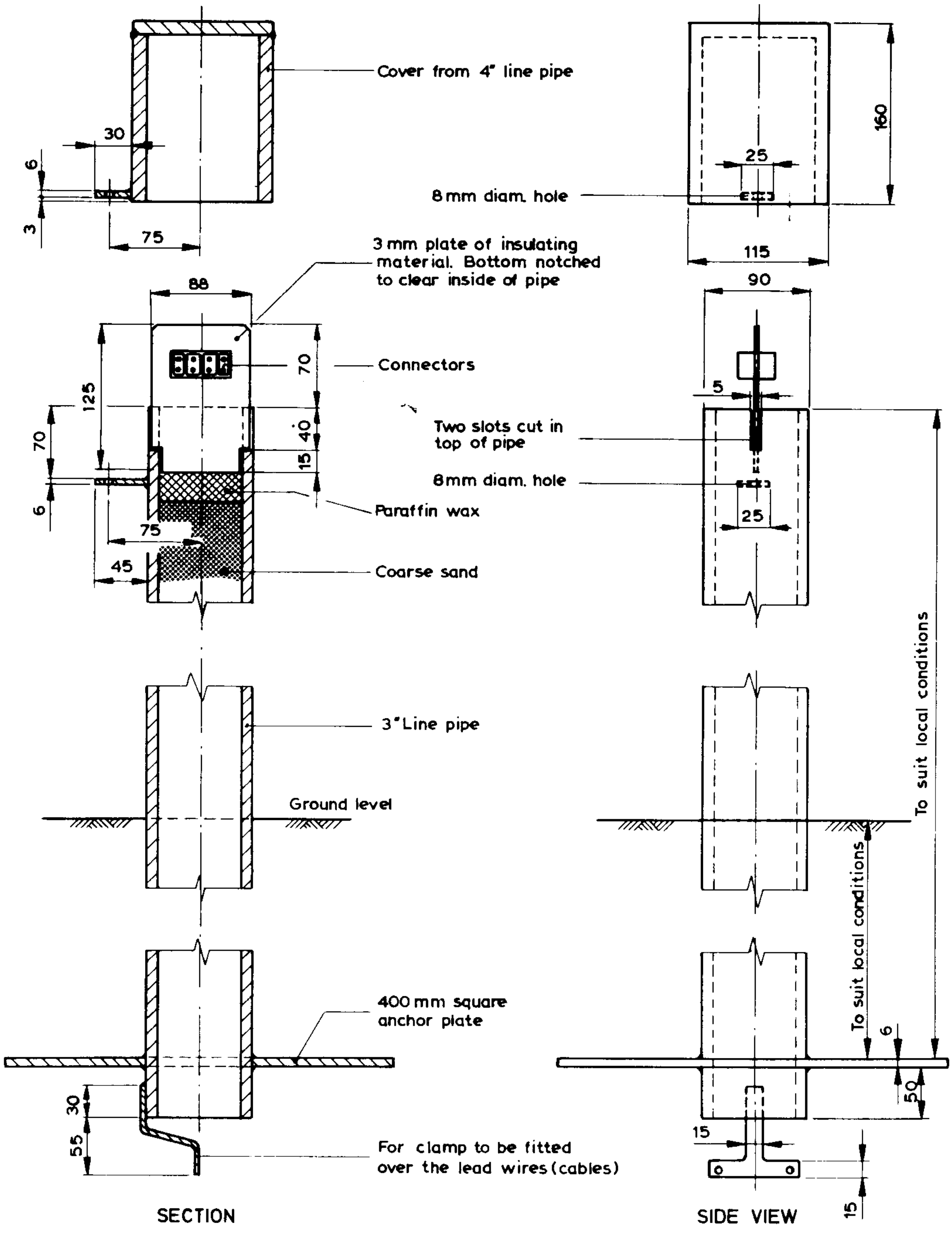
Anodes used to provide protection in water should be evenly distributed over the surface of the structure.

The spacing between anodes used to protect pipelines varies between one anode every 150 metres (bracelets offshore) to one anode (bed) every 5 kilometres (well-coated landline).

4.6 ANODE SPECIFICATION

A specification for sacrificial anodes is given in Appendix 1.

Fig. 4-1 TYPICAL CURRENT-MEASURING BOX



Dimensions in mm

Fig. 4-2 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.

5. PROTECTION BY IMPRESSED CURRENT

5.1 GENERAL

When cathodic protection is provided by means of an impressed direct-current, the anodes or groundbeds are buried in the soil at considerable distance to the side of the structure or pipeline to be protected. The minimum recommended distance from a buried structure to be protected is 100 metres. If the structure is located offshore the distance can be less but care shall be taken not to overprotect the nearest position. The positive lead of the external source of direct current is connected to the anode and the negative load is connected to the structure. Several anodes may be connected to one source of direct current as shown in Fig. 5-1 The resulting flow of current is from the anode through the soil to the pipe.

Because chlorine is liberated and water is consumed at the groundbed, the latter shall be sited in wet positions so that their electrical resistance can be maintained at a low value, whilst ventilation of the groundbed shall be attended to by allowing gas dissipation through porous top soil.

5.2 CURRENT SUPPLY

5.2.1 General

To deliver the necessary current from the groundbed, i.e. the anode through the soil to the protected structure or pipeline, i.e. the cathode, the circuit shall be completed by connecting a source of direct current of adequate voltage and current capacity between the cathode and anode. Transformer-rectifiers, are usually used to supply the direct current, whereas in special cases where no AC supply can be made available, power can be generated with motor generator sets, solar power units or wind mills. See Appendix 2.

5.2.2 Transformer-rectifiers

The transformer-rectifiers used shall fulfill the electrical regulations applicable for the area where these are placed The unit can be either oil- or air-cooled and the rectifying elements either selenium or silicon. The selenium type is not sensitive to short overloads but silicon is. Selenium rectifiers have to be loaded to their maximum capacity occasionally (once per year) to avoid the tendency to block under low load.

Cable glands shall be placed such that they are always above the oil. Tapping of the transformer shall either be through front-mounted switches or through the relocation of straps also mounted on the front panel.

The construction of the transformer-rectifier units shall fulfil the requirements of the hazardous area classification applicable for the site. When installed outdoors, the enclosure shall be weatherproofed in accordance with the minimum degree of protection IP 54 of IEC publication 529.

The number of steps in the adjustment required depends on the maximum DC output capacity of the unit. More than 60 steps are seldom required, 24 will usually suffice. The outgoing circuit shall be provided with a volt and ampere meter mounted on the front panel.

5.2.3 Cables

For cathodic protection work it is customary to use cross-linked polyethylene-insulated, PVC- or polyethylene-sheathed copper conductor cables, with cross sections depending on the current carried and the circuit resistance limits. Fig. 4-2 gives an approximate indication of the cable sizes required for various current loads. When long runs of cable are required, larger cross-sectional areas may be needed to keep the voltage drop within acceptable limits.

For use in sea water, cables should be protected against marine organisms. Marine borers (teredos) often cause early failure of anode cables. Application of cable provided with anti-teredo tape (copper foil) offers sufficient protection.

5.3 ANODE MATERIALS

5.3.1 General

Any current-conducting material could be used for the anodes or groundbeds, but for reasons of economy the material used is that which will have a low consumption rate at an acceptable cost. Materials such as carbon steel scrap, cast iron scrap, graphite cylinders and special alloy rods are employed. The consumption rates are given below:

CONSUMPTION RATES IN SEA WATER OF IMPRESSED-CURRENT ANODE MATERIALS

Impressed-current anode material	Typical anode current density in salt water service A/m^2	Nominal consumption rate kg/Ay
Pb-6%-Sb-1%Ag	160-220	0.05-0.1
Platinum (plated on substrate)	500-1000	6×10^{-6}
Platinum (wire, or clad on substrate)	1000-5000	1×10^{-5}
Graphite	10-40	0.2-0.5
Fe-14.5%Si-4.5%Cr	10-40	0.2-0.5
Scrap steel	-	7-9

5.3.2 Steel scrap

In some cases steel scrap is used as an impressed-current anode. Abandoned oil or water wells can be quite suitable. The sections are thin, however, and early failure is likely. Another weakness is the anode cable connection which should preferably not contact the soil.

5.3.3 Cast iron scrap

Cast iron scrap generally has the advantage of being thick in section and of such form that any one piece will be in soil of more or less uniform resistivity. Moreover, a graphite surface is left exposed as the outer iron is consumed, so that the remaining iron with its graphite surface acts as a graphite anode, thus reducing the rate of iron consumption. Old engine blocks are examples. The anode cable connection remains the weak point.

5.3.4 Silicon iron

Silicon iron has been found to be a suitable anode material. It is expensive and extremely brittle, however, it is used on quite a large scale for groundbeds, and is in such applications, surrounded by a carbonaceous backfill.

5.3.5 Graphite

Graphite anodes have a low rate of consumption. The choice between graphite and silicon iron often depends on availability in a given area.

Graphite anodes are generally cylindrical in shape, though other forms are available. The graphite is impregnated with wax-or resin which reduces flaking or disintegration of the anodes as the graphite is consumed. The anodes are supplied with terminal connections, and with cables if required. The most commonly used sizes of graphite anodes range from 65 mm in diameter by 0.75 m long to 0.15 m in diameter by 1.8 m long.

When installed in soil, impregnated graphite anodes are generally used, with a backfill of carbonaceous material such as coke breeze. Provided this type of backfill is used, current densities of up to 11 A/m^2 of anode surface may be obtained. In sea water current densities also of up to 11 A/m^2 may be employed, but in fresh or brackish water the current densities should not exceed 2.7 A/m^2 in fresh water or 5.4 A/m^2 in brackish water. At these outputs the rate of graphite consumption is extremely low, but at higher outputs the surface of the graphite deteriorates excessively due to the formation of gas and this causes a higher rate of anode consumption. However, the current output can be increased temporarily, for example to provide initial polarization of the protected structure, without causing serious deterioration of the anode.

Graphite anodes are brittle and require careful handling during transport, storage, and installation. If much earthwork has been done on the site where the anodes are to be installed, the long graphite cylinders may be broken by subsequent earth movements due to consolidation, and in such instances, the anodes should be inserted in steel tubes, and the annular space packed with backfill.

5.3.6 Lead alloy

An alloy of lead, silver, and antimony (1% of silver, 6% of antimony) has shown promise for use in salt water. At a current density of 108 A/m^2 the annual consumption is about 85 g/A.

The alloy has good mechanical properties and can be cast or extruded to any desired shape.

5.3.7 Platinized titanium or platinized niobium

This anode material has been applied on a large scale in both salt and brackish water. It is not satisfactory for use in soil or in the mud or close to the sea bottom. Niobium and titanium themselves rapidly develop on their surfaces an adherent oxide layer of high electrical resistance. This oxide layer prevents corrosion of the metal, so that the titanium/niobium acts purely as an inert support for the platinum, which need be applied only to a relatively small area as it can withstand a very high current density. The titanium oxide is more sensitive to breakdown at an overvoltage than is niobium oxide.

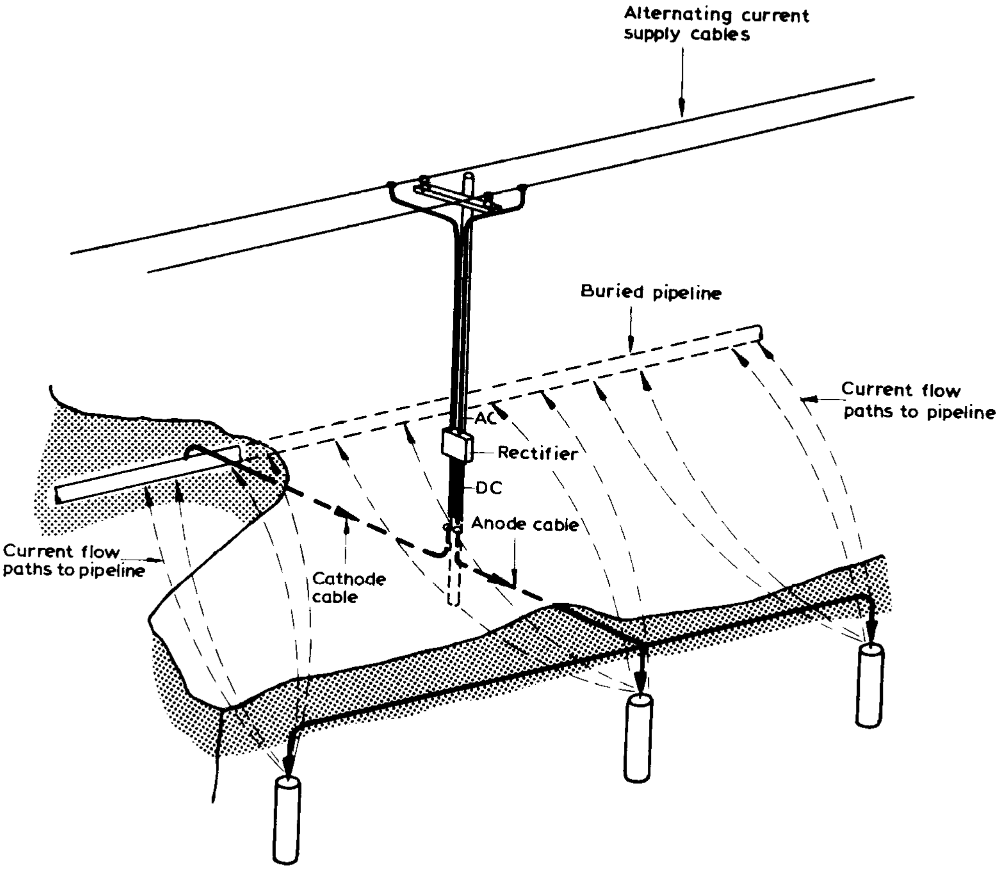
Platinized anodes have good mechanical properties and their higher initial cost is offset by their long service life.

Although the current density limit is high, up to 540 A/m^2, the anodes with titanium as a carrier shall be run at a low voltage, i.e. approximately 8-10 V maximum.

A further limitation is that the passage of an alternating current will bring about the rapid disintegration of the platinum layer. The ripple from the alternating current transformer-rectifier supplying current to such anodes shall be kept below approximately 5%. With a single-phase transformer-rectifier the ripple is frequently far in excess of this figure. The difficulty does not usually arise with three-phase transformer-rectifiers used for supplying current to platinized titanium anodes.

Provided the conditions regarding the current density, applied voltage, and ripple limitations Are Observed, The Platinum Layer Which Is Normally Only About 2.5 µm In Thickness Has A Life expectancy of 10 years. If longer life is required, a thicker platinum layer shall be used. It may still be too early to judge the suitability of platinized anodes for protection of systems for a 25- year or longer period.

Fig. 5-1 TYPICAL LAY-OUT FOR PROTECTION USING IMPRESSED CURRENT



6. COATINGS AND CATHODIC PROTECTION

6.1 INFLUENCE OF COATINGS ON CATHODIC PROTECTION CURRENT REQUIREMENTS

Although it is technically possible to protect bare (buried or immersed) steel structures and pipelines by applying cathodic protection only, it is seldom desirable to do so because of the cost of providing the large current required and, often the difficulty of arranging anodes so as to give a uniform current distribution. A good coating of high insulating value greatly reduces the current required to maintain the steel at the required steel-to-soil potential and also provides a more uniform spread of current from the anodes, see (10.3). A protective coating should therefore always be applied to any buried structure or pipeline which is to be cathodically protected.

6.2 INFLUENCE OF CATHODIC PROTECTION ON COATINGS

The current required to protect a structure or pipeline is approximately proportional to the area of bare steel. Theoretically, therefore, cathodic protection should be unnecessary when the steelwork is perfectly coated. In practice, coatings are often damaged in transport or during laying, or may contain imperfections such as pin holes. Even in low-corrosivity soils the slightest discontinuity in the protective coating may result in severe local corrosion, so that when corrosive conditions exist even coated structures or pipelines should be given cathodic protection.

Pipeline coatings of bitumen, coal tar or epoxy coal tar type are never much affected by properly applied cathodic protection. However, a potential more negative than -2.0 V with reference to a copper/copper sulphate electrode may damage the coating by causing hydrogen evolution on the steel surface.

Cathodic protection of painted or metal sprayed and painted structures should be considered carefully because oil-based paints may be saponified by the alkalinity developing at the cathodically protected surface; sprayed aluminium or zinc may be attacked in a similar way. The surface potential shall therefore be maintained as closely as possible to the value needed for protection, and over-protection avoided.

Recommended `off'-potential limits for underground coatings (to $Cu/CuSO_4$ half-cell) are:

Epoxy powder fusion-bonded	-1.5 V	Epoxy coal tar	-1.5 V
Asphalt enamel	-2.0 V	Polyethylene	-1.0 V
Tape wrap	-1.5 V		

7. INSULATING FLANGES AND RESISTANCE BONDS

7.1 INSULATING FLANGES

7.1.1 General

Pipelines which are to be cathodically protected should have an insulating flange at both ends, to prevent current loss to other installations. A typical insulating-flange assembly is illustrated in Fig. 7-1 Besides the type of gasket shown in Fig. 7-1, one without bolt holes and fitting inside the circle formed by the bolt shanks may be used. These are cheaper, but when they are used it is desirable, and in some cases essential to fill the space between the outside diameter of the raised face and that of the flange with a suitable insulant, e.g. a pipe coating material.

Both types of gaskets are available with a thin neoprene facing which helps to ensure a better seal. These should of course not be used in lines transporting liquids that may attack neoprene.

In other circumstances when the use of flanges is impractical, insulating joints are fitted. A typical example of an insulating joint is shown in Fig. 7-2.

Insulating flanges and joints should, as far as practicable, be located aboveground. Where this is not possible, they should be well-coated in order to prevent leakage of current through the soil.

7.1.2 Safety precautions

In hazardous areas where the insulating flanges are exposed, protective covers should be provided in order to avoid the risk of causing a spark by accidentally short-circuiting the resistance, e.g. by laying a tool across the flanges.

7.1.3 Offshore

Where the (steel) structure as well as the pipeline(s) are cathodically protected, insulating flanges are sometimes, left out. If pipelines are short interfield lines, this practice is not objectionable. Trunk lines should however always be electrically separated from structures as the impact of some local inadequacy of the (bare) structure protection would be enormous on the relatively small anodes used for the (coated) pipeline protection.

7.2 RESISTANCE BONDS

The use of an insulating flange will eliminate current flow to the unprotected part of the line but in certain circumstances stray current from the protection system may enter the isolated section at one point and leave it at another, thereby inducing severe corrosion at the latter point.

To prevent this, a resistance bond may have to be connected across the insulated flange, permitting sufficient protective current to flow to the isolated section of the line, and return via the resistance bond to the protected section, to overcome the effect of the stray currents.

The use of both insulating flanges and resistance bonds is considered In (7.3).

7.3 USE OF INSULATING FLANGES AND RESISTANCE BONDS

7.3.1 Isolation of section of a pipeline

The normal distribution of current flow from a groundbed or anode to a coated pipeline `AB' is shown in Fig, 7-3, Diagram A. Assuming that it is unnecessary to provide cathodic protection for the section `AC', Diagram B shows the effect on current flow of inserting an insulating flange at `C'. Section `AC' is no longer protected and the whole output of the groundbed is concentrated on section `CB'. The current density in this section of the line may then be larger than necessary, and it may he possible to reduce the output of the current source with a consequent saving in costs.

7.3.2 Isolation of branches

If cathodic protection is provided for a coated pipeline connected to an uncoated branch pipeline leading to say a buried structure such as a tank, a large proportion of the total current output from the groundbed will be drained away to the branch pipeline and buried structure.

This situation leaves the main pipeline under-protected. The condition could be corrected by installing a larger current source, but apart from the increased capital and operating costs this would over-protect the main pipeline. The recommended method is to insert an insulating flange in the branch line at its junction with the main line, thereby diverting the whole of the output of the groundbed to the main line.

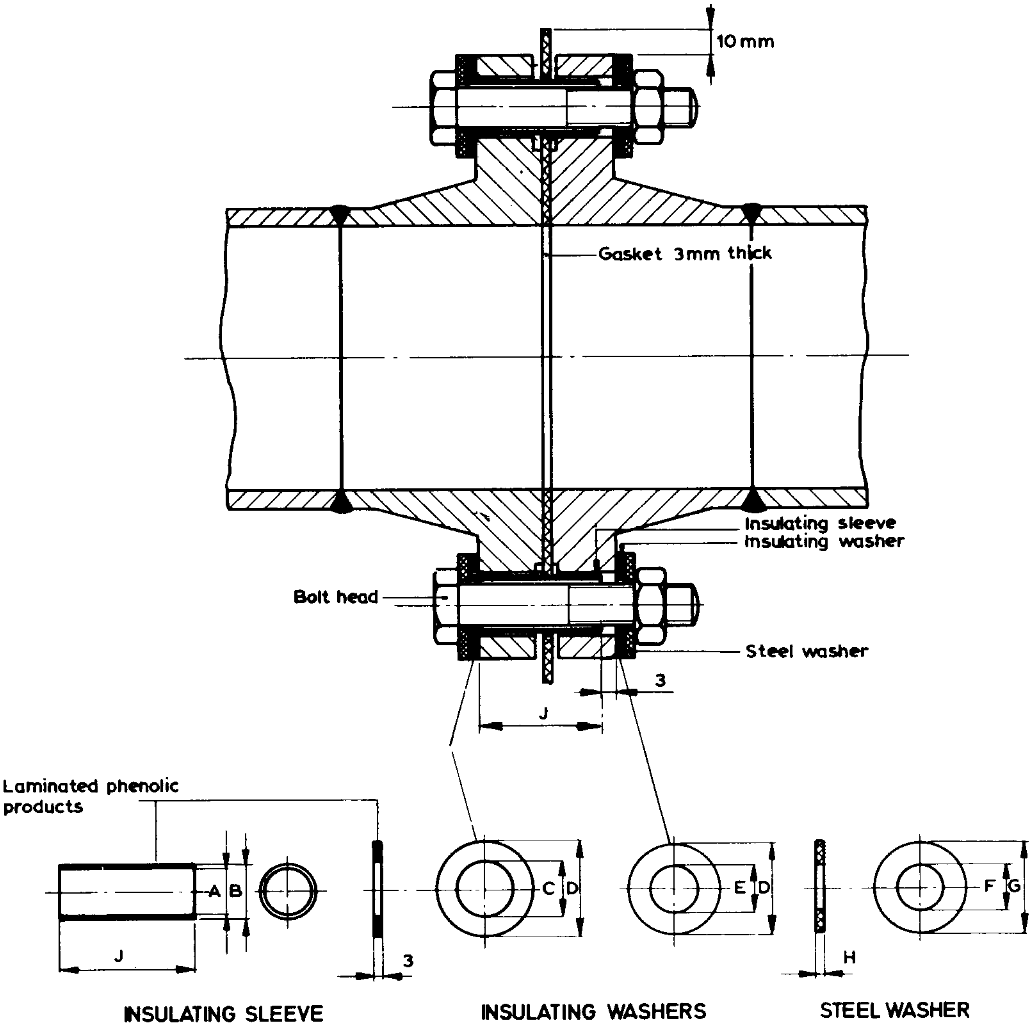
However, if the branch line is completely isolated from the main line, stray currents from the groundbed may still reach the tank, depending on the location of the anode, flow through the branch line to a point near the main, and return to the main through the soil. This would cause heavy corrosion at the point where the current leaves the branch line for the soil. If this cannot be prevented by proper groundbed location, the recommended procedure is to fit a resistance bond across the insulating flange. This will permit sufficient current to be taken by the branch line and tank to prevent serious corrosion to themselves, but will leave the major part of the current output available to give full protection to the main line. These conditions are illustrated in Fig. 7-4.

7.3.3 Isolation of casings at road and rail crossings

At road and rail crossings pipelines are often encased in sleeves of larger diameter pipe. Pipelines which are cathodically protected shall be isolated from the sleeve, as otherwise the sleeve would be protected but the carrier pipe would be shielded.

In practice, it is often difficult to maintain electrical separation of the pipe and the sleeve, and from the point of view of cathodic protection it is a great advantage if sleeves can be omitted.

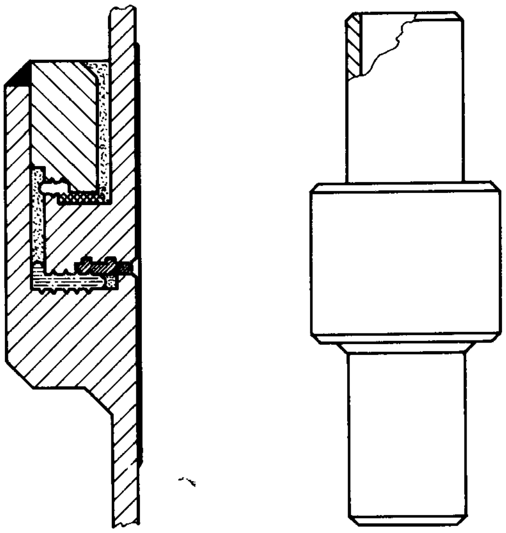
Fig. 7-1 TYPICAL INSULATING FLANGE ASSEMBLY



Diameter of bolts in.	Dimensions in millimetres									
	Diameter of bolt holes	Sleeves		Insulating washers			Steel washers			Diameter of spot face
		A	B	C	D	E	F	G	H	Minimum
1/2	19	14	16	17	29	14	14	29	2.5	30
5/8	22	17	19	20	35	17	17	35	3	37
3/4	25	20	22	23	41	21	21	41	3	43
7/8	29	23	25	26	48	24	24	48	4	49
1	32	27	29	29	54	27	27	54	4.5	56
1 1/8	35	30	32	33	60	30	30	60	5	62
1 1/4	38	33	35	36	67	33	33	67	5	68
1 1/2	44	40	41	42	79	40	40	79	5	81

Note : Use only raised face flanges
This design is suitable for ANS 150, 300 and 600 ratings

Fig. 7-2 TYPICAL INSULATING JOINTS



max. 150 atm.

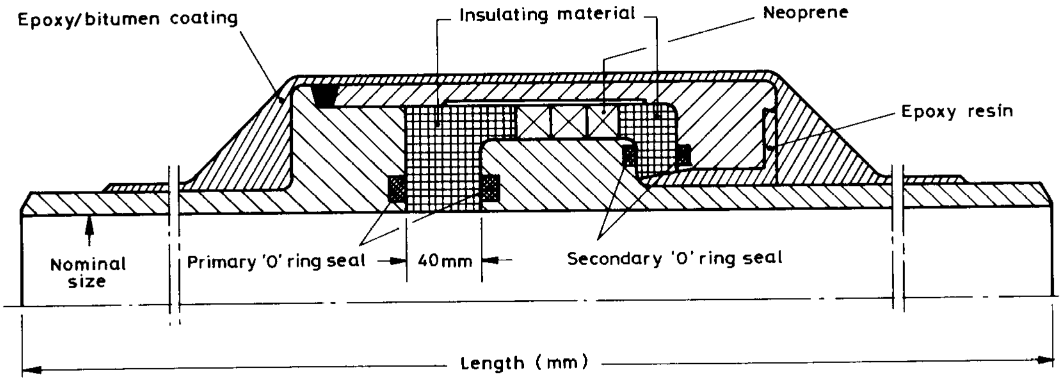


Fig. 7-3 ISOLATION OF COATED PIPELINE

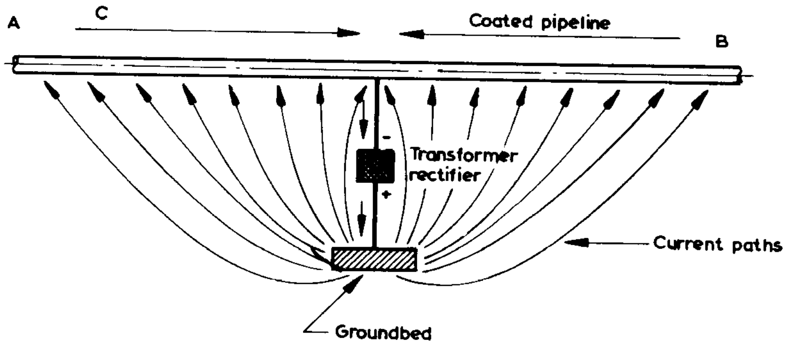


DIAGRAM A - NORMAL CURRENT DISTRIBUTION

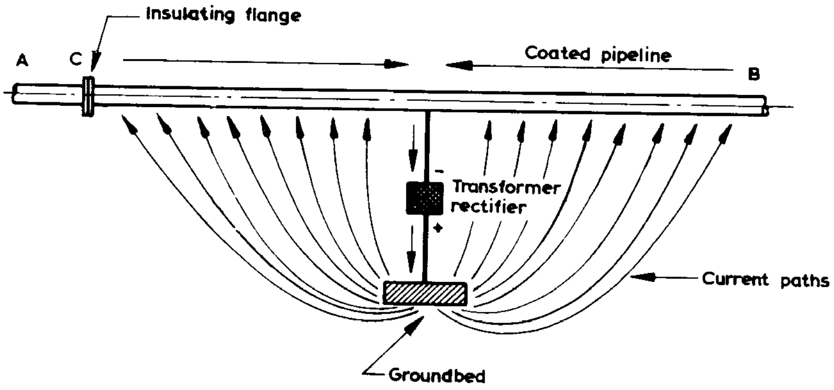
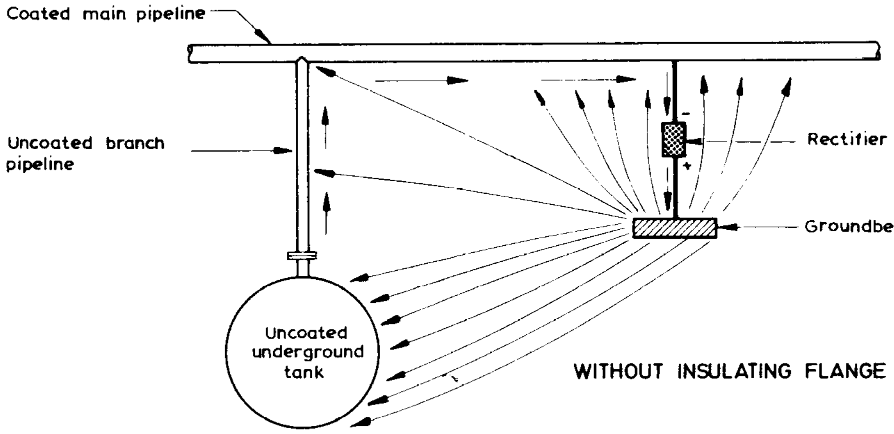
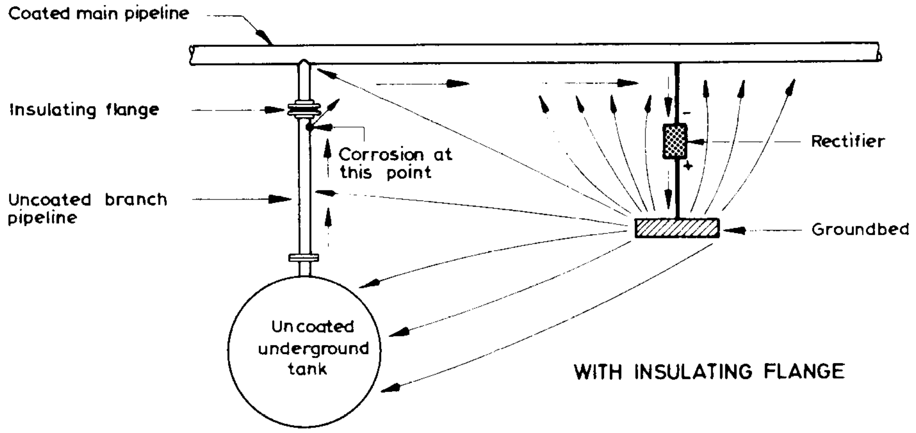


DIAGRAM B - EFFECT OF INSERTING INSULATING FLANGE

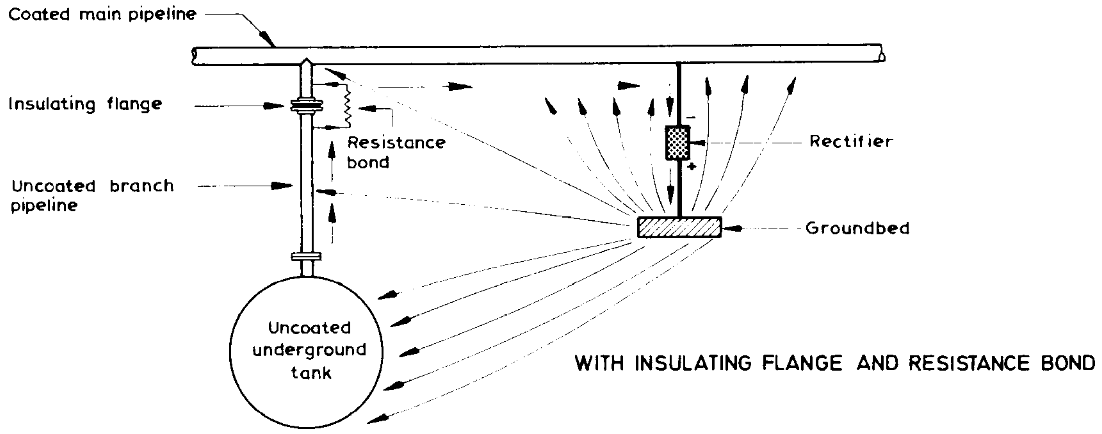
Fig. 7-4 ISOLATION OF UNCOATED BRANCH PIPELINE AND TANK



WITHOUT INSULATING FLANGE



WITH INSULATING FLANGE



WITH INSULATING FLANGE AND RESISTANCE BOND

8. ELECTRICAL INTERFERENCE EFFECTS

8.1 STRAY CURRENTS

The effect of stray currents in the soil or water causing corrosion has been mentioned briefly in (2.2) and illustrated in Fig. 2-2.

These stray currents are returning currents from large direct-current systems employing an earth or with an uninsulated return patch, such as a railway, tramway, welding generator, etc.; interruptions in the return path may multiply locally the strength of the stray currents. The most satisfactory method of dealing with stray currents would be to eliminate them at the source by suitable insulation or other means, but this is often impossible or extremely costly and it is then necessary to allow for the interference of stray currents when designing the cathodic protection system.

Only general information can be given here on the design of cathodic protection systems to guard against stray currents, as conditions vary so widely.

The main consideration is that the final steel-to-soil potential after the system is installed should be as uniform as possible over the whole of the protected structure or pipeline. To achieve this, extra rectifiers and anode systems shall generally be provided in the vicinity of the points where the stray currents leave the steel to re-enter the soil. In the case where these points are near the railway, e.g. at railway crossings, the exit of stray current can be prevented by connecting the structure, via a resistor and a rectifier, to the railway. This will make cathodic protection possible, as it considerably reduces effects of peaks in the stray current exit to earth. Potential-controlled rectifiers are often required. Railroad operators are often reluctant to provide connections as the signaling system could become adversely affected.

8.2 OTHER CATHODIC PROTECTION SYSTEMS

Electrical interference effects may also arise from cathodic protection systems themselves, mainly with impressed-current systems. Thus the current applied to a protected structure or pipeline may be picked up by a neighbouring and unprotected one, for example where a protected pipeline crosses an unprotected one as shown in Fig. 8-1. The unprotected pipeline becomes cathodic at the point where the current is picked up (A), and anodic at the point where the current eventually leaves the line (B), resulting in protection at `A' and corrosion at `B'. Since point `B' becomes anodic, the pipe-to-soil potential measured with a copper/copper sulphate electrode becomes more positive when the rectifier is switched on. A change to positive in potential of more than 50 millivolts when the rectifier is switched from `off' to `on' indicates an objectionable degree of stray current corrosion.

Electrical interference effects are negligible with sacrificial-anode systems, as these anodes are placed much nearer to the protected structure than to any unprotected steelwork and because their driving voltage is usually much lower than that of impressed-current system groundbeds.

8.3 REMEDIAL MEASURES

Measures against stray currents from outside sources have been mentioned in (8.1).

As regards interference effects arising from the currents intentionally put into the earth by protection systems themselves, it shall be ensured that neighbouring structures are not adversely affected.

Sometimes interference can be prevented by bonding the neighbouring structure or pipeline to the protected one, so that electrically the two become a single unit, and then applying cathodic protection to the combined unit. This is the recommended method for use where structures are close together, as for example a pipeline which is lying in a common right of way with neighbouring pipelines. For a combined system of this type a decision should be reached with other owners or operators before the cathodic protection system is designed and installed.

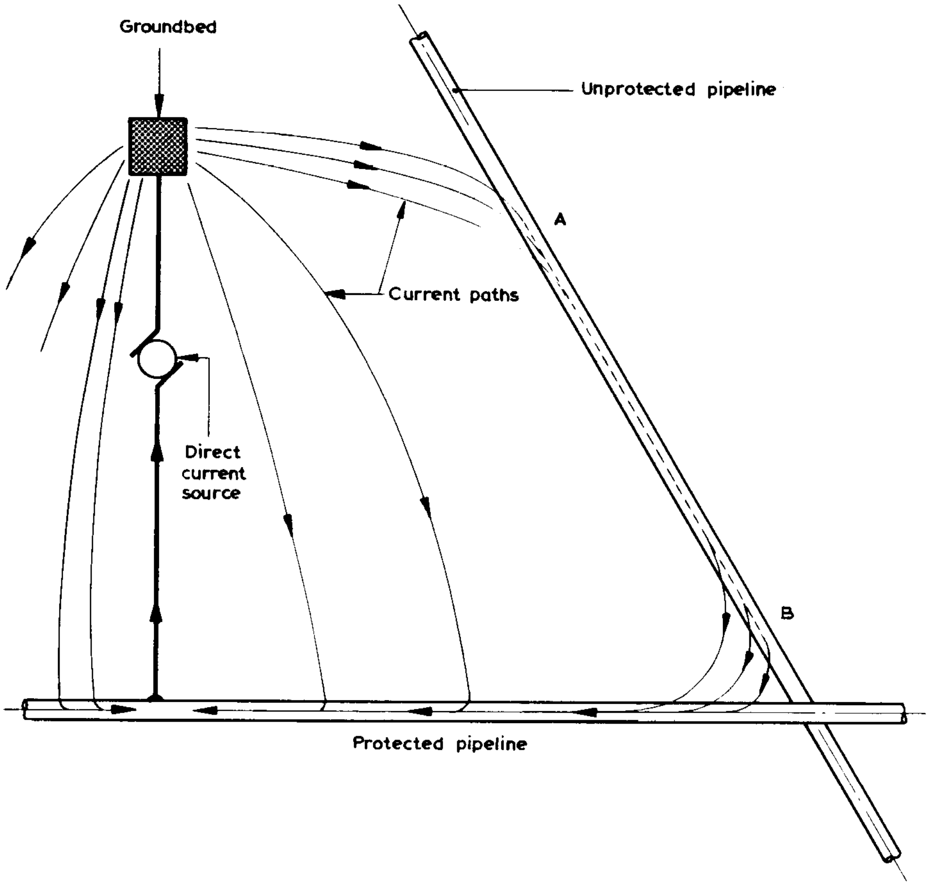
The first step is to determine whether the second structure is adversely affected. This is done by noting if any change occurs in the steel-to-soil potential of the unprotected structure when the cathodic protection current is switched from `off' to `on'. Measurements should be taken where the current may be expected to leave the unprotected structure, which is the place where the structures are nearest to each other. If the steel-to-soil potential becomes more positive, i.e. anodic, by 50 millivolts or more when the cathodic protection is switched `on', the unprotected structure is liable to increased corrosion as a result of the operation of the protection system.

The application of resistance bonds to eliminate corrosion by interference is based upon the principle that the current collected by the unprotected pipeline should be conducted via a metallic conductor to the protected structure. The electrical resistance of this bond is made high enough to prevent too much current from flowing to the unprotected structure. The resistance bonds are installed where the structures are nearest to each other and controlled so that no current leaves the unprotected structure to earth; this is checked by measuring the pipe-to-soil potentials of the unprotected pipe with rectifier current `off', and `on'.

8.4 OTHER SOURCES OF INTERFERENCE

Telluric currents and induced alternating currents can be of particular importance on transmission pipelines. The effects and remedies are dealt with in Section 10.

Fig. 8-1 EXAMPLE OF CURRENT PICK-UP BY NEIGHBOURING STRUCTURE FROM CATHODIC PROTECTION SYSTEM



9. MONITORING CATHODIC PROTECTION SYSTEMS

9.1 GENERAL

After a cathodic protection system has been installed it should be checked periodically to ensure that the equipment is functioning correctly and that the protected structure is being maintained at the required potential.

Changes may occur due to causes such as deterioration of coatings, changes of soil resistivity with seasonal rainfall, changes in the resistance of groundbeds, anode wastage, etc.

Besides, the detailed information related to the design, construction and commissioning of the installation, records should be kept of current outputs and protective potentials. The data shall be analysed after each survey and corrective action taken soonest but within one month. Whenever a cathodic protection system is installed the necessary instruments should be purchased to enable the engineer-in-charge to make the required measurements, see (3.).

After a protective current has been applied, whether by an impressed-current cathodic protection system or by the use of sacrificial anodes, polarization of the protected structure occurs, causing a gradual fall in current requirements. The rate at which polarization occurs depends on the nature of the medium surrounding the structure and on the current density; the time elapsing before the current requirement falls to a steady value while maintaining the structure at the desired potential may vary from a few days to many months.

9.2 IMPRESSED-CURRENT SYSTEMS

During the polarization period with impressed-current systems, regular checks of structure potential and transformer-rectifier output should be made in order to avoid gross over-protection.

The frequency of subsequent T/R readings depends on the reliability of the power supply. Readings taken once per fortnight are often chosen to start with.

Once the trend has been established the period between readings can be increased. Once the steady state has been achieved 2-monthly or 3- monthly intervals should suffice.

During the polarization period the current output of the transformer-rectifiers should be progressively reduced to maintain the steel-to-soil potential at its desired level.

Particularly in high-resistivity soils voltage drop through the soil as a result of applied current for cathodic protection can be considerable. As a result the potentials measured on the surface over the pipe whilst the current is `on' will not reflect the potential at the pipe surface.

In order to measure a more true potential the current is switched off momentarily, the potential (the `off' potential) is measured immediately after interruption (within seconds). This potential is not affected by any voltage drop in the soil. Transformer-rectifiers can be obtained with automatic and synchronizable interrupters for this purpose.

9.3 SACRIFICIAL ANODES

During the polarization period, regular checking of potentials shall be carried out to obtain early warning in case the system is inadequate.

The potential of the protected structure can never become more negative that the anode potential itself. The latter is usually well within the range of acceptability.

Current output from the anodes is self-regulating since with further depressed potentials of the structure, the driving force between anode and cathode becomes smaller. This automatically results in a lower current drain. Calculation will show that zinc and aluminium anodes can provide approximately twice the design current at the very start of the polarization period, with the advancement of the polarization the current gradually reaches the equilibrium state (which could be lower than the design current drain).

With anodes used suspended under water and accessible, an indication of the probable remaining life can be obtained by periodic lifting and weighing. A comparison of the rate of wastage will also show the extent to which individual anodes are contributing to the protective system.

When sacrificial anodes are used to protect condenser end-plates, box coolers, and similar equipment, visual inspection together with potential measurements provide a method of checking.

9.4 LINE CURRENT MEASUREMENTS

To obtain data for the calculation of coating resistivity or on current flow and distribution in a complex pipeline network, line currents are measured. The differences in the pipe-to-soil potential measurements along the pipeline, together with the known resistance of the pipe, can be used for calculating the current flowing in the pipeline by applying Ohm's law. Such currents in the line are generally due to the nature of the soil surrounding the pipe, though they may also be caused by stray currents from direct-current traction systems or other electrical systems in the neighbourhood, see (8.).

The steel pipe resistance is given in Fig. 10-2. Unless very high currents flow, the measured voltage drop over a certain length of pipe is very small. Such measurements may therefore suffer from considerable error.

10. PROTECTION OF BURIED PIPELINES

10.1 GENERAL

Whenever submarine or buried pipelines are to be laid, cathodic protection should be considered as anti-corrosion measure supplementary to the protective coatings described in DEP 30.48.00.10-Gen.

The corrosion history of other pipelines or steel structures in the neighbourhood will often indicate the degree of corrosion to be expected, but a soil survey may be necessary to provide sufficient data for a rational installation design.

The provision of a cathodic protection scheme should be considered early, at the pipeline design stage, and should not be added as an afterthought when the pipeline is completed, but be ready the moment the pipeline is constructed.

For an old line already showing signs of corrosion, a current-drainage test is often the best and quickest method to assess the insulating value of the coating.

Whenever a cathodic protection system is installed, regular records should be kept of pipe-to-soil potentials, voltage and current readings of rectifiers, and current output, where possible, of sacrificial anodes. Such data can provide valuable information on the general condition of the pipe coating, see (9.).

The presence of sulphate-reducing bacteria shall always be considered and in regions where there is evidence of their presence or the character of the soil favours their growth, the pipe-to-soil potential should be maintained at a value not more positive than - 0.95 V with reference to the standard copper/copper sulphate electrode, see (2.3).

10.2 CHOICE OF SYSTEM

10.2.1 General

An impressed-current system is usual for the cathodic protection of buried pipelines. Dependent on the price and availability of electric current and the terrain through which the pipeline passes, sacrificial anodes may sometimes be considered. In other cases power may be generated through solar panels, by windmills or otherwise.

An indication of current-density requirements for steel in different media is given in (2.3.3).

10.2.2 Impressed-current system

The choice of anode material is governed by local circumstances. The characteristics of the various types of anodes are described in (5.3).

The most suitable sites for groundbeds can best be determined by soil-resistivity measurements. The groundbed resistance should be as low as possible, and therefore they should always be located in low-resistance, permanently moist soil.

The installation of potential-controlled rectifiers should be considered in cases where stray currents play a role.

10.2.3 Sacrificial anodes

The use of sacrificial anodes is preferred when one or more of the following conditions apply:

- There is a lack of trained personnel to maintain the electrical equipment associated with impressed-current systems.
- The pipeline route is unsuitable for the disposition of the cables, transformer-rectifiers, and groundbeds required for impressed current.
- A current supply is not available or the source is so distant that cable costs are excessive.
- Cathodic protection is to be applied only at `hot spots', e.g. at pockets of low-resistance soil in an otherwise generally high-resistance soil.

- The pipelines are in a highly congested area where an impressed-current system could cause interference with other buried steel structures.
- The pipeline is submarine or in low-resistivity marsh.

The method for installing sacrificial anodes is described in (4.4),

10.3 COATINGS

The relationship between coatings and cathodic protection is described in (6.).

Pipeline coatings should be made as near perfect as economically acceptable. Cathodic protection should never be regarded as a substitute for adequate coating and wrapping. Tape coatings however are reason for concern, although often sold as easy to apply and not sensitive to inexperienced applicators, many problems have arisen. These originated from omission of primer, lack of adequate tape overlap, uneven application leading to wrinkles and blisters, poor application of rockshield or even omission of it and the use of coarse backfill instead of sand. As a result taper disbond (always a problem at the overlap) and cathodic protection currents are shielded. If the coating is defective, the initial cost of the cathodic protection installation will be unnecessarily high and progressive deterioration of the coating leads to an increasing current demand in order to maintain the protective pipe-to-soil potential.

Apart from increasing current costs, such circumstances may necessitate additions to the transformer-rectifier and groundbed systems, or the installation of an increasingly uneconomic number of sacrificial anodes. Interference, too, will become increasingly difficult to combat if any increase in groundbed current output is required.

The effect of pipe coating quality on the spread of protective potential from a groundbed is shown in Fig. 10-1.

10.4 ATTACHING CABLES

The accepted method of attaching cathodic protection cables to a pipeline is by means of thermit welding, as for other structures. However, in order to avoid detrimental effects, particularly on pipes made of high-strength steel, the thermit charge should be no bigger than 15 g, nor the cable heavier than 16 mm^2. If it is necessary to attach heavier-cable, then the strands should be separated into groups with a cross section no larger than 16 mm^2 and each group be attached separately to the pipe. Alternatively the heavier cable could be thermit-welded without restrictions, to a doubler plate which can then be attached to the pipe by welding.

10.5 TELLURIC CURRENT

Geomagnetic field variations associated with the ionospheric currents establish large-scale systems of electric currents within the earth by a process of electromagnetic induction. The global pattern of these currents flowing near the surface of the earth is known to be extremely complex due to factors such as the wide range of electrical conductivities of different strata.

The frequency of the fluctuations has been recorded to be a matter of one per several hours.

A pipeline of considerable length being positioned favourably could pick-up and discharge telluric currents. If the current picked-up is considerable in comparison with the total current applied for corrosion prevention (which could be the case with a very well-coated pipeline in high-resistivity soil) the effect of telluric current on such a system would become noticeable and may have to be corrected.

A number of countermeasures can be taken to combat ill effects from telluric currents. Sectioning the line by insertion of insulation flanges or joints will reduce long line current flow. Installation of discharge points by providing zinc or magnesium anodes at strategic locations will reduce the risks of corrosion at discharge of current at coating imperfections.

It is strongly recommended to obtain expert advice if a case is found suspect.

10.6 ALTERNATING-CURRENT EFFECTS

Alternating currents induced in pipeline systems running parallel with power lines especially, have no influence on the corrosion of the cathodically protected lines but can generate voltages that require mitigation.

It is not uncommon that pipelines and power transmission systems share a right of way. Rules and regulations exist for guidance on earthing of the power transmission system and the distances to be maintained between these and the pipeline(s) in question.

If routing the pipeline close and parallel to an overhead high-voltage system cannot be avoided, a study should be conducted by experts to determine which sections of the pipeline are influenced by a short circuit to earth and to what extent.

In several countries safety recommendations have been published; the more detailed ones are:

- Verband Schweizerischer Elektrizitatswerke (SEV)
  `Richtlinien für Sicherheitsmassnahmen bei der Annüherung von Starkstromanlagen an Rohrleitungsanlagen zur Beförderung flüssiger oder gasförmiger Brenn-und-Treibstoffe'.
  Association of Swiss Electricity Board (SEV), `Guidelines for safety
  measures in case of proximity of oil and gas pipelines with high-tension systems'
- in Germany: `Technische Empfehlung Nr. 7'
  `Massnahme bei Bau und Betrieb von Rohrleitungen im Einflussbereich von Hochspannungsleitungen'.

  `Technical recommendation No. 7'
  `Measures during construction and operation of pipelines within the area of influence of high-tension lines'

Some of the main distances that should be maintained are:

- during the construction of a pipeline, it should be separated from the vertical projection of the nearest high-voltage line by at least 10 m for safety reasons
- valve stations, safety releases, etc., projecting above the ground are not to be installed within 30 m
- between the pipeline and the earthing pit of the transmission tower the minimum distance shall be additional 3 m for a max. earth-fault current of 5 kA, plus 0.5 m for every additional kA.

Special attention should be paid to the cathodic protection of pipelines and the overvoltage protection for rectifiers.

At valve stations a steel net buried around the valve and electrically bonded to the pipelines may be required for the protection of personnel.

It is generally advisable to discuss special requirements with the local power company or the labour inspectorate; especially during construction of a pipeline restrictive regulations may be imposed by the local power company.

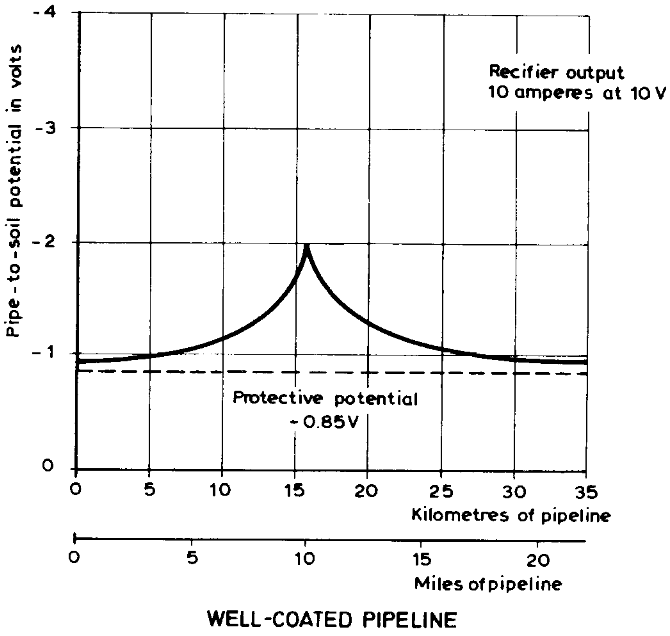
Apart from AC high-voltage overhead lines, danger can also result from electric railways and tramlines. To predict the extent of the influence a detailed study by a specialized firm will be required.

10.7 PIPELINE GROUNDING

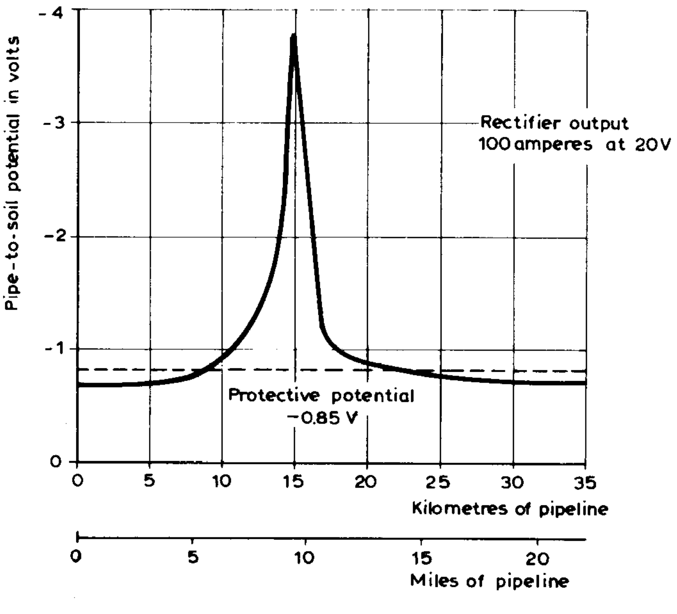
The most effective location for a grounding installation on a buried pipeline is at a point where the induced voltage is maximum. A good ground established at such a point serves to null the local exponential voltage distribution. However, the mitigating effects of this ground installation are negligible at an adjacent voltage peak located more than 8 to 10 km away. (The exact distance is a function of the pipeline characteristics.) Therefore, a ground should be established at each induced voltage maximum.

Effective reduction of the induced AC potential on a buried pipeline requires a very low grounding impedance, generally of the order of one to two ohms or even less.

Fig. 10-1 PIPE-TO-SOIL POTENTIAL DISTRIBUTION ON WELL,-COATED AND BADLY-COATED PIPELINES



WELL-COATED PIPELINE



BADLY-COATED PIPELINE

Fig. 10-2 STEEL PIPE RESISTANCE

Pipe size inches	Outside diameter inches	Wall thickness, inches	Weight per foot, pounds	Resistance Micro ohms per foot	Micro ohms per meter
2	2.375	0.154	3.65	79.2	260.
4	4.5	0.237	10.8	26.8	87.9
6	6.625	0.280	19.0	15.2	49.9
8	8.625	0.322	28.6	10.1	33.1
10	10.75	0.365	40.5	7.13	23.4
12	12.75	0.375	49.6	5.82	19.1
14	14.00	0.375	54.6	5.29	17.4
16	16.00	0.375	62.6	4.61	15.1
18	18.00	0.375	70.6	4.09	13.4
20	20.00	0.375	78.6	3.68	12.1
22	22.00	0.375	86.6	3.34	11.0
24	24.00	0.375	94.6	3.06	10.0
26	26.00	0.375	102.6	2.82	9.25
28	28.00	0.375	110.6	2.62	8.60
30	30.00	0.375	118.7	2.44	8.0
32	32.00	0.375	126.6	2.28	7.48
34	34.00	0.375	134.6	2.15	7.05
36	36.00	0.375	142.6	2.03	6.66

Based on steel density of 489 pounds per cubic foot and steel resistivity of 18 microhm.cm

11. PROTECTION OF UNDERGROUND TANKS

11.1 GENERAL

The protection of buried tanks (e.g. tanks at gas stations or mounded LPG tanks) is basically similar to the protection of buried pipelines. A coating as specified in DEP 30.48.00.10-Gen. provides the primary protection. As with pipelines, it is impractical to provide a perfect coating and, in addition, damage may be caused during the handling and burying of the tank. The small areas of steel thus exposed can often be conveniently and economically protected cathodically.

For the protection of a few tanks only, the use of sacrificial magnesium-alloy anodes is recommended. The number of anodes required can be determined as described in (4.3).

For the protection of a larger number of tanks, an impressed-current system may be a more economic choice. The calculation of current requirements, siting of the anodes, interconnection of tanks by bonds, and correct placing of insulating flanges in a complicated system of pipework, will generally be a task for a cathodic protection specialist.

11.2 PROTECTION BY SACRIFICIAL ANODES

11.2.1 Siting of anodes

Anodes should preferably be sited on a line normal to the long axis of the tanks at a distance of about 5 m from the outside surface of the tank; if two anodes are used one should be positioned on each side of the tank. For a well-coated tank the siting of the anodes is not critical, and they may be sited to suit conditions, at a distance of approximately 3-6 m from the tank.

The anodes should be buried at a depth which places them in permanently moist soil.

11.2.2 Method of attachment

The lifting lugs situated at either end of the tank provide convenient points of attachment for anode cables. The lugs should be scraped carefully to expose the bare metal, and the cable end attached by bulldog camp or by thermit welding; the coating should then be made good.

For tanks which are already buried, the cable can be connected to the vent pipe.

The cables from the tanks should preferably be connected to the cables from the anodes via a measuring box, including a measuring wire from the tank to enable periodic checks of the steel-to-soil potential to be made, as well as current measurements of the anodes.

11.3 PROTECTION BY IMPRESSED CURRENT

11.3.1 General

For a large group of tanks, an impressed-current system of protection is often the most suitable and a more economic solution. The need for frequent checks should however not be overlooked.

An even spread of protection shall be ensured by suitable distribution of the anodes.

11.3.2 Anode materials

Graphite or high-silicon cast iron anodes are recommended.

11.4 INSULATING FLANGES AND JOINTS

Insulating flanges or joints should be installed in the lines to and from the tanks if no requirement is foreseen for cathodic protection of those lines. The insulation shall be placed close to the tank.

Provided the buried lines have a good coating, the whole system can be taken up in the cathodic protection.

For an underground tank connected to a filling station, an insulating flange or insulating joint in the filling line at the pump is sufficient, but buried sections of the filling line and any other pipes should be well-coated and not in contact with other metal structures.

After assembly, the resistance across the flange or joint should be checked with one end free of contact with the soil or any equipment to ensure that the insulation has not been damaged during fitting.

12. PROTECTION OF SUBMARINE PIPELINES

12.1 GENERAL

The low and uniform resistivity of sea water simplifies design of protection systems for submarine pipelines.

Sacrificial anodes placed in the form of bracelets around the pipe is the preferred method. In any case an insulation shall be inserted at both ends of the pipeline preferably above the highest high-water mark, to prevent current drainage from the landward part of the pipeline system and the offshore facility at the other end. For short lines between fields, insulation may be omitted.

Submarine lines are seldom close enough to other structures to interfere with them, although old steel wire rope, anchor chains, wrecks, etc., on the sea bed and in contact with the lines will cause difficulties by draining the protective current if in metallic contact.

The use of impressed-current systems should be kept at the very minimum.

12.2 METHODS OF APPLICATION

12.2.1 Current requirements

A current density of about 160 mA/m^2 of bare steel is necessary during the first weeks of operation to form a calcareous layer on the pipe. This layer acts as an insulating coating and reduces the current density required to maintain full protection to between 45 and 55 mA/m^2 provided that the line is not purposely or accidentally buried in mud, in which case the figures would be reduced to 20 mA/m^2.

The total current required depends on the area of bare steel on the pipeline to be cathodically protected, and for this reason submarine pipelines should be well-coated before laying.

The current required to protect a coated line depends on the area of steel in contact with the electrolyte, which is in turn dependent on the quality of the coating. For estimating current requirements, the area of exposed steel on a new line coated to conform to the recommendations given in DEP 30.48.00.10-Gen. may be assumed to be between 2 and 5% of the total external surface area. This figure is dependent on conditions during the application of the coating and on the estimated coating damage which may occur during the laying of the line and the presence of a weight coating. For existing pipelines on which the original coating has deteriorated, it may be necessary to use a higher area than 5%, depending on the estimated extent of the deterioration.

12.2.2 Sacrificial anodes

For protection of submarine pipelines by sacrificial anodes the latter are normally applied as `bracelets', see Fig. 12-1, at intervals along a new line. Zinc is the standard bracelet anode material.

For the installation of anodes on pipelines operating above 50 °C an alternative approach is required to prevent undue consumption or potential reversal. The anodes are then used in blockform and placed alongside the line with a cable connection to the line. Specialist advice shall be sought for further details.

12.2.3 Impressed current

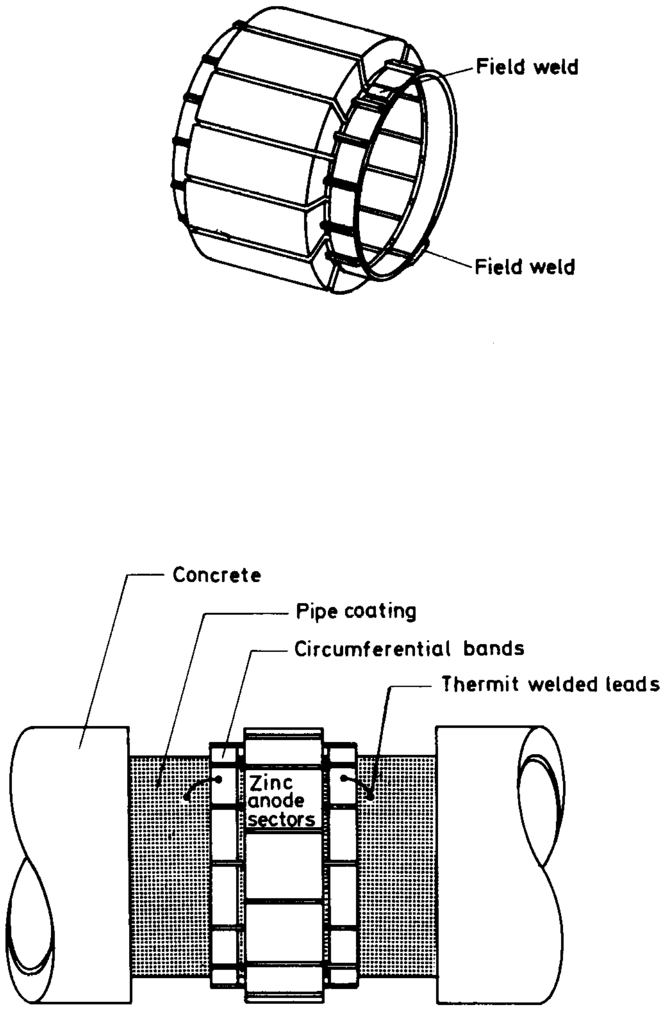
An impressed-current system comprises a transformer-rectifier, with anodes placed in the sea below the low-water mark at the shore end of the pipeline at a distance of 90-150 m from the line. With impressed-current, the current output can be adjusted, first to obtain the high initial output needed to polarize the line and build up the calcareous coating, and subsequently to give the steady lower output required for normal operations. The distance over which such a system can work effectively is at best 40 km from the drain point.

12.2.4 Potential measurements

Unless a submarine pipeline is readily accessible for divers, potential measurements are costly to carry out. Nevertheless the pipe potentials are the only indicators to judge the adequacy of the protection. Potential measurements taken close to the pipe are the most accurate and informative. Contact with the pipe can be made at anode bracelets.

A number of techniques is available that claim to measure accurately the potential gradients around a submarine pipeline. From these measurements the presence of coating defects and their severity is deducted. In addition some information on potential is obtained. The accuracy of these measurements is low and their value limited contrary to what is advertized. As these measuring systems are relatively new, improvements can be expected.

Fig. 12-1 TYPICAL ZINC BRACELET FOR UNDERSEA PIPELINES



Note: Bracelet is mounted over the pipe coating and is connected by thermit welded leads to the pipeline proper.
After fixing the anode, the spaces between it and the existing concrete to be filled with either concrete or hot mastic.
The circumferential surface of the anode shall not be covered.
Care shall be taken not to bring reinforcing of the weight coat in contact with pipe or anode.

13. PROTECTION OF MARINE STRUCTURES

13.1 GENERAL

The term marine structures covers a large variety of objects such as piers, jetties, dolphins, offshore drilling and production platforms.

Corrosion is at maximum at a small distance below the water line and gradually decreases with depth. In mud, corrosion is usually much less severe. The submerged steel surface and the steel in the mud can be cathodically protected.

Corrosion in the spray zone above water level may be severe and protection shall be given by the use of coatings and adequate corrosion allowance.

13.2 METHODS OF PROTECTION

13.2.1 General

Either sacrificial anodes or impressed-current systems or a combination of both may be used to protect marine structures. The use of impressed-current systems should be done with utmost care as the risks for inadequate protection are considerable.

13.2.2 Current requirements

Current required for cathodic protection varies with oxygen content and flow conditions of the water, see (2.3.3). In the case of doubt, expert advice should be sought.

13.2.3 Impressed current

An impressed-current system may be provided with scrap iron anodes, suspended or on the sea bed, or with suspended platinized titanium anodes, the anodes being located in such a way as to obtain a uniform current distribution. A typical diagram of a cathodic protection system for the sheet piling of a pier is given in Fig. 13-1. The pier consists of an earth fill enclosed by sheet steel piling which has been coated with epoxy coal tar. Both water and soil sides receive current from anodes located facing the respective sides.

Application of an impressed-current system on steel offshore platforms shall be done with utmost care. The mechanical weakness especially of such systems and the design aspects related to polarization current require expert advice.

13.2.4 Sacrificial anodes

It is frequently far more attractive, for reasons of the high degree of dependability, the immediate availability and subsequent maintenance, to use zinc or aluminium anodes for cathodic protection. These can be fixed prior to placing the structure. The system can be designed to last for any length of time.

For offshore structures aluminium mainly is used as this material provides the highest long-term output per unit weight.

13.3 PRECAUTIONS

13.3.1 General

When marine structures are cathodically protected, adequate precautions shall be taken to avoid interference effects when using impressed current and also to ensure that danger does not arise through the production of sparks when ships, barges, etc.,make or break electrical contact with the protected structure, see (17.).

Marine conductors (protective pipes through which wells are drilled) are often closely packed in the conductor bay area. Care shall be taken that adetquate current densities are available for the protection of the marine conductors. Full electrical continuity may not always be provided and special measures may be required to ensure this.

13.3.2 Interference

The effect of the cathodic protection impressed current on other structures should be checked, and, if some influence is found, these structures should be protected by draining a small current through a resistance bond, see (7.2) and (8).

13.3.3 Potential limits

A potential no more negative than - 1200 mV to Ag/AgCl is acceptable for low-strength steels. In all other cases advice from specialists shall be sought together with authorities' approval.

13.4 EXAMPLE: OFFSHORE STRUCTURE CATHODIC PROTECTION DESIGN

13.4.1 Design data

Total surface area	10 000 m^2 in water 1000 m^2 in mud 5 oil wells
Current density (2.3.3) North Sea-northern	100mA/m^2 in water 20 mA/m^2 in mud 5 Amps per well
Design life	25 years
Aluminium anode consumption	3.6 kg per Amp year (aluminium indium)
Anode potential	-1.1 V to Ag/AgCl

13.4.2 Anode weight/number

Total current required 10 000 x 0.100 + 1000 x 0.02 + 5 x 5 = 1045 Amps
During a period o f 25 years: 1045 A x 25 years = 26 125 Amp years
Anode weight required 26 125 x 3.6 = 94 050 kg
Weight per anode (standard size) 330 kg nett
Number of anodes (244 x 25.2 x 24.4 cm^3) 285 pcs

13.4.3 Check on maximum current output anodes

Refer (4.3.3.3) formula $R = \left(\frac{\rho}{2\pi L} (\ln \frac{4L}{r} - 1) \right)$

in which : R = 0.0635 in the new state

R = 0.0686 when halfway through its life

R = 0.0800 at the end of its life (core only)

Driving voltage on protected structure : 1100-800 = 300 mV

on new structure : 1100-700 = 400 mV

Anode outputs at the respective driving voltages:

at launch $\frac{.400}{0.0635}$ = 6.30 A: for 285 pcs 1795 A

halflife / protected $\frac{.300}{0.0686}$ = 4.37 A: for 285 pcs 1246 A

endlife / protected $\frac{.300}{0.08}$ = 3.75 A: for 285 pcs 1068 A

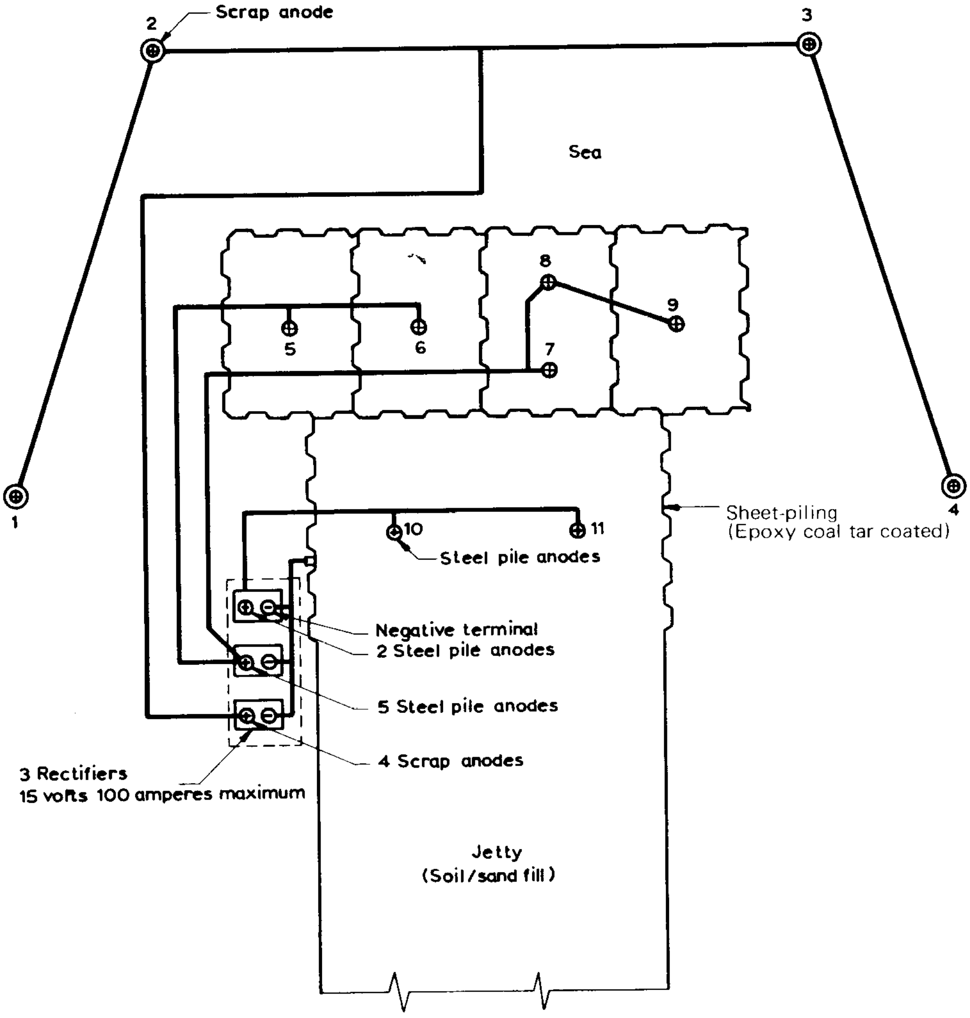
The above indicates that anodes can deliver sufficient current throughout their life and that initial current density at launch can reach a level of approximately 175 mA/m^2 which is considered as sufficiently high.

Assuming that polarization takes place within the first year after which anode dimensions should still be as new, the structure potential will change to a more negative value so that the (assumed) equilibrium current density of 100 mA/m^2 is received:

$\frac{1045}{285}$ = 3.67 A / anode, so driving force = 3.67 x 0.0635 = .232V, thus 285 the

expected structure potential becomes -.867 V.

Fig. 13-1 TYPICAL DIAGRAM SHOWING CATHODIC PROTECTION OF JETTY



14. PROTECTION OF HEAT EXCHANGERS

14.1 BOX COOLERS

14.1.1 General

Because of the high water temperature and the heavy current requirement, an impressed-current system is recommended for the cathodic protection of box coolers, although the space available for the anodes is small and their dimensions and numbers will need to be limited.

The high water temperatures prevailing in box coolers, often over 40 °C make the self-corrosion rate of magnesium too high to allow sacrificial magnesium alloy anodes to be used satisfactorily.

Zinc anodes are unsatisfactory because they supply too low a current and at higher temperatures their polarity with respect to steel may be reversed, see (4.2).

14.1.2 Current requirements

With sea water as the cooling medium and water temperatures of up to 45 °C, the current density required for the cathodic protection of steel is 110-220 mA/m^2.

The walls of the box cooler are usually gunited and the current required for protection is then negligible.

To calculate the current required for cathodic protection for a specific case tests may be done, but a calculation using the data given above is usually sufficient.

Because of the close proximity of the anodes to the cathodically protected tubes, tube-to-water potentials should be used with caution, and the points where these check measurements are taken should be as remote as possible from the anodes.

The tube-to-water potentials should be maintained at -0.85 V with reference to the standard copper/copper sulphate electrode.

14.1.3 Anode materials

As stated in (14.1.1), the space available for the anodes is small and their dimensions and number shall be limited.

Because of their small size and the ease with which they can be fabricated to special shapes, platinized titanium anodes are particularly suitable for use in box coolers with either fresh or salt water.

14.1.4 Checking

To check whether anodes are performing satisfactorily, it is recommended that facilities are provided for measuring the current in the leads to the anodes.

The adequacy of the number and distribution of anodes in a box cooler should be ascertained by measuring tube-to-water potentials. An additional check can be obtained by means of test coupons installed in the box and connected to the cooler by a cable.

14.2 SHELL-AND-TUBE HEAT EXCHANGERS

Carbon steel parts in shell-and-tube heat exchangers using corrosive water as a cooling medium, should be protected from galvanic attack stimulated by the non-ferrous tube plate by fitting either zinc or magnesium anodes. In strongly corrosive water, such as sea water, zinc is used. For less corrosive water magnesium is more suitable. The size of the anode chosen will depend on conditions in each case, but it shall in any case not be so great as to interfere with the water flow.

Methods of fixing the anodes are shown in Standard Drawings S 21.072 and S 21.073.

15. PROTECTION OF OIL WELL CASING

15.1 GENERAL

The cause of casing corrosion may be related to the presence of sulphate-reducing bacteria, acidic water, or corrosion cells set up between formations containing water of different salt content or between casing and flow lines.

Leaks which develop in the casing of a well constitute a serious problem and are expensive to repair. Damage may also be inflicted to the annulus by water entering through casing leaks.

Cathodic protection prevents corrosion only on the outside surface of the casing; therefore, before cathodic protection is installed it shall be established that leaks are being caused by corrosion from the outside.

15.2 METHODS OF PROTECTION

15.2.1 Current

The current density required for protection varies from 5 to 30 mA/m^2 of casing surface area, dependent on environment and cementing. Average values of protection currents for wells of different depths are as follows:

Approximate depth m	Current in amperes
900	2
1500	5
2400	30

The current required for the protection of a well is determined by measuring the potential of the well head with respect to a remote copper/copper sulphate reference electrode, applying a current which is increased in steps.

The required current is determined from the potential/current relationship, see (3.4).

As an additional check, electric currents in the casing can be measured using a tool equipped with spring-loaded contacts spaced at 7.5 m intervals, which is run inside the casing. From the potential difference between these contacts the direction and magnitude of electric currents flowing in the casing can be derived by means of Ohm's law, or by comparison with a calibrating current. In this way it can be checked whether the cathodic protection prevents electric current from leaving the casing. A check before applying current will show the effect more clearly.

15.2.2 Impressed current

A transformer-rectifier with an anode system of graphite, silicon iron or the casing of an abandoned well is usually applied.

The anodes are placed at a distance of 30-60 m from the well, or in a central position when more wells are protected with one rectifier and a groundbed. The method of placing the anodes is similar to the method of installing anodes for pipeline protection, see (4.4).

The well head of the protected well should be insulated from the flow lines, by means of insulating flanges or joints, to prevent loss of current to other structures and to prevent stray currents.

When several wells are protected in one system, each should be connected via a resistor and a 0.01 ohm shunt (for current measurement) to the negative pole of the direct-current source. A more modern approach is the use of current regulators or current gates. These limit the current returning from the well to a preset value independent of currents drained from other parts to the rectifier. The often used return current path are the surface flow lines. This eliminates the need for long cabling. Insulation is then also required at the gathering station unless the station is included in the cathodic protection system.

15.2.3 Sacrificial anodes

Magnesium-alloy anodes can be used when a low current is required. In general they are suitable for protecting only the upper 60-90 m of a well. In other instances the current required necessitates the use of an impressed-current system.

15.3 STRAY CURRENTS

15.3.1 `Surface shoe effect'

The difference in potential caused by cathodic protection, between the oil string and the surface string, can give rise to bridging of the current at the shoe of the surface string. This is known as the `surface shoe effect' and could cause corrosion of the oil string opposite the shoe of the surface string, due to electric current leaving the oil string at this depth and flowing through the electrolyte to the shoe of the surface string.

Observations in the field as well as theoretical calculations have shown, however, that the corrosion due to `surface shoe effect' is negligible. The contention that this effect will cause serious corrosion unless a metallic connection is made between the two strings at the shoe, is incorrect.

15.3.2 Currents set up by cathodic protection

Cathodic protection current picked up by casings of other wells may cause corrosion at places where the current leaves them. Unprotected wells situated within about 450 m of a protected well or its groundbed, should therefore be protected against stray currents. To accomplish this, a current of about 1 ampere should be drained continually from the wells, either by connecting via a resistor to the cathodic protection system or by installing magnesium-alloy anodes.

Flow lines should be checked for stray currents and resistance bonds installed where necessary, see (8.).

15.4 APPLICATION

Under the effect of steam injection for secondary oil recovery, corrosion can be aggravated considerably as a result of the increased temperature. In areas where casing leaks were a seldom occurrence, the leak rate can become unacceptably high. To prevent this from occurring the timely application of cathodic protection is required.

Offshore, usually no special requirements are needed for wells on steel structures as these will receive protection from the total system. On concrete structures however, special measures may be required.

16. PROTECTION OF CRAFT

16.1 GENERAL

The methods of cathodic protection considered in this section are generally applicable to craft of the types used by operating companies for inland and coastal trade and to craft used in production and exploration areas. Recommendations given do not necessarily apply to large ocean-going craft where, because of the long periods spent in open water, corrosion problems of a different nature arise and the overall economics of operation favour cathodic protection systems which are not applicable to vessels making short trips with frequent loading and discharging.

16.2 EXTERNAL PROTECTION OF HULLS

16.2.1 General

The external protection of hulls is provided mainly by paint coatings, and the recommendations given in DEP 30.48.00.10-Gen., should be strictly followed.

However, the protective paint coating may be removed from localized areas by mechanical damage, and erosion corrosion is common at parts of the stern frame and the leading edge of the rudder; preferential corrosion occurs also at rivet heads and welds. Cathodic protection can be of value in preventing or greatly reducing corrosion at these areas.

The cathodic protection of hulls can be achieved by the use of sacrificial anodes, zinc, aluminium, magnesium or by impressed-current systems employing platinized titanium anodes.

16.2.2 Current

A current density of 45-55 mA/m^2 is sufficient to protect bare steel in static sea water but, see (2.3.3).

However, if there is relative movement between the steel and the sea water, up to 160 mA/m^2 may be required.

16.2.3 Sacrificial anodes

Magnesium or aluminium-alloy or high-purity zinc anodes can be used either for the whole hull protection, when they should be fitted at intervals around the hull, or for local protection, e.g. protection of the stern frame or the rudder itself, see (4.2).

Because of their greater driving voltage, magnesium-alloy anodes are recommended for craft operated partially or wholly in brackish or substantially fresh water. The steelwork under and for 0.9 m around the anode should be painted with an alkali-resistant paint such as `EPIKOTE' coal tar.

Zinc is being used increasingly as an anode material because of its longer life and virtual freedom from paint stripping. The use of zinc is recommended for craft operating in sea water.

Sacrificial anodes are welded to the hull by means of the projecting steel strips which are an integral part of the anode construction.

16.2.4 Impressed current

The required current shall be generated on board and supplied to anodes either trailed from the stern or fixed through the hull plates.

The trailing anode system is applicable only to craft operating for long periods in open water and is not considered in this section.

16.2.5 Propeller protection

In cathodic protection systems provision may be made to include the propeller. A slip ring is fitted to the propeller shaft at a convenient point and a positive connection is made to the hull by means of metal brushes riding on the slip ring. To ensure adequate Continuous low-resistance contact, it is recommended that the contact surfaces of the slip rings should be silver-plated or should incorporate solid silver inlays, and that the brushes should be of a self-lubricating type. Wear rates cannot be predicted, but provision should be made for replacement between periodic dockings until experience is gained.

16.3 EFFECT OF CATHODIC PROTECTION ON HULL PAINT

16.3.1 General

When cathodic protection is in operation, the electrochemical reaction at the cathode results in the formation of free alkali. The concentration of free alkali is a function of the current density, and therefore of the depression of interface potentials. Hence, either the craft's hull (cathode) should be painted with a highly alkali-resistant paint or the current density should be restricted at all times to such a level that the concentration of free alkali at the cathode is too low to attack the paint.

16.3.2 Paint systems for hulls

If the hull is painted in accordance with the recommendations given in

DEP 30.48.00.10-Gen., paint stripping difficulties should not arise with zinc anodes. The Special Marine Primer (MESC 86.01.34.100.1) is sufficiently alkali resistant to be unaffected even in the immediate vicinity of the anode.

With magnesium-alloy sacrificial anodes, or the fixed anodes of an impressed-current system, the hull plates shall be coated with a more resistant paint for a distance of approximately 0.9 m around the anode. `EPIKOTE' coal tar paint is recommended for this purpose, the steel surface being shot-blasted before the paint is applied.

When an impressed-current system is in use, regular checks should be made to ensure that the current output does not exceed that necessary to maintain all parts of the hull at a potential not less negative than -0.85 V with reference to a copper/copper sulphate electrode. Excessive current is unnecessary and may cause paint stripping.

16.4 PROTECTION OF CARGO AND BALLAST TANKS

Cathodic protection for cargo and salt water ballast tanks is effective only when a large proportion of the craft's time is spent in ballast. For coastal and inland craft used by operating companies, and in production areas, the period spent in ballast is seldom long enough for the necessary degree of polarization to occur, and it is recommended that where experience indicates internal protection to be necessary this should be provided by the use of `EPIKOTE' paint as specified in DEP 30.48.00.10-Gen., possibly supplemented with sacrificial anodes.

If indeed cathodic protection is used, only zinc anodes are permissible, as both aluminium and magnesium may give rise to sparking in some circumstances.

17. SAFETY PRECAUTIONS

As cathodic protection necessitates the use of electrical equipment, certain safety precautions shall be taken in hazardous areas.

Safety precautions for rectifiers, switches and cables are the same as for any other electrical equipment. The potential difference between cathodically protected steel structures and the surroundings means that contact with another steel structure may produce a spark. The breaking of contact, especially, may produce a spark. The energy released by sparking is strongly influenced by circuit parameters such as inductance, resistance, applied potential, physical nature of the contacting surfaces, rate of breaking of the contact, etc., and it is not always possible to predict whether an incendiary spark will be produced in a given instance. It is recommended therefore, that every cathodic protection installation should be regarded as potentially dangerous and precautions should be taken to avoid sparking.

When designing a cathodic protection system to be installed in a potentially dangerous area, the latest edition of any applicable recommendations, regulations, code of practice, etc., such as for example the `Model Code of Safe Practice in the Petroleum Industry' and `The International Tanker Terminal Safety Guide', should be consulted and its requirements or recommendations taken into account in the design and subsequent operation of the system.

Before separating two parts of a cathodically protected system the break point shall be bridged by a cable to avoid sparks. The bridge shall be maintained until the parts are rejoined.

For more details on safety aspects related to cathodic protection reference is made to

BS CP 1021. Aspects such as: general requirements for transformer rectifiers, voltage gradients over buried groundbeds, danger of electric shock to divers, earth-fault currents on buried structures, hydrogen evolution in closed systems, explosion hazards, chlorine evolution.

18. ECONOMIC CONSIDERATIONS

18.1 APPLICATION AND ECONOMIC JUSTIFICATION

When steel structures or pipelines are to be buried in aggressive soil or immersed in salt, fresh, or brackish water, it is recommended that cathodic protection should be considered as a standard addition to the anti-corrosion protection given by coatings. Wherever possible, cathodic protection should be considered at the design state.

In any specific case, the economic justification of cathodic protection can be proven only by comparing the capital and operating costs for such protection with the estimated long-term maintenance costs which would be expected to arise if cathodic protection were not applied. The latter will often be difficult to quantify.

18.2 COST OF CATHODIC PROTECTION

The cost of a well-designed cathodic protection system is often only a few percent of the total investment for the installation to be protected. For guidance a figure of 5% is considered realistic.

19. REFERENCES

In this manual reference is made to the following publications.*

NOTE: The latest issue of each publication shall be used together with any amendments/supplements/revisions to such publications.

It is particularly important that the effect of revisions to international, national or other standards shall be considered when they are used in conjunction with DEPs, unless the standard referred to has been prescribed by date.

Painting and coating	DEP 30.48.00.10-Gen.

AMERICAN STANDARD

US Military Specification	MIL-A-18001H

Obtainable from
Superintendent of Documents,
Government Printing Office
Washington DC 20402, USA

BRITISH STANDARDS

Cathodic protection	BS CP 1021

Issued by
British Standards Institution,
2 Park Street, London W1A 2BS,
England

Model Code of Safe Practice in the Petroleum Industry	Part 1 - Electrical Safety Code
International Oil Tanker and Terminal Safety Guide	

Issued by
Heyden & Son Ltd.,
Hillview Gardens,
London NW4 2JQ,
England

INTERNATIONAL STANDARD

Classification of degrees of protection provided by enclosures	IEC publication 529

Issued by:
Central Office of the IEC,
Sales Departments,
1, rue de Varembé,
1211 Geneva 20, Switzerland

Copies can be obtained through the
national standards organizations

20. STANDARD DRAWINGS

In this manual reference is made to the following standard drawings, the latest issue of which shall be used.

	Standard drawing
Magnesium and zinc sacrificial anodes for tubulars	S 21.072
Steel sacrificial plates in bronze floating heads and channels for tubulars of 350 mm nom. dia. and larger	S 21.073

21. APPENDICES

	Appendix
Specification for the supply, inspection, and testing of sacrificial anodes	1
Power generators	2

APPENDIX 1 SPECIFICATION FOR THE SUPPLY, INSPECTION, AND TESTING OF SACRIFICIAL ANODES

1. GENERAL

This specification covers the requirements for supply, identification, inspection, and testing of sacrificial anodes made of zinc or aluminium-indium.

The specification shall be included in all purchase orders for anodes, intended for use on offshore installations and pipelines.

The ordering/purchasing documents shall specify required dimensions of anode, steel core, and brackets and nett and gross weight of anodes, or alternatively reference shall be made to a supplier's standard type and size of anode or anode assembly.

2. ANODE MATERIALS

a) Aluminium-indium anodes: to be obtained from an approved supplier.*

b) Zinc anodes.

Zinc anodes shall meet the requirements of US Military Specification A-18001H.

3. IDENTIFICATION OF ANODES

Each anode shall be clearly marked with the type of material (trade name), the cast number, and a piece serial number. The numbers of any rejected anodes shall not be used again for replacement anodes.

4. DOCUMENTATION

The supplier shall provide full documentation on number, size, weight, type of anodes, type of steel inserts, dimensions, results of spectro analysis on casting samples, results of checks on anode potentials, anode efficiency, and destructive testing, and results of any other test(s) required to be done by the supplier.

Any certificates issued by an inspection agency shall be included in the documentation.

* For operating companies having a service agreement with SIPM or SICM, approved suppliers shall have had their anodes tested and accepted at Royal Dutch Shell Laboratory at Amsterdam on the passivation behaviour of the anode material at room temperature and 5° C.

5. TESTING OF ANODES

The supplier shall carry out the following tests:

a) A full spectrographic analysis of each cast. The results shall be within the limits as published by the supplier (for aluminium-indium anodes) or meet the requirements of US Military Specification A-18001 H (for zinc anodes).

b) A short-term voltage test in sea water (natural or synthetic) of 5 °C for each cast:

For Al: duration of test 3 hours minimum, current density 1 mA/cm^2.

Anode potential (active) to be minus 1050 mV (saturated calomel) or more negative. Anode potential (at rest) minus 1100 mV (saturated calomel).

For Zn: 3 hours minimum, 0.75 mA/cm^2 current density, potentials respectively minus 1000 mV and minus 1050 mV (saturated calomel).

c) A short-duration capacity test for aluminium-indium anodes only.
This test, either impressed current or hydrogen evolution, to be done on samples cut from production anodes.

One-fifth of the number of heats to be tested, with minimum one test per order. Anode capacity to be minimum 2420 Ah/kg.

d) A destructive testing of one anode of each anode type/design, where nett weight of the anode exceeds 100 kg, to check the bonding between anode material and steel core in cross-sectional areas.
The anode material shall be bonded to the steel core over a minimum of 90% of the total surface, while no individual discontinuity or void in the bonding shall exceed 25 mm in length.

6. QUALITY OF ANODE CASTINGS

The as-cast anode surface shall be free of surface slag or other embedded material.

Cracks are not acceptable, except in the form of micro (hairline) cooling cracks. Maximum width 1 mm.

Shrinkage cavities shall not exceed 10 mm in depth, as taken from the anode surface. Slag inclusions are not acceptable.

Tolerance on the dimensions of anodes, position of anode inserts and gross weight of anodes, to be plus and minus 2%.

7. QUALITY OF STEEL INSERTS

Any type of steel core, insert, or bracket shall be fabricated from fully-killed low-carbon steel, pipe material to be ASTM A 106 Gr. B or BS 3602-HFS27, and plate/strip to be ASTM A 185 grade C or BS 1501-151 Gr. 26A, to be substantiated by mill certificates.

Steel cores and inserts shall be blast-cleaned to a near-white metal finish, standard Sa 2 $^1/_2$, and have this finish at the time of casting.

8. INSPECTION

Inspection during and after fabrication of anodes shall be carried out by the contractor, and by the principal (or his representative) at his option.

Inspection shall cover the following as a minimum:

a) Dimensional checking, identification, weight, and quality of castings on at least 5% of the number of anodes from each cast.

b) Quality of steel inserts before casting, and surface preparation on at least 5% of inserts for the batch of anodes from each cast.

c) Quality of steel-anode bonding on the anode from each order, selected for destructive testing.

d) Inspection of results of spectro analysis, voltage tests, and capacity tests, done by supplier.

e) After transport to installation site, a final visual check to be carried out to ensure that anodes have not been damaged during transport and handling.

9. ACCEPTANCE/REJECTION

Acceptance/rejection of anodes may be on a total inspection of all anodes, manufactured against the particular purchase, basis, or on a sample basis only, at the sole discretion of the principal.

Where any of the requirements, mentioned in this specification, are not met, the anodes and the relevant batch of anodes will be rejected.

APPENDIX 2 POWER GENERATORS

1. TRANSFORMER-RECTIFIERS

Oil-cooled T/R's shall be shipped without oil. The tank is usually not strong enough to withstand transport and handling whilst full. The transformer oil shall be packed in separate drums.

2. SOLAR POWER SYSTEMS

When ordering a complete system, the following remarks shall be taken into account:

a. Solar panel capacity is temperature-dependent. A guarantee shall be required from the supplier that the rated capacity can be maintained under the prevailing climatic conditions and free supply of additional panels is agreed in case of non-compliance. Spare positions on the panel-supporting structure are recommended.

b. Current regulators shall have sufficient capacity. The supplier must be informed that system output may well be quite low for some time, but that the regulator shall also be capable of discharging at full system capacity. The current regulator shall also prevent discharge of storage batteries below the limits set for the batteries. The regulator shall be of module type construction for easy replacement/maintenance.

c. It should be realized that storage batteries require a charge at high rate at intervals of 1 2 years. Provisions shall be included to facilitate such a charge.

d. Encasements shall be rigid, corrosion resistant and dust- and waterproof. Access to components inside shall be unrestricted.

3. WINDMILLS

a. Current regulators: see 2b above.

b. Maintenance on bearings and brushes shall be simple so that a quick change-over can be made with a minimum of interruption in the power supply.

4. DIESEL GENERATORS

a. The engine used shall be of the latest model with a guaranteed long-term spare part supply.

b. A dual system shall be used with a regular automatic change-over.

c. Automatic change-over shall become blocked if one unit has stopped because of a fault.

d. A preventative maintenance schedule shall be prepared and followed.