INSPECTION STANDARD

FOR

MONITORING CATHODIC PROTECTION SYSTEMS

CONTENTS :

PAGE No.

APPENDICES:

1. SCOPE

1.1 This Inspection Standard provides survey requirements to ascertain that corrosion control systems installed on buried or submerged structures are properly designed, operated and effectively maintained.

1.2 This Standard also provides information concerning techniques, equipment, measurements and test methods used in field application.

1.3 This Standard deals with inspection of coatings in conjunction with cathodic protection for it's efficiency on current distribution.

1.4 This Inspection Standard is related to the standards IPS-E-TP-820 and IPS-C-TP-820 and shall be used in conjunction with the aforesaid standards.

2. REFERENCES

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

BSI (BRITISH STANDARD INSTITUTE)

BS 148	"Specification for Unused Mineral Insulating Oils for Transformers and Switchgear"
BS CP 1003	"Electrical Apparatus and Associated Equipment for Use in Explosive Atmospheres of Gas or Vapor other than Mining Application"
BS CP 1021(1973)	"Code of Practice for Cathodic Protection"

AS (AUSTRALIAN STANDARD)

AS 2832.1 (1985)	"Guide to the Cathodic Protection of Metals, Pipes, Cables and Ducts"
AS 2832.2 (1991)	"Guide to the Cathodic Protection of Compact Buried Structures"
AS 2832.3 (1992)	"Guide to the Cathodic Protection of Fixed Immersed Structures"
AS 2832.4 (1994)	"Guide to the Cathodic Protection of Internal Surfaces"

DNV (DET NORSKE VERITAS-OFFSHORE STANDARDS)

DNV RP B 401 (1976)	"Rules for the Design, Construction and Inspection of Submarine Pipelines and Pipeline Risers"
DNV RP B 403 (March 1987)	"Monitoring of Cathodic Protection Systems"
DNV RP B 404 (1977)	"Rules for the Design, Construction and Inspection of Offshore Structures"
DNV Technical Note A5/1 Rev. 1	"Cathodic Protection Evaluation"

NACE (NATIONAL ASSOCIATION OF CORROSION ENGINEERS)

NACE R.P 01-76	"Control of Corrosion on Steel Fixed Offshore Platforms Associated with Petroleum Production"

NACE Task Group T.7L.4	"Collected Papers on Cathodic Protection Current Distribution"
NACE Task Group T.10.1	"Cathodic Protection Criteria- a Literature Survey"
NACE R.P 0169-83	"Control of Corrosion on Underground or Submerged Metallic Piping Systems"
NACE R.P 0187-87	"Recommended Practice-Design Consideration for Corrosion Control of Reinforced Steel in Concrete"

ASTM (AMERICAN STANDARDS FOR TESTING AND MATERIALS)

ASTM C 876-87	"Half Cell Potentials of Uncoated Reinforcing Steel in Concrete"

IPS (IRANIAN PETROLEUM STANDARD)

IPS-E-TP-820	"Engineering Standard for Electrochemical Protection"
IPS-E-TP-274	"Engineering Standard for Coating"
IPS-C-TP-274	"Construction Standard for Coating"

3. DEFINITIONS AND TERMINOLOGY

Aerobic

Environment containing oxygen, for instance normal sea water.

Anaerobic

Environment not containing oxygen, for instance sea bottom mud.

Anode

The electrode of an electrolyte cell at which oxidation occurs.

Attenuation

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

Attenuation constant "a"

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

Backfill

A low resistance moisture holding material surrounding buried anode for the purposes of increasing the effective area of contact with soil.

Cathode

The electrode where reduction reaction occurs on its surface.

Cathodic protection

A means of rendering a metal immune from corrosive attack by using direct current.

Current density

The direct current per unit area, generally expressed as milliamper per square meter. Current density required to achieve cathodic protection varies depending on environment and metal being protected.

Deep anode bed

Type of ground bed using a drilled vertical hole to contain impressed current anodes. Typical depth range from 30-400 meters to reach moist low resistivity soil. Presently current output is up to 150 Amperes for hole.

Electrolyte

The soil or liquid adjacent to and in contact with a buried or submerged metallic structure, including moisture salts and other chemicals contain therein.

Sacrificial anode

A metal which is less noble than steel in e.m.f or galvanic series and when coupled with steel in an electrolyte provides sacrificial protection by a current flow in the structure that opposes the corrosion current.

Ground bed

A group of manufactured electrodes or scrap steel which serves as the anode for the cathodic protection of buried or submerged metallic structures.

Holiday

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

Impressed current

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

IR drop (or Voltage drop)

Significant structure-to-electrolyte potential component due to flow of current through the electrolyte. Often the IR drop component is negligible in low resistivity soil and sea water but must always be considered in high resistivity soil, disbonded coating, large current levels and proximity to structure.

Protection potential

A term used in cathodic protection to define the minimum potential required to suppress corrosion.

Remote earth

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

Test access hole

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

Test station (test box)

Permanent wires attached to the structure and led to a convenient location or box for potential measurements.

Tafel slope

When an electrode is polarized, it frequently will yield a current potential relationship over a region which can be approximated by:

$$\eta = \pm \beta \log \frac{i}{io}$$

Where:

η	is change from open circuit potential.
i	is the current density.
β	is constant. The constant β is also known as the tafel slope, if this behavior is observed.

A plot on semilogarithmic coordinates is known as the tafel line and the overall diagram is termed a tafel diagram.

Tafel segment

The Tafel segment is that portion of Tafel curve that deviates from the straight line with decreasing current.

4. UNITS

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

5. GENERAL

5.1 Corrosion control system is effective when it is properly designed, constructed and maintained. Therefore without a comprehensive inspection program, both during construction for a designed system and operation, the investment for deign, material and installation of protection systems may be wasted.

5.2 Inspection of a cathodically protected system are necessary to ensure that protection of the structure is in accordance with applicable criteria, and that each part of the cathodic protection system is operating satisfactorily and if changes are noted, then action is taken to return the system to a protection conditions. This inspection is possible by periodic inspection of units and recording their current and voltages, measuring structure to soil (or water) potentials and most of all interpretation of data's obtained.

5.3 Records of all information pertinent to effective maintaining of cathodic protection system and other changes and adjustment during the life of system shall be kept and be available for further survey and inspection when required.

5.4 The conditions of the coating applied to a protected structures will have a considerable effect on structure/-electrolyte potentials, then inspection of the coating shall be made during construction and commission (see IPS-C-TP-820) and when opportunities arise care needs to be taken to minimize damage to coating during such an inspection.

5.5 To ensure that over protection does not cause accelerated disbondment of the coating or other deleterious effects, a potential corrected for voltage gradient error shall be measured.

6. CRITERIA FOR CATHODIC PROTECTION

The following criteria as stated by IPS-E-TP-820 shall be used:

6.1 General

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

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

6.2 Buried Pipes

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

Coated buried pipelines shall have a minimum pipe-to-soil polarized potential of -0.850 (off) (see Clause 3.2 of DIN 30676, 1985) Volt with reference to copper/copper sulfate half cell. The potential shall be measured immediately after interrupting all the cathodic protection systems influencing the pipeline structure, where it is not practical to measure the interrupted or polarized potential on a pipe, the general guideline for the protection criteria shall be as follows:

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

6.2.2 The presented values in 6.2.1 for buried pipelines are based on satisfactory coating application and in soils with low to intermediate resistivity (<2000 ohm-cm).

If the coating is particularly exposed to wear and mechanical damage or deteriorated due to ageing and/or the pipe is buried in high resistivity aerated soils, higher values must be used due to IR drop in (on) potential measurements (see also 7.2.3).

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

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

Note:

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

6.3 Tanks Exteriors

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

6.4 Submerged Pipelines

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

6.5 Offshore Structures and Ship Hulls

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

6.6 Tank, Pipe and Water Box Interiors

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

6.7 Well Casings

In general, onshore well casings shall be considered adequately protected when a polarized casing-to-soil potential of -1.0 (off) volt to a copper/copper sulfate reference cell is measured with the cell located close to the casing and the cathodic current momentarily interrupted.

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

6.8 Potential Limits

The potential limits for coated pipes shall be as specified in Table 2.

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

METAL OR ALLOY	CONDITION	REFERENCE ELECTRODE							
		Copper/Copper Sulfate		Silver/Silver Chloride** Sea-Water		Silver/Silver Chloride Saturated KCl		Zinc /(Clean) Sea-Water	
		min.	max.	min.	max.	min.	max.	min.	max.
Unalloyed and low alloy ferrous materials	At temp. below 40°C	-0.85	N.A*	-0.80	N.A	-0.75	N.A	+0.25	N.A
	At temp. higher than 60°C	-0.95	N.A	-0.90	N.A	-0.85	N.A	+0.15	N.A
	In an aerobic media with high activity and sulfates reducing bacteria and sulfides	-0.95	N.A	-0.90	N.A	-0.85	N.A	+0.15	N.A
	In an aerobic and in anaerobic media with low activity of sulfate reducing bacteria and sulfides	-0.85	N.A	-0.80	N.A	-0.75	N.A	+0.25	N.A
	In sandy soils with resistivities greater than 50000 ohm.cm	-0.75	N.A	-0.70	N.A	-0.65	N.A	+0.35	N.A
Stainless steel with a chromium of at least 16% by weight, for use in soil and fresh water	At temp. below 40°C	-0.10	N.A	-0.05	N.A	0.00	N.A	+1.00	N.A
	At temp. higher than 60°C	-0.30	N.A	-0.25	N.A	-0.20	N.A	+0.80	N.A
Stainless steels with a chromium content of at least 16% by weight, for use in salt water		-0.30	N.A	-0.25	N.A	-0.20	N.A	+0.80	N.A
Copper; copper/nickel alloys		-0.20	N.A	-0.15	N.A	-0.10	N.A	+0.90	N.A
Lead		-0.65	-1.70	-0.60	-1.65	-0.55	-1.60	+0.45	-0.60
Aluminum in fresh water		-0.80	-1.10	-0.75	-1.05	-0.70	-1.00	+0.30	0.00
Aluminum in salt water		-0.90	-1.10	-0.85	-1.05	-0.80	-1.00	+0.20	0.00
Aluminum in soil		-0.95	-1.20	-0.90	-1.15	-0.85	-1.10	+0.15	-0.10
Steel in contact with concrete		-0.75	-1.30	-0.70	-1.25	-0.65	-1.20	+0.35	-0.20
Galvanized steel		-1.20	N.A	-1.15	N.A	-1.10	N.A	-0.10	N.A

*** Not applicable**

**** Silver/silver chloride/sea water, (salinity 32-38%), in brackish water (salinity < 32%), the potential reading from an open electrolyte reference electrode must be corrected for the lower chloride concentration. For measurements in such water a closed electrolyte reference electrode is advantageous.**

TABLE 2 - POTENTIAL LIMITS FOR CATHODIC PROTECTION BURIED PIPES COATED WITH DIFFERENT COATING SYSTEMS

COATING SYSTEM	OFF POTENTIAL (REF. $Cu/CuSO_4$ V)
Epoxy powder fusion-bonded	-1.5
Asphalt and coal tar enamel	-2.0
Plastic tape (Laminate)	-1.5
Epoxy coal tar	-1.5
Polyethylene	-1.0

Notes:

1) All potentials have been rounded to the nearest multiple of 0.05 V. The figures for electrodes in which sea-water is the electrolyte are valid only if the sea-water is clean, undiluted and aerated.

2) Aluminum

It is not at present possible to make firm recommendations for the protection of aluminum since this metal may corrode if made too strongly negative. There are indications that corrosion can be prevented if the potential is maintained between the limits shown in Table 1. Alternatively, it has been recommended in the case of pipelines to make the metal electrolyte potential more negative than its original value by 0.15 V.

3) Lead

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

4) Stainless steels

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

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

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

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

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

5) Steel in concrete

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

7. PERIODIC INSPECTION

Periodic inspection of cathodically protected structure includes following survey and measurements:

7.1 Potential Survey

7.1.1 General

The best way to judge the effectiveness of a cathodic protection system is by measurements, at selected points, of the structure/electrolyte potentials, which should be maintained more negative than the minimum values given in cathodic protection criteria (see Clause 6).

7.1.2 Potential survey intervals

7.1.2.1 Cathodic protection potential surveys shall be carried out at time intervals determined from a consideration of the system parameters, including the type of cathodic protection system, the nature of the environment, the presence or absence of stray current and the structure operating conditions.

7.1.2.2 The frequency at which it is necessary to recheck galvanic anode system depends ultimately upon the history of the structure and similar structures in the same locality. However, toward the end of effective life of galvanic anodes a recheck of protective potentials may be necessary every month i.e. having a regular intervals.

7.1.2.3 With regard to impressed current system, in addition to complete potential surveys occasional surveys shall also be carried out in areas where there is pipeline conjunction with many foreign lines crossings. More frequent checks, e.g. monthly, shall be made in areas that are considered particularly from the standpoint of corrosion and are vital to operation. The critical areas include but not limited to places where interference correction bonds or facilities for stray current correction installed, gaps and crevices on offshore pipelines, platforms and jetties, tidal and splash zone areas, points of minimum protection and drainage.

7.1.2.4 Generally following time intervals shall be used for potential measurements and associated tests as a minimum. Shorter time intervals may be considered where necessary.

- Pipelines: every 2 months
- Municipal Gas Network: every 2 months
- Jetties: every month
- Tank farms and plants: every 3 months
- Offshore platforms: every 6 months
- Sealine Risers: every month
- Offshore pipelines: every 3 years
- Ships and cargo tankers: every 6 months
- Internal of vessels and tanks: every month
- Cased crossing : every 2 months
- Hot spots protected by galvanic anodes: every month
- Galvanic anode system: every 2 months.

7.1.3 Test equipment for potential survey

Measurement of potential between a structure and its surrounding electrolyte shall be made by using suitable equipment. If suitable voltage measuring equipment are not used (or if the right equipment are not used properly, and care in handling of equipment are not exercised) observed potential value may be misleading or completely meaningless. Therefore, due attention shall be given to selection of the test equipment, type, required accuracy and they shall be maintained in good working condition at all times. Followings are essential equipment for potential measurements. Appendix A gives general information on the types of meters and equipment.

7.1.3.1 Reference electrodes

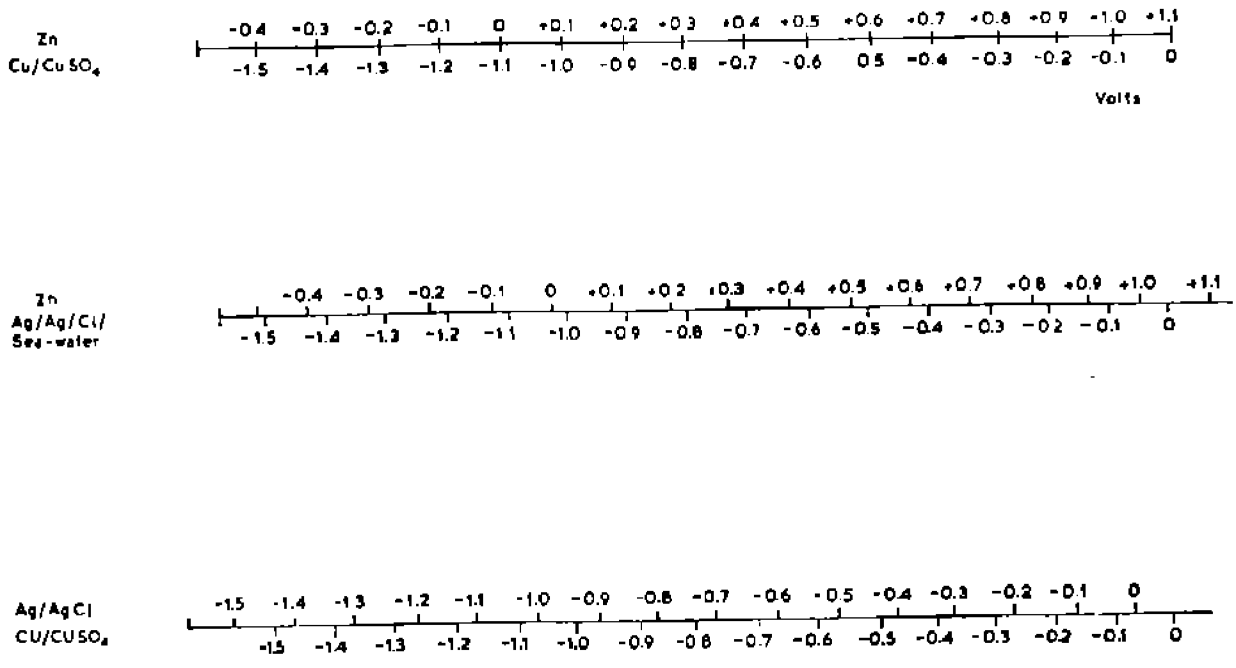
The potential of cathodically protected structure to be measured with respect to a suitable reference electrode. Normally used electrodes for potential measurements are:

- Copper/copper sulfate electrode
- Silver/silver chloride electrode
- Zinc electrode

Approximate comparison of potentials of these electrodes are given in Fig. 1.

Copper/copper sulfate is the most common type of electrode used in measuring the level of protection of buried structures.

Silver/silver chloride is wildly used in potential measurements of submerged structures such as jetties, offshore platforms, ship hulls and other marine structures.



APPROXIMATE COMPARISON OF POTENTIALS USING ZINC, Cu/CuSO$_4$ AND Ag/AgCI REFERENCE ELECTRODES
Fig. 1

Pure zinc electrode may be use as permanent reference electrodes in marine structures and under the bottom of storage tanks.

The reliability of potential measurements can be enhanced by using sophisticated systems such as sonar electrical potential unit. Different types of available reference electrodes are described in Appendix A.

7.1.3.2 Potentiometer and voltmeter

Different types of potentiometer or voltmeter may be used depend on requirements. Any conventional voltmeter will take some current and its reading is subject to correction. However if the voltmeter resistance is high in comparison with the external circuit resistance, the correction factor is very low. In view of this, high resistance voltmeter shall be used for cathodic potential measurements.

Potentiometer-voltmeter shall be used in measuring potentials in areas having high resistivity (i.e. over 2000 ohm-cm).

Potentiometer is more accurate in potential measurements and can be used as a bias facility to measure potentials by a null current potentiometric method or as a millivolt source for calibration checks on other instruments. Different types of appropriate meters, portable or in the shape of monitoring panels are described on Appendix A.

7.1.4 Procedure to be observed

Following shall be observed in taking potential readings:

- Test equipment shall be in order or proper working conditions.
- For close potential reading of pipelines the reference electrode shall be placed on the ground surface, directly above the pipeline.
- The porous plug of copper-copper sulfate electrode should be in firm contact with moist soil. In dry areas, it is necessary to moisten the earth around electrode with fresh water to obtain good contact and reduce electrode to earth resistance.
- Do not permit grass or weeds (particularly when they are wet) to contact exposed electrode terminals, because they affect the observed figures.
- In high resistivity soil (more than 2000 ohm/cm) use potentio-voltmeter or potentiometer to obtain more accurate readings.
- Make sure to connect the right wire to the right terminals of the meter i.e. connect the reference electrode to the positive and test point to the negative terminal of meter.
- Select the most proper instrument range to get the most accurate reading.
- For offshore structures with complex geometry or where shielding can occur at some points such as nodes, the reference electrode may be located by a diver or a remotely operated vehicle at these points, and readings be taken. Such readings can then be related to readings taken with a reference electrode placed adjacent to the side of the structure.
- Care should be taken to ensure that the structure component to which the measuring voltmeter is connected is not carrying a substantial cathodic protection current with impressed current systems, in particular, parts of the structure may be carrying a large current and hence cause a significant voltage drop error in the measurement.
- In measuring the potential of a ship or tanker, make sure it is not in contact with jetty structure.
- As corrosion of buried or submerged pipelines is mainly attributable to sulfate reducing bacteria in an anaerobic environment, the protective potential shall be adjusted to at least -0.95 V (off) with respect to $Cu/CuSO_4$ electrode in all soils other than pure sand.
- In municipal gas net works potential measurements shall be done just on provided test points. Measurements on house gas risers is not allowed (see also IPS-C-TP-820).

7.2 Potential Survey of Buried Steel Pipes

7.2.1 Instruments

Copper/copper sulfate half-cells are the most common type of reference electrodes. Commonly available models are shown in Fig. A.2 and the operating principle in Fig. 2 below:

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 meg-ohm 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.

7.2.2 Potential measurements

The method of potential measurement is as follows:

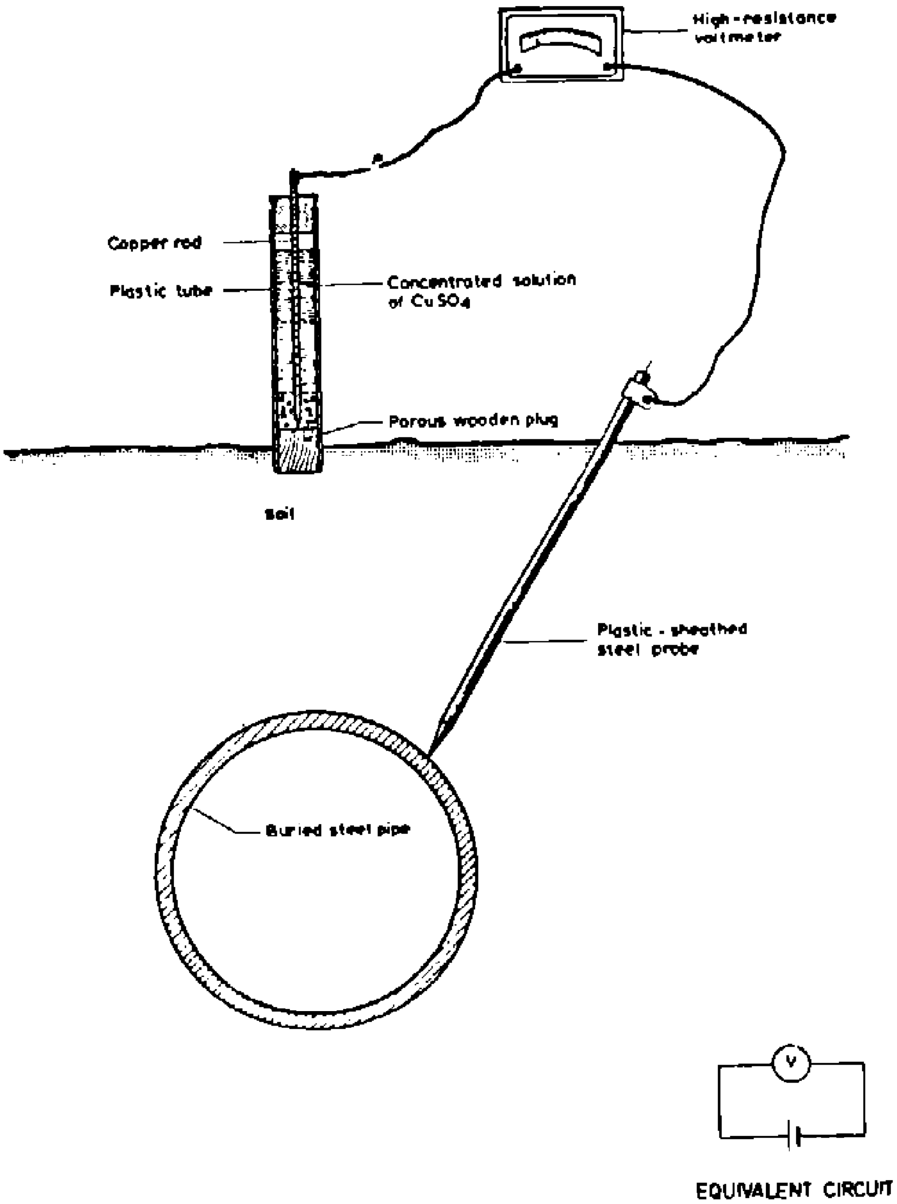
7.2.2.1 Place the porous plug of the electrode firmly into contact with the soil, moistening the area of contact if the soil is very dry. Electrical contact then exists between the steel pipe, the soil electrolyte and the porous plug of the reference electrode. The circuit is completed by connecting 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 kilometer markers.

7.2.2.2 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. 2.

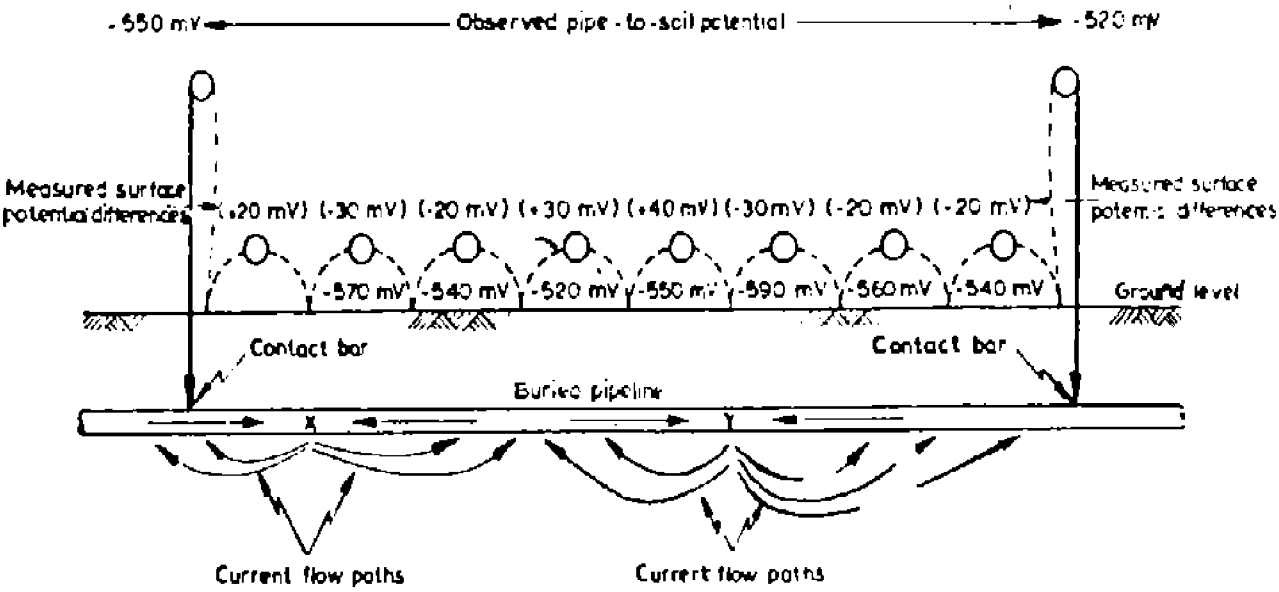
7.2.2.3 Provided that the reference electrode is not more than 0.5 m from above the top of the pipeline, sufficiently accurate results for most purposes will be obtained. Several readings may be made at each contact of the probe with the pipeline by moving the reference electrode to different points on the soil surface along the rout. 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 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.

Calibration

Calibration of measuring electrodes shall be carried out before and after each potential survey. For calibration there should be at least two copper sulfate electrodes in the test kit. These should be matched in potential. The matching may be checked before and after each potential survey. The potential difference shall not exceed 10 millivolts when the electrodes placed side by side in the same soil or water. If the difference is excessive, contamination of one or both is indicated. In this case they should be cleaned by dipping in 10% solution of nitric acid and after rinsing the electrodes.



TYPICAL MEASUREMENT OF PIPE-TO-SOIL POTENTIAL
Fig. 2



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

PIPE-TO-SOIL POTENTIAL SURVEY
Fig. 3

7.2.3 Compensation for the IR drop component in cathodically protected pipelines

Pipe to soil potentials measured against a reference electrode placed on the soil when the protective current is switched on, always incorporate an IR drop caused by the resistance of the ground, coating, holiday and that in the metallic portions of the circuit. Therefore the corrosion engineer must consider voltage drops other than those across the structure-electrolyte boundary when interpreting any soil to pipe potential to conclude the true pipe to soil potential. The most frequent techniques have been used to remove the unwanted IR drops form pipe to soil potentials are as following:

7.2.3.1 The IR drop component can be eliminated by making I=O if all current to the pipe can be shut-off, or by making R = O if the reference electrode is moved extremely close to either a bare pipe or the controlling holiday on a coated pipe (see DIN 30676).

7.2.3.2 A holiday simulation probe* can be installed to eliminate the stray current IR drops in measured pipe to soil potentials on critical areas of coated pipelines, or all IR drops if the applied cathodic protection current can be interrupted.

Note:

*** A probe electrically connected to the buried pipeline and then installed close to the pipeline surface to permit the flow of protective and stray currents to the exposed tip. Measurements of IR drop free potentials were then possible, by disconnecting the probe from the pipeline and recording the potential by normal means.**

7.2.3.3 On bare or coated pipelines, the IR drop components can be eliminated, and true pipe-to-soil potentials can be determined by the stepwise current reduction technique.

Note:

The stepwise current reduction technique developed by Barlo and Fessler. In this technique current reduces in steps and corresponding IR drops determines with each step. By extrapolating the cumulative IR drops to a value corresponding to zero current, the total IR drop in a potential measurement can be established.

Followings are some important notes on instant off potential measurements which corrosion engineer have to consider:

- In most cases it is not possible to shut off all current to the pipeline as a result of stray current, multiple protection system, galvanic ground beds and current flowing between more polarized small coating defects and less polarized larger coating defects.

- The measured instant off potential on a coated pipeline corresponds to that of the largest freely exposed holidays, with smaller holidays having more negative potentials.

- The measured instant-off potential on a coated pipeline having shielded holidays (i.e. detached coating) will have less negative true potentials than a coated pipeline having freely exposed holidays, and the apparent instant off potentials may not always correspond to the least negative potential of all holidays.

- On a coated pipeline with a transverse voltage gradient of more than 3.3 mV/m (10 mV/ft)* or on a bare pipeline, the IR drop component can cause measured pipe to soil potentials to be more negative than actual.

*** Note:**

A measurable gradient of at least 3.3 mV/m measured transverse to the pipe and referenced to a Cu/$CuSO_4$ electrode indicate a pipeline with a poor coating requiring IR drop correction.

7.2.4 Over protection

To ensure that over protection does not cause accelerated disbondment of the coating or other deleterious effects, a potential corrected for voltage gradient error shall be measured.

7.2.5 Potential survey at cased crossings

7.2.5.1 General

Complete cathodic protection of pipelines can not be accomplished with short circuit between carrier pipe and casing pipe which is usually used at road or railway crossings. With the short circuit in place, cathodic protection current gathers on the outside surface of the casing (which are commonly uncoated) and flows along the casing to the point of metallic contact between carrier pipe and casing. The protective current then flows along the pipeline back to the rectifier or sacrificial anode. A single bare casing pipe, if in metallic contact with pipe can absorb as much cathodic protection current as several kilometers of pipeline. Therefore periodic inspection and testing to ensure the insulation of cased pipe at crossing is essential. This inspection is made by potential measurement and comparing the figures of casing pipe with that of carrier pipe.

7.2.5.2 Potential survey

Potential survey at cased crossing will consist of casing to electrode potential reading versus carrier pipeline to electrode reading. This test can coincide with the routine survey along pipelines. A difference in the readings is qualitative indication of satisfactory insulation between casing and carrier pipe. A more detailed test of insulation can be carry out by interrupting the cathodic protection current and measuring the potential of casing and pipeline with respect to a reference cell. If pipeline potential changes between on and off conditions while the casing potentials remain steady it indicates effective insulation. If the potentials of both casing and pipeline change similarly as the current changes, a short circuit is indicated.

7.2.5.3 Locating the point of short circuit

Further test can be carried out to locate the point of short circuit between casing and pipeline. For further information and test method reference is made to Appendix B.

7.2.5.4 Potential tests at insulating devices

7.2.5.4.1 General

Insulating equipment consist of insulating flanges, insulating joints/couplings and insulating unions. Insulating flanges and joints on transmission lines are used to separate the pipelines electrically from refineries, plants, platforms, terminal facilities, pumping station, compression stations, tank farms and city stations. Insulating joints and flanges may also be used to divide the line into sections or blocks so that failure of cathodic protection facilities or development of contacts with other metallic structures will limit loss of protection to a section. This practice of sectionization is most used in distribution system and where stray current from underground, domestic networks, subways and other systems presents problem and reasonably spaced insulating joints may be helpful in controlling stray current pickup and discharge.

Insulating union (mono-bloc) have wide application on offshore platforms where the possibility of short circuit by water droplets exist if use ordinary insulating flanges. Also insulating unions in 2 inches and below are extensively used to separate the city gas network from residential or commercial service line upstream of gas pressure regulator and meter.

7.2.5.4.2 Insulation test

Proper functioning of the insulating device is important for effective operation of cathodic protection systems. Test for effectiveness of insulating devices involves interrupting the source of cathodic protection current on one side of the device and measuring the potential on both sides of that. If the insulation is effective, the potential on the protected side will change as the interrupter operates while the potential on the unprotected side will remain constant.

7.2.5.4.3 Locating of insulation defect and measuring the percentage of "leakage"

If an insulation flange is found defective step by step test shall be made to locate the defect and repair it. For test procedures reference is made to Appendix B.

7.2.5.4.4 Test intervals

Insulation test shall be made during the potential survey along pipeline.

7.2.5.4.5 Lightning arrestor

In case the pipelines are connected to oil storage tank farms, the insulating device prevents discharge of lightning current to other structures. This current may damage insulation in the event of lightning storm. To overcome this problem lightning arrestor is installed across the insulating device. The arrestor bridge insulating device. By doing so, lightning current is easily discharge without any damage to insulation. During periodic check of the insulating device the lighting arrestors shall be thoroughly inspected to ensure that they are in good shape and having proper connection at either side of the insulating device.

7.3 Potential Survey of Cathodically Protected Reinforced Concrete

7.3.1 General

Cathodic protection is increasingly being used to prevent corrosion of steel reinforcement (rebar) in concrete structures.

Although the use of metal-to-electrolyte potential survey with respect to reference electrode is the primary technique for ascertaining when protection is achieved, unlike soil and water electrolytes, concrete presents some unique peculiarities when testing with reference electrodes. Measurements are complicated, primarily owing the fact that it is not possible to reach the metal surface when it is buried under 50-100 mm of concrete, and secondly the concrete is usually a fairly high-resistivity electrolyte. Embedded electrodes, corrosion coupons and probes, electrochemical impedance, electrochemical noise, linear polarization techniques are available for this purpose. The most wildly used in situ test method to investigate the corrosion and protection of steel in concrete is half cell potential mapping. This technique is covered by ASTM C 876-87 (1987 F) (see Appendix B).

7.3.2 Potential measurement

7.3.2.1 To maximize the control and prevent unwanted side effects build-up, the concrete structures under cathodic protection, shall frequently be monitored by potential measurement. The frequency of control measure is more critical for impressed current systems than galvanic one's.

7.3.2.2 Due to the fact that reinforcement bar is embedded in 50-100 mm of concrete, and concrete is high resistivity electrolyte that it's resistivity is not homogeneous due to the simple variation in chemical and moisture content of the aggregate, or climatic conditions from one day to another, care must be taken in measurement to compensate the IR drops. In this regard the most acceptable criterion is "instantaneous off" potential measurement in impressed current systems. It is defined as the potential obtained not less than 0.1 second and not more than 1.0 second following interruption of direct current. The well protected structures will have the potential values between -200 and -250 mV more negative than silver/silver chloride half cell.

Based on another criterion, the concrete society (1989) recommended the following criterion for protection; a minimum of 100 mV potential decay over all representative points, subject to a most negative limit of -1.1 V with respect to a silver/silver chloride half-cell. The decay period is typically 4 hours but can vary with the rate of depolarization or potential decay.

For accuracy in measurements note the followings:

- Use high internal resistance (i.e. 200 megaohm) voltmeter.

- To decrease contact resistance between portable reference electrode and concrete, wet the surface site by using biodegradable detergent in water.

- For reinforced concrete in air, a difference of 200 mV between sites in close proximity may indicate active corrosion.

- Concrete surfaces that have been subject to carbonation indicate potentials of -100 mV more negative than would be ordinarily be encountered.

- If concrete is repaired, make sure that half cell is not placed on non-conductive repair materials.

7.3.3 Electrodes and probes for concrete other than in Table 1

7.3.3.1 Permanent reference electrode

These electrodes is fitted into the concrete structures during construction of structures. The stability of the available conventional electrodes is questionable over long periods of time in concrete. Therefore the use of permanent electrodes for accurate steel/concrete potential measurements or for the control of automatic potentiostatic T/R is of doubtful value. The use of relatively stable electrodes (such as graphite) for the short term measurement of potentials, such as for the 4 hours requirement in the 100 mV polarized potential decay criterion, or points of structures which are not accessible, can be considered.

7.3.3.2 Resistance probe (corrosometer type)

These probes shall be fitted within the concrete structures during construction. They measure the extent of corrosion on a tubular steel element connected to the reinforcing in the concrete by accurately measuring the change in resistance of the element resulting from corrosion. The element of the probe essentially become part of the reinforcing matrix.

7.3.3.3 Rebar probe

These probes are use to measure the current or current densities collected at particular locations in the reinforced concrete, to determine the extent of cathodic protection distribution or current flow. Probe comprises a section of reinforcing bar electrically separated from the main reinforcing except for cabled connection, that incorporates a current measurement device.

7.3.3.4 Macro cells

This cells are similar to rebar probes except they deliberately installed in a local surrounding of particularly highly chloride-contaminated concrete. If these macro-cell bars corrode, current will flow then into concrete to discharge on other cathodic areas of reinforcing and return through the monitored cable connection. If cathodic protection is fully effective in the area of this most actively corroding bar, it will overcome the corrosion current, and the current measured in the monitored cable connection will change direction.

7.3.3.5 Associated problems with overprotection in concrete

Over protection should be controlled because it damages the structures as following:

- Ionic movement in concrete due to passing cathodic protection current resulting hydrogen gasification at the concrete-steel interface and thereby weakening the mechanical bond.

- Many prestressed and post tensioned structures incorporated the use of high strength steels (i.e. 100000 psi yield strength or more) are susceptible to hydrogen embrittlement.

- Acidic ions move toward anode which is embedded in concrete lowering the alkalinity then delimitation of the surface may be initiated.

- Overprotection cause unwanted heat around anode and cause cracking of concrete.

7.3.3.6 Stray current

Reinforcement rebar of concrete structures are very susceptible to stray current damage. At discharge point a current of one ampere can dissolve 9 kg of steel per year, which on thin reinforcing bar can be disastrous and over a relatively short time premature failure can be rapidly induced. Therefore all reinforcement cages shall be bounded together and test shall be done (Section 8) and corrective measures shall be taken.

7.4 Potential Survey of Offshore Structures

7.4.1 General

Protective measure of marine structures is greatly dependent on the environmental conditions and furthermore on the geometry and surface condition of the steel surfaces. The decisive environmental parameters are temperature, sea water chemistry, flow conditions and growth of marine fouling. These parameters vary with the geographical location, depth and season. The nucleation and growth of a calcareous layer which retarding the diffusion flux of oxygen onto the steel cathode differ at various locations and depth. Flow velocities of sea water has a detrimental effect on polarization. For deep waters, due to lower sea water current, more current densities require for initial polarization. Therefore to get correct information about the condition of the cathodic protection system, it is important that the locations for potential measurements are carefully selected and electrodes placed as close as possible to the steel surface to minimize voltage drop in sea water.

7.4.2 Criteria for cathodic protection

The criteria for cathodic protection shall be in accordance with Clause 6.1.1.

7.4.3 Reference electrodes

In sea water potential measurements shall be performed with reference to silver/silver chloride half cell. The use of copper/copper sulfate is limited due to the fact if may be contaminated by chloride ions.

Zinc is not an accurate reference electrode since it is unstable in sea water. But due to the long lifetime of zinc electrode, if shall only be used to get an estimate of the protective level.

7.4.4 Methods of measurement

To locate the reference electrode as close as possible to the structure surface, different means may be used:

a) Reference electrode may be carried by divers.
b) Measuring electrode is carried by R.O.V (Remotely Operated Vehicle) or a submarine.

Where diving or use of R.O.V is difficult or impossible due to high cost, the reference electrode may be lowered from the surface to a specified series of depth for readings. Measurements taken in this way are relatively inaccurate as the distance between the reference electrode and steel surface is difficult to control.

7.4.5 Potential measurements with a diver-operated unit

7.4.5.1 General

7.4.5.1.1 A measuring electrode, a high impedance voltammeter (≥ 10 M ohm) and a metal tip for making contact to the steel, are built into a single tool which is easy to handle by the diver. When potential measurements are performed, the metal tip is pressed against the steel surface or anode and the potential is read on the unit's digital display. The diver reports the reading orally to the surface.

7.4.5.1.2 The metal tip is connected to the positive terminal of the built-in voltmeter while the measuring electrode is connected to the negative. Negative potentials will then be read on the display.

7.4.5.1.3 On some diver operated units the metal tip is connected to the negative terminal whilst the measuring electrode is connected to the positive. For such units the sign of all potential figures given within this section will be opposite.

7.4.5.2 Calibration

7.4.5.2.1 Calibration of measuring electrodes should be carried out before and after each potential survey. In order to become stable, the measuring electrodes should be submerged for at least 1 hour, before calibration is performed. Saturated calomel electrodes should be used for calibration. These electrodes should also be controlled to select the best electrode. Control of saturated calomel electrodes is only necessary before each potential survey, and thereafter every 24 hours.

7.4.5.2.2 Three saturated calomel electrodes should be used for calibration. They must be properly marked to distinguish between them. A high impedance (≥ 10 M ohm) voltmeter should be included in the equipment. Alternatively, if the measuring electrode can be removed from the diver operated unit, the units built-in voltmeter may be used (see Clause 7.4.5.2.5). The electrodes should be kept at constant temperature at least one hour prior to and during the control of the calibration electrodes. The temperature should be the same as for calibration of the measuring electrode.

7.4.5.2.3 For simplification, the saturated calomel electrodes are called 1, 2 and 3. The following procedure may be used to select the best electrode.

Remove the rubber cap from the electrode's tip. Saturated calomel electrode No. 1 (SCE 1) is connected to the positive terminal of the voltmeter. While SCE 2 is connected to the negative. The tip of the electrodes are submerged in the sea water, and the potential difference is read on a voltmeter. The value should be logged. Then SCE 2 is replaced with SCE 3. The potential difference between SCE 1 and SCE 3 is measured and logged. At last, SCE 1 is replaced with SCE 2. The potential difference between SCE 2 and SCE 3 is measured and logged.

Acceptable readings are: ±2 mV (form -2 mV to +2 mV).

The following principles are suggested for selection of the best electrode:

- If all readings are within the acceptable range, any electrode may be used.
- If one reading is out of range, the electrode not included in this reading should be used.
- If only one reading is within the range, either of the two electrodes used in this reading should be used.
- If all readings are out of range, either of the two electrodes with least potential difference may be used. However, the electrode used should be labeled and sent to a laboratory for control.

Electrodes which are suspected to give wrong potential readings should be renewed or sent to a laboratory for control.

7.4.5.2.4 Various types of diver-operated units exist. Different procedures have to be used to calibrate these types of units. The various types are:

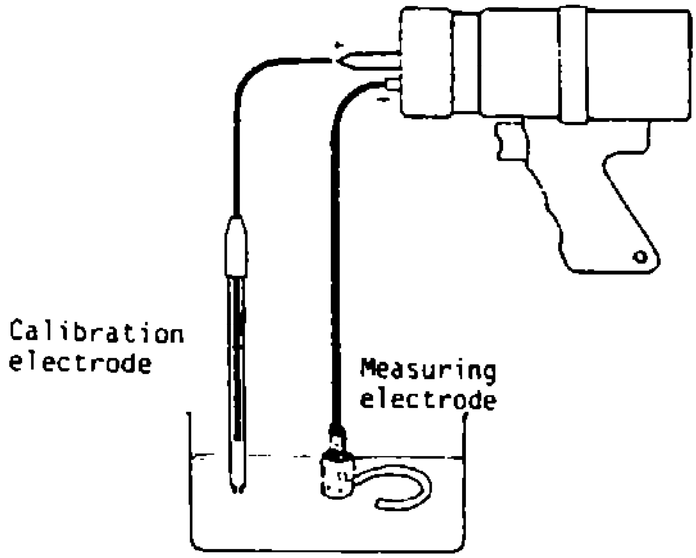
- Units with removable measuring electrode.
- Units which can be submerged during calibration using calomel electrodes.
- Units calibrated by use of zinc and saturated calomel electrode.

7.4.5.2.5 On some diver-operated units it is possible to remove the measuring electrode. The following equipment is necessary to perform the potential measurements:

- Diver-operated unit.
- Three saturated calomel electrodes.
- Cable for connection between measuring electrode and diver-operated unit.
- Clamp.
- Saturated potassium chloride solution.

The measuring electrode is pulled out of the connector on the unit. An electric conductor is connected in-between the electrode's connector and the unit's connector (see Fig. 4). It should be ensured that the electrical contact is satisfactory. The measuring electrode is to be submerged into sea water. If the electrode's connector or conductors are not watertight, neither of them must be in any contact with sea water (indicated on Fig. 4). The selected calibration electrode (see 7.4.5.2.2) is connected to the unit's metal tip, for instance by a clamp. The tip of the calibration electrode is submerged, and the potential difference is read on the unit's display, and the value is logged. Acceptable reading is: -5 mV ±5 mV (from -10 mV to + 0 mV). If the potential difference is outside these limits, the results obtained during the potential survey should be corrected.

An additional voltmeter may be used instead of the unit's built-in voltmeter. The measuring electrode is connected to the negative terminal of the voltmeter, and the saturated calomel electrode is connected to the positive. The procedure is the same as given above.



PRINCIPLE FOR CALIBRATION
Fig. 4

7.4.5.2.6 On some diver-operated units it is possible to connect the saturated calomel electrode to the metal tip of the unit by an electrical conductor. The conductor is connected to the metal tip by a watertight sealing. The electrical conductor must be water proof. The following equipment is necessary to perform the potential measurements:

- Diver-operated unit.
- Three saturated calomel electrodes.
- Watertight sealing.

Then diver-operated unit can be totally submerged into sea water while only the tip of the saturated calomel electrode is submerged. The potential difference between saturated calomel electrode and measuring electrode can then be read on the unit's display as described in Clause 7.4.5.2.5. Acceptable reading is: -5 mV ±5 mV. If the potential difference is outside these limits, the results obtained during the survey should be corrected.

7.4.5.2.7 For several diver-operated instruments it is not possible to calibrate as described in Clauses 7.4.5.2.5 or 7.4.5.2.6. For such instruments an alternative procedure should be used. The following equipment is necessary in order to perform the potential measurements:

- Diver-operated unit.
- Three saturated calomel electrodes.
- High impedance voltmeter (> 10 M ohm).
- Cable.
- Clamp
- Piece of zinc, either pure or anode zinc.

The saturated calomel electrodes should be controlled according to Clause 7.4.5.2.2. The selected calibration electrode is connected to the negative terminal of the voltmeter and submerged in sea water. The piece of zinc is connected to the positive terminal by using the clamp and cable. The piece of zinc is then submerged in sea water. It should be ensured that only the zinc is submerged, not the clamp or cable. The potential difference between zinc and saturated calomel electrode is read on the voltmeter and logged. The reading will be in the range of -1.00 -1.05 V. The cable and clamp are disconnected from the zinc piece. Then the potential of zinc is measured directly with the diver-held unit, and the result is logged. The potential will normally be in the range -1.00 -1.05 V. It should be noted that the diver-operated unit should be submerged for at least one hour before calibration to become stable. It is important that the two measurements are carried out in rapid succession to ensure that the zinc potential does not vary. The potential between the measuring electrode and zinc ($E_{Ag/AgCl/sea\ water/Zn}$) is subtracted from the potential between saturated calomel electrode and zinc ($E_{calomel/sea\ water/zinc}$) as follows:

- $E_{Ag/AgCl/sea\ water/Zn}$
- $E_{calomel/sea\ water/Zn}$
- $E_{Ag/AgCl/sea\ water/calomel}$

Acceptable difference is -5 mV ±5 mV (from -10 mV to + 0 mV). If the potential difference is outside these limits, the results obtained during potential survey should be corrected.

7.4.5.3 Electrical contact between metal tip and steel or anode material

7.4.5.3.1 Before measurements on steel surfaces are carried out, a light cleaning of marine fouling should be carried out at the point on the steel surface where the measurement is taken. Before the metal tip of the instrument is in contact with the steel surface, the relatively noble potential of the metal tip will be read on the instrument. When electrical contact between steel surface and metal tip is established, the potential reading will immediately become more negative.

7.4.5.3.2 At the points on the anodes where the potential measurements are taken, the potentials should immediately become more negative. The potential change will depend on type of alloy and anode current output. See Table 1 for final potentials. Insufficient electrical contact may cause potential readings in the range -0.60 to -0.90 V vs Ag/AgCl.

7.4.5.4 Check of equipment during potential survey

7.4.5.4.1 The diver should bring with him a piece of zinc during potential surveys. If the potentials are not within the acceptable ranges the unit should be checked against the zinc piece. This reading should be reported together with the unacceptable reading. The zinc surface should be thoroughly cleaned by wirebrushing. If a value less negative than -1.02 V (Ag/AgCl) is measured on the zinc piece, the equipment should be taken to the surface for calibration with saturated calomel electrode.

7.4.5.5 Check of battery voltage and voltmeter

7.4.5.5.1 The battery voltage should be checked regularly. Minimum allowed battery voltage should be checked and will depend on type of voltmeter. The voltmeter may be checked by measuring known voltages in the actual range. This may be done by using mercury batteries which have stable voltages.

7.4.5.6 Check of watertight sealing

7.4.5.6.1 Watertight sealings should be checked visually. Some sealings should be lubricated with silicone grease to be waterproof. Any leak of the sealings in the measuring circuit may cause erroneous readings.

7.4.6 Potential measurements with surface voltmeter, cable and measuring electrode

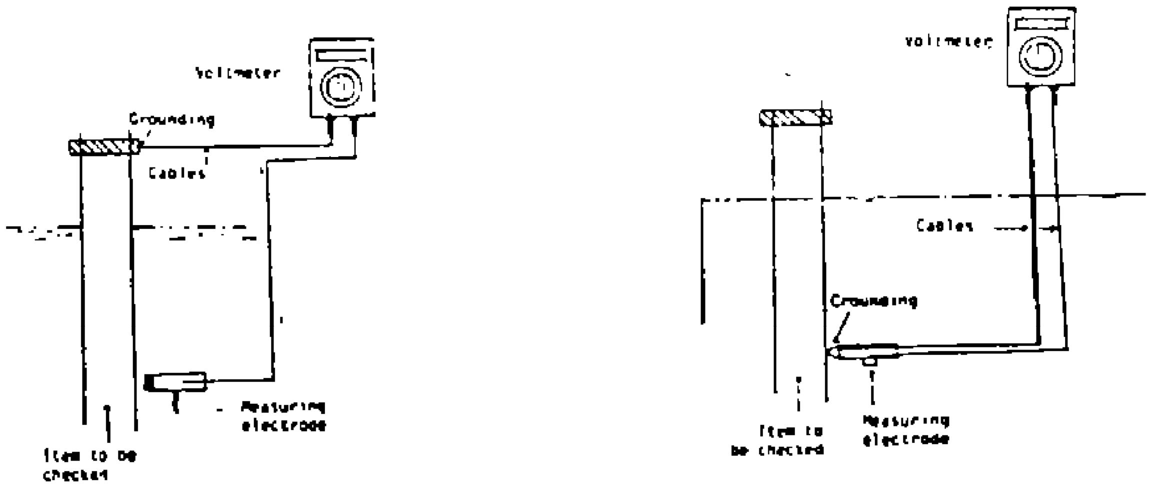
7.4.6.1 General

7.4.6.1.1 The technique consists of using a high impedance (≥ 10 M ohm) voltmeter, a measuring electrode and insulated connecting cables. The positive terminal of the voltmeter is grounded to the structure, usually above water level, while the negative terminal is connected to the measuring electrode through a cable. The voltmeter is located above water level. See Fig. 5.a. The diver moves the electrode to various parts of the structure. Potentials are read on the voltmeter above water. The reading is taken when the diver is holding the measuring electrode in a stable position at the measuring point. When the reading is taken, the exact position of the measuring electrode must be known.

7.4.6.1.2 Alternatively, the measuring electrode and a metallic tip for making contact to the steel are built into a tool. Two cables or a two-core cable connect the metallic tip and measuring electrode to a surface voltmeter (see Fig. 5.b). The diver moves the electrode to various parts of the structure. When potential measurements are performed, the metallic tip is pressed against the measuring point and the potential is read on the surface voltmeter. When the reading is taken, the exact position of the measuring electrode must be known.

7.4.6.1.3 The following equipment is necessary to perform the potential measurements:

- Measuring electrode with cable.
- High impedance voltmeter.
- Two clamps for grounding to structure.
- Grounding cable.
- Three saturated calomel electrodes.
- Saturated potassium chloride solution.



a) **b)**

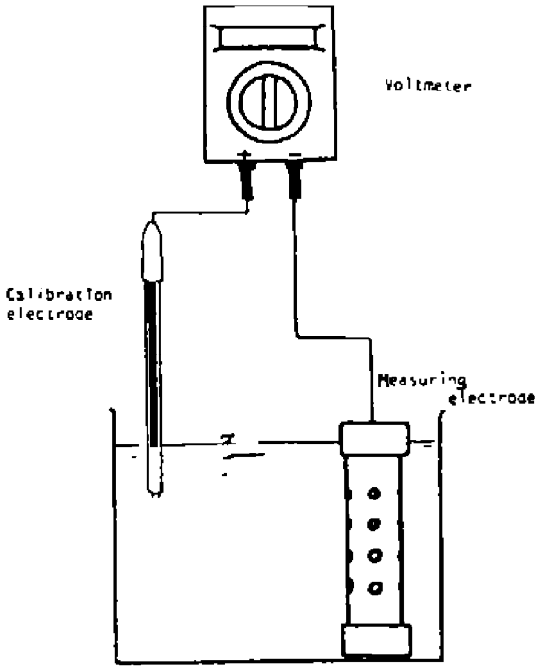
SCHEMATIC WIRING DIAGRAM FOR POTENTIAL MEASUREMENTS
Fig. 5

7.4.6.2 Calibration

7.4.6.2.1 Calibration of measuring electrodes should be carried out before and after each potential survey. Saturated calomel electrodes should be used for calibration. However, these electrodes should also be controlled to select the best electrode. Control of calibration electrodes is only necessary before each potential survey, and thereafter every 24 hours.

7.4.6.2.2 The control of saturated calomel electrodes shall be carried out in accordance with Clause 7.4.5.2.2.

7.4.6.2.3 Firstly, the measuring electrode should be submerged in fresh sea water for minimum 1 hour for stabilization. Then the measuring electrode is connected to the negative terminal of a high impedance (≥ 10 M ohm) voltmeter. The selected saturated calomel electrode (see Clause 7.4.6.2.2) is connected to the positive terminal of the voltmeter. The tip of the electrode is submerged (see Fig. 6). The potential difference is read on the voltmeter, and the value is logged. Acceptable reading is: -5 mV ±5 mV. If the potential difference is outside these limits, the results obtained during the potential survey should be corrected.



CALIBRATION OF MEASURING ELECTRODE
Fig. 6

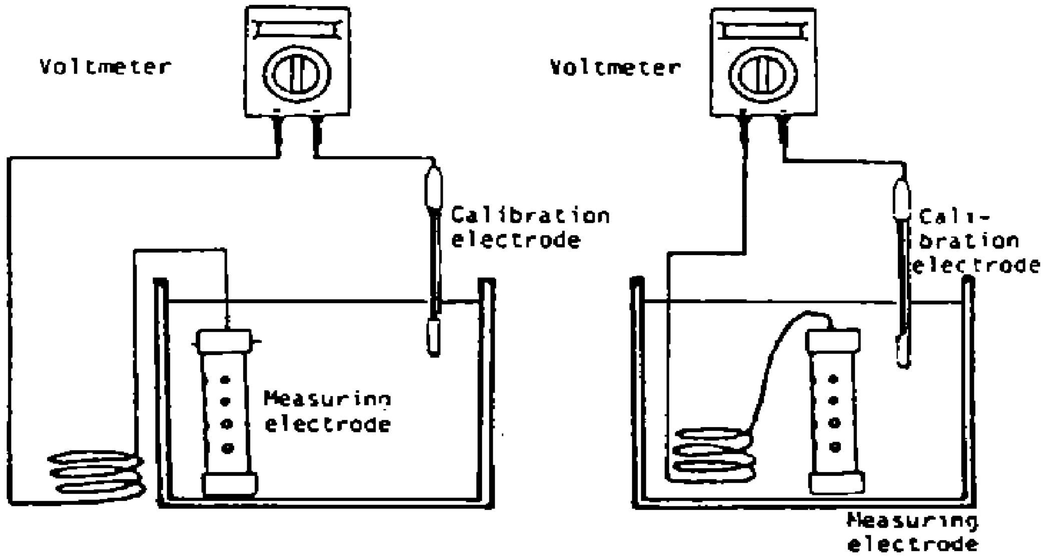
7.4.6.2.4 An alternative to the use of the silver/silver chloride/sea water electrode as measuring electrode is the use of silver/silver chloride/saturated potassium chloride electrode. The silver chloride plated silver in the Ag/AgCl/Sat.KCl electrode is located in a housing containing a saturated potassium chloride solution. The silver chloride plated silver in the Ag/AgCl/sea water electrode is directly exposed to sea water. The potential the Ag/AgCl/Sat.KCl is not influenced by the sea water composition. The electrolytical contact between the silver chloride plated silver and sea water is achieved by porous plug.

7.4.6.2.5 The same procedure for calibration of the electrode as described in Clause 7.4.6.2.3, may be used for the Ag/AgCl/Sat.KCl electrode. Acceptable potential difference between the saturated calomel electrode and the Ag/AgCl/Sat.KCl electrode is +40 mV ±5 mV. If the potential difference is outside these limits, the results obtained during the potential survey should be corrected. The positive limit for cathodic protection of steel in aerobic environments will be approximately -0.755V, and the negative limit will be approximately -1.005 V for this electrode.

7.4.6.3 Check of cable insulation

7.4.6.3.1 Any failure of conductor insulation may cause erroneous potential readings. The magnitude of the error will depend on the size and location of the insulation damage.

7.4.6.3.2 When checking the cable insulation, the cable with measuring electrode is connected to one of the terminals of a voltmeter. The other terminal is connected to a saturated calomel electrode. The measuring electrode not the cable, is submerged into sea water. The same is done with the calibration electrode. The potential between the two electrodes is read on the voltmeter (see Fig. 7.a). The cable to the measuring electrodes is then also submerged, and the potential between the measuring electrode and saturated calomel electrode is read on the voltmeter (see Fig. 7.b). The difference between the two readings should not be more than ±2 mV. If the difference is more than ±2 mV, the cable may be damaged, and it should be renewed. If the readings are unstable, it may be caused by the electrodes which need some time to stabilize (at least 1 hour).



a) b)

SKETCHES FOR CHECK OF CABLE INSULATION
Fig. 7

7.4.6.4 Check of grounding connection to structure above water

7.4.6.4.1 When potential measurements are carried out, the positive terminal is connected to the structure. This part of the structure should be in electrical contact with the submerged part of the structure. To establish electrical contact to the structure, a clamp is often used. Coating, dirt, etc. should be removed before the clamp is fastened. If the electrical connection is unsatisfactory, the potential readings will be shifted to less negative values.

7.4.6.4.2 Special attention should be paid to grounding when the survey is being undertaken from a survey vessel.

7.4.6.4.3 The magnitude of the error in potential reading will depend on the impedance of the voltmeter and the resistance across the grounding. The resistance across a coating layer may be several mega-ohms which may lead to significant errors. The magnitude of the error will decrease with increasing internal impedance of the voltmeter.

7.4.6.4.4 The electrical contact between clamp and structure can easily be checked with a multimeter. The clamps should have a metallic tip or needle for easily establishing an electrical contact. The following procedure may be used for checking the electrical contact between clamp and structure:

Coating, rust and dirt are removed at two locations on the structural part until bright metal appears. Two clamps are fastened at these locations. They are connected to a multimeter with two cables. The resistance between the clamps is measured with the multimeter. The reading should be less than 1 ohm. If not, the electrical connection is unsatisfactory and must be improved. If the electrical connection is found satisfactory, clamp No. 2 is removed, whilst Clamp No. 1 is used further for potential measurements. It is important that Clamp No. 1 is not removed since this may change the electrical contact resistance.

7.4.7 Sub-sea pipeline potential survey

The cathodic potential and electric field gradient of the submarine pipelines may be measured continuously by 3 electrode systems. The electrodes can be fitted to any pipeline inspection vehicle and the potential profiles and field gradient readings obtained along the pipeline transferred to a digitizer. This system measures 5 reading per second. This rate gives on reading every 10 cm when the ship traveling at 1 knot. Pipeline cathodic potential readings will be plotted on a chart against distance along the pipe (for more detail see Appendix B).

7.4.8 Time intervals

When considering a galvanically protected steel structures is sea water the most critical period during the polarization process is the first 6 - 12 months. If the structure achieves full polarization during this period and maintenance current density levels are consistent with criteria levels, then it is unlikely that any long term problems will develop. Thereafter semi-annual potential survey of fixed offshore structures and for subsea installation every 3 years should normally be carried out. For jetties under impressed current systems monthly potential measurement and for ships, internal of water tanks and cofferdam every 6 month should be done.

7.4.9 The extent of the potential survey

Survey program for offshore structures shall cover all major parts of the installation such as nodes, pile guides, pile sleeves, conductors and their supports, partly closed compartments where under protection is likely to occur. Also:

- Corrosion seems to be prevented by cathodic protection in crevices filled with stagnant sea water. However in crevices with flowing sea water cathodic protection has limited effect. Therefore in these crevices the potential outside of them plus the potential drop should be equal to or more negative than the protective level.

- Use high impedance voltmeter (> 10 M ohm) to compensate IR drop.

- Before measurements, a light cleaning of marine fouling shall be carried out.

- Check the equipment during potential survey.

- Check for grounding connection to structure above water.

- Control of distance from measuring electrode to structure is very important. This distance shall be as small as possible (i.e. maximum 50 mm).

- Look for overprotection of highly stressed members.

- Potential measurements may be disturbed by electromagnetic noise which is pitched-up by the cable, this noise may be caused by communication equipment, radar, etc.

- Any defect in reference electrode cable insulation may cause erroneous potential readings. The magnitude of the error will depend on the size and location of the insulation damage (to check cable for damage see Appendix B).

- Check the battery voltage of voltmeter regularly. This may be done by using mercury batteries which have stable voltages.

7.5 Inspection of Rectifiers

7.5.1 General

This Section outlines procedures and practices for inspection of rectifiers. Being source of protection current, rectifiers shall be inspected at least on bi-weekly basis. During the inspection, D.C voltage and current outputs shall be observed and recorded. Any changes in voltage and current from normal operation figures should be recorded and the reason should be determined.

7.5.2 Records

Readings of rectifier output shall be recorded on a form prepared for this purpose and forwarded to designated office where they compared with prior readings to determine abnormality (see Form 2).

7.5.3 Major points for routing inspection

Inspection of rectifier stations shall include following as a minimum:

- Observing and recording readings of DC voltmeter and Ammeter.

- Observing and recording figures of AC kilo Watt -hour meter.

- Where seasonal variation cause substantial changes in rectifier current output, rectifier taps may require adjustment during routine inspection to prevent overprotection.

- Inspection for level of transformer oil in the tank.

- Inspection for appearance of silica-gel breather. If the color is changed to purple, replace the cartridge and reactivate the old one by heating in an oven.

- If the system is for protection of internal surfaces of a water tank and the system is not automatically controlled, manual adjustment of current should be done to prevent overprotection where the tank is empty or partially filled. This may cause sever deterioration of coating.

7.5.4 Annual inspection

In addition to the above mentioned items, at least once per year (usually at the time of complete annual survey) rectifiers shall be inspected systematically for the following:

- Inspection of exterior and interior of units for cleanliness and good shape of paint.

- Inspection of all bolted current carrying connections for tightness and cleanliness.

- Inspection of all ventilating screen in air cooled units. In case of obstraction of air-vent, cleaning the vent.

- Inspection of indicator meters for accuracy and calibration if required.

- Inspection of insulated wires to see if insulation has cracked or been damaged.

- Oil shall be clear and almost colorless in oil immersed units. A cloudy or turbid appearance indicates a failing oil. If this is observed, sample of oil shall be taken from drain point of the tank. The sample shall be tested in accordance with BS 148. A failing oil shall be replaced with proper grade of transformer oil suitable for low tension AC power supply.

- Inspection of all protective devices such as fuses, circuit breakers lightning arrestors and earth connections shall be done, to ensure they are undamaged and in satisfactory condition.

- If the system is installed in the hazardous atmosphere and the equipment is flame proof inspect and follow the recommendations in Parts 1 and 2 of BSI CP 1003 and specially inspect earthing system and circuit breaker and surge diverter.

- Check for performance and efficiency of rectifying stack of unit, specially those located under hot weather condition. This is very important where the rectifier energy supply is from regional supply and the annual cost of power exceeds the replacement cost of stack.

7.6 Inspection of Ground Bed

7.6.1 General

This section deals with inspection and routines to ensure the continued effective operation of impressed cathodic protection ground bed, both onshore for buried structures and offshore for jetties and ship hulls and submarine pipeline.

7.6.2 On land ground bed

Inspection of ground bed shall be made in conjunction with inspection of rectifier. The inspection shall include followings as a minimum:

7.6.2.1 Inspect and ensure that there has been no disturbance of the earth above the header cable and line of anodes. If construction activity is noted in vicinity of ground bed, the inspector shall notify the authorized parties to prevent unintentional damage to the ground bed. If new construction involves are installation underground structures, test shall be conducted to determine whether they will be effected by field potential gradient or stray current.

7.6.2.2 Inspect to ensure that no part of the ground bed is subject to washing (by flooding etc.) or exposure of cables. If such a failure observed, the insulation of cables shall be checked for damage and damaged points shall be marked and recorded for latter repair or maintenance.

7.6.2.3 If the ground bed is the type of replaceable deep anode system, periodic inspection shall be carried out for gas blockage, anode dimension, retrofit rope and cable.

7.6.2.4 If cathodically protected rebar in concrete structure is located in the ground or above ground, acidic conditions may generated during cathodic protection current discharge at the anode-concrete interface which may affect both concrete and anode. Therefore visual inspection of ground-bed should be done periodically for any apparent changes in concrete surface conditions particularly to detect lamination and cracking due to the temperature rise or acidic condition causes around ground beds in highly resistance concrete.

7.6.3 Submerged ground beds

The two most commonly used impressed anodes for offshore structures are platinized titanium and niobium anodes. The anodically formed magnesium dioxide on the surface of these anodes in sea water, will adversely affect performance by favoring oxygen evolution over chlorine evolution. The anodic dissolution rate of platinum is approximately 10 times greater when oxygen evolution is the predominant reaction. Silting of platinized anode will shorten the anode life due to acid attack to both the platinum and titanium or niobium substrates.

Also the formation of scale, biofouling, the presence of some certain organic materials, low frequency AC ripple and even short periods of current reversal could adversely affect anode performance. Therefore these anodes shall be inspected by divers annually, and in the case of shielding the passage of current by fallen non-conductive sheets, marine growth or silt, cleaning shall be done. Also divers shall thoroughly inspect the route of anode’s cable for probable cable mechanical damage by impeller of ships, falling objects etc.

In harsh environments of sea, it is desirable to inspect impressed anode cables passing thorough the splash zone. If the cables passing through conduits, they shall be inspected for mechanical damage.

7.7 Inspection of Offshore Sacrificial Anodes

Offshore platforms, ships and submarine line mostly protected by sacrificial anodes. Although these systems are designed for a specific period of time, known as designed life, but due to unknown environmental changes or events of increasing the surface area which have to be protected by anodes, the consumption of anodes will increase and the overall life of the cathodic protection system will be affected. To estimate the remaining life of anodes and for future maintenance planning, it is necessary to inspect at least every 5 years the sacrificial anodes of such structures. This inspection consist of cleaning the anode surface, dimensional measurements, calculate the consumed percentage of anode and prediction the remaining life of the system. Anodes’ potential shall be measured during inspection. Potential readings of sacrificial anodes shall be close to the figures in Table 3. If the measured potential is less negative than figures in Table 3 it means the current output is high and caused the anode be polarized to relatively positive potentials. Readings more negative than those figures in Table 3 may be erroneous. In this case the measuring equipment shall be checked and the reference electrode shall be calibrated.

TABLE 3 - POTENTIALS OF SOME SACRIFICIAL ANODE ALLOYS AT AMBIENT TEMPERATURES

ALLOY	ENVIRONMENT	POTENTIAL VOLT vs. Ag/AgCl
Al-Zn-Hg	Sea-water	-1.00 to -1.05
Al-Zn-In	Sea-water	-1.05 to -1.10
Zn	Sea-water	-1.00 to -1.05

7.8 Current Survey

7.8.1 General

This survey helps to determine the distribution of current along a cathodically protected structure. This test shall be conducted on pipeline annually and on plants when and where required.

7.8.2 Pipelines

Permanent test leads provided on pipeline (see IPS-E-TP-820) are used to determine the direction and amount of current flowing in a particular length and span of pipe. Two methods have been used for current measurement of pipelines:

a) Two wires method.
b) Four wires method.

In first method the wires bridge a span of known length (usually 30 to 60 meters), therefore by measuring the potential drop across the span together with the polarity of instrument connections the direction and amount of current can be determined. The amount of current can be calculated by ohm's law where the resistance of span of pipe extracted from available steel pipe resistance table.

In four-wire method, at each end of the test span two test wires are connected. The two inner lead serve as current measuring and measuring of external circuit resistance, the two outer leads are used for calibration the test span. This method permits more accurate pipeline current measurements. The length of pipe span and pipe resistance can be accurately measured in this method by using outside leads and passing a known amount of current between them.

For more detail see Appendix B.

7.8.3 Offshore structures

To ensure the effective current distribution on a cathodically protected offshore structures many computerized program is available. Also in the circuit of each anode of some cathodic protection system a fuse in installed. By using a shunt and voltmeter it is possible to measure the current passing to each anode. This shall be done every 6 months and any differences with respect to the previous measures shall be recorded.

If the impressed current cathodic protection system is one of the automatically. Controlled current type, then the modular units shall be inspect and calibrated bi-monthly.

8. INSPECTION FOLLOWING FAILURE REPORT

8.1 General

Periodic inspection and survey may indicate failures or unusual conditions in protection system. Problems revealed during periodical survey are dealt with in this section for further inspection.

8.2 Increase in Circuit Resistance

If periodic inspection of rectifier output indicates a drastic increase in circuit resistance of system, further inspection survey is required to locate the nature of problem.

When an increase in resistance is noted but the circuit is not completely open (i.e. rectifier ammeter indicates some current output, though less than usual), a conductive type cable locator receiver can be used to follow the A.C hum on the cable. If this indicates the cables (negative and positive including ground bed header) are in proper condition, then one or more anodes may have failed. If there is a header cable break along the line of anodes, the signal will drop to essentially zero in the vicinity of the break.

To locate the failed anodes, two reference electrode shall be used to determine over-the-line potential profile (made along the line of anodes with the rectifier energized). Potentials being measured between a remote reference and a copper sulfate electrode located over the line and moved by 60 to 90 cm increments along the line of anodes. The potential profile will show positive potential peaks at each working anodes. Any missing peak, then show the position of anodes that are no longer working and require repair or replacement.

In the case of deep well ground beds, gas blockage may be the cause for increased resistance. Impressed anodes of submerged systems may be covered by silt, scale or biofouling and cause the increase in circuit resistance.

8.3 Stray Electric Currents

Where the presence of stray electric currents is suspected, e.g. in proximity to d.c. electric traction systems or where varying structure/electrolyte potentials indicate the possibility of such currents, it is sometimes necessary to determine more accurately the extent of stray current effect on the structure. This can be done by plotting the potential field in the area, using a stationary reference electrode, or a structure, as a reference point. The effect due to the operation of the electric traction system can be found by making a potential survey during the time the system is working and repeating the tests after the system has been shut down.

8.4 Tests for Electrical Continuity

Tests shall be carried out whenever the continuity of the structure is in doubt, to locate any discontinuities (see Appendix B).

8.5 Problems Associated with Galvanic Anode Installation

Due to low driving voltages available from galvanic anodes, resistance in the connection can cause a marked decrease in their current outputs. Therefore if there is a marked decrease in the output of a galvanic anode and there is no reason to believe that it is reaching the end of its life, then inspection shall be done for broken header cable or anode lead. Also all connections between anode lead and pipe cable in test box shall visually be inspected for cleanliness and tightness.

9. INSPECTION AND SURVEY FOR EFFICIENCIES OF COATINGS

9.1 General

Adequate corrosion protection of buried or submerged metallic pipelines can be achieved by using a combination of two corrosion control methods:

1) coatings, and
2) cathodic protection.

Also for structures such as ship's hulls, wharf, bulkheads and the interior of tanks, the coating and lining must serve as a part of the cathodic protection system. Dielectric materials applied to the metal surface exposed to the corrosive environment isolate the metal from corrodent and provide primary barrier against attack.

Cathodic protection completes the protection program by counteracting the electrochemical dissolution of the metal surface at damaged locations or flaws in the coating. Where the coating is not bonded to the pipe surface, the problem is how to protect beneath the coating. The void or crevice between the pipe surface and the coating may contain corrosion products, deposits, or electrolyte. Unbonding due to poor application of pipe coating and disbonding which means the bond of the coating to the metal surface has been disrupted, usually by the effects of cathodic protection, has deleterious effect on the efficiency of cathodic protection. The usual cathodic protection inspection and potential measurements do not detect the state of polarization of the pipe surface beneath unbounded coating.

This Section describes the different inspection methods and techniques to evaluate the effectiveness of coating. The need for these tests is felt when unusual variations is observed in pipe to soil potential profile.

9.2 Coating Resistance Measurement

This is the most practical method used for determining the effectiveness of a coating. This method is based on direct measurement of coating resistance by measuring current and voltages across a section of pipe in field. In this method useful data on current requirements for cathodic protection can also be taken concurrently.

A current interrupter automatically switch off the circuit of some batteries, as power source, temporary ground bed and pipeline. Then potential and line current measurement continue to change in accordance with the established on-off cycle. Test data may be taken for a section of 8 kilometers. The average ΔV in millivolts divided by the current collected ΔI in milliamperes will give the resistance to earth, in ohms, of the pipeline section tested. For more detail of test method refer to Appendix B.

9.3 Attenuation Test Method

Coating effectiveness may be evaluated using attenuation method which involves a limited amount of field measurements by interruption of rectifier(s). The measurements lead to a figure which is termed "attention constant" per kilometer.

From this figure spread of protective current can be evaluated and the approximate distance between drain points can be estimated. Rating tables (see Table 4) for attenuation constant can be used for interpretation of taken field data and describe the relative effectiveness of pipe coating. Also based on the attenuation constant value, the maximum distance between drain points can be estimated and location for installation of new rectifiers, to supplement ineffective cathodic protection system, may be decided. For more detail on test method and calculation refer to Appendix B.

TABLE 4 - SPREAD OF PROTECTION RELATIVE TO ATTENUATION CONSTANT

Rating Level	SPREAD OF PROTECTION		
	Range of Values Attenuation Constant "a" per km	Evaluation of Spread of Protection	Approximate Distance Between Drain Points (see Note) km
1	Less than 0.025	Excellent (E)	Over 128
2	0.025 to 0.050	Very Good (VG)	64 - 128
3	0.050 to 0.10	Good (G)	32 - 64
4	0.10 to 0.20	Fair (F)	16 - 32
5	0.20 to 0.40	Poor (P)	8 - 16
6	More than 0.40	Very Poor (VP)	Less than 8

Note:

Based on assumed values as follows:
dV_0 (to remote cell at each drain point) 1000 mV.
dV_x (At mid-point between drain points due to each of drain points to give total change at drain point of 200 + 200 = 400 mV) 200 mV

e.g.: For "a" = 0.025

$$x = \frac{\text{Ln } 1000 - \text{Ln } 200}{0.025} = \frac{6.90 - 5.30}{0.025} = \frac{1.60}{0.025} = 64.0$$

Distance between drain points is 2X = 128 km

9.4 Pearson Method

Holidays (defects) in the coating of a buried pipeline may be located by this method. Also large disbonding in pipe coating may be find. It can be used successfully only if a pipeline has been carefully backfilled and the soil is compact around it. Also there must be some moisture content in the surrounding soil. The system include a source of A.C transmitter with A.C signal being impressed upon the pipe. Most of the current flows between the pipe and earth at discontinuities in the coating, which operator can be detected by means of an amplifier and pick-up headphone at the surface. For more detail see Appendix B.

9.5 Coating Inspection by C-Scan

This system is based on current attenuation along the pipe and is largely automatic. An electrical current applied to a well wrapped buried metal pipeline will decrease gradually with increasing distance from the current injection point, as the current escapes to earth through the coating. If the coating has as uniform thickness and bonding to the pipe, the strength of the signal current on the pipe will decline logarithmically. But if there is a low resistance electrical path from the pipe direct to the soil at any point, there will be a substantial local increase in the rate of loss of signal current.

Based on this theory it will identify sections of pipeline between measurement points where coating defect exist. By using a computer, data can be monitored or stored on disk or tape for further analysis. For more information see Appendix B.

9.6 Visual Inspection

Where the structure is exposed for any purpose it shall be examined for protection level and if coated, the condition of the coating shall be assessed and recorded as part of the history of cathodic protection system. This shall also be considered for internal of storage tanks and vessels, ship's hull and water box of heat exchanger.

By continuous pipe-to-soil potential logging technique it can be identified localities of pipelines which fail to comply with protective criteria. Excavation of bell hole to reach the pipe surface and visual examination of coating at this anomaly section reveals the coating condition. Close interval pipe-to-soil potential survey around the pipe in excavated section indicate the real potential drop in soil above the pipe. Visual inspection also helps to obtain information on bacteria activity around the pipe and if so, cathodic protection level has to be corrected.

Visual inspection also gives evidence of the type of coating deficiency i.e. unbonding which is usually due to poor material or application versus disbonding which cause by overprotection. For those offshore structures and ships where the weight saving is significant, coating offers special advantages in reducing the total amount of required protection current and anodes. Therefor diver visual inspections of coating is necessary for providing reliable long term corrosion protection to offshore structures.

In ship hulls and their ballast tanks, coating prolong the anode life, then increase the replacement intervals. This in turn bring down the high cost of dry docking. Routine inspection of coating in conjunction with anodes dimensional measurements during deballasting will indicate the both efficiency of coating and anode performance.

Since the space in water boxes of exchangers and pressure vessels are limited, it is not possible to install massive sacrificial anodes. Coating will reduce the surface area and required current densities. Routine inspection of these surfaces shall be a part of overhaul program in plants to ensure effective corrosion protection.

9.7 Over the Line Potential Survey

In routine inspection, pipe to soil potential is measured every kilometers along the pipeline or where test points have been installed.

When unusual variations in pipe to soil potentials is observed, an over-the-line potential survey helps to pinpoint locations of low point in potential profile which need close attention. For measuring closely spaced potential readings, i.e. 15 meters, two methods can be used. These methods are discussed in Appendix B.

10. DATA RECORDING AND ANALYSIS

10.1 Data Recording

10.1.1 Records shall be used to demonstrate the operational history at any time during the working life of a cathodically protected system. For this reason, it is recommended that records be retained for the life of structure

Printed forms shall be used to record field data. The forms use for following purposes:

- To save inspector's time in field, by minimizing the amount of writing.
- To establish a uniform manner for recording and easy comparison of results and recognition of changes.

10.1.2 The corrosion engineers may design forms to suit their particular requirements. However following information should be included:

a) Dates of survey and current control procedures applied.
b) For anode replacements, types, location and date of replacement.
c) Any damage to the structure, nature and extent of repairs carried out.
d) Condition of coating at failure points and remedial action taken.
e) The location of any structure corrosion observed and, if possible, the cause of corrosion.
f) Details of any alterations made to the structure.

10.1.3 Followings are some forms which may be used for general purposes:

Company ' Name
Title of The Department
Potential Survey Readings

Date of Test from .... to .... **Pipeline Designation**
km .... to km ....(Test Section) **Surveyer's Name ....**
Sheet....................... of...

km POST *	PIPE TO SOIL POTENTIAL - MILLIVOLT WITH REF. TO COPPER SULFATE	REMARK
		Notes shall be made of special points (e.g. insulating flanges/ joints, cased crossing etc.

*** In case of city gas net work "Test Point Identification".** **Form No. 1**

Company' Name
Title of The Department
Transformer/Rectifier Inspection

Rectifier Station Designation	Rectifier Ratings		Power Supply *	Operating Output		Rectifier Operation **		Timer	Silica Gel Breather ***	Notes and Recommendation
	Volts	Amps		Volts	Amps	As Found	As Left			

*** 3 ph or single phase**
**** OK or OFF**
***** OK or replaced**
INSPECTOR'S NAME : ....

Form No. 2

10.2 Analysis of Data

In evaluation of results from inspection and potential measurements, corrosion specialists shall always be consulted when irregular values have been recorded.

Irregular potentials readings may be caused by either systematic or random measurement errors.

10.2.1 Sacrificial system

10.2.1.1 Less negative potentials

Possible reasons for potentials less negative then -0.85 V ($Cu/CuSO_4$) in connection with sacrificial anode cathodic protection systems are:

- Low design current density
- Consumed anodes

- Loss of anodes
- Passivation of anodes by inferior chemical composition
- Bad distribution of anodes
- Larger coating breakdown than expected
- Larger surface area than expected

10.2.1.2 Too negative potentials

Too negative potentials seldom occur in connection with sacrificial anode cathodic protection. One reason may be that the potential readings are taken close to anodes.

10.2.2 Impressed current system

10.2.2.1 Less negative potentials

When impressed current system are utilized, potentials less negative than the minimum value (see Clause 6) may be caused by:

- Failure on fixed impressed current anodes.
- Failure on fixed reference electrodes.
- Failure on cables.
- Failure on rectifiers.
- Unsatisfactory distribution of anodes.
- Low design current density.
- Larger coating breakdown than expected.
- Larger buried submerged steel surface area than expected.

10.2.2.2 More negative potential

Potentials more negative than the maximum values (see Table 2) may occur in connection with impressed current systems, especially close to anodes. Possible causes may be:

- High anode current output
- Unsatisfactory distribution of anodes.
- Failure on fixed reference electrodes for potentio-statiscally controlled impressed current systems.
- Failure on rectifiers.
- Failure on potential reading.
- Failure on anode shields
- IR drop.

10.2.3 Possible causes for irregular potential reading on sacrificial anodes of submerged structure

- Passivation; may be as high as the potential of -0.7 V (Ag/AgCl).
- Polarization of anode due to large anode current output.

10.2.4 Rectifiers data analysis

10.2.4.1 Applied voltage normal, current low but not zero:

- Deterioration of anodes or ground beds.
- Drying out of soil around ground bed, or some anodes no longer immersed.
- Accumulation of electrically-produced gas or marine growth around anodes.
- Disconnection of some of the connections to individual anodes of ground bed or anode system.
- Disconnection of part of protected structure.

10.2.4.2 Applied voltage normal-current zero:

- Severance of anode or cathode cables.
- Complete failure of anodes.

10.2.4.3 Both current and voltage are low:

- Tapping on transformer set too low.
- Transformer or rectifier failing.
- Electricity supply faulty.

10.2.4.4 Applied voltage and current correspondingly high:

- Tapping on transformer set too high.

10.2.4.5 Applied voltage and current normal but structure potential in sufficiently negative:

- Break in continuity bond or increased resistance between point of connection and point of test.

- Greatly increased aeration of soil at or near point of test due to drought or increased local drainage.

- Alteration of environment causing rapid depolarization, or increase in oxygen content of water due for example, to reduce level of pollution.

- Faulty isolation equipment.

- Protected structure shielded or otherwise affected by new structures.

- Failure of cathodic protection system on another part of the same structure or on a secondary structure bonded to it.

- Deterioration of, or damage to, protective coating.

10.2.4.6 Applied voltage and current normal but potential abnormally negative:

- Break in continuity bonding at position further from the point of application than the point of test.
- Decreased aeration of soil or electrolyte at point of test.
- Reduction in rate of flow of electrolyte.
- Secondary structures have been removed or have been cathodically protected or bond to them broken.

10.2.4.7 Applied voltage and current normal but structure/electrolyte potential fluctuates:

- Interference from d.c source.

10.2.4.8 Applied voltage and current normal but structure/electrolyte potential is positive:

- Immediate action shall be taken by inspector if abnormally positive potentials indicate that connection have, in some way, been reversed.

11. INTERFERENCES

11.1 General

Interference from cathodic protection arises where a foreign structures intersects the direct current path between the anode and cathode. Where the current enters the structure the effect is cathodic. Where if leaves the structure the effect is anodic, and the rate of corrosion of that position may be increased.

Galvanic anodes do not usually cause interference to other structures. Interference problems are more probable with impressed current systems because of the electrolyte voltage gradients usually associated with the pipe or anodes. Therefore interference is discussed under two separate headings as cathode field and anode field interferences.

Testing shall be carried out and remedial actin shall be taken to correct adverse effect to foreign structures. Follow up testing is necessary specially when there is an increase in cathodic protection current above that originally applied to the primary structure.

11.2 Cathode Field Interferences

11.2.1 General

When a structure is placed under cathodic protection. The electrolyte in immediate vicinity becomes more negative. This creates a "cathode field" in the surrounding of the protected structure. If a portion of foreign structure is located in this cathode field, current will tend to be discharged from the foreign structure because the soil in the cathode field will be more negative with respect to the foreign structure.

11.2.2 Measurements of cathode field interferences

Test may be conducted by measuring the potential of foreign structure with respect to a half cell at the area of strongest cathodic field. Readings shall be taken with the cathodic protection power source alternately switched "on" and "off". A tendency for interference is indicated if the potential of the unprotected structure increases (because less negative) when the power source is turned "on" and current is drained from the protected structure. An example of measurements and interpretation of results is illustrated in Appendix B.

11.3 Anode Field Interferences

11.3.1 General

The electrolyte is more positive in the vicinity of an impressed cathodic protection ground bed. If a portion of foreign structure lies within this field it will tend to pickup current from surrounding positive electrolyte. This current will flow in the structure toward positive electrolyte. This current will flow in the structure toward a less positive area (such as at low resistivity area) in order flow to the protected structure. If the current is discharged over a sufficiently large area, the current density will be very low, and negligible damage to the foreign structure will result, but if it is discharged to the soil in a limited area, rapid corrosion may occur. While anode field interference will not induce corrosion on the foreign structure in the area of current pick-up, in case of coated structure, it is quite possible that the induced potential, may be high enough to damage the coating.

11.3.2 Measurements of anode field interferences

Where an unprotected structure passes through, or lies within, an anode field, steel to electrolyte potentials of the unprotected structure shall be measured near the anode and at several points remote from the anode. Steel to electrolyte potentials will be more negative near the anode and less negative remote from the anode.

11.4 Corrective measurers

If tests indicate any tendency for interference it shall be reported to corrosion specialist for corrective measures.

Bonding the structures through resistor, use of galvanic anodes and extra coating as electrical shield are same customary methods to eliminate interferences.

APPENDICES

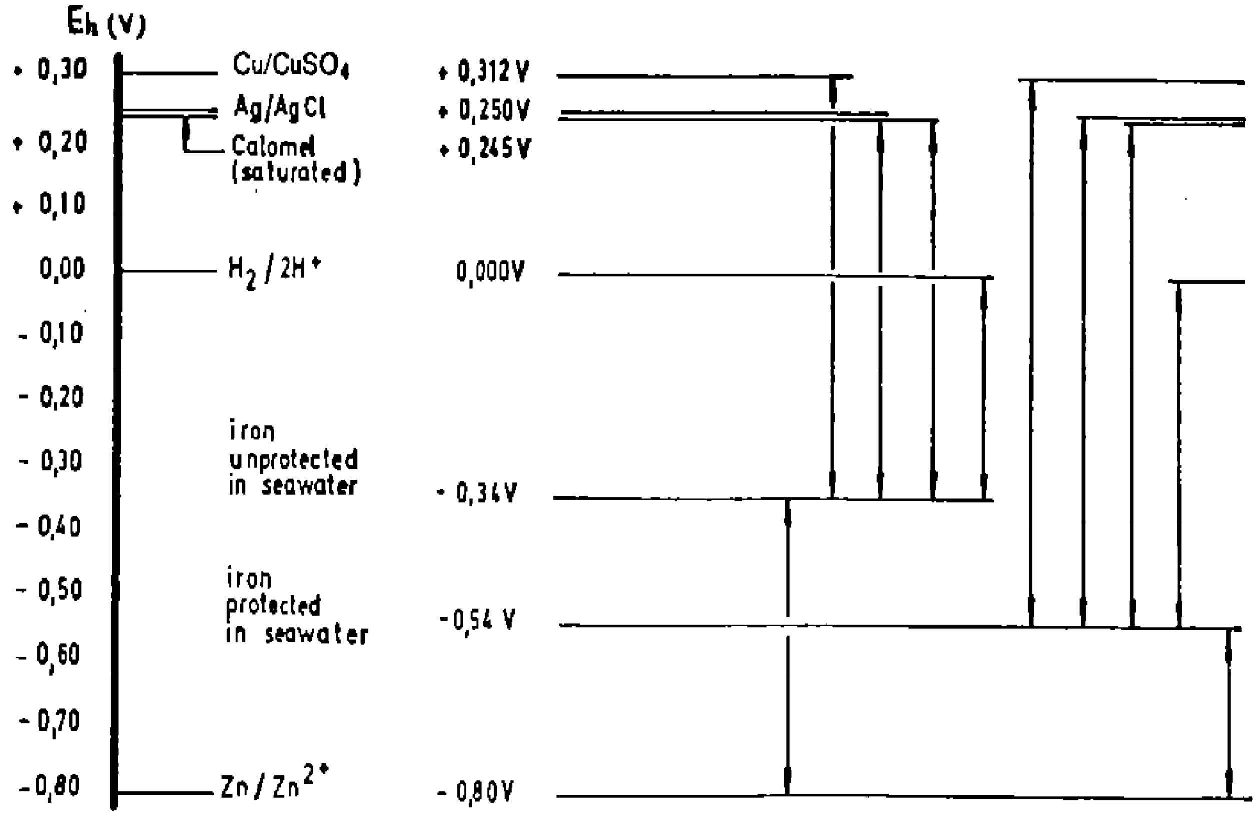
APPENDIX A
METERS AND EQUIPMENT

A.1 Reference Electrode

The potentials of metals given in electrochemical series are relate to the so-called "Standard Hydrogen Electrode" S.H.E of which the potential is set arbitrarily at ±0 mV. Such an electrode consists of a platinum wire or platinum mesh which is immersed in a solution with hydrogen ion activity of 1 and flushed with hydrogen gas at atmospheric pressure (760 Torr = $1.013.10^5$ Pa). Handling of such an electrode is naturally very awkward. In practice therefore it is replaced by so called reference electrodes. The most important reference electrodes and their potentials against S.H.E are reproduced in Fig. A.1. The characteristics of these are shown in Table A.1.

A.1.1 Copper/copper sulfate electrode

A.1.1.1 The most common type of electrode used for measuring the level of protective potentials of a buried pipeline and other buried structures is the copper/copper sulfate reference electrode. Typical copper/copper sulfate electrodes are shown in Fig. A.2.



REFERENCE ELECTRODES
Fig. A.1

(to be continued)

APPENDIX A (continued)

TABLE A.1 - CHARACTERISTICS OF REFERENCE ELECTRODES

REFERENCE ELECTRODE	CELL	POTENTIAL TO STANDARD HYDROGEN ELECTRODE AT 25°C V	dE/dT V/°C
0.1 N calomel	$Hg/Hg_2Cl_2/KCl$ (0.1 N)	0.334	-0.7×10^{-4}
0.1 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	0.250	—
Copper sulfate	$Cu/CuSO_4$ (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.

A.1.1.2 Copper sulfate electrode has a half cell potential which is reasonably constant under a wide range of soil conditions provided that the electrode is kept clean. There shall be at least two copper sulfate electrodes in the test kit. These shall be matched in potential. The matching may be checked periodically by measuring the potential difference between the two when replaced side by side in same soil. For best performance, the potential difference should not exceed about 10 millivolts. If the difference is excessive, contamination of one or both is indicated. In this case they should be cleaned and refilled with fresh solution. The copper rod may be cleaned by submerging in a 10 percent solution of nitric acid for a few minutes. It should be rinsed well with distilled water before reassembling. The electrode shall be kept full of saturated copper sulfate solution with a few excess copper sulfate crystals or powder to ensure that the solution will remain saturated. The solution shall be replaced with fresh one periodically to avoid contamination. The porous plug shall be kept covered when not in use to avoid drying out. If the electrode does dry out, replace the porous plug.

A.1.2 Silver/silver chloride electrode

This electrode is widely used in potential measurements of submarine pipelines, jetties, wharves, platforms and internal of water tanks which are under cathodic protection. Copper sulfate may be contaminated by chloride ions then its use in sea water is limited. Fig. A.3 shows typical silver/silver chloride half cells.

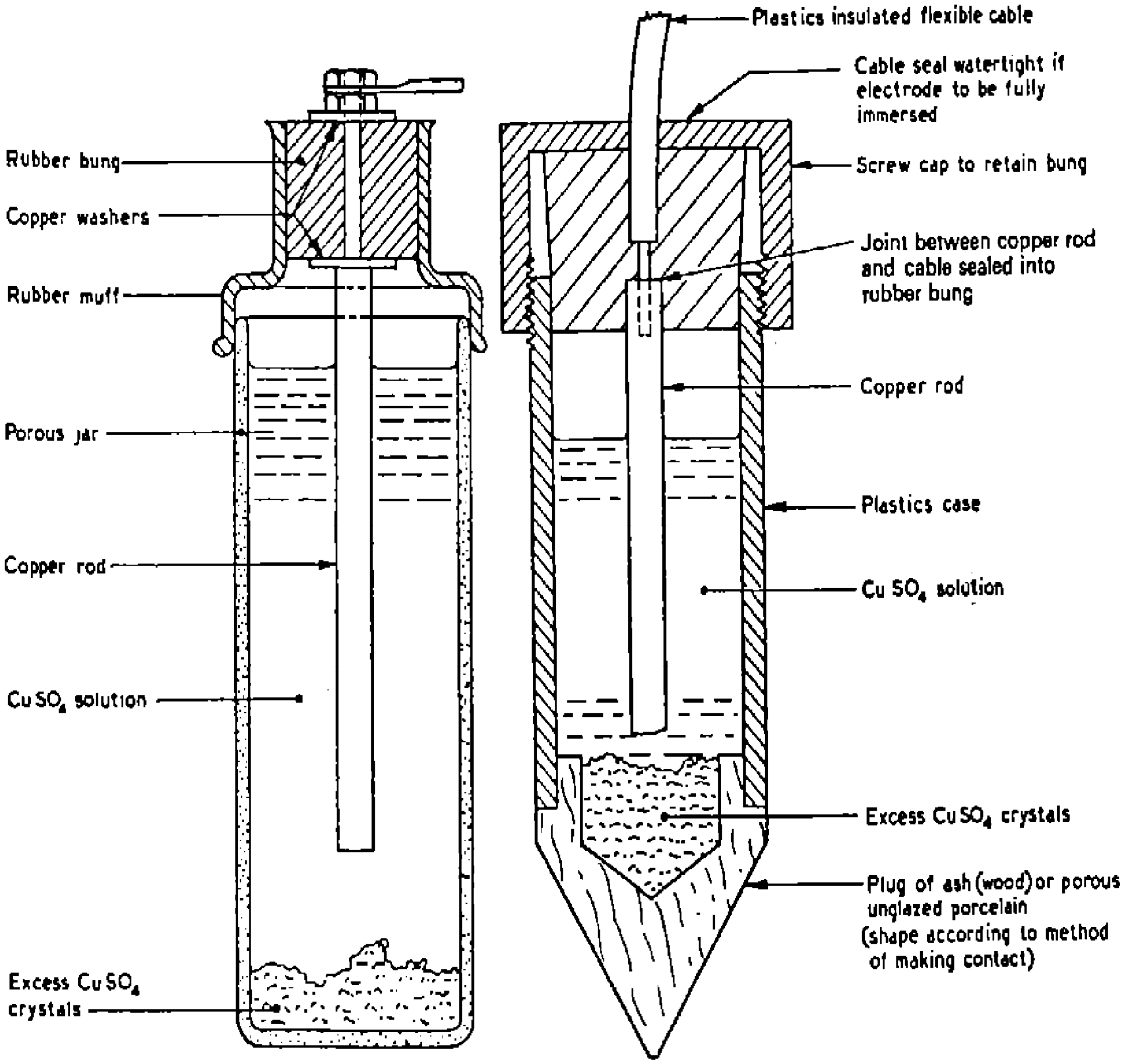
A.1.3 Pure zinc electrode

Zinc should not be considered as an accurate electrode since it’s potential is unstable in sea water. It shall only be used to get an estimate of the protective level.

Due to the long lifetime of zinc electrodes, they may be used as permanent electrodes. This electrode may be used at points which are not accessible such as center of storage tank’s bottom. The reading with respect to zinc is subject on the type of zinc and its surface condition. In both sea water and soil variation is in the range of 50 mV. Fig. A.4 shows different type of zinc electrodes.

(to be continued)

APPENDIX A (continued)



a) b)

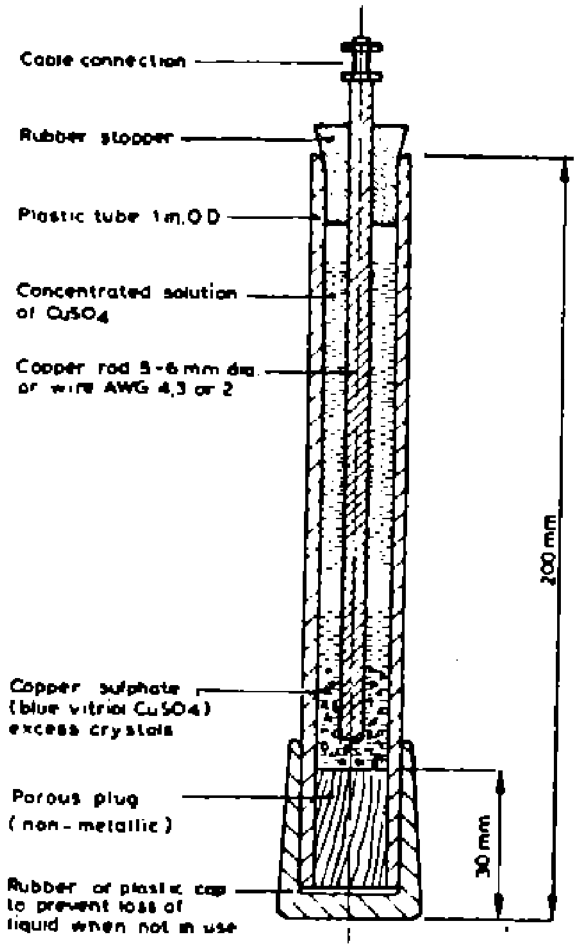
Note:

The type shown in (b) if made robust enough and of suitable length can be used for probing.

TYPICAL COPPER SATURATED COPPER SULFATE REFERENCE ELECTRODES
Fig. A.2

(to be continued)

APPENDIX A (continued)



c)

Note:

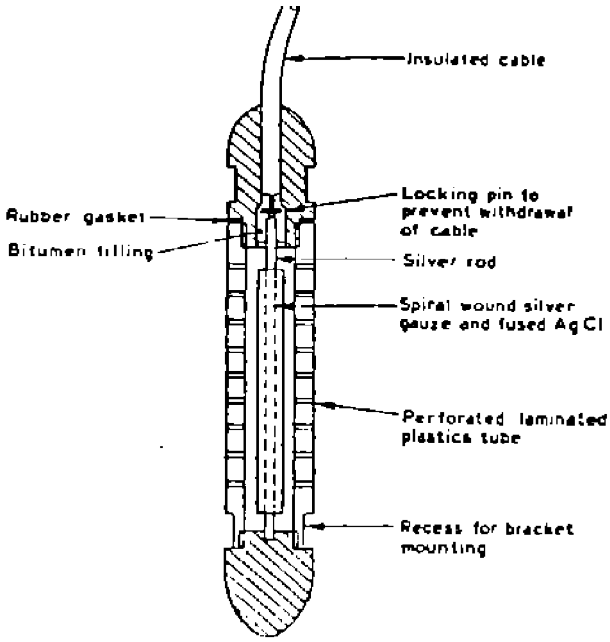
Contact with soil made through porous plug.

SIMPLE MODEL OF COPPER/COPPER SULFATE HALF-CELL
(REFERENCE ELECTRODE)

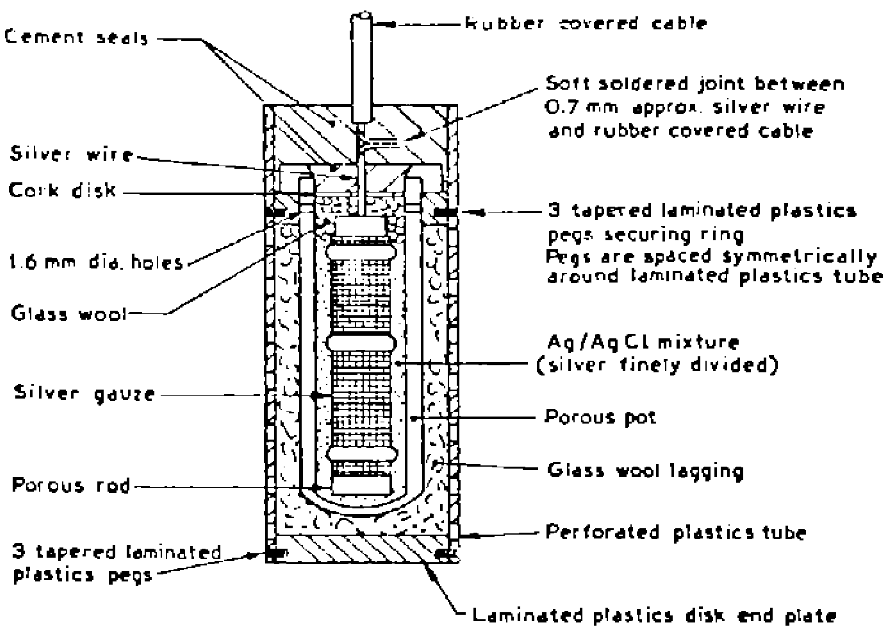
Fig. A.2 (continued)

(to be continued)

APPENDIX A (continued)



a) Admiralty pattern



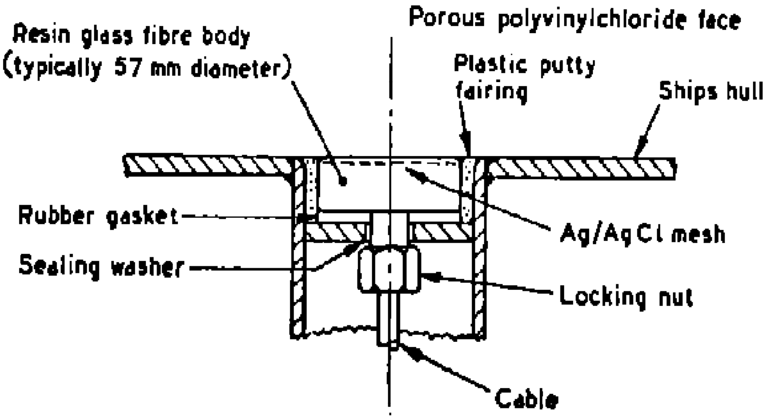
b) Revised pattern-fused silver chloride

TYPICAL SILVER/SILVER CHLORIDE REFERENCE ELECTRODES

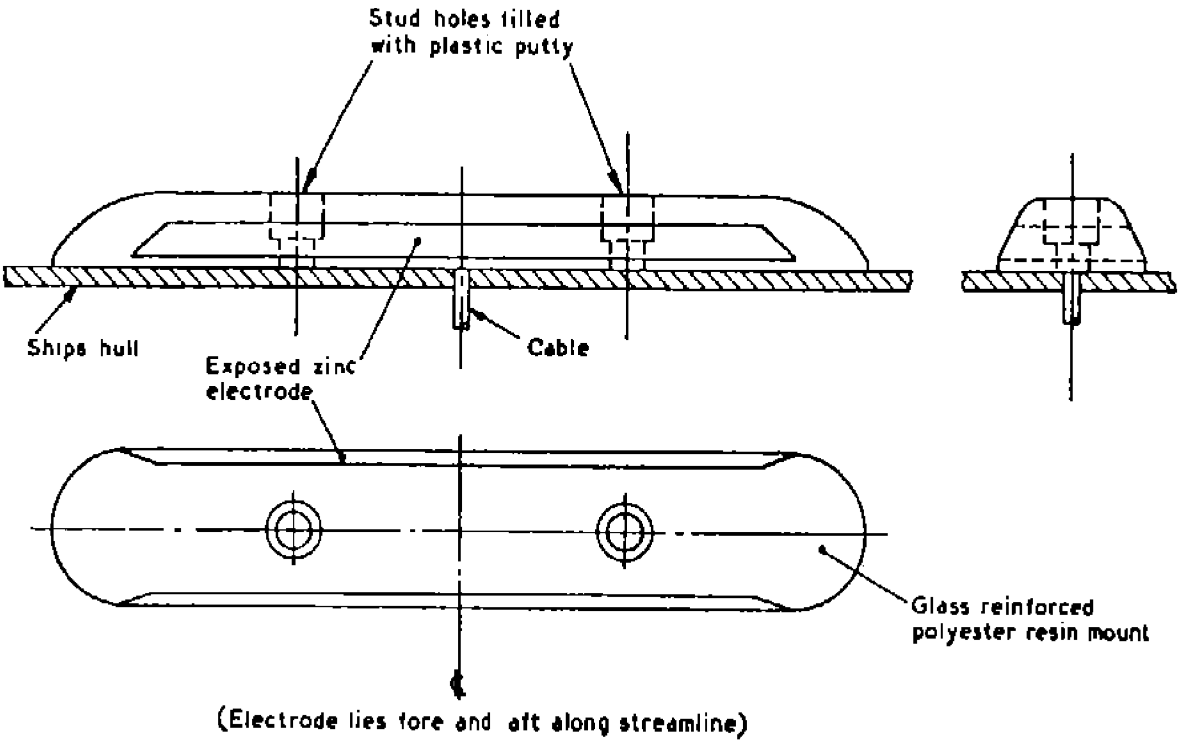
Fig. A.3

(to be continued)

APPENDIX A (continued)



i) Ag/AgCl reference electrode



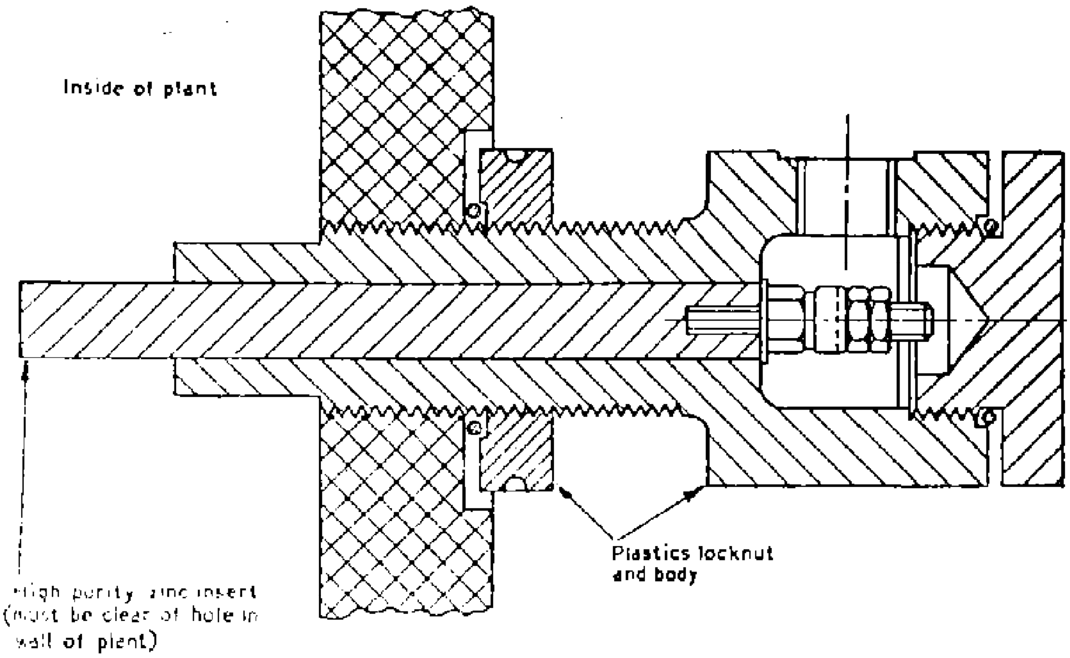
ii) Zinc electrode

a) Typical reference electrodes for mounting on ship's hulls

TYPICAL REFERENCE ELECTRODES FOR MOUNTING INSIDE PLANTS & SHIP'S HULLS
Fig. A.4

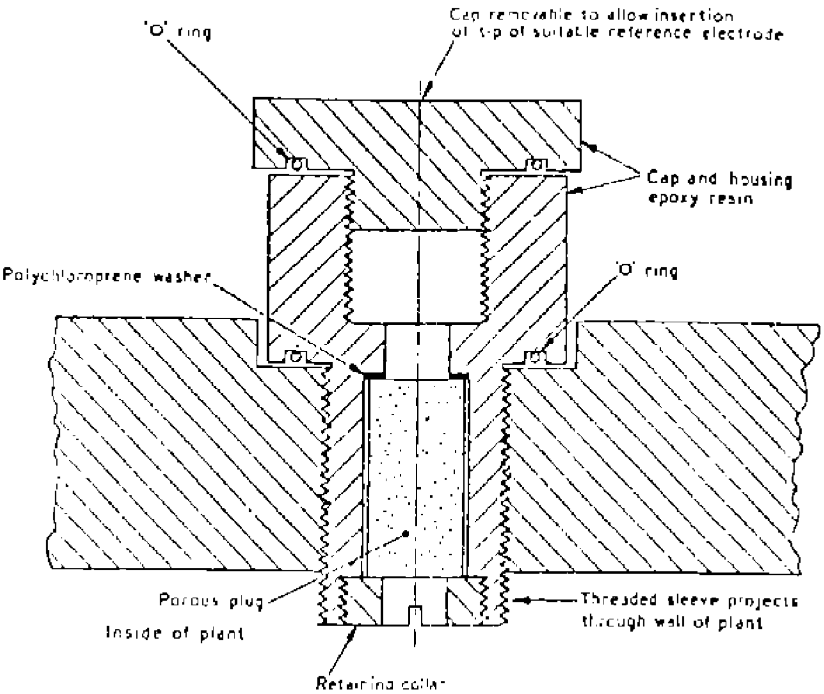
(to be continued)

APPENDIX A (continued)



b) "Screw-in" zinc electrode for measurement of metal/electrolyte potential inside plant

b) "Screw-In" zinc electrode for measurement of metal/electrolyte potential inside plant



c) Porous plug reference point for measuring metal/electrolyte potential inside plant

Fig. A.4 (continued)

(to be continued)

APPENDIX A (continued)

A.1.4 Calomel electrode

The calomel electrode is a half cell made of mercury-mercurous chloride mixture in contact with a solution either saturated potassium chloride or normal potassium chloride (see Table A.1). The solution contacts the electrolyte through a porous plug the same way as copper sulfate electrode does. The stable half cell potential of calomel electrode makes it suitable for calibration purposes. Laboratory type electrodes usually constructed in glass.

A.2 Potentiometer and Voltmeter

A.2.1 Conventional voltmeter (high resistance)

In measuring potentials between pipeline and electrolyte, the circuit resistance includes voltmeter resistance and external circuit resistance (the resistance of test leads connecting the voltmeter with pipeline and electrode, the pipe to earth resistance and the electrode to earth resistance).

In most cases the major part of the external circuit resistance is electrode to earth resistance; therefore, the electrode shall be placed on moist soil during measurement. The electrode in contact with the surface of 1000 ohm-cm soil will have a resistance to earth in order of 50 ohms. Any conventional voltmeter will take some current and its reading is subject to correction. Correction factor is reversely proportional to voltmeter resistance. If the voltmeter resistance is high compared with the external circuit resistance, the correction factor will be desirably low so that for practical application correction factor is not needed.

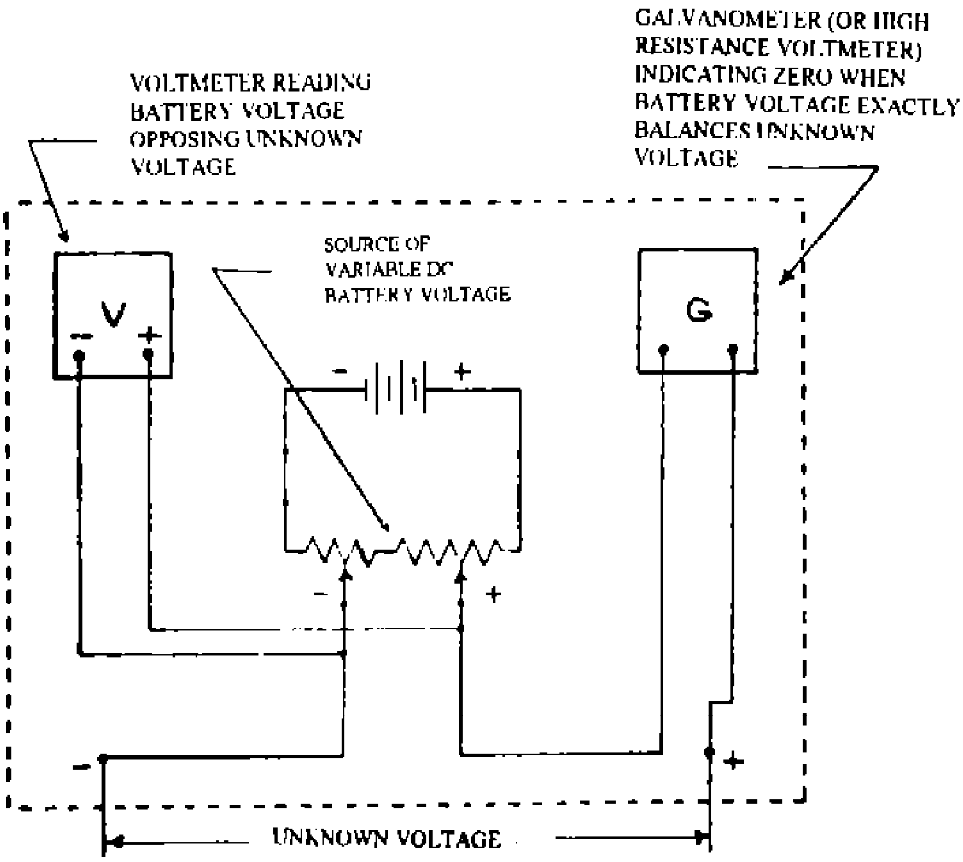
In view of the above, high resistance or high sensitivity voltmeter is required for measuring potentials between pipeline and reference electrode. High sensitivity voltmeter has a resistance of 50,000 ohms per volt or higher. D.C voltmeter with sensitivity of 200,000 ohms per volt with various ranges of full scale voltage are normally used for pipe to electrode potential measurement. This is a sufficiently sensitive instrument which keeps error in potential reading low enough for practical field conditions and the observer can be satisfied that the potential reading taken is sufficiently accurate.

A.2.2 Potentiometer-voltmeter

This instrument is used for measuring pipe to electrolyte potential in areas having high resistivity soil. By using this instrument the effect of high resistance in the measuring circuit will be reduced to a negligible amount. This instrument operates by matching the unknown potential to be measured with a variable-voltage battery supply. A sensitive galvanometer built in the instrument indicates the matching of the two potentials. The indicating voltmeter then measures the matched battery voltage. By this means the operating current for the voltmeter is taken from the low resistance battery circuit rather than from the high resistance measuring circuit. Fig. A.5 illustrates the fundamental circuitry of potentiometer-voltmeter.

(to be continued)

APPENDIX A (continued)



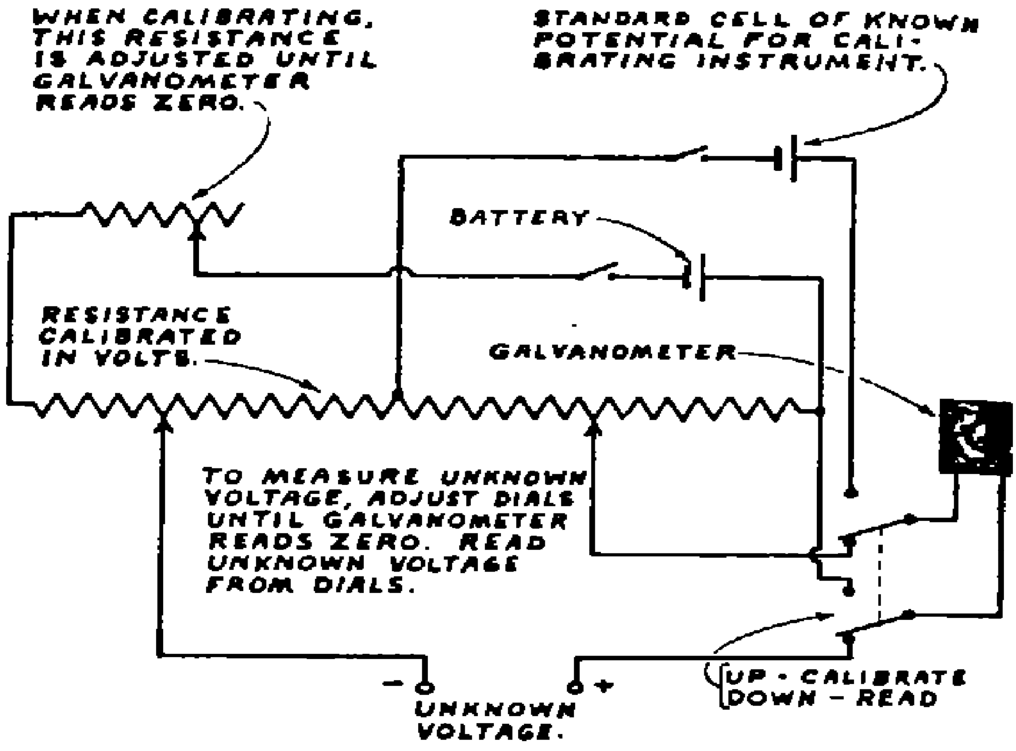
POTENTIOMETER-VOLTMETER CIRCUIT DIAGRAM
Fig. A.5

A.3 Potentiometer

There is difference between potentiometer and potentiometer-voltmeter. The resistance across the battery terminals of potentiometer is calibrated so that the voltage taken from it to balance the unknown voltage can be read from indicating dials or solid wires, eliminating the need for an indicating voltmeter. The balance is indicated by a sensitive galvanometer the same way as potentiometer-voltmeter. Circuitry of a potentiometer is illustrated in Fig. A.6.

(to be continued)

APPENDIX A (continued)



POTENTIOMETER SCHEMATIC DIAGRAM
Fig. A.6

In some cases dispite the accuracy and advantage, a potentiometer or potentiometer-voltmeter may be impractical to be used. For instance in stray current areas potential changes are rapid and it is difficult to keep these instruments on null balance and as such it is impractical to use potentiometer or potentiometer-voltmeter. In this case direct reading voltmeter can be used provided that correction factor of the meter is established for the particular range and multiplied by the reading taken to obtain true potential value.

To obtain external circuit resistance and establish correction factor, potential shall be measured on 2 ranges of specific voltmeter with a known internal resistance. Assume that comparative readings are -0.92 volt on 2 volt range and -0.85 volt on the 1 volt range using a voltmeter having a sensitivity of 62500 ohms per volt. Internal voltmeter resistance will then be 125000 ohms on 2 volt range and 62500 ohms on the 1 volt range. The external circuit resistance in ohms (R) and correction factor can then be obtained as follows:

$$0.92 \times \frac{125000 + R}{125000} = 0.85 \times \frac{6200 + R}{62500}$$

Form the above

R (External circuit resistance) = 11,200 ohms

(to be continued)

APPENDIX A (continued)

and correction factors:

for 2 Volt range $$\frac{125000 + 11200}{125000} = 1.085$$

for 1 Volt range $$\frac{62500 + 11200}{62500} = 1.179$$

Using the above correction factors, true potential will be:

On 2 Volt range **$0.92 \times 1.085 = -1.00$ Volt**

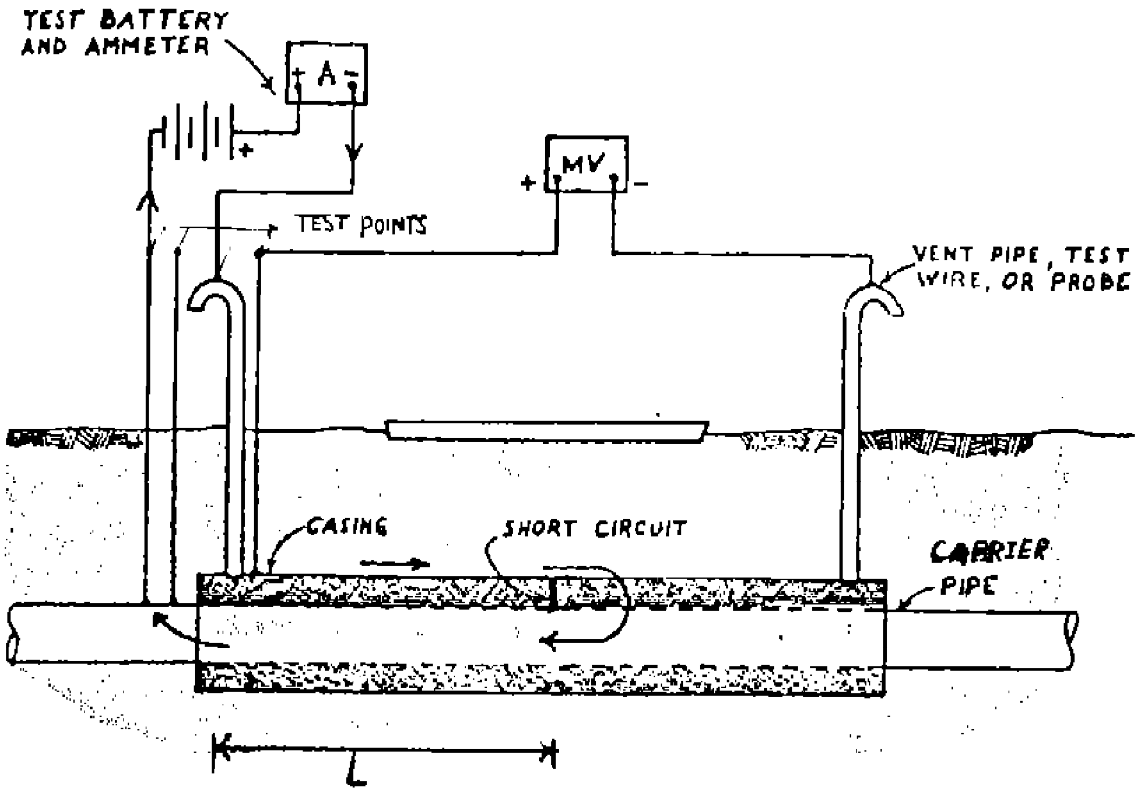
On 1 Volt range **$0.85 \times 1.179 = -1.00$ Volt**

APPENDIX B
TEST METHODS

B.1 Test Methods for the Short Circuit Point

B.1.1 Locating casing short circuit

Tests can be carried out to locate the point of short circuit. Fig. B.1.1 illustrates the test points and tests set-up.



LOCATING CASING SHORT CIRCUIT
Fig. B.1.1

As shown in Fig. B.1.1 battery current, which is measured by ammeter, is passed between the pipe and casing. This current will flow along the casing to the point of short circuit where it will transfer to the carrier pipe and return to the battery. A millivoltmeter connected between the two ends of the casing will indicate a value dictated by the measured current flowing through the casing resistance, IR drop within the casing length which the current actually flow through. Having the voltage and current value, resistance of casing span, which is subject to current flow, can be obtained. The resistance corresponds to length of casing between the point of short circuit and millivoltmeter connection at the left end of the casing.

Knowing size and thickness (or weight per unit length) of the casing, its resistance per unit length can be estimated using Table B.1.

(to be continued)

APPENDIX B (continued)

TABLE B.1 - STEEL PIPE RESISTANCE (1)

PIPE SIZE INCHES	OUTSIDE DIAMETER, INCHES	WALL THICKNESS, mm	WEIGHT PER METER kg	RESISTANCE (2) OF ONE METER IN ohms × 10^{-6}
2	2.375	3.91	5.43	259.84
4	4.5	6.02	16.07	87.78
6	6.625	7.11	28.27	49.89
8	8.625	8.18	42.56	33.15
10	10.75	9.27	60.27	23.40
12	12.75	9.53	73.81	19.10
14	14.00	9.53	81.25	17.36
16	16.00	9.53	93.16	15.14
18	18.00	9.53	105.00	13.44
20	20.00	9.53	116.97	12.06
22	22.00	9.53	128.73	10.95
24	24.00	9.53	140.87	10.02
26	26.00	9.53	152.69	9.24
28	28.00	9.53	164.59	8.57
30	30.00	9.53	176.65	7.99
32	32.00	9.53	188.40	7.49
34	34.00	9.53	200.31	7.04
36	36.00	9.53	212.21	6.65

1) Based on steel density of 7.83 gr/cm³ and steel resistivity of 18 micro-ohm-cm.

2) $$R = \frac{78.38 \times \text{Resistivity in Microohm - cm}}{\text{Weight per meter}} = \text{Resistance of one meter of pipe in ohm} \times 10^{-6}$$

Therefore, length of casing span which is subject to current flow can be obtained using following formula:

$$\text{Length (L in meter)} = \frac{\text{Millivolt observed} \times 10^{-3}}{\text{Current observed in Amps} \times \text{Resistance per meter of casing pipe in ohms}}$$

The length obtained is distance between the point of short circuit and millivoltmeter connection at the left end of the casing.

Short circuit may not be in the casing itself. It may be due to contacts between the test point wires and the casing vent (or the end of the casing itself) or between the test wires and test point conduit mounted on the casing vent. Therefore, inspection shall include through examination for these possible contacts.

B.1.2 Insulation tests

B.1.2.1 Locating of insulation defects

If an insulating flange is found defective step by step check shall be made as follow:

B.1.2.1.1 An insulated bolt sleeve may be broken down. The shorted bolt may be removed and insulation replaced. To determine which bolt is defective, it is necessary to check each bolt electrically. To check each bolt an ohmmeter may be used for checking resistance between pipeline (flange face) and the bolt. Bolts which are shorted will have zero resistance to the pipe.

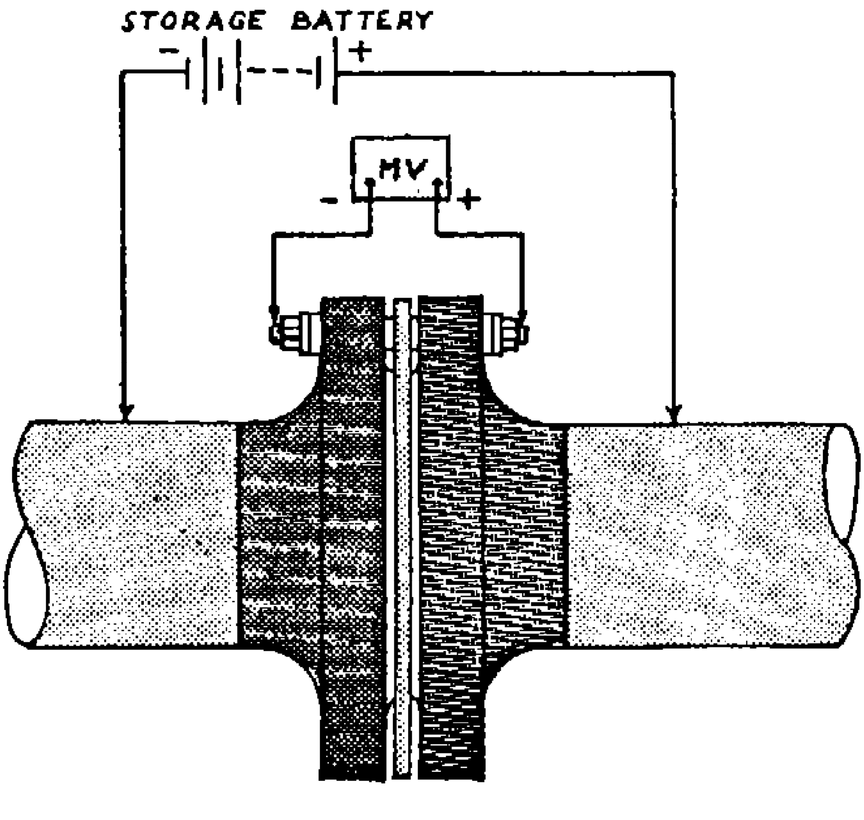
(to be continued)

APPENDIX B (continued)

B.1.2.1.2 If all bolts have a high resistance to the pipe, examine properly the outer surface of flange once more to ensure that there is nothing that could cause the short. If there is nothing on the outer surface, then check any possible by passing pipe, since if they are not insulated would give the indication of a shorted flange.

B.1.2.1.3 If result of examination on step B.1.2.1.2 above gives no indication of a shorted flange, gasket is shorted and it will be necessary to take the line out of service to replace the gasket.

In the case of a shorted insulated flange having bolts insulated on one side only, the ohmmeter test would not be usable because all bolts will have metallic contact and low resistance to the pipe. One method of checking the bolts on such a flange is to remove one bolt at a time and inspect the insulation for damage. This is a laborious and time taking job on a large flange. It may be done electrically as illustrated by Fig. B.1.2.



CHECKING INSULATED FLANGE FOR SHORTED BOLTS
Fig. B.1.2

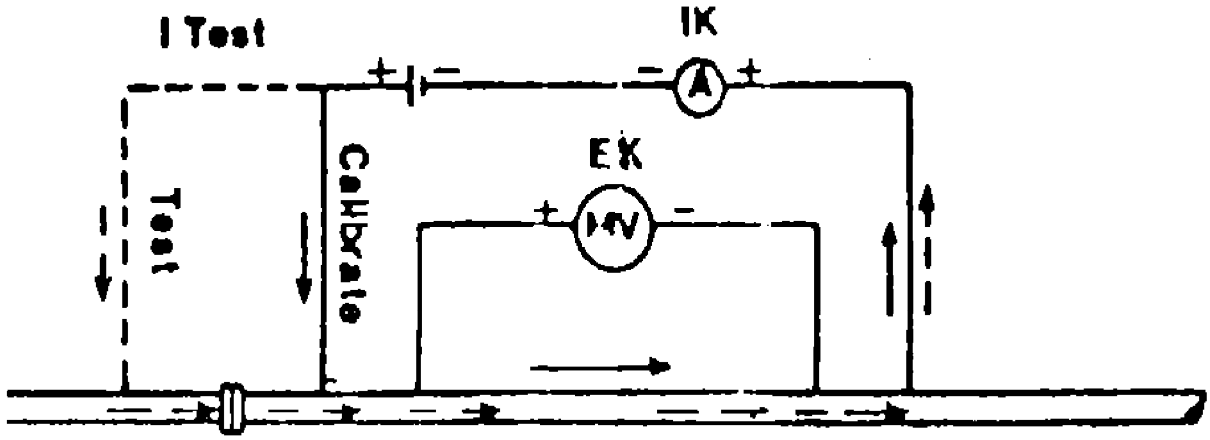
With a millivoltmeter connected between the two ends of each bolt in turn, a heavy current (such as from a storage battery as shown in Fig. B.1.2) is momentarily passed through the shorted flange. Any shorted bolts will carry this current and show a deflection on the millivoltmeter. Satisfactory insulated bolts will show no deflection.

(to be continued)

APPENDIX B (continued)

B.1.2.2 Measuring the percentage of "leakage"

Where desired, a test can be conducted to obtain the percent of "leakage" of an insulating device. This is shown in Fig. B.1.3.



LEAKAGE TEST
Fig. B.1.3

Leakage Test

Insulating joints or fittings may become partially or completely shorted due to lightning or other causes. The integrity of insulating fittings must be tested by some reliable method. Since the performance of these devices is generally critical to the operation of cathodic protection systems. One way to measure the percentage of leakage is illustrated below:

Example:

Given the following data:

1) Calculate the calibration factor: $\mathbf{K} = \dfrac{\mathbf{IK}}{\mathbf{\Delta EK}} = \dfrac{\mathbf{Amps}}{\mathbf{mV}}$

2) Calculate the percent leakage : % leakage = $\dfrac{\mathbf{K \times E\ (Test) \times 100}}{\mathbf{I\ (Test)}}$

Calibration:	**IK = +38.0 Amps**
	EK = +33.5 mV
Test:	**I Test = +6.0 Amps**
	E Test = +4.40 mV

Calculate: $\mathbf{K} = \dfrac{\mathbf{IK}}{\mathbf{\Delta EK}} = \dfrac{\mathbf{38.0\ Amps}}{\mathbf{33.5\ mV}} = \mathbf{1.13\ A/mv}$

% leakage $= \dfrac{\mathbf{K \times E\ Test}}{\mathbf{I\ Test}} \times \mathbf{100} = \dfrac{\mathbf{1.13\ A/mV \times 4.40\ mV \times 100}}{\mathbf{6.0}} = \mathbf{82.9\%}$

(to be continued)

APPENDIX B (continued)

B.2 ASTM-Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel Bar in Concrete [1)]

This Standard is issued under the fixed designation C 876; the number immediately following the designation indicates the year original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproved superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

B.2.1 Scope

B.2.1.1 This test method covers the estimation of the electrical half-cell potential of uncoated reinforcing steel in field and laboratory concrete, for the purpose of determining the corrosion activity of the reinforcing steel.

B.2.1.2 This test method is limited by electrical circuitry. A concrete surface that has dried to the extent that it is a dielectric and surfaces that are coated with a dielectric material will not provide an acceptable electrical circuit. The basic configuration of the electrical circuit is shown in Fig. 2.1.

B.2.1.3 The values stated in inch-pound units are to be regarded as the standard.

B.2.1.4 This Standard may involve hazardous materials, operations, and equipment. This Standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this Standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

B.2.2 Referenced document

B.2.2.1 ASTM Standard

G3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing[2)].

B.2.3 Significance and use

B.2.3.1 This test method is suitable for in-service evaluation and for use in research and development work.

B.2.3.2 This test method is applicable to members regardless of their size or the depth of concrete cover over the reinforcing steel.

B.2.3.3 This test method may be used at any time during the life of a concrete member.

B.2.3.4 The results obtained by the use of this test method shall not be considered as a means for estimating the structural properties of the steel or of the reinforced concrete member.

B.2.3.5 The potential measurements should be interpreted by engineers or technical specialists experienced in the fields of concrete materials and corrosion testing. It is often necessary to use other data such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to half-cell potential measurements, to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure.

1) This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C 09.03.15 on Methods of Testing the Resistance of Concrete to its Environment. Current edition approved May 29, 1987. Published July 1987. Originally published as C 876-77. Last previous Edition C 876-80.

2) Annual Book of ASTM Standard, Vol. 03.02.

(to be continued)

APPENDIX B (continued)

B.2.4 Apparatus

B.2.4.1 The testing apparatus consists of the following:

B.2.4.1.1 Half cell

B.2.4.1.1.1 A copper/copper sulfate half cell (see Note) is shown in Fig. B.2.2. It consists of a rigid tube or container composed of a dielectric material that is nonreactive with copper or copper sulfate, a porous wooden or plastic plug that remains wet by capillary action, and a copper rod that is immersed within the tube in a saturated solution of copper sulfate. The solution shall be prepared with reagent grade copper sulfate crystals dissolved in distilled or deionized water. The solution may be considered saturated when an excess of crystals (undissolved) lies at the bottom of the solution.

B.2.4.1.1.2 The rigid tube or container shall have an inside diameter of not less than 25 mm (1 in); the diameter of the porous plug shall not be less than 13 mm (½ in); the diameter of the immersed copper rod shall not be less than 6 mm (¼ in), and the length shall not be less than 50 mm (2 in).

B.2.4.1.1.3 Present criteria based upon the half-cell reaction of $Cu \rightarrow Cu^{++} + 2e$ indicate that the potential of the saturated copper/copper sulfate half cell as referenced to the hydrogen electrode is -0.316 V at 22.2°C (72°F). The cell has a temperature coefficient of about 0.0005 V more negative per °C for the temperature range from 0 to 49°C (32 to 120°F).

Note:

While this test method specifies only one type of half cell, that is, the copper/copper sulfate half cell, others having similar measurement range, accuracy, and precision characteristics may also be used. In addition to copper/copper sulfate cells, calomel cells have been used in laboratory studies. Potentials measured by other than copper/copper sulfate half cells should be converted to copper/copper sulfate equivalent potential. The conversion technique can be found in Practice G3 and it is also described in most physical chemistry or half cell technology text books.

B.2.4.1.2 Electrical junction device

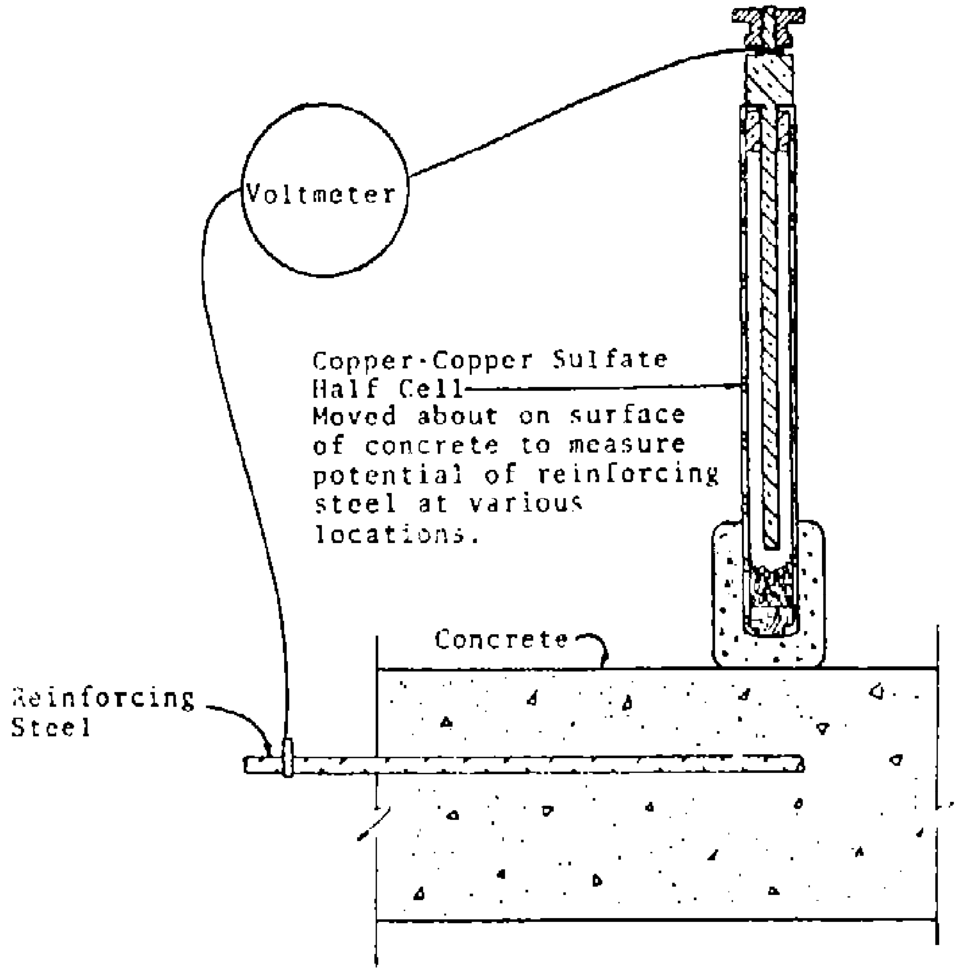
An electrical junction device shall be used to provide a low electrical resistance liquid bridge between the surface of the concrete and the half cell. It shall consist of a sponge or several sponges pre-wetted with a low electrical resistance contact solution. The sponge may be folded around and attached to the tip of the half cell so that it provides electrical continuity between the plug and the concrete member.

B.2.4.1.3 Electrical contact solution

In order to standardize the potential drop through the concrete portion of the circuit, an electrical contact solution shall be used to wet the electrical junction device. One such solution is composed of a mixture of 95 mL of wetting agent (commercially available wetting agent) or a liquid household detergent thoroughly mixed with 5 gal (19 L) of potable water. Under working temperatures of less than about 10°C (50°F), approximately 15% of either isopropyl or denatured alcohol must be add to prevent clouding of the electrical contact solution, since clouding may inhibit penetration of water into the surface to be tested.

(to be continued)

APPENDIX B (continued)



COPPER/COPPER SULFATE HALF CELL CIRCUIT
Fig. B.2.1

B.2.4.1.4 Voltmeter

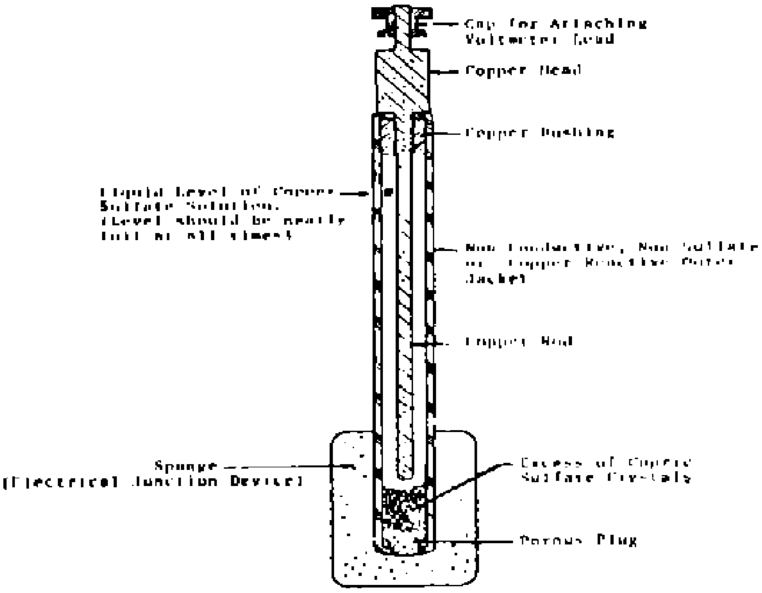
The voltmeter shall have the capacity of being battery operated and have ±3% end-of-scale accuracy at the voltage ranges in use. The input impedance shall be no less than 10 MΩ when operated at a full scale of 100 mV. The divisions on the scale used shall be such that a potential difference of 0.02 V or less can be read without interpolation.

B.2.4.1.5 Electrical lead wires

The electrical lead wire shall be of such dimension that its electrical resistance for the length used will not disturb the electrical circuit by more than 0.0001 V. This has been accomplished by using no more than a total linear of 150 m (500 ft) of at least AWG No. 24 wire. The wire shall be suitably coated with direct burial type solution.

(to be continued)

APPENDIX B (continued)



SECTIONAL VIEW OF A COPPER/COPPER SULFATE HALF CELL
Fig. B.2.2

B.2.5 Calibration standardization

B.2.5.1 Care of the half cell

The porous plug shall be covered when not in use for long periods to ensure that it does not become dried to the point that it becomes a dielectric (upon drying, pores may become occluded with crystalline copper-sulfate). If cells do not produce the reproducibility or agreement between cells described in Section B.2.11, cleaning the copper rod in the half cell may rectify the problem. The rod may be cleaned by wiping it with a dilute solution o hydrochloric acid. The copper sulfate solution shall be renewed either monthly or before each use, whichever is the longer period. At no time shall steel wool or any other contaminant be used to clean the copper rod or half-cell.

B.2.6 Procedure

B.2.6.1 Spacing between measurements

While there is no pre-defined minimum spacing between measurements on the surface of the concrete member, it is of little value to take two measurements from virtually the same point. Conversely, measurements taken with very wide spacing may neither detect corrosion activity that is present nor result in the appropriate accumulation of data for evaluation. The spacing shall therefore be consistent with the member being investigated and the intended end use of the measurements (see Note).

Note:

A spacing 1.2 m (4 ft) has been found satisfactory for evaluation of bridge decks. Generally, larger spacings increase the probability that localized corrosion areas will not be detected. Measurements may be taken in either a grid or a random pattern. Spacing between measurements should generally be reduced where adjacent readings exhibit algebraic reading differences exceeding 150 mV (areas of high corrosion activity). Minimum spacing generally should provide at least a 100 mV difference between readings.

(to be continued)

APPENDIX B (continued)

B.2.6.2 Electrical connection to the steel

B.2.6.2.1 Make a direct electrical connection to the reinforcing steel by means of a compression-type ground clamp, or by brazing or welding a protruding rod. To ensure a low electrical resistance connection, scrape the bar or brush the wire before connecting to the reinforcing steel. In certain cases, this technique may require removal of some concrete to expose the reinforcing steel. Electrically connect the reinforcing steel. In certain cases, this technique may require removal of some concrete to expose the reinforcing steel. Electrically connect the reinforcing steel to the positive terminal of the voltmeter.

B.2.6.2.2 Attachment must be made directly to the reinforcing steel except in case where it can be documented that an exposed steel member is directly attached to the reinforcing steel. Certain members, such as expansion dams, date plates, lift works, and parapet rails may not be attached directly to the reinforcing steel and, therefore, may yield invalid readings. Electrical continuity of steel components with the reinforcing steel can be established by measuring the resistance between widely separated steel components on the deck. Where duplicate test measurements are continued over a long period of time, identical connection points should be used each time for a given measurement.

B.2.6.3 Electrical connection to the half cell

Electrically connect one end of the lead wire to the half cell and the other end of this same lead wire to the negative (ground) terminal of the voltmeter.

B.2.6.4 Pre-wetting of the concrete surface

B.2.6.4.1 Under certain conditions, the concrete surface or an overlaying material, or both, must be pre-wetted by either of the two methods described in Clause B.2.6.4.3 or B.2.6.4.4 with the solution described in Clause B.2.4.1.3 to decrease the electrical resistance of the circuit.

B.2.6.4.2 A test to determine the need for pre-wetting may be made as follows:

B.2.6.4.2.1 Place the half cell on the concrete surface and do not move.

B.2.6.4.2.2 Observe the voltmeter for one of the following conditions:

a) The measured value of the half cell potential does not change or fluctuate with time.
b) The measured value of the half cell potential change or fluctuates with time.

B.2.6.4.2.3 If condition (a) is observed, pre-wetting the concrete surface is not necessary. However, if condition (b) is observed, pre wetting is required for an amount of time such that the voltage reading is stable (±0.02 V) when observed for at least 5 min. If pre-wetting cannot obtain condition (a) either the electrical resistance of the circuit is too great to obtain valid half-cell potential measurements of the steel, or stray current from a nearby direct current traction system or other fluctuating direct-current, such as arc welding, is affecting the readings. In either case, the half-cell method should not be used.

B.2.6.4.3 Method a for pre-wetting concrete surfaces

Method A for those conditions where a minimal amount of pre-wetting is required to obtain condition (a) as described in Clause B.2.6.4.2.2. Accomplish this by spraying or otherwise wetting either the entire concrete surface or only the points of measurements described in Clause B.2.6.1 with the solution described in Clause B.2.4.1.3. No free surface water should remain between grid points when potential measurements are initiated.

(to be continued)

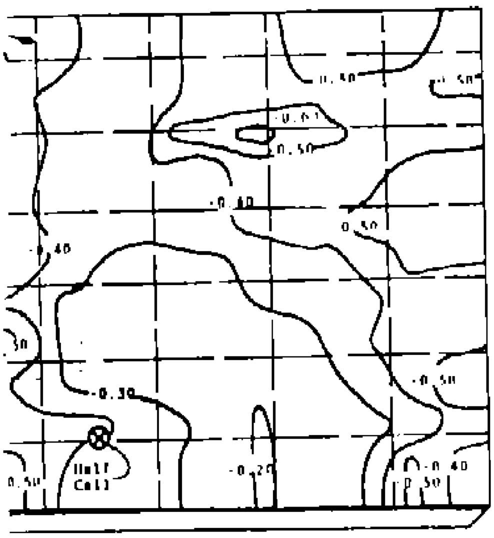
APPENDIX B (continued)

B.2.6.4.4 Method B for pre-wetting concrete surfaces

In this Method, saturated sponges with the solution described in Clause B.2.4.1.3 and place on the concrete surface at locations described in Clause B.2.6.1. Leave the sponges in place for the period of time necessary to obtain condition (a) described in Clause B.6.4.2.2. Do not remove the sponges from the concrete surface until after the half cell potential measurements, place the electrical junction device described in Clause B.2.4.1.2 firmly on top of the pre-wetting sponges for the duration of the measurement.

B.2.6.5 Underwater, horizontal, and vertical measurement

B.2.6.5.1 Potential measurements detect corrosion activity, but not necessarily the location of corrosion activity. The precise location of corrosion activity requires knowledge of the electrical resistance of the material between the half cell and the corroding steel. While underwater measurements are possible, results regarding the location of corrosion must be interpreted very carefully. Often it is not possible to precisely locate points of underwater corrosion activity in salt water environments because potential readings along the member appear uniform. However, the magnitude of readings does serve to indicate whether or not active corrosion is occurring. Take care during all underwater measurements that the half cell does not become contaminated and that no part other than the porous tip of the copper/copper sulfate electrode half cell comes in contact with water.



EQUIPOTENTIAL CONTOUR MAP
Fig. B.2.3

B.2.6.5.2 Perform from horizontal and vertically upward measurements exactly as vertically downward measurements. However, additionally ensure that the copper/copper sulfate solution the half cell makes simultaneous electrical contact the porous plug and the copper rod at all times.

(to be continued)

APPENDIX B (continued)

B.2.7 Recording half cell potential values

B.2.7.1 Recording the electrical half-cell potentials to the nearest 0.01 V. Report all half cell potential values in volts and correct for temperature if the half cell temperature is outside the range of 22.2 (72 ±10°F). The temperature coefficient for the correction is given in Clause B.2.4.1.1.3.

B.2.8 Data presentation

B.2.8.1 Test measurements may be presented by one or both methods. The first, an equipotential control map, provides a graphical delineation of areas in the member where corrosion activity may be occurring. The second method, the cumulative frequency diagram, provides an indication of the magnitude of affected area of the concrete member.

B.2.8.1.1 Equipotential contour map

On a suitably scaled plan view of the concrete member, plot the locations of the half cell potential values of the steel in concrete and draw contours of equal potential through points of equal or interpolated equal values. The maximum contour interval shall be 0.10 V. An example is shown in Fig. B.2.3.

B.2.8.1.2 Cumulative frequency distribution

Toe determine the distribution of the measured half-cell potentials for the concrete member, make a plot of the data on normal portability paper in the following manner:

B.2.8.1.2.1 Arrange and consecutively number all half-cell potentials by ranking from least negative potential to greatest negative potential.

B.2.8.1.2.2 Determine the plotting position of each numbered half-cell potential in accordance with the following equation:

$$f_x = \frac{r}{\Sigma n + 1} \times 100$$

Where:

- f_x is plotting position of total observations for the observed value, %.
- r is rank of individual half cell potential, and
- Σn is total number of observations.

B.2.8.1.2.3 Label the ordinate of the probability paper "Half Cell Potential (Volts, CSE)", where CSE is the designation for copper/copper sulfate electrode. Label the abscissa of the probability paper "Cumulative Frequency (%)", Draw two horizontal parallel lines intersecting the -0.20 and -0.35 V values on the ordinate, respectively, across the chart.

B.2.8.1.2.4 After plotting the half cell potentials, draw a line of best fit through the value (see Note). An example of a completed plot is shown in Fig. B.2.4.

Note:

It is not usual to observe a break in the straight line. In these cases, the line of best fit shall be two straight lines that intersect at an angle.

(to be continued)

APPENDIX B (continued)

B.2.9 Interpretation of results [3)]

B.2.9.1 Laboratory testing of reinforced concrete specimens indicates the following regarding the significance of the numerical value of the potentials measured. Voltages listed are referenced to the copper/copper sulfate (CSE) half cell.

B.2.9.1.1 If potentials over an area more positive than -0.20 V CSE, there is a greater than 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement.

B.2.9.1.2 If potentials over an area are in the range of -0.20 to -0.35 V CSE, corrosion activity of the reinforcing steel in that area is uncertain.

B.2.9.1.3 If potentials over an area are more negative than -0.35 V CSE, there is a greater than 90% probability that reinforcing steel corrosion is occurring in that area at the time of measurement.

B.2.9.1.4 In laboratory tests where potentials were more negative than -0.50 V, approximately half of the specimens cracked due to corrosion activity.

B.2.9.1.5 Positive readings, if obtained, generally indicate a poor connection with the steel, insufficient moisture in the concrete, or the presence of stray currents and should not be considered valid.

3) The following published reports give supportive detail for interpretation of results:

Spellman, D.L., and Stratfull, R.F., "Concrete Variables and Corrosion Testing", Highway Research Record No. 423;

Stratfull, R.F., "Half Cell Potentials and the Corrosion of Steel in Concrete", Highway Research Record No. 433; and,

Clear, K.C., and Hay, R.E., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs", Federal Highway Administration, Vol. 1 and 2, Interim Reports FHWA-RD-73-32 and 33, April 1973.

B.2.10 Report

B.2.10.1 The report shall include the following:

B.2.10.1.1 Type of cell used if other than copper/copper sulfate.

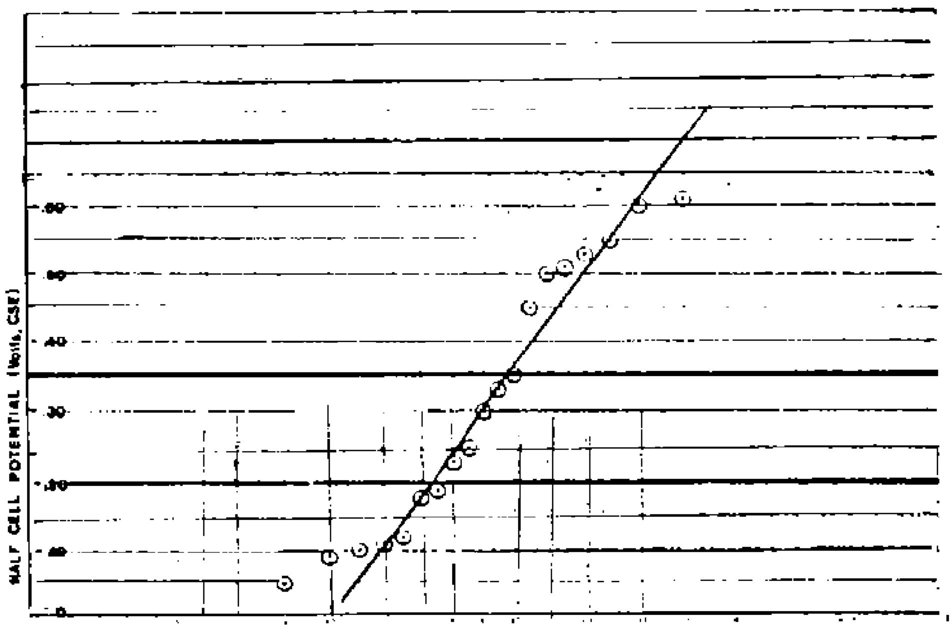
B.2.10.1.2 The estimated average temperature of the half cell during the test.

B.2.10.1.3 The method for pre-wetting the concrete member and the method of attaching the voltmeter lead to the reinforcing steel.

B.2.10.1.4 An equipotential contour map, showing the location of reinforcing steel contact, or a plot of the cumulative frequency distribution of the half-cell potentials, or both.

(to be continued)

APPENDIX B (continued)



CUMULATIVE FREQUENCY DIAGRAM
Fig. B.2.4

B.2.10.1.5 The percentage of the total half cell potentials that are more negative than -0.35 V.

B.2.10.1.6 The percentage of the total half cell potentials that are less negative than -0.20 V.

B.2.11 Precision and bias

B.2.11.1 The difference between two half cell readings taken at the same location with the same cell should not exceed 10 mV when the cell is disconnected and reconnected.

B.2.11.2 The difference between two half cell readings taken at the same location with two difference cells should not exceed 20 mV.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this Standard. Users of this Standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This Standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this Standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing your should make your view known to the ASTM Committee on standards, 1916 Race St., Philadelphia, PA 19103.

(to be continued)

APPENDIX B (continued)

B.3 Sub-See Pipeline Cathodic Protection Survey Method (CPSS)

B.3.1 Introduction

This Section provides a narrative description for CPSS Subsea Pipeline Cathodic Protection Survey System. It describes the components of the system that will be provided, operations and results. Fig. B.3.1 below illustrates the system.

B.3.2 System components

The system provided by CPSS consists of the following components:

- Probe
- Remote Reference Electrode
- Digitizer
- Data Receiver/Monitor
- Compute with Software Controlled Data Recording
- Survey Engineers

In the following paragraphs each component is described in terms of what it does and how it links with the rest of the system.

B.3.2.1 Probe

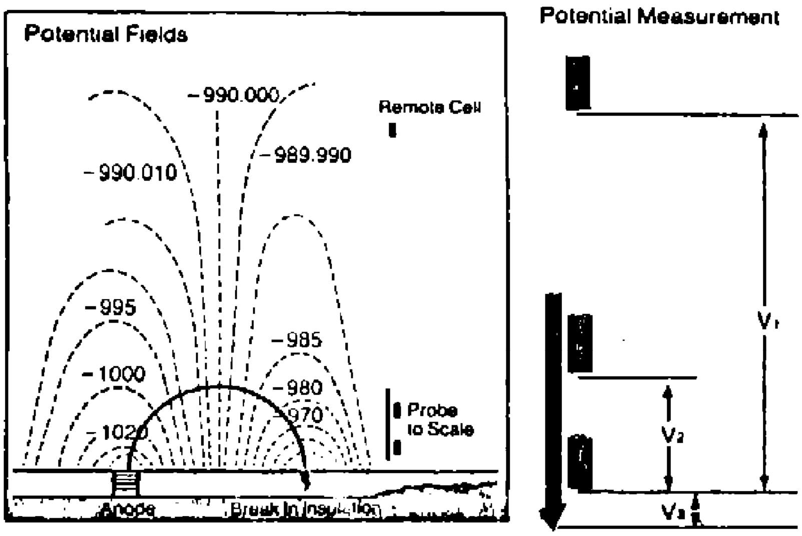
The probe is the primary data gathering instrument for the survey. Its design, with two precisely located reference electrodes allows measurement of radical field gradient. A spiked tip permits measurement of pipeline potential and facilitates positive contact with anodes or pipe metal from which calibration measurements may be taken.

A shock absorbing bracket attaches the probe to the manipulator arm of the submersible. The bracket design ensures stable contact during measurement of anode and pipe metal potentials and absorbs the stresses placed on the probe during accidental strikes attendant to normal operation.

(to be continued)

APPENDIX B (continued)

Theoretical Principle

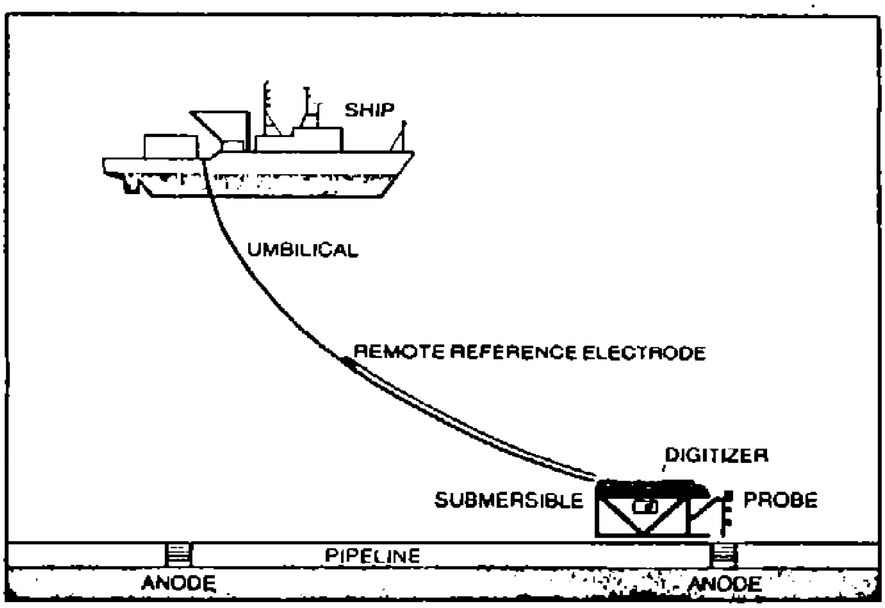


The CPSS 4 system measures accurately 3 potential differences.

Remote to probe V_1
Field gradient V_2
Tip contact form pipe/anode to probe V_3

During data analysis these measurements are integrated with distance or position information. Scale profiles of real pipeline potentials are then plotted and included in the report.

Operational Arrangement



SUBSEA PIPELINE CATHODIC PROTECTION SURVEY SYSTEM
Fig. B.3.1

(to be continued)

APPENDIX B (continued)

An armoured electrical cable connects the probe to the digitizer. A sleeve on the probe and recesses on the digitizer protect the underwater connectors from accidental damage.

B.3.2.2 Remote reference electrode

The remote reference electrode provides a "remote earth" or reference zero against which to measure the data obtained by the probe. During operation it is positioned 50 to 100 meters from the probe, well away from any electrical fields caused by anodes, the pipe or the submersible. An electrical cable connects the electrode to the digitizer. Both the electrode and its cable are clipped to the submersible's umbilical, as shown in Fig. B.3.1.

B.3.2.3 Digitizer

The digitizer converts the information from the probe and the remote electrode to a digital signal and transmits it through the submersible's umbilical to the data receiver on board the ship. A digital signal is used because it is relatively unaffected by electrical noise interference and a digital signal can be transmitted without loss of accuracy over much greater distances than an analogue signal. The digitizer is powered by low voltage D.C. via a cable connected to the umbilical junction box. It is secured firmly to the submersible with clamps to prevent movement.

B.3.2.4 Data receiver/monitor

The data receiver/monitor, receives the signal from the digitizer via the submersible umbilical. Information arrives at a rate of five times per second, giving a fast response to rapidly changing potentials, and the digital data is transmitted to the computer for high accuracy recording. The signal channels for remote electrode and field gradient are, in addition, converted to analogue form and feed a two-pen chart in the recorder monitor. This chart provides a convenient, real-time, pictorial record of changing pipeline potential and radial field gradient.

The analogue signal for the potential of the pipeline versus remote electrode is also routed via an offset correction circuit to a digital voltmeter and thence it may be taken to the Customer's video writer if desired. This digital voltmeter gives an approximate indication of pipe potential during a dive.

B.3.2.5 Computer and software-controlled data recording

The computer is used to process and record all information relevant to each dive. Information arrives along the link from the data receive, from the navigation system, from the internal clock, the pipe tracker, if fitted, and from the computer's keyboard. Under software control, this large volume of data is compressed prior to recording on cassette tapes to maximize the effective capacity of each cassette.

The record of potentials and gradients is of extremely high accuracy in order that the eventual analysis will be of the highest quality. All records are linked to time so that any additional information such as corrected navigation fixes recorded during the dive may be added later.

In addition to its data recording function, the computer provides a software controlled display of all relevant data channels on its internal digital read-out.

B.3.2.6 Engineers

To permit 24 hours operation, two Engineers should operate the survey. During operation, space in a dry environment must be provided for the computer, monitor and at least one Engineer. The Engineer must be able to communicate easily with the Submersible Operator at all times.

(to be continued)

APPENDIX B (continued)

B.3.3 Survey operation

During the survey, the submersible travels along the pipeline at a speed of 0.5 to 2 kilometers per hour. The probe is held vertically in the manipulator arm so that its tip is approximately 20 centimeters above the pipe's center line. For buried pipelines the submersible must have a pipe-track system to keep the probe above the center line of the pipe. Burial depth information is also required. Potential readings are taken at a rate of five per second.

Changes in the potential trace on the chart usually give advance warning that anodes, damaged areas, or other points of interest are being approached. The Engineer can then warn the Submersible Operator to slow the vehicle down to prepare for more careful examination of those areas. When the point of interest is reached, the manipulator arm is moved so the probe spike can be stabbed into the relevant area. A good contact is confirmed by a stabilized signal and the reading and navigation fix number are recorded.

Occasionally damage to the pipe coating beneath the concrete will show up in the potential readings but will not be readily identifiable visually. In this, and similar instances. The Submersible Operator can be advised to perform additional visual inspection to try to determine the nature and severity of the damage.

Following these general procedures, the survey thus proceeds to completion:

B.3.4 Survey results

B.3.4.1 On a real-time basis during the survey, the system provides the following results:

- Pipeline cathodic protection potential.
- Anode potentials and approximate output currents.
- Position identification of coating damage.

As mentioned earlier, these results are sufficiently detailed to enable immediate identification of problem areas.

B.3.4.2 After returning to office Engineers will then analyze the recorded data utilizing the comprehensive, detailed and accurate information to produce a report covering the following:

- General pipeline condition.

- Analysis of pipeline cathodic protection levels corrected for ohmic drops in sea water and mud using the combination of high accuracy field gradient measurement, together with potential measurement.

- Analysis of bracelet anodes, with a table showing anode locations, corrected potentials and output currents.

- Analysis of areas of particular importance or unusual interest (coating damage, spool pieces, anode sleds, clamps, risers, insulating flanges etc.) supported by a table of relevant data.

B.3.4.3 Pipeline cathodic protection levels will be plotted on a chart against distance along the pipe. This will be based on position fixed recorded during the dive and analysis of start and stop times. If more accurate, processed navigation fix information is available, this can be used to produce a plot of potential against corrected position.

(to be continued)

APPENDIX B (continued)

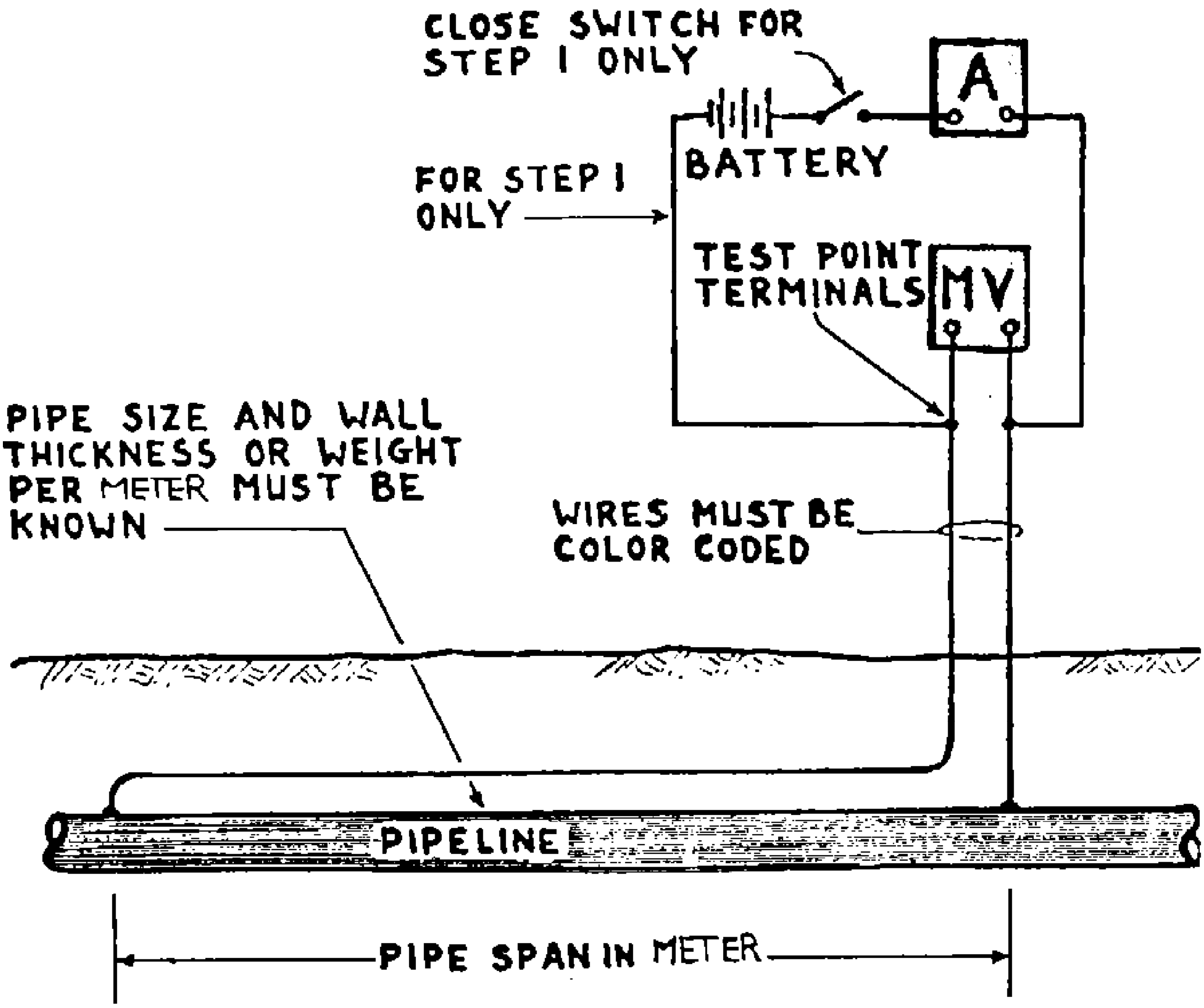
B.4 Line Current Survey Test Method

This survey helps to determine the distribution of current along a cathodically protected pipeline. Permanent test leads provide on pipeline are used to determine the direction and measure the amount of current flowing in a particular length and span of pipe.

This survey should be conducted on pipeline annually. Test procedures to carry out this inspection are outlined hereunder:

B.4.1 Test procedure with test point consisting of two wires:

B.4.1.1 The two wires bridge a span of known length. At each point of measurement, while making a line current survey, the potential drop across the span is observed and recorded together with the polarity of instrument connections to indicate the direction of current flow. Currents may be calculated by ohm's law after determining the span resistance of the pipe being surveyed (from Table B.1) and the resistance of the test circuit.



CURRENT MEASUREMENT, 2 - WIRE TEST POINT
Fig. B.4.1

(to be continued)

APPENDIX B (continued)

B.4.1.2 Following is procedure for the test:

Step 1

Measure the circuit resistance of the test leads and pipe span by passing known battery current through the circuit and measuring the resulting voltage drop across the test point terminals.

Step 2

Measure the voltage drop across the test point terminals caused by the normal current flowing in the pipeline. Usually since an instrument with range suitable for these measurements will have a low internal resistance, the resistance of the lead wires may induce a substantial error in the reading obtained.

This will be millivolts or fractions of a millivotl.

Instrument resistance and the value of lead wire resistance must be known and correction made for the resistance of the external circuit (measured in Step 1). Note polarity of meter connection to test point terminals and indicate direction of current flow (+ to -) along the pipeline:

$$\textbf{R.B Correction factor} = \frac{\textbf{Resistance of external circuit + Resistance of voltmeter}}{\textbf{Resistance of voltmeter}}$$

Step 3

Using pipeline resistance Table B.1, determine the resistance of the pipeline span.

Step 4

Calculate the pipeline current flow by ohm's law:

$$\textbf{Current in milliamps} = \frac{\textbf{Corrected millivolt drop (from Step 2)}}{\textbf{Pipe span resistance in ohms}}$$

Table for steel pipe resistance (Table B.1) may be used as a general guide to pipeline resistance. This table is based on Steel resistivity of 18 microhm-cm. Steel resistivity varies between 15-23 microhm-cm. 18 microhm-cm is used as an average.

B.4.1.3 Following is an example of determining line current flow on a 75 cm (30 in) pipe, 61 m (200 ft) span with 9.5 mm (0.375 in) wall thickness (or weighing 177 kg per meter with pipeline direction of EAST-WEST).

Step I

Battery current	1.2	Amp
Resulting voltage drop across the test point terminals	0.108	Vikt
External circuit resistance	$\frac{0.108}{1.2} = 0.09$	ohm

(to be continued)

APPENDIX B (continued)

Step II

Potential drop across the test point terminals caused by normal current (protective current) flowing in the pipeline (on 2 mV range of an instrument with resistance of 1000 ohm per volt. or 2 ohm per 2 millivolt)	0.16	millivolt
Correction factor = $\frac{2 + 0.09}{2}$	1.045	
Corrected potential drop across the test point terminals caused by normal current flowing in the pipeline	$0.16 \times 1.045 = 0.17$	mV
Polarity of meter	West end terminal	+ Ve

Step III

Resistance of pipeline span (200 ft, 30, 0.375 w.t	$2.44 \times 10^{-6} \times 200 = 0.00049$	ohm

Step IV

Pipeline current (protective current) flow	$\frac{0.17 \text{ mV}}{0.00049 \text{ ohm}} = 346$	milliamp
Direction of current flow ⟶		West to east

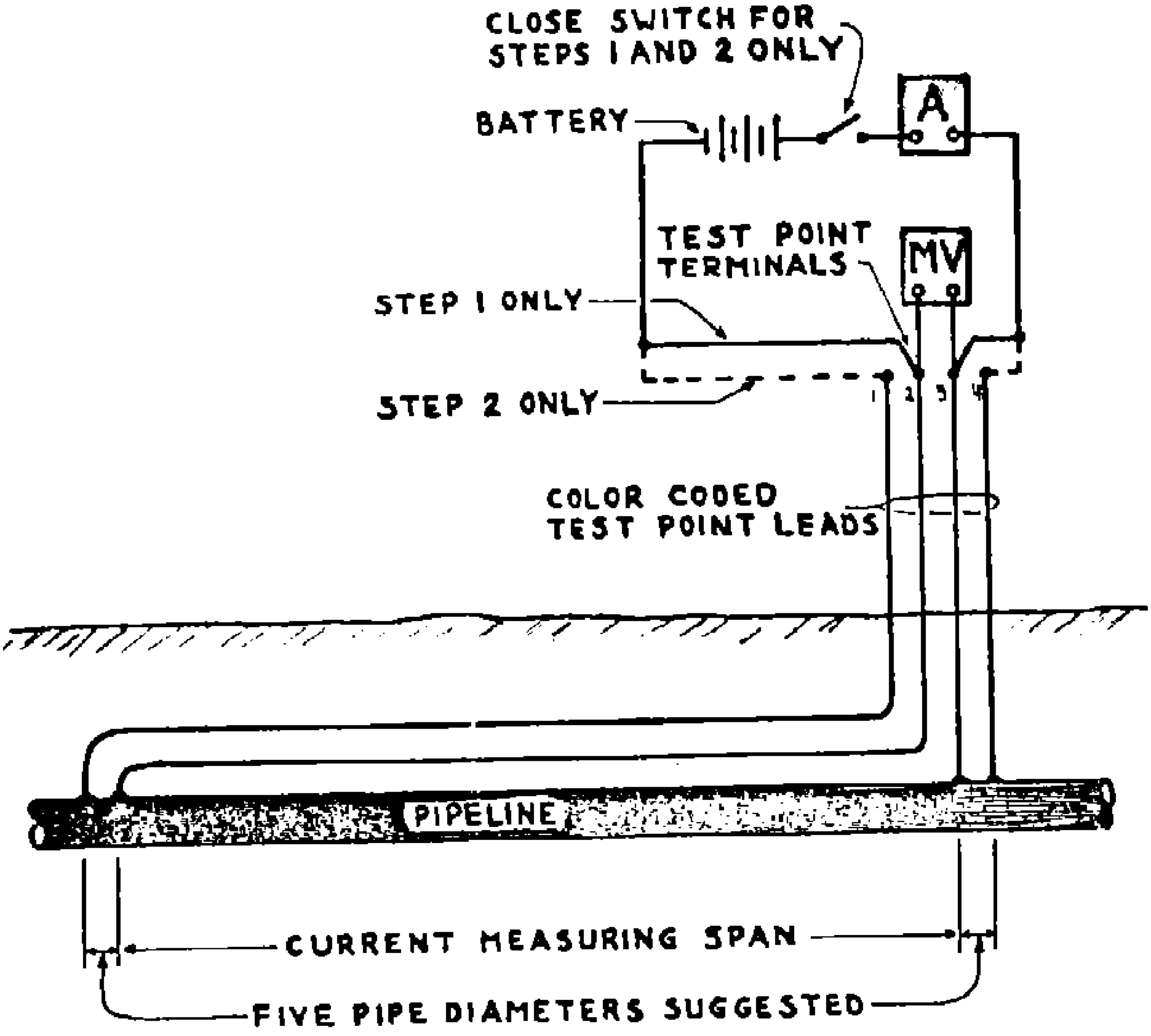
B.4.2 Test procedure with test point consisting of four wires

B.4.2.1 In 4 wires test point for line current measurement two wires are connected at each end of the test span. The 4 wires have different colors to be distinguished from one another. The two inner leads serve as current measuring and measuring of external circuit resistance; the two outer leads are used for calibrating the test span. The four wire calibrated line current test point permits more accurate pipeline current measurements. The reason being each span can be calibrated accurately. This avoids errors in length of pipe span and pipe resistance which is possible when using the two wire test point.

B.4.2.2 The general arrangement for a pipeline current measurement is shown in Fig. B.4.2.

(to be continued)

APPENDIX B (continued)



CURRENT MEASUREMENT, 4 - WIRE TEST POINT
Fig. B.4.2

B.4.2.3 Following is procedure for the test:

Step 1

Measure the circuit resistance of the test leads and pipe span (between terminals 2 and 3) by passing known battery current through the circuit and measuring resulting voltage drop across terminals 2 and 3.

Calculate resistance in ohms by application of ohm's law (resistance $= \frac{\text{Volt}}{\text{Amps}}$).

(to be continued)

APPENDIX B (continued)

Step 2

Calibrate the span by passing a known amount of battery current between the outside leads (terminals 1 and 4) and measure the change in potential drop (corrected for the effect of circuit resistance) across the current measuring span (terminals 2 and 3). Divide the current flow in amperes by the change in potential drop in millivolts to express the calibration factor in (amperes per millivolt). Normally this calibration needs to be done only once for the same location. The calibration factor may be recorded for subsequent tests at the same location. However, on pipelines where the operating temperature of the pipe changes considerably (with accompanying changes in resistance), more frequent calibration is necessary; pipelines carrying hot fuel or gas trunk line at outlet of compressor station are typical examples of lines needing frequent calibration.

Step 3

Measure the potential drop in millivolts across the current measuring span (terminals 2 and 3) caused by the normal pipeline current. Apply correction factor for circuit resistance. Calculate current flow by multiplying the corrected potential drop by the calibration factor determined in Step 2.

Also note direction of current flow.

B.4.2.4 Following is a sample determination of current flow using 4 wires test point. In this sample use is made of the same pipeline section as used for the example of 2 wire test point. Steps to be taken for determining line current in 4 wires procedure is as follow:

Step I

Circuit resistance between terminals 2 and 3 measured as 0.09 ohms (refer to Step I of example of determining line current for 2 wires test point under B3.1.4).

Step II

Ten Amperes of battery current is passed between terminals 1 and 4.

Corrected potential drop (with current ON)	5.08	mV
Corrected potential drop (with current OFF)	0.17	mV
Change in potential drop ΔV	4.91	mV
Calibration factor	$\frac{10 \text{ Amps}}{4.91 \text{ millivolt}} = 2.04$	Amps per millivolt

Step III

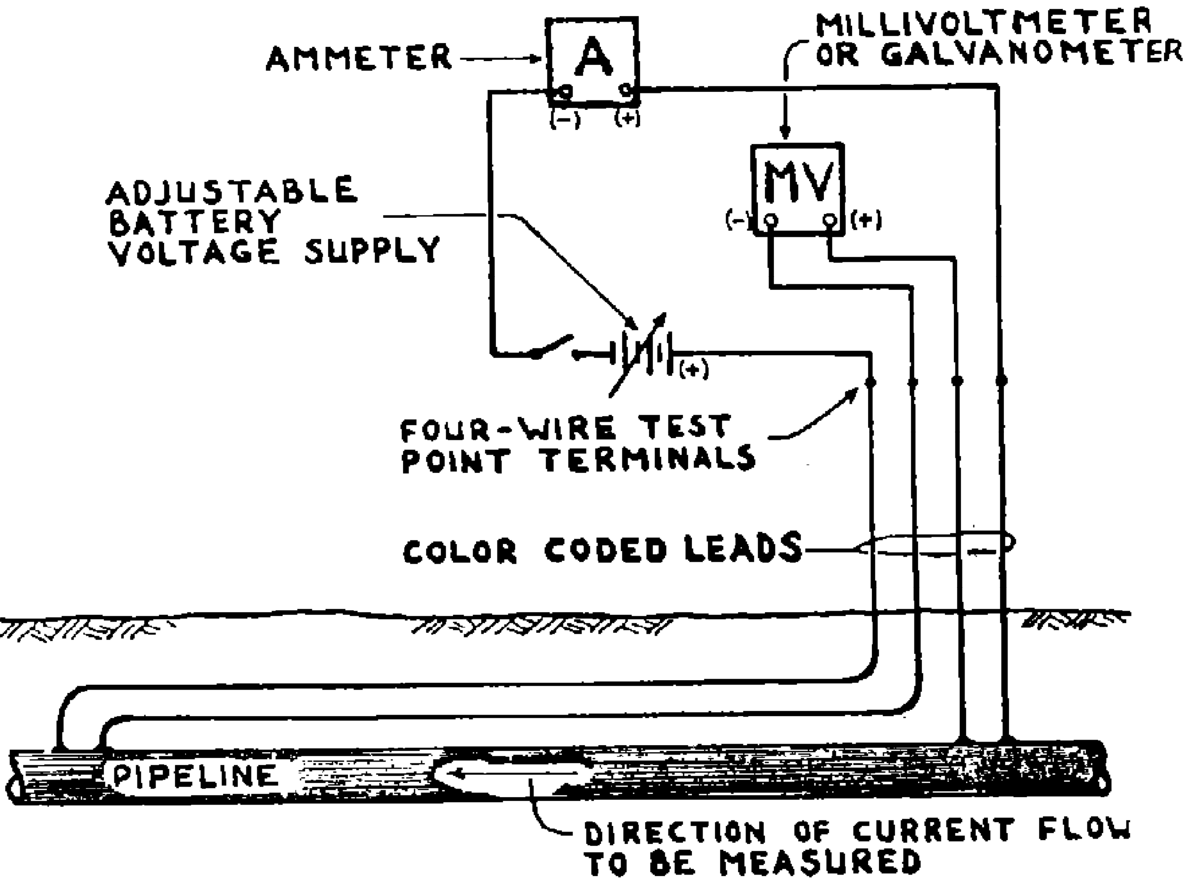
Corrected potential drop across current measuring span (terminals 2 and 3) caused by normal	0.17	mV
pipeline current (protective current) Polarity	West end terminal	+Ve
Pipeline current flow (protective current) flow	0.17 mV × 2.04 Amps per mV = 0.34	Amps
Direction of current flow	West to east	

(to be continued)

APPENDIX B (continued)

B.4.2.5 Test procedure using null Amp test circuit for line current measurement

This is an effective method of measuring line current. In this method use is made of a null Ampere test circuit. The circuit is illustrated in Fig. B.4.3.



NULL AMMETER CIRCUIT
Fig. B.4.3

As shown in Fig. B.4.3, 4 wires test point is used in this method with a sensitive galvanometer connected between the inner pair of wires. Current from the battery is forced to flow between the outer pair of wires in opposition to the protective current flowing in the pipe. With the battery output adjusted to give a zero deflection on the galvanometer, the ammeter in series with the battery will read the protective current originally flowing in the pipe.

This method is most effective with permanent 4 wires test point on buried lines where all pipe connections are at essentially the same temperature to avoid thermal potentials.

The sensitivity of the test will depend on the sensitivity of the galvanometer. The galvanometer needs not to be calibrated but should have, preferably, a sensitivity of one millivolt or less full scale to permit measuring reasonably small amount of current in large pipelines.

(to be continued)

APPENDIX B (continued)

B.5 Computer Modeling of Offshore Cathodic Protection Systems Utilized in CP Monitoring

B.5.1 General

Offshore structures with large dimensions and structural complexity combined with high current density requirements for protection, represents a combination where the traditional potential measurements have proved inadequate.

Many computerized modeling techniques have been developed for analysis of offshore cathodic protection systems. Following are some references on computer modeling which may be used in CP analysis.

B.5.2 Computerized modeling techniques

The finite difference and finite element methods are numerical discretisation procedures for the approximate analysis of complex boundary value problems. Development of these methods have to a large extent followed the rapid development of electronic computers and have been applied successfully for many years in various fields of engineering like structural stress analysis, heat conduction etc. There is now a growing interest in computerized modeling of CP systems, both for improving CP designs as well as for analysis of readings and for "diagnostics" of CP performance as indicated above.

Iterative solutions of the finite difference from of the Laplace’s Equation for electrochemical systems were applied in 1964 by R.N. Fleck[5]. The Finite Difference Method (FDM) has been employed in modeling of offshore CP systems and CP generally in the 1970’ies [1,6,7,8,9]. This include direct solution of the linear equations using simple Gaussian elimination combined with an iteration procedure for adaptation to non-linear boundary conditions[8]. Published papers on application of the Finite Element Method (FEM) include work by A.W. Forrest et a1[10], J.W.Fu[11] and H.P.E. Helle et a1[12].H.P.E. Hellet et a1 also made a comparison of the FEM technique with discrete Source-Sink method where it was conclude that the FEM was the most favorable of the two.

Despite high efficiency, i.e. low computer time for solving the linear equations when employing the FEM technique, the finite element method has become dominating in numerical analysis, largely due to the fact that it is more easily adapted to complex geometry. Multipurpose program packages now available are therefore most often based on the FEM technique.

Recently there has also been considerable development in application of integral equations and Boundary Element methods in potential theory and similar problems. Achievements are reduction in the size of the numerical problem. As far as is known, such methods have not yet been used in CP modeling.

B.5.3 Short theoretical background

Based on the requirement to continuity of electrical charges in an electrolyte, it can be shown that variations in the electrochemical potential, E obey the Laplace’s equation:

$$\mathbf{V^2E = 0} \qquad \textbf{(Eq. 1)}$$

Calculation of the potential variation along cathodically protected structures involves the solution of this equation, which for cylindrical coordinates in three dimensions is written:

$$\frac{\partial^2 E}{\partial r^2} + \frac{1}{r}\frac{\partial E}{\partial r} + \frac{\partial^2 E}{\partial \theta^2} + \frac{\partial^2 E}{\partial Z^2} = 0 \qquad \textbf{(Eq. 2)}$$

(to be continued)

APPENDIX B (continued)

Where:

r is radius.
θ is angle.
z is direction of the axis.

In order to solve this equation, appropriate boundary conditions must be specified. These are given by geometry of the structure, i.e. dimensions and position of anodes, of steel members, or areas exposed steel in the case of a coated structure with coating defects, position of the structure in water relative to the mud line etc. Furthermore the reaction kinetics for anodes and protected steel must be specified. Provided homogeneous electrolyte, a relationship exists between the current density (i_s) at the electrode surfaces (anodes and exposed steel) and the potential gradient:

$$i_s = -\sigma \frac{\partial E}{\partial n_s} \qquad \text{(Eq. 3)}$$

Where:

n_s is normal to the exposed electrode surface and
$\sigma = L/\rho$ is the conductivity of the sea water.

In the case of a coated and insulated surface the current density is reduced to zero:

$$\frac{\partial E}{\partial n_s} = 0 \qquad \text{(Eq. 4)}$$

The boundary conditions at the electrode surfaces are given by the reactions taking place. These reactions are non-reversible, i.e. displaced from equilibrium. One of the half reactions is dominating on the electrode surface and the external behavior is written on the form:

$$i_{electrode} = i_{corr} \left(10^{\eta/ba} - 10^{-\eta/bc}\right) \qquad \text{(Eq. 5)}$$

Where:

i_{corr} is corrosion current density for the electrode.
b_a **and** b_c are anodic and cathodic tafel slopes, and the overvoltage,
η is defined as :

$$\eta = E - E_{corr} \qquad \text{(Eq. 6)}$$

E_{corr} is corrosion potential of the electrode.

It should be observed that the two tafel slopes, b_a and b_e refer to different reactions on the same electrode, and that these furthermore may differ locally on the electrode surfaces, i.e. on protected steel and on the sacrificial anodes. Change with time are also observed in the polarization characteristics. Consideration deviations from the theoretical relationship of equation[5] are found frequently. In addition E_{corr} for anodes and cathodic areas may differ as well as. It has therefore been found necessary to tabulate data obtained from testing and offshore monitoring:

$$i_{electrode} = f(E) \qquad \text{(Eq. 7)}$$

For cathodically protected steel in sea water $i_{electrode}$, in addition to being a function of E depend on environmental conditions in the sea like O_2 content, temperature, salinity, and water flowrate. As already indicated above the current density will furthermore change with time reflecting the build up of scale, calcareous deposits and marine growth on the steel.

Descaling of the steel structures during winter storms in harsh offshore areas, finally may result in much higher than average current density requirements locally on the protected steel. The importance of including such local variations in the analysis have been proved.

(to be continued)

APPENDIX B (continued)

B.5.4 Numerical solutions

Numerical solutions to this problem using the finite difference method have been presented in the reference[1,5,7,8,9], both for two-dimensional and three-dimensional systems. By Taylor expansion, the differential Eq. 1 is transformed to a set of linear equations on the form:

[C] [E] = [I] **(Eq. 8)**

Where:

I is the current,
E is the potential.
C is the conductivity matrix.

Using a simple physical analogy it is shown that this corresponds to replacing the continuum, i.e., the sea water by a network or a mesh of elements as shown in Fig. B.4.1. Neighbor elements are connected by conducting bars, each bar of electrical resistance equal to the resistance of the electrolytic element in the same direction. Utilizing ohm's and Kirchhoff's laws a set of equations are obtained, on the form of (Eq. 8) above, one equation per element.

The finite element technique has been described previously (see reference 13, 10, 11, 12). The application of this method involves a numerical procedure where the differential, (Eq. 1) and the appropriate boundary conditions are handled simultaneously by a functional (see 13, 10, 11, 12). Minimizing this functional is equivalent to solving (Eq. 1) for the appropriate boundary conditions. The problem is discretised by dividing the electrolyte/sea water into a number of finite elements (in a similar fashion as for FDM) e.g. tetrahedral, and approximating the potential in each element by a simple function.

Obviously, CP modeling of complex offshore structures requires high flexibility in regard to mesh refinement, for adaptation of local boundary conditions, geometry etc. Running the programs furthermore require large computers with considerable capacity to handle the large numerical problems involved in an offshore CP analysis.

B.5.5 Analysis of existing CP systems

Computerized modeling can be used in different ways to take the full advantage of readings obtained with various CP monitoring techniques. Once a problem of unsatisfactory CP performance has been detected, the cause(s) to the problem and the requirements for rectification need to be established. Of primary importance is to define additional current requirements for satisfactory protection of the structure. In this regard the computer models have been used for analysis of current density and potential readings to accurately estimate:

- Current output from sacrificial anodes.
- Current consumption on exposed steel at different protective levels (different potentials).

Such data provide a sound basis for estimating additional current requirements and for re-design of the CP system.

Other application have included:

- Analysis and definition of typical potential profiles at nodes and other confined and critical areas. Such profiles are subsequently used for predication of the potential in the subject area on the basis of a few potential readings at specified reference positions. The number of readings to be taken, and thereby the diving time is effectively reduced.

- Analysis of interference effects caused by impressed current anodes of high current output or between cathodically protected structures.

(to be continued)

APPENDIX B (continued)

B.5.6 Performance of sacrificial anodes

Data on operational status of the sacrificial anodes are very useful for different purposes. Of vital interest is to check that the anode really is operating, secondly to obtain current drain, e.g. as a basis for CP re-design, for estimating remaining life and to obtain data on current output versus potential as a means of checking its capabilities to increase the current output in periods of high loads.

Over the last few years has been an increasing application of equipment for electric field strength/current density monitoring in CP surveys of offshore Structures (2 and 3). Probes for RCV and diver operations are used to measure the electric field strength at typical stand-off anodes, at sacrificial bracelet anodes on pipelines etc.

As is obvious, there is a strong reduction in the field strength and in local current density with increasing distance from the anode surface. Accordingly there is a need to relate the reading, obtained at a specified distance from the anode, back to the anode surface. This is achieved by comparison of measured field strength values with figures obtained from computer modeling of the same anode geometry. By modeling of the anodes for different conditions, i.e. for different current output levels, the output from an anode is found simply by comparison of the reading with tabulated figures for known current output.

In monitoring of platform anodes, readings are obtained at well defined positions, i.e. at specified distance from the anode surface. For this purpose the probe is provided with a support or spacing piece. Preferably this should be manufactured to keep the probe at a min. of 10-15 cm distance from the anode surface, to avoid too strong effects of local variations over the anode surface in the anodic current density. When monitoring long, rod-shaped offshore anodes, 2-3 readings per anode may therefore be required to obtain results of good accuracy. Still efficiency is maintained with a typical figure of 15-20 anodes monitored per hour.

Surveys of submarine pipelines are normally conducted using RCVs and manned submersibles with the probe carried in front of the vehicle. The electric field strength variations along the pipeline are continuously monitored and logged on magnetic tape. Although the sensor-to-pipe distance can be measured, such data are not always monitored.

Results from numerical modeling of a bracelet anode are some curves. The various curves represent variations in the radial field strength along the pipe axis and for different radial distances, and for a current output corresponding to 1000 mA/m². As observed from these curves, the field strength in the radial direction is strongly reduced with increasing distance from the pipe. However, it is also obvious that the shape of the field strength curves is strongly dependent on the radiel distance. By computerized analysis, also making use of a curve fitting procedure this is utilized:

- To estimate the radiel distance between the sensor and the pipe on passing the anode bracelet.

- To estimate the current output from the anode (a technique has been developed to obtain potential profile data for pipelines, anode output and remaining life, see reference 2).

B.5.7 Analysis of attenuation curves at sacrificial anodes

By computer modeling a section of a structure, including one or a few sacrificial anodes potential profile may be obtained. In this case the number of anodes, surface area of exposed steel and boundary conditions generally have been fitted to cause the anodes supply an output corresponding to 1000 mA/m². This typical profile, also named the attenuation curve is mainly reflecting the current output from the anodes. (This may not always be true, as for instance at nodes and complex areas where e.g. "shadow" effects may add considerable IR drops in the sea water.)

The accuracy of such estimates are expected to be slightly inferior to readings obtained using electric field strength/current density monitor equipment. Errors may be introduced by inaccurate reference electrodes as well as by unsatisfactorily defined polarization characteristics for the exposed steel. An error of ±10 mV in the ΔE figure for the anode would in this case represent an error of 7-9% in the current output estimate. On comparison of readings obtained with the two methods they seldom differ by more than 20% for any anode.

(to be continued)

APPENDIX B (continued)

B.5.8 Potentials in nodal areas-improved efficiency in potential surveys of nodes

Potential profiles for nodes and similar shielded areas on a structure have often been found to be critical, i.e. such areas exhibits the least satisfactory potential levels. An example of such a nodal area with a total of 8 members meeting at the joint has been modeled. Anodes attached outside the nodal area. As is observed an IR drop of 50-60 mV is obtained across the nodal area in this particular case. Figures for such IR drops in excess of 60 mV may not be unusual.

However, with increasing use of RCVs in inspection of the steel structures it has often proved inconvenient or even impossible to obtain potential readings in such narrow corners of the steel members, and readings in the potentially most critical areas are lost.

Under such conditions computer modeling has been used to provide estimates of the (relative) potential profile at the nodes. Potential-and field strength readings are used in mapping of boundary conditions in a few selected areas. These data are subsequently used in modeling of a large number of nodes of different geometry, to provide similar potential profiles. These profiles are subsequently utilized in future potential surveys:

- It is now sufficient to make potential readings at a few selected reference positions, each located for convenient access 2-3 meter outside the node. These reference readings are used for calibration of the (relative) potential profiles above, to obtain the complete profile for the node area each time a survey is conducted.

In an early test of this technique potential readings at a node were found to fit the predict profile with maximum deviations of 10 mV.

For more information see Collected Papers on Cathodic Protection Current Distribution by NACE Task Group T-7L-4.

B.5.9 References

1) **Strommen R., Rodland A.:** Paper No. 241, Conf. Corrosion/80, March 1980, Chicago, Illinois

2) **Strommen R., Rodland A.:** Paper No. 241, Conf. Corrosion/80, March 1980, Chicago, Illinois

3) **Backhouse G.H.:** Ibid, Paper No. 108

4) **The Portancorin Probe:** Technical Description. Corrocean Engineering A/S, Trondheim-Norway 1980

5) **Fleck, R.N.:** Numerical Evaluation of Current Distribution in Electrical Systems. M.Sc. thesis Univ. of California, Sept. 1964

6) **Strommen R.:** Unpublished Reports, SINTEF-NTCH, Trondheim, Norway, 1974

7) **Strommen R.:** Trans. I Mar E, 1979, Vol. 91 NSC Conf. Edinburgh

8) **Strommen R.:** Numerical Methods for the Calculation of Current and Potential Distribution in Galvanic Cells and Cathodic Protection System 2nd Israel-Norwegian Techn. & Scientific Symposium, Electrochemistry

9) **Sale, J.P.:** The Evaluation of Anodes Configurations for the Internal Cathodic Protection of Pipes. Conf. on Corrosion and Protection of Pipelines. English Electric Computers Ltd

10) **Forrest A.W.Jr.et el:** Paper No. 150, Conf. Corrosion/80, March 1980, Chicago, Illinois

11) **Fu.J.W.:** Paper No. 115, Conf. Corrosion/81, April 1981, Toronto, Ontario, Canada

(to be continued)

APPENDIX B (continued)

12) **Helle H.P.E. et al:** Corrosion Vol. 37, No. 9, Sept. 1981 P. 522

13) **Zienkieviz O.C:** The Element Methods, McGraw-Hill, 1977

14) **R.D Strommen, W.Keim, J.Finnegan, P. Mehdizadeh:** "Advances Cathodic Protection Modeling Utilizing the Boundary Element Method", Corrosion/86, National Association Corrosion Engineers, Houston, TX., 1986

15) **R.D. Strommen:** "Review of Offshore CP Design Criteria Based on in-situ Current Density Measurements", UK Corrosion 85, 1985

16) **E.A. Levings, W.M. McKie, R.D. Strommen:** "Murchison Cathodic Protection System", UK National Corrosion Conference, 1982

(to be continued)

APPENDIX B (continued)

B.6 Coating Resistance Measurement Method

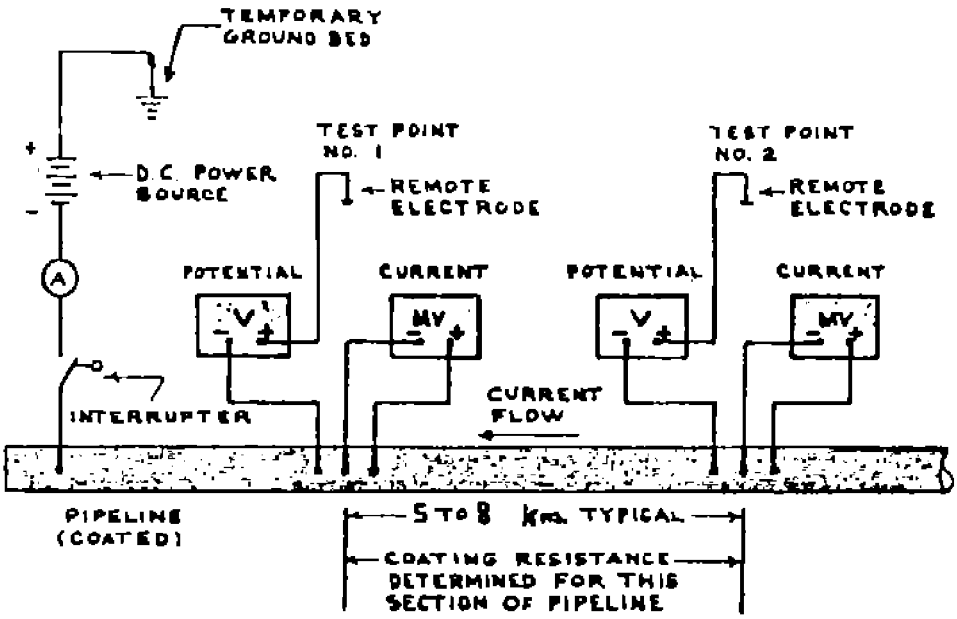
B.6.1 General

The electrical resistance of the coating is expressed as the resistance per average square meter of coating. This may also be expressed as conductance in microhms per average square meter (which is the reciprocal of the electrical resistance multiplied by one million). Coating resistance of a buried or submerged pipeline may be determined by following methods:

B.6.2 Current-voltage change method

This is the most practical method used for determining the effective resistance or conductance of the coating in a pipeline section. This method is based on calculating coating resistance directly from current and voltage change measurement obtained from field tests.

Test set up and arrangement is illustrated in Fig. B.6.1.



COATING RESISTANCE AND CATHODIC PROTECTION CURRENT REQUIREMENT TESTS
Fig. B.6.1

The procedure for determining the coating resistance or conductivity using this method is as follows

B.6.2.1 To perform the test, batteries will be sufficient as a source of power supply. A current interrupter automatically switch the circuit on and off (usually 30 seconds on and 15 seconds off). The interrupter also assures the inspector when at remote locations that the battery installation is operating properly and draining current from pipeline as long as his potential and line current measurement continue to change in accordance with the established on-off cycle.

B.6.2.2 Test data may be taken for a section of 8 kilometers. Testing can be continued section by section in each direction from the power source until changes in observed currents and potentials (as the current interrupter switches on and off) are insignificant. The length of the section which can be maintained at -0.85 V or better will be established at the same time.

(to be continued)

APPENDIX B (continued)

On coated pipeline systems provided with test points for potential and line current measurement, a survey will proceed rapidly. Survey can be carried out by a single inspector. For maximum accuracy, however, two engineers in radio communication can observe data simultaneously at each end of each section tested. This becomes essential if the pipeline under test is affected by variable stray current.

B.6.2.3 To obtain data for calculation of coating resistance, readings are taken of pipeline at each end of each test section as follows:

B.6.2.3.1 Potential readings to remote copper sulfate electrode with interrupter ON and OFF.

B.6.2.3.2 Pipeline current with interrupter on and off

From these readings the change in pipe potential (ΔV) at the change in line current (ΔI) at each end of the section can be determined. The difference of the two ΔI values will be the test battery current collected by the line section when the current interrupter is switched on. The average of the two ΔV values will be the average change in pipeline potential within the test section caused by the battery current collected.

The average ΔV in millivolts divided by the current collected in milliamperes will give the resistance to earth, in ohms, of the pipeline section tested. Knowing the length and diameter of pipe in the section tested, its total surface area in square meter may be calculated.

Multiplying the pipe-section to earth resistance by the area in square meter will result in a value of ohms per average square meter. This is the effective coating resistance for the section tested.

Some inspectors express coating condition in terms of coating conductivity in mhos or microhms. This is simply matter of conversion. The reciprocal of the resistance per average square meter is the conductivity in mohs. The reciprocal times 10^6 is the conductivity in micromhos. A sufficient number of readings should be taken to insure acceptable precision.

B.6.3 Following is an example of how this test method can be implemented:

Test Section

Test Section is 5,000 meter of 12″ Dia. coated line which lies between Test Point 1 and Test Point 2 (see Fig. B.6.1). Wall thickness of the pipe is 9.52 mm (0.375 in).

B.6.3.1 Test data taken at test Point No. 1 are as follows:

B.6.3.1.1 Pipe/soil potentials (Ref. copper sulfate electrode) are:

	-1.75	Volts	ON
	-0.89	Volts	OFF
ΔV =	-0.86	Volts	

B.6.3.1.2 Potentials drops across test section are:

+0.98	mV	ON
+0.04	mV	OFF

B.6.3.1.3 Span calibration is 2.30 Amperes per millivolt (see Clause B.4.2.3 Step 2).

B.6.3.1.4 Pipeline current

	+2.25	Amps	ON
	+0.09	Amps	OFF
ΔI =	+2.16	Amps	

(to be continued)

APPENDIX B (continued)

B.6.3.2 Test data taken at test Point No. 2.

B.6.3.2.1 Pipe/soil potentials (Ref. copper sulfate electrode) are:

	-1.70	Volts	ON
	-0.88	Volts	OFF
ΔV =	-0.82	Volts	

B.6.3.2.2 Potentials drop across test section are:

+0.84	mV	ON
+0.02	mV	OFF

B.6.3.2.3 Span calibration is 2.41 Amps per mV.

B.6.3.2.4 Pipeline current

	+2.03	Amps	ON
	+0.05	Amps	OFF *
ΔI =	+2.08	Amps	

B.6.3.3 Calculation of coating resistance:

B.6.3.3.1 Average $\mathbf{\Delta V = \dfrac{-0.86 + (-0.82)}{2} = -0.84}$ Volt [form B.6.3.1.1 and B.6.3.2.1].

B.6.3.3.2 Current collected 2.16-2.08 = 0.08 Amps. [readings from B.6.3.1.4 and B.6.3.2.4].

B.6.3.3.3 Pipe to earth resistance $= \mathbf{\dfrac{0.84\ V}{0.08\ A} = 10.5}$ ohms.

B.6.3.3.4 Surface area of test section 4785 square meter.

B.6.3.3.5 Effective coating resistance 10.5 × 4785 = 50242 ohms per average square meter.

B.6.3.3.6 Coating conductance $\mathbf{\dfrac{10^6}{50242} = 19.9}$ microhms per average sq. meter.

*** Negative current indicates current flow in opposite direction.**

(to be continued)

APPENDIX B (continued)

B.7 Test Method and Calculation for "Attenuation Constant"

B.7.1 General

Coating effectiveness of pipeline may be evaluated using attenuation method which involves a limited amount of field measurements.

The measurements lead to a figure which is termed "Attenuation Constant" per kilometer. From this figure spread of protective current can be evaluated and the approximate distance between drain points can be estimated.

When the original design fails to provide complete cathodic protection due to sharp drop of pipe/soil potential along pipeline, the estimated distance would tell the designer where to put rectifiers for supplementary protection. "Attenuation Constant" is derived from the attenuation equation (see B.7.2). The equations describe the interrelation of factors affecting degree of protection achieved at any specific location on a cathodically protected pipeline. The factors are as follows:

- Total current drain.

- Radial resistance of path from the pipe surface to remote earth. This factor includes both the resistance of the path through the coating on the pipe and the resistance through the soil.

- Diameter and wall thickness of the pipe.

- Distance of the location from the drain point.

B.7.2 The basic formulas for attenuation are as follows:

$$dV_x = dV_o \, e^{-ax} \qquad \text{(Eq. 1)}$$

Where:

dV_x	is change in potential as distance x km from the drain point in millivolts.
dV_o	is change in potential at the drain point with cell directly over pipe in millivolts.
e	is constant 2.72 (base of natural logarithms).
a	is attenuation constant-per kilometers.
x	is distance from drain point kilometers.

$$\text{Ln } dV_x = \text{Ln } dV_o + \text{Ln } e^{-ax} \qquad \text{(Eq. 2)}$$

$$\text{Ln } dV_x = \text{Ln } dV_o - ax \qquad \text{(Eq. 3)}$$

$$a = \frac{\text{Ln } dV_o - \text{Ln } dV_x}{x} \qquad \text{(Eq. 4)}$$

Eq. 4 is the basis for constructing the attenuation graph for each value of attenuation constant. In addition to above, it can also be shown that the following relationships apply:

$$a = \sqrt{\frac{R_S}{R_L}} \qquad \text{(Eq. 5)}$$

(to be continued)

APPENDIX B (continued)

Where:

R_S is longitudinal resistance in the pipe wall (ohms per kilometer).
R_L is leakage resistance or radial resistance from the pipe surface to remote earth (ohms-kilometer).

$$R_s = \frac{\rho L}{A} \qquad \textbf{(Eq. 6)}$$

Where:

ρ is resistivity of the steel pipe usually estimated at 18 michrohm-cm unless actual resistivity is known.
L is unit pipe length-in this case 1 km or 1×10^5 cm.
A is cross section area of pipe in sq-cm

$$R_L = \frac{\rho}{2nL} \mathrm{Ln} \frac{D}{r} \qquad \textbf{(Eq. 7)}$$

Where:

ρ is average resistivity of soil around pipe to remote earth ohm-cm.
D is distance from pipe surface to effectively "remote" earth.
r is pipe radius in same units as (D).

Also the following relationships is applicable:

$$a = \frac{R_s}{R_k} \qquad \textbf{(Eq. 8)}$$

Where:

R_S is as shown in Eq. 6.
R_K is characteristic resistance of the entire line looking in one direction only from the drain point.

For a line uniform in both directions from drain point:

$$P_K = 2R_G \qquad \textbf{(Eq. 9)}$$

Where:

R_G is resistance of the entire line looking in both directions from the drain point.

$$R_G = \frac{dV'_o}{dI} \qquad \textbf{(Eq. 10)}$$

Where:

dV'_o is change in potential at the drain point related to a remote cell.
dI is current drain change which causes dV'_o.

From this $$R_K = \frac{2dV'_o}{dI} \qquad \textbf{(Eq. 11)}$$

$$a = \frac{R_s dI}{2dV'_o} \qquad \textbf{(Eq. 12)}$$

(to be continued)

APPENDIX B (continued)

For a line on which there are rectifiers spaced a distance 2AL kilometers apart; the relationship is:

$$\mathbf{dV_m = dV_o \cosh al} \qquad \text{(Eq. 13)}$$

Where:

dV_m is change in potential at the mid-point between rectifiers.

Practically the same value for dV_m is obtained if the following 2 values are added:

$$\mathbf{dV_{AL} = dV_{Ao}\, e^{-aAL}}$$

$$\mathbf{dV_{BL} = dV_{Bo}\, e^{-aBL}}$$

Where values (dV_{AL}), (dV_{Ao}) and (a_A) all relate to rectifier (A).

$$\mathbf{dV_m = dV_{AL} + dV_{BL}}$$

B.7.3 Significance of attenuation constant

B.7.3.1 To put the various levels of attenuation constant in perspective, graph showing the effective spread of protection for various values of attenuation constants (from 0.05 to 0.5 per km) has been prepared (see Fig. B.7).

B.7.3.2 Method of calculation

B.7.3.2.1 It is assumed that the potential change at the drain point is to be 1000 mV from the static pipe/soil potential.

Thus, if the static pipe/soil potential is about 500 mV the maximum pipe/soil potential would be 1500 mV (all potential values are with reference to copper sulfate electrode).

B.7.3.2.2 To construct the graph, the value of potential change was calculated for the 10 km distance for each value of attenuation constant and the value so calculated was plotted on the 10 km line.

A straight line was then drawn from $\Delta V = 1000$ at km zero through the point plotted at km 10 for the particular value of "a".

For example:

If $\Delta V = 1000$
$X = 10$ km
$a = 0.50$ per km

$$\mathbf{Ln\ \Delta V_x = Ln\ \Delta V_o - a_x = 6.90 - (0.5 \times 10) = 1.90}$$

$$\mathbf{\Delta V_x = 6.7}$$

B.7.4 Example use of graph relating to attenuation constant

If the static potential is assumed to be -500 mV to copper sulfate electrode and the desired minimum potential is -900 mV to copper sulfate (allowing 50 mV safety factor) then the minimum potential change due to each rectifier, at the midpoint (between rectifiers) would have to be:

$$\mathbf{\frac{900 - 500}{2} = 200\ mV}$$

(to be continued)

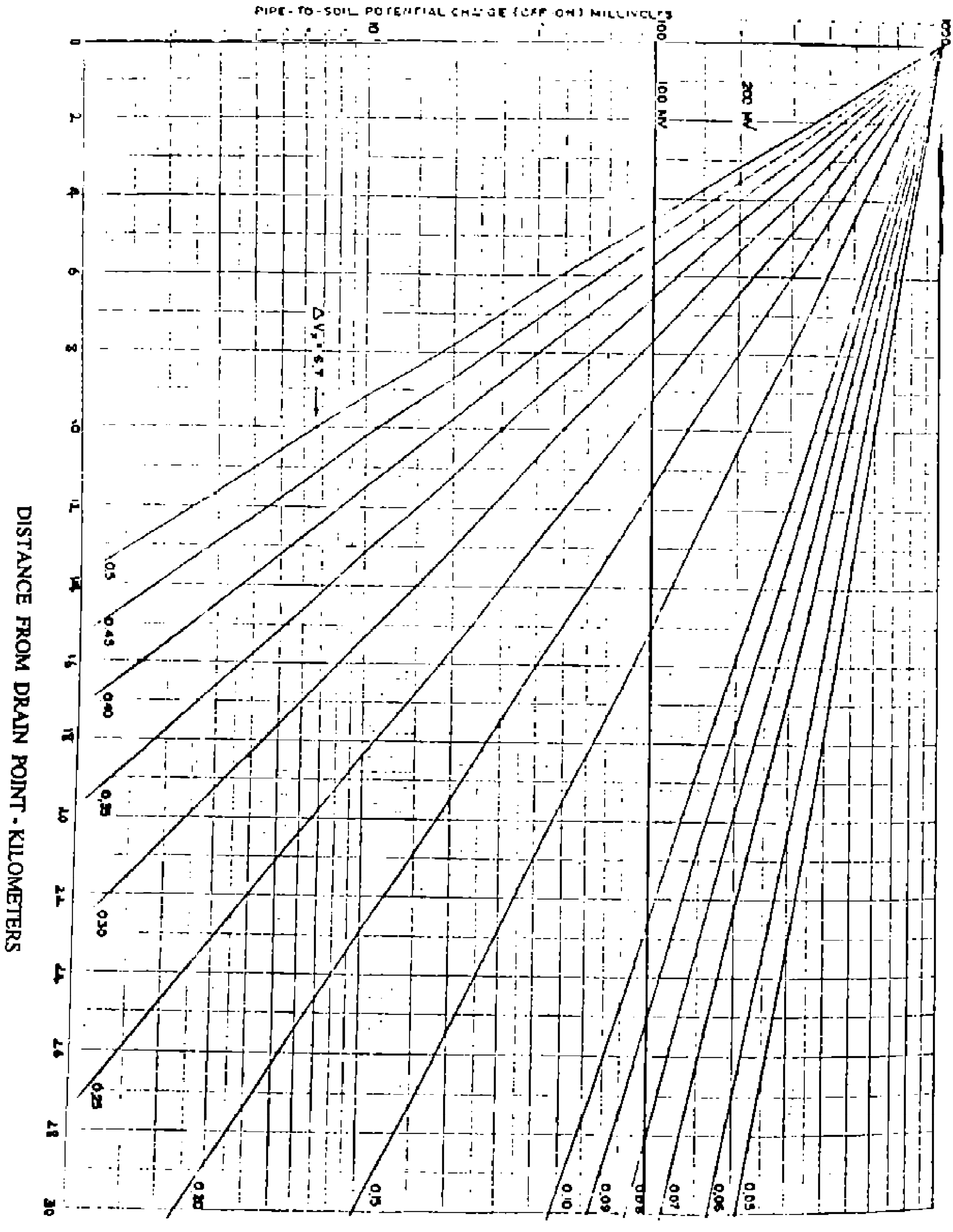
APPENDIX B (continued)

From the graph it will be seen that the distance from the drain point at which this potential change (200 mV) is just achieved is a function of the attenuation value.

For instance, if the attenuation constant is 0.45 per km, the distance at which the potential change attainable is 200 mV is 3.6 km. In order to achieve protection to the 900 mV minimum level with this value of attenuation constant it would be necessary to space the rectifiers 2 × 3.6 or 7.2 km apart. To put the various levels of attenuation constant in perspective a rating table (Table 4) has been prepared. This table can be used to describe the relative effectiveness of any coating, as installed, in terms of attenuation constant per kilometer of the line concerned. Based on the attenuation constant value, approximate distance between drain points can be estimated and location for installation of new rectifier to supplement ineffective cathodic protection system may be decided.

(to be continued)

APPENDIX B (continued)



GRAPH SPREAD OF PROTECTION RELATING TO ATTENUATION CONSTANT
Fig. B.7.1

(to be continued)

APPENDIX B (continued)

B.8 Coating Inspection by Pearson Method

B.8.1 General

The Pearson survey is an above ground survey technique used to locate coating defects in buried pipelines named after J.M. Pearson who developed the technique. The survey compares the potential gradients along the pipeline measured between two movable electrical ground contacts. The potential gradients result from an injected AC signal leaking to ground at coating defects or metallic objects within the pipeline trench

B.8.2 Equipment

The equipment required for the survey comprises:

- Transmitter to provide an AC signal of approximately 1000 Hz for conventional pipeline coatings e.g. enamel, tape, extruded coating etc. and a reduced frequency of 175 Hz for thin film coating e.g. fusion bonded powder epoxy, etc. The transmitter is powered from internal batteries or for long surveys from an external high capacity battery.

- Receiver, hand held, self-contained, battery operated with pick-up sensitivity controls, audible warning, ear-phone output and in some cases, recording capability. The receiver is tuned to the transmitter frequency.

- Earth contact set of boot cleats, studded boots or modified aluminum ski poles.

- Connecting cable harness between earth contacts and receiver.

- Earth spike and connecting cables for transmitter.

The above equipment is normally all contained in a portable box for easy transportation. Total weight is approximately 25 kg.

Optional equipment available from some suppliers enables the instrument to be used as a general purpose pipe/cable locator and comprises:

- Signal level meter on receiver.
- Pipe location antenna.
- Pipe depth indication.
- Signal recorder and playback chart recorder or interface to a portable computer.

B.8.3 Procedure

The equipment is set up as shown diagrammatically in Fig. B.8.1. The transmitter is electrically connected with one lead to the pipeline, usually by connecting to a cathodic protection test lead or an accessible part of the pipeline, and the other lead to a good remote earth and then energized.

Using the receiver in the pipe locating mode, or a separate pipe locator, the section of pipe to be tested is located and identified to enable the survey operators to follow the route of the pipe exactly above the pipe. For record purposes, it may be useful to insert pegs at measured intervals.

The survey may be carried out with an impressed current cathodic protection system energized. However, any sacrificial anodes, bonds to other structures or similar are best disconnected prior to commencing the survey to ensure they do not mask defect areas or drastically reduce the length that may be surveyed from one injection point. With the line located, the receiver is then connected via the cable harness to the earth contacts worn or held by the two operators such that at all times earth contact is made by each operator. The connecting cable provides for a separation of 6-8 m between the operators.

(to be continued)

APPENDIX B (continued)

Surveying should commence at a sufficient distance from the transmitter and earth spike to minimize interference from the transmitter and/or return current flow in the earth.

The two operators walk over the top of the pipeline to locate coating defects as shown in Fig. B.8.1. When the front contact approaches a defect an increased signal level is indicated in the earphones by an increase in volume or by a higher reading on the receiver signal level meter. As the front contact passes the defect, the signal fades and then peaks again as the rear contact passes over the defect.

The defect is logged on the record sheet at a measured distance from a reference point (by triangulation if possible) and/or may be indicated with a marker or non-toxic paint. The signal is recorded automatically for later interpretation if the receiver is fitted with recording equipment. Where the signal is not easily interpreted or where there may be more than one defect within the span of the operators, this may be clarified by surveying at right angles to the pipeline i.e. one operator walks over the pipeline and the second walks parallel to the pipeline at 6-8 m from the pipeline. In this mode each defect is indicated as the operator over the pipeline traverses the fault. This is utilized when using recording equipment.

The above procedures are general and in all cases the equipment manufacturer's instructions are to be followed.

B.8.4 Data obtained

The information obtained from a Pearson survey is the change of signal intensity at probable defect locations.

For instruments without a signal level meter only the location and the operator's aural interpretation of the signal strength can be recorded. Where a signal level meter is fitted, further data concerning the rate of increase and decrease and the maximum signal level may be recorded, together with intensity variations around the defect location which can assist in analyzing the magnitude and disposition of the defect. This is done automatically when the receiver is of the recording type.

B.8.5 Presentation of data

Defect indications are either by audible tone or by the signal meter level. The accuracy of recording signal level changes either manually or automatically and the locations where they occur is very important to enable further investigations to be carried out.

Locations of probable defects can be measured to fixed points so that they may be returned to at a later date.

In addition to recording the probable defect locations, valuable information may be gained by recording various observations of the signal levels on the meter, which will assist in the evaluation of the probable defect. For example, if the signal level rises to a peak rapidly and then falls away, or if it rises steadily and remains high for a distance before decaying, these characteristics may be recorded. This is done automatically if the receiver is of the recording type (see Fig. B.8.2.A).

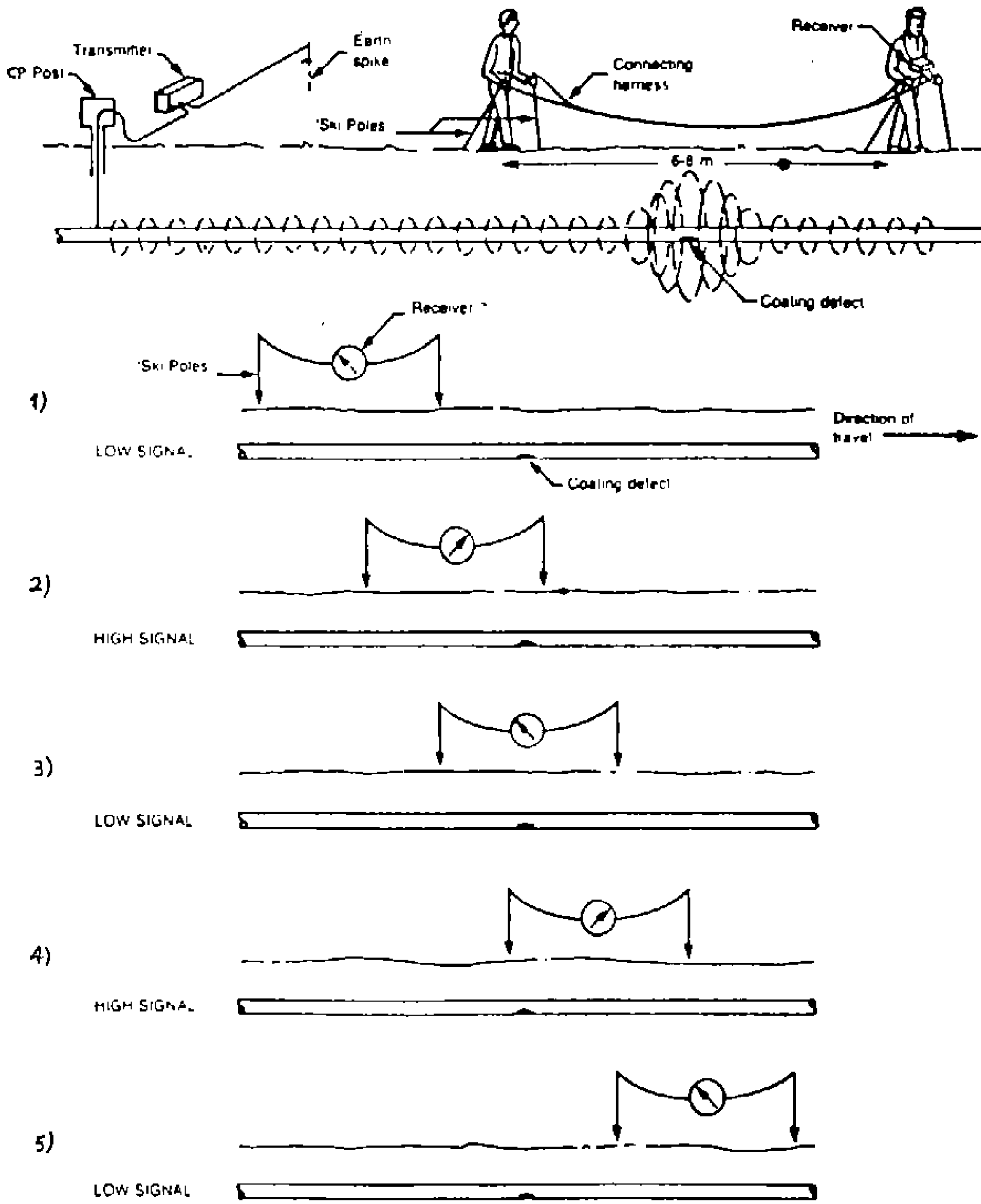
The survey record sheet may provide space to adequately note all pipeline features, reference points, other services crossing, signal intensity levels and characteristics etc. to enable the results of the survey to be analyzed and determine areas where further investigations or remedial measures are required (see Fig. B.8.2.B).

Where repeat surveys are carried out, these records can be compared and may show further deterioration of the condition of the coating.

(to be continued)

APPENDIX B (continued)

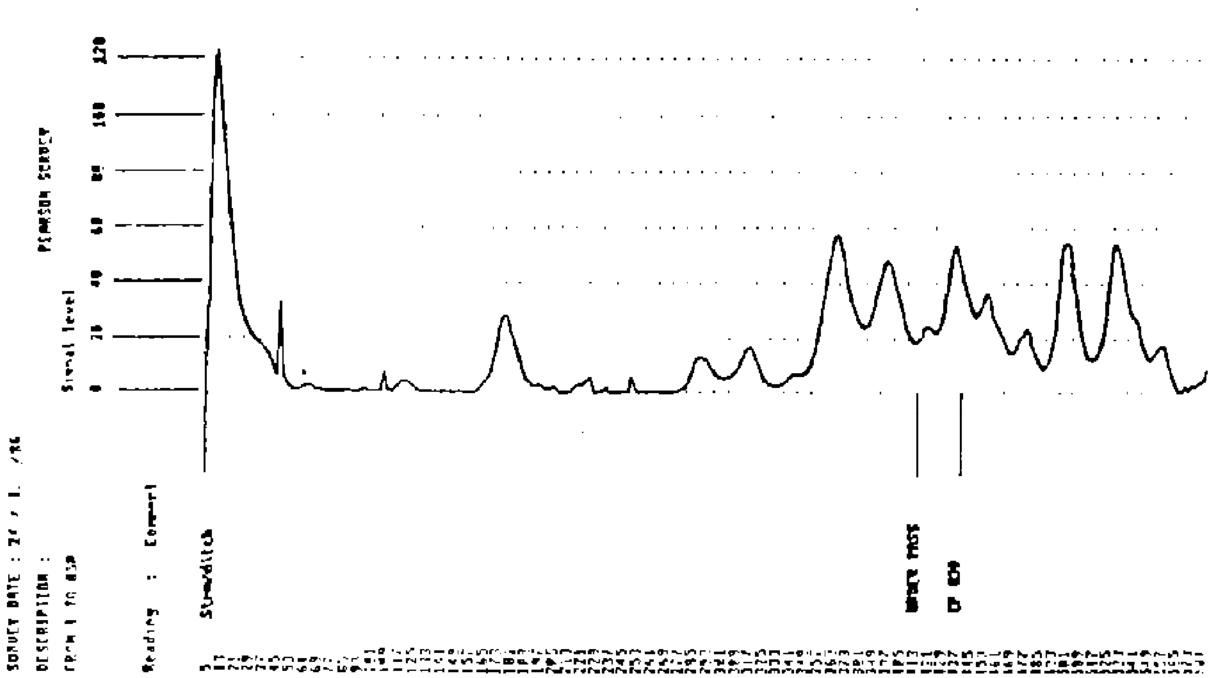
Principle of the Pearson Survey



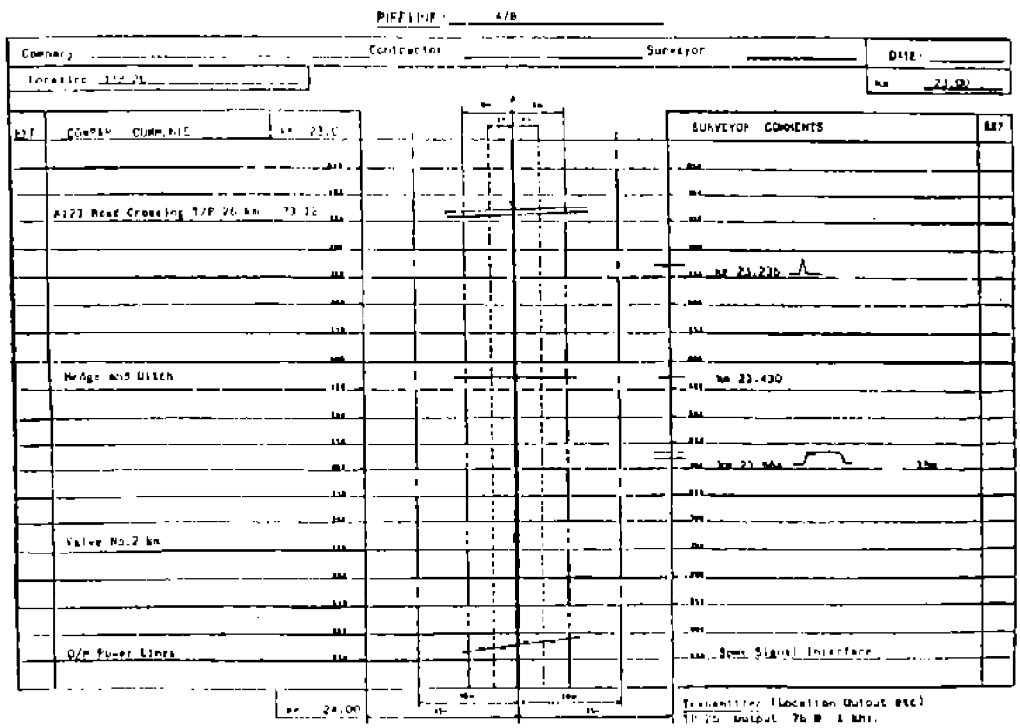
TYPICAL SIGNAL LEVEL ON PASSING A COATING
Fig. B.8.1

(to be continued)

APPENDIX B (continued)



TYPICAL OUTPUT FROM RECORDING PEARSON EQUIPMENT
Fig. B.8.2.A



TYPICAL SURVEY RECORD SHEET
Fig. B.8.2.B

(to be continued)

APPENDIX B (continued)

B.9 Coating Inspection by C-Scan System

B.9.1 General

This system introduces the latest technique of above-ground coating inspection. The system locates coating defects on buried pipelines and provides an assessment of external coating quality. In addition to coating condition, the system can also be used to locate contact or connection points between buried services which can be of great importance on proper functioning of pipeline cathodic protection. The system is based on current attenuation survey. The current attenuation is the only technique which gives a value (attenuation) which is a direct indication of the pipeline coating.

Excavations confirmed almost all defect location detected by C-Scan. The C-Scan located the defects found by the Pearson survey and also located defects which the Pearson survey did not find. At the end of a survey (or whenever required) the detector unit may be plugged into any computer or printer and the survey report can be printed out in full. Alternatively, the data can be displayed on a computer monitor or stored on disk or tape for further analysis.

The coating condition of a pipeline can be monitored over its working life. This is done by repeating the general survey at intervals of 3 to 5 years. The results of the repeat surveys are compared with those from the first survey to monitor any deterioration of the coating with age (ageing effect on coating condition).

B.9.2 C-Scan system features

Operation of the C-Scan detector is largely automatic. When required prompt messages, instruction messages, and warnings are displayed to the operator to guide him through the survey sequence.

The operating frequency of the system has been selected to minimize interference from commonly occurring sources. The filtering system and the directional nature of the detector antenna help to eliminate almost all suspicious signals. The C-Scan system includes the following items:

- Signal generator with built-in charger.
- Generator/pipe connector lead.
- Generator/earth connector lead provided with extension. Set of earth spikes, complete with connector leads.
- Detector unit containing power pack, antenna and computer.
- Spare power pack for detector unit.
- Charger for detector power packs.

B.9.3 Performing survey by C-Scan

The C-Scan system uses a generator to apply an a.c. signal to the pipe, and this is done by connecting one of the generator output leads to the pipeline at a cathodic protection test point, valve or access point; the other lead of the generator is attached to a remote earth.

A constant a.c. signal (set by the operator) is applied to the pipeline. The applied a.c. signal will flow along the pipeline in both directions, decreasing in magnitude as the signal leaks to earth through the coating. At coating defects, where the pipeline is in direct contact with the soil, the signal leakage to earth is greater.

A detector is used to measure the strength of the a.c. signal on the pipe. The operator starts making measurement. The first measurement is made at least 100 meters from the point of injection, usually at a fence or other identifiable feature. The detector will automatically take 1000 readings of the magnetic field and will compute and display to the operator the depth to the center line of the pipeline and the signal level (strength of the remaining signal current). If required, the detector unit will also record (store) this data and give it a (marker) number for subsequent reference.

(to be continued)

APPENDIX B (continued)

This procedure is then repeated at the next survey point, usually the next road crossing or the next cathodic test point. The attenuation is calculated from these values and gives a direct indication of the coating condition in that section.

An initial survey, called the general survey, may be carried out on a pipeline by taking measurements at road crossings and points of easy access with intervals of approximately one kilometer. This will identify sections of pipeline between measurement points where coating defect exist. The defect location may be defined by progressively halving the distance in the suspect section until it has been reduced to a practical length where a detailed close interval current loss survey can be carried out.

B.9.4 Advantages of the system

The main advantages of this system are as follows:

B.9.4.1 Rapid assessment of the system.

B.9.4.2 Accurate defect location and depth determination.

B.9.4.3 Repeating the survey at regular intervals to monitor coating condition during working life of the pipeline.

B.9.4.4 Survey can be carried out in plant areas where the pipe is covered by concrete or tarmac.

B.9.4.5 No need to walk the entire length of the pipeline and areas of difficult access, such as rice fields etc.

B.9.4.6 Survey includes road, rail, river crossings, etc.

B.9.5 Theoretical background

An electrical current applied to a well wrapped buried metal pipeline will decrease gradually with increasing distance from the current injection point, as the current escapes to earth through the coating.

If the coating has a uniform thickness and separates the pipe from the surrounding soil at all points, the strength of the signal current on the pipe will decline logarithmically, and the rate of decline will be dependent primarily on the effective resistance of the coating in use (resistance per average square meter of coating), and the area of coating in contact with the soil per unit length of pipe (i.e. for a given coating, the decline is proportional to the circumference of the pipe).

It shall be borne in mind that because of the relative magnitude of the resistance involved, local changes in soil resistivity can usually be ignored.

If there is a low resistance electrical path from the pipe direct to the soil at any point, there will be a substantial local increase in the rate of loss of signal current. Such a low resistance path could arise from the followings:

- Improper applied coating.
- Mechanical damage to the coating before, during and after application.
- Decay of the coating due to soil stress or bacterial effects.
- Disbonding of the coating from the pipe (provided that ground water has penetrated into the gap to create an electrical path to earth).
- A leak in the pipe itself causing the coating to fail at the leak point.

Because the resistance of such an electrical path to earth is likely to be several orders of magnitude less than the resistance of the undamaged coating, the resultant loss of current, even from a single small fault of a few square millimeters, can usually be detected by a significant increase in the apparent rate of current decline over quite a long length of pipe.

(to be continued)

APPENDIX B (continued)

In practice, the existence of one or two small faults on a section of pipeline several hundred meters in length can usually be tolerated because cathodic protection system is expected to prevent, corrosion resulting from these faults. In this case it may not be necessary to locate the specific faults immediately but the rate of logarithmic decline of current between two specific points can be logged for future reference so that any deterioration of the condition of the pipeline coating can be monitored.

The logarithmic rate of decline of the current (which is known as attenuation level) is measured in terms of millibels ($^{1}/_{100}$ of decibel) per meter. This rate of decline of the current is effectively independent of the applied current so that it is virtually and absolute indication of the average condition of the coating between two given points at the date when the survey is made.

If the attenuation level over a given section of pipeline is particularly high, serious faults (or a large number of small faults) in the protective coating are indicated. Intermediate readings of attenuation levels can be taken to identify the worst sections. The survey can be made extensively over the suspect section at close intervals (3-5 meters) and readings of actual current levels in this section can be taken, recorded and plotted. By so doing and noting the place where the rate of current decline is steepest, the precise location of faults (generally to an accuracy of 1-2 meters) can be determined. This locates the defect to the extend that excavation for visual check and repair is justified.

B.9.6 Operation principle

B.9.6.1 As mentioned earlier, this system of coating evaluation is based on current attenuation level. The main operating components of the system are "The Signal Generator" and "The Detector Unit".

The Signal Generator is attached to the pipeline and also to an appropriate earth point, and produces a constant a.c. signal which passes along the pipe.

The detector unit measures the electromagnetic field radiating from the pipeline and uses this to:

a) Locate the pipeline.
b) Determine the depth of the pipe.
c) Determine the residual strength of the signal current at the observation point.

The above data can be stored in the memory of the detector unit's computer and is used to compute and store current attenuation rates between any two given observation points.

The complete record of the survey (with time and data) may be printed out at the end of the survey to provide a permanent record.

B.9.6.2 Signal generator

The C-Scan signal generator contains of followings:

B.9.6.2.1 Power supply consisting of six 12 volt batteries. Capacity of each battery is 5 amperes/hour.

B.9.6.2.2 A built in charger suitable for mains input of 110 or 240 Volts single phase with frequency of 50 or 60 Hz respectively.

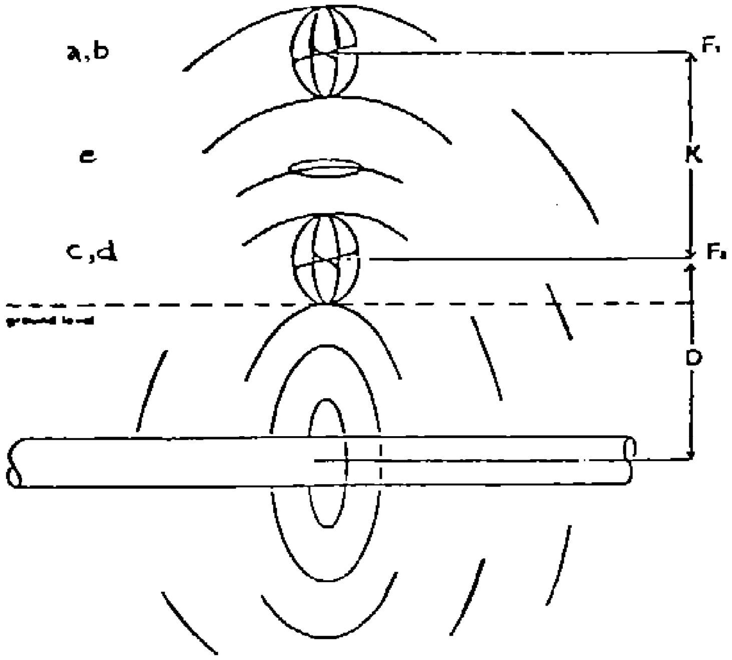
B.9.6.2.3 The inverter-frequency changer which inverts the output of the signal generator to a sine wave signal at a frequency of 937.5 Hz, with a nominal maximum voltage of 60 V.

The maximum current obtainable is approximately 1 Ampere. The Root Mean Square value of the current being produced is displayed on the digital ammeter of the instrument. The value is expressed in milliampere.

The actual level of current produced is set by the surveyor using the instrument's controls. Once set, this current level will be maintained at a constant level (despite any transient changes in soil resistivity), until the batteries are exhausted. In tests, the unit when fully charged, has maintained a constant output of 750 mA for up to 16 hours continuous operation.

(to be continued)

APPENDIX B (continued)



Vector sum of a, b = F1 (Field strength)

Coil e, gives zero when overhead

Vector sum of c, d = F2 (Field strength)

Depth of pipe $D = K \frac{F_1}{F_2 - F_1}$

RMS Current = D × F2 × Constant on Pipe

PRINCIPLES OF OPERATION
Fig. B.9.1

B.9.6.3 Detector unit

The detector unit consist of two vertical tubes joined by two smaller cross tubes, the upper one of which serves as a carrying handle. The taller vertical tube contains parts as hereunder:

- The antenna system.
- The keyboard and liquid crystal display which are mounted on the top of the tube.

The other vertical tube contains the computer, the power supply and the printer lead. The antenna consists of five large diameter air cored coils. Two of these are at the bottom of the tube with their axes horizontal and at right angles to each other (c and d). Another identical pair (a and b) is at the top of the tube approximately 80 cm above the first pair, and a fifth coil with its axis vertical (see Fig. B.9.1).

B.9.6.4 Principle of operation (see Fig. B.9.1)

In operation, the computer calculates the vector sum of the field strength measured by the two pairs of coils (ab and cd) and indicates to the operator that it has acquired the signal radiating from the buried pipe. The LCD gives an indication of the field strength and guides the operator towards the pipe. A comparison of the field strengths at the top and bottom of the antenna, with the strength of the field measured by the vertical axis (e) coil, is used to tell the operator when he is close to the pipeline.

When the field measured by the (e) coil falls below a threshold value, the instrument tells the operator to stop because is overhead. Once the instrument is stationary in the overhead position for a few seconds, it will automatically collect a sample of 200 readings of the field strength values at the top and bottom of the antenna over a period of approximately four seconds. Provided the standard deviation of the sample is below a threshold value, the computer will then calculate the depth of the pipe (below the center of the bottom coil pair) and the strength of the residual signal current on the pipe.

(to be continued)

APPENDIX B (continued)

The depth (in meters) and current value (in milliampere) are shown on the LCD for a few seconds, and if the operator takes no action, the instrument will repeat the sample and calculation routine.

Using the keyboard, and following the prompts appear on the display, the operator can store the display data (which is mathematically given a reference number), and request the computer to calculate the logarithmic attenuation of the signal from any previous location stored in its memory. This information is displayed on the LCD and may also be stored if required. The computer can store up to 100 complete sets of data (location reference number, depth of pipe, strength of signal current, distance from a previous location reference, and logarithmic attenuation of the signal), in millibels per meter, between the two points. At the beginning of each survey, the computer will also not automatically the time and data using its internal clock. This information will also appear on the subsequent printout. Current readings obtained in the course of a close interval survey to locate specific faults, are not stored for printout, as they are unlikely to be relevant to subsequent surveys. These readings are generally noted down for plotting purposes by the operator during the course of the operation.

At the end of a survey (or whenever required) the detector unit may be plugged into a standard computer printer and the survey report may be printed out. Alternatively, the data may be displayed on a computer monitor or stored on disk or tape for further analysis.

The detector unit is powered by a nickel-cadmium rechargeable power pack providing enough power for continuous running for over 20 hours.

In addition, there is a separate built-in lithium power source to maintain the data stored in the memory and the operation of the clock, when the power pack has been unplugged. This power source has an estimated life of ten years.

The C-Scan system is not immune to electromagnetic interference, but it incorporates a number of features which are designed to keep such interference to a minimum. The feature include:

a) The generation of a pure sine wave so that no complex harmonic are produced.

b) The use of a carefully selected frequency with virtually no harmonics in common with other frequencies in general use.

c) The collection of 200 signal "samples" over a period of approximately four seconds to eliminate transient interference.

The instruments in not affected by presence of mains a.c. current. Nor any residual ripple of cathodic protection rectifier affects operation of the system.

(to be continued)

APPENDIX B (continued)

B.10 Coating Evaluation by Electromagnetic Current Attenuation Survey

B.10.1 General

The electromagnetic current attenuation survey is an above-ground survey technique used to locate coating defects on buried pipelines, and provide a comparative assessment of coating quality.

An a.c. signal is applied between the coated pipe and remote earth. When the signal current flows along a straight conductor (pipeline), it creates a magnetic field, cylindrical in shape, around the pipeline. The shape of this field is not affected by the presence of pipeline coating, by different types of soil, or non-reinforced concrete, tarmac, etc. It is possible by electromagnetic induction to detect and measure the intensity of this signal with an antenna.

The applied a.c. signal will flow along the pipeline in both directions, decreasing in magnitude as the signal leaks to earth through the capacitive and resistive effects of the coating. At coating defects, where the pipeline is in direct contact with the soil, the signal leakage to earth will be more significant. (See Fig. B.10.1.A.)

Thus signal losses over a section of pipeline are due to the following:

- Dielectric and resistive losses due to the nature and quality of the coating.
- Capacitive losses of the a.c. signal to earth.
- Discrete points of coating damage resulting in steel/soil contact.
- Metallic contact with other buried conductors.

Where the current is observed to attenuate at a constant rate over a long section of the line, these losses are due to the intrinsic characteristics of the pipeline coating rather than resulting from evenly spaced holidays of similar area. (See Fig. B.10.1.B.) Where a metal to soil contact exists, the signal loss greatly increases at this point, clearly indicating the presence of a coating defect. (See Fig. B.10.2.A and B.)

B.10.2 Equipment

The equipment required for the survey comprises:

- Transmitter to provide an a.c. signal of approximately 1000 Hz. Thin film coatings may require a reduced frequency in the order of 200 Hz. The transmitter is powered from internal batteries. Longer surveys may require the use of an external high capacity battery.

- Receiver, hand-held with integral antenna for monitoring and indicating the location of pipeline, depth of pipeline and signal strength of the electromagnetic field.

- Earth spike and connecting cables for transmitter.

The above equipment is normally contained in a plastic or aluminum box. Total weight is between 15 and 30 kg dependent on manufacturer.

Some equipment is fitted with microprocessor control enabling current flowing and attenuation rates to be computed and data to be stored and printed out on completion of the survey. Optional equipment available may enable the instrument to be used for general purpose pipe/cable locating, Pearson survey etc.

(to be continued)

APPENDIX B (continued)

B.10.3 Procedure

The equipment is set up as shown diagrammatically in Fig. B.10.3.A. The transmitter is electrically connected with one lead to the pipeline, usually by connecting to a cathodic protection test lead or any accessible part of the pipeline, and the other lead to a good remote earth. The transmitter is energized and set to the appropriate output.

The survey may be carried out with an impressed cathodic protection system energized. However, any sacrificial anodes, bonds to other structures or similar are best disconnected prior to commencing the survey to ensure they do not mask defect areas or cause excessive signal loss, thereby reducing the length that may be surveyed from one transmitter location.

The first measurement is made at a sufficient distance from the transmitter and earth spike to minimize interference from the transmitter and/or return current flow in the earth. The receiver "location" mode is used to accurately position it directly above the pipeline.

The depth to the center line of the pipeline and the signal level, corrected for depth, is measured and recorded.

This procedure is then repeated at the next measurement point. Subtraction of the two values gives the signal loss between the two measuring points. To calculate the attenuation rate, the signal loss is divided by the distance between the two measuring points. This may be computed manually or by an in-built micro-processor.

The survey proceeds, taking measurements at intervals until the intensity of the signal is insufficient to be monitored accurately. At this point, the transmitter is moved and the above procedures repeated for the next section of the pipeline.

The length of pipeline surveyed from any one transmitter location may vary from less than 200 m to in excess of 20 km depending upon the quality of the pipe coating, the size of the pipeline, the resistivity of the soil, etc.

A survey cannot be conducted over the last 2 to 3 km of a well coated pipe or 0.5 km where high losses are present working towards an electrical isolating device. Either the transmitter should be located at the isolating device or the device should be temporarily bonded across.

An initial survey may be carried out on a pipeline by taking measurements at road crossing and points of easy access with intervals of approximately 1 km. This will identify sections of pipeline between measurement points where coatings defects exist. The defect location may be defined by progressively halving the distance in the suspect section until it has been reduced to a practical length where detailed measurements would then be applied. (See Fig. B.10.2.C.)

Measurements are to be avoided at locations where pipe bends or other metallic services are present as there will be a distortion of the magnetic field giving erroneous readings.

The above procedures are general and in all cases the equipment manufacturer's instructions are to be followed.

B.10.4 Data obtained

The data recorder from an electromagnetic current attenuation survey would be:

- Location reference.
- Chainage.
- Distance between measurements.
- depth.
- Signal level corrected for depth.

(to be continued)

APPENDIX B (continued)

From this data, the following may be calculated:

- Signal level attenuation.
- Signal level attenuation rate.

Fig. B.10.5 shows a typical data record sheet.

B.10.5 Presentation of data

The results of the survey may be presented in one of the following formats:

a) Tabular (see Fig. B.10.3.B).
b) Graphical - plot of signal level against distance (see Fig. B.10.4.A).
c) Histogram - plot of section attenuation or attenuation rate against distance (see Fig. B.10.4.B and C).

B.10.6 Criteria and interpretation

The criteria for determining coating quality are not precise and differ from one pipeline to another.

The attenuation rate is primarily dependent on the overall quality of the coating and the coating area per unit length of pipeline, i.e., it is a function of quality and circumference. "Quality" is related to a combination of: type of coating, general age and condition and the presence or absence of discrete faults due to mechanical damage or other factors. Attenuation rates are not affected by changes in wall thickness and are only marginally affected by changes in soil resistivity except in extreme situations such as deserts or where there is very poor or non-existent coating over long lengths of pipe.

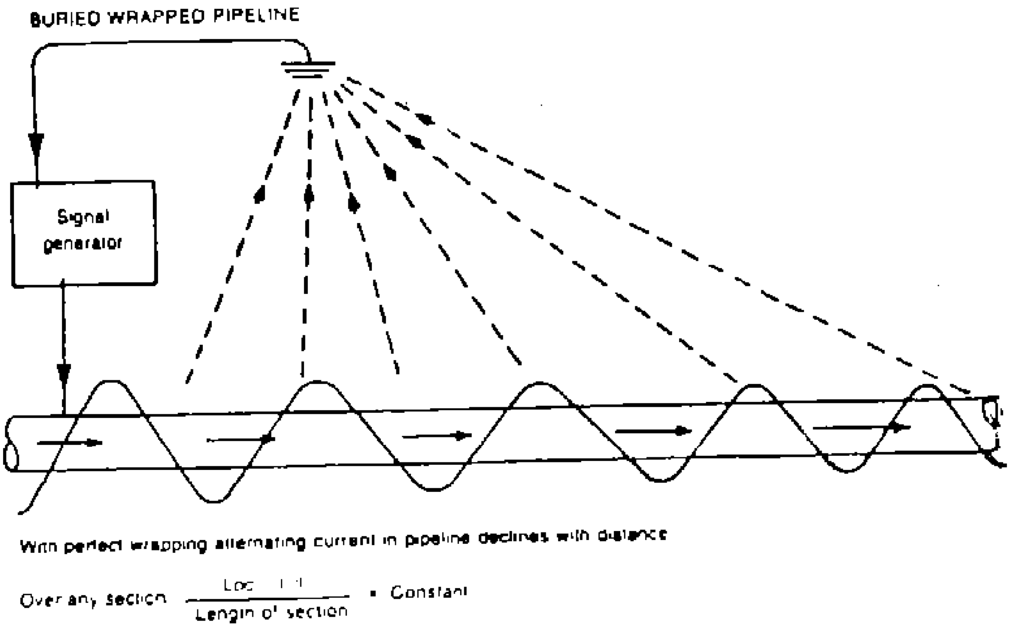
From the data, the average attenuation rate of the pipeline can be determined. Any significant change of gradient on the graph or increase in section attenuation rate on the histogram may be treated as a suspected defect.

Where intervals of measurement are irregular or very small, the histogram plot of attenuation rate against distance may be misleading and a plot of attenuation against distance may be preferred.

A high signal loss may not be present at a substantial coating defect in high resistivity soil. Because of the high soil resistivity, the loss of current will be restricted. However, the corrosion risk at such an undetected defect will be reduced since the corrosion current would also be restricted by the high soil resistivity.

(to be continued)

APPENDIX B (continued)



CURRENT ATTENUATION
Fig. B.10.1.A

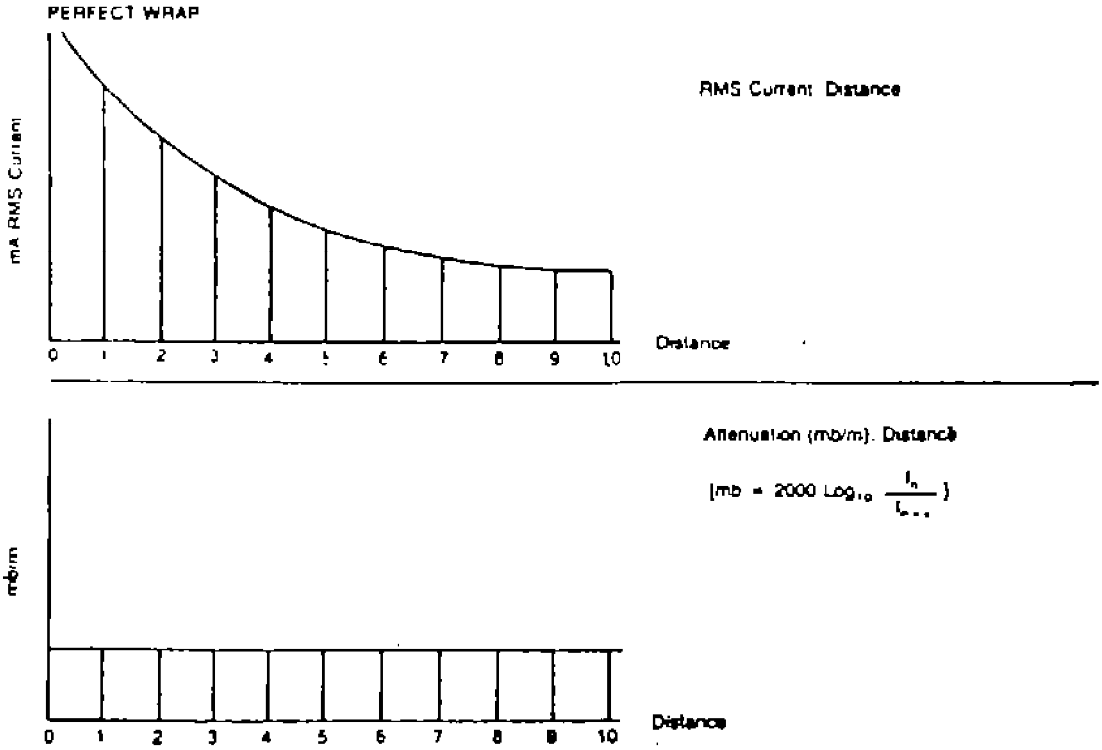


Fig. B.10.1.B

(to be continued)

APPENDIX B (continued)

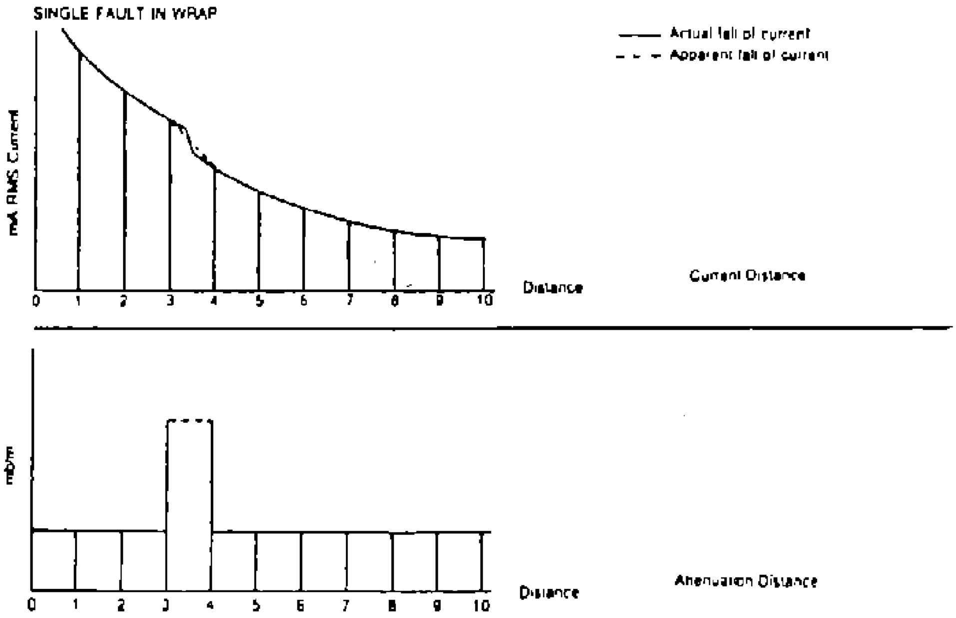
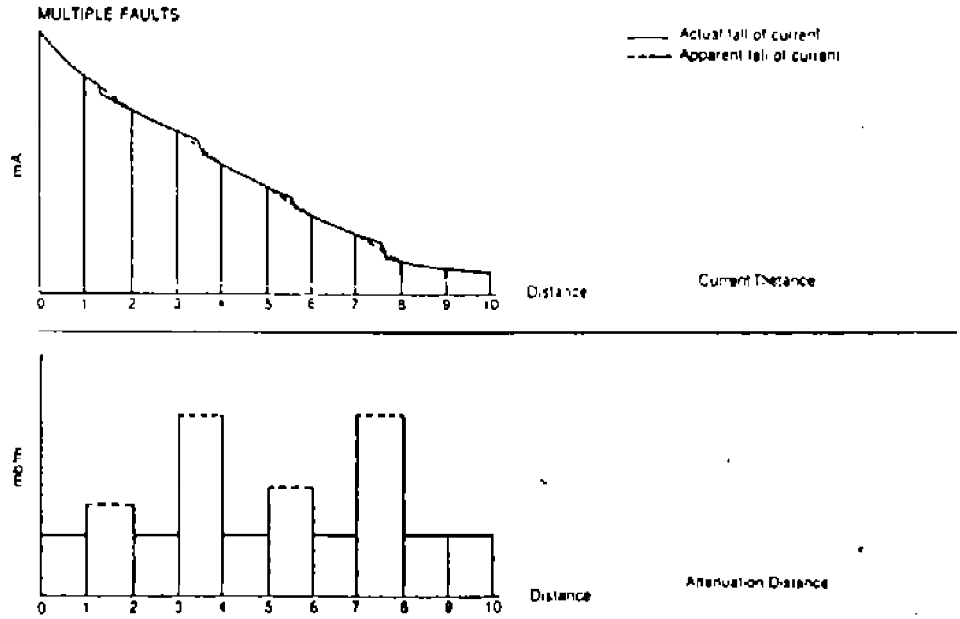


Fig. B.10.2.A



CURRENT ATTENUATION
Fig. B.10.2.B

(to be continued)

APPENDIX B (continued)

CURRENT ATTENUATION

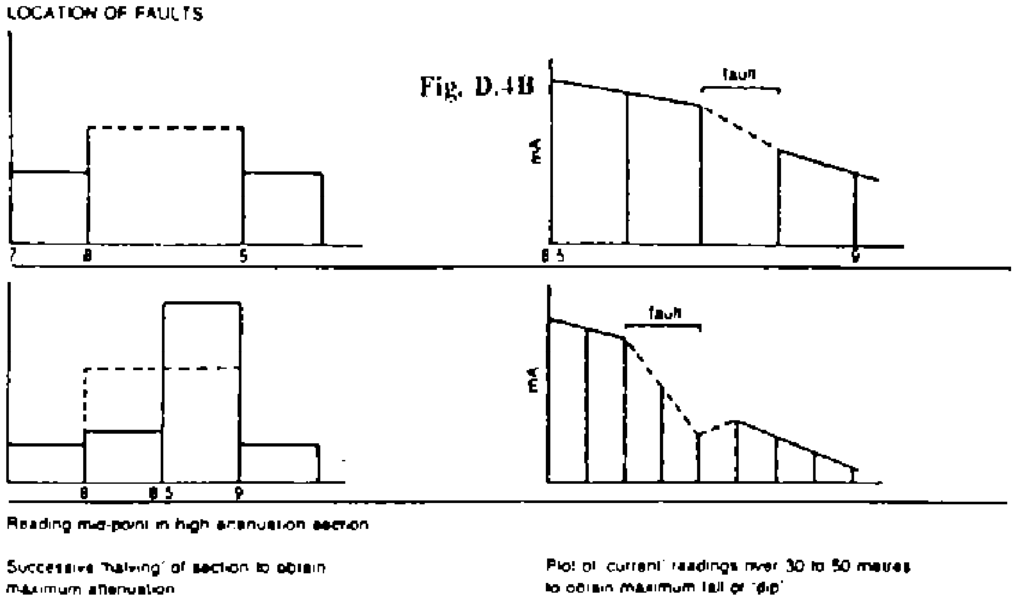
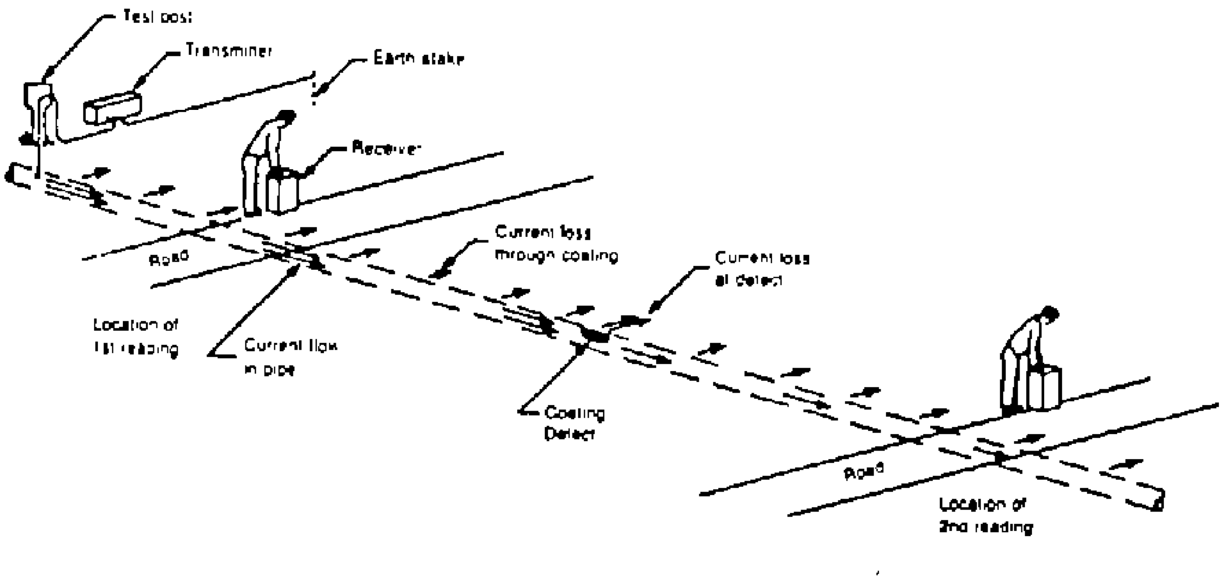


Fig. B.10.2.C



PRINCIPLE OF ELECTROMAGNETIC CURRENT ATTENUATION SURVEY
Fig. B.10.3.A

(to be continued)

APPENDIX B (continued)

PIPELINE A16 DATE 21/4/86 LOCATION T/P 12

SIGNAL APPLIED AT: T/P 11 OUTPUT LEVEL : 82 SHEET 1 OF 1

(a) LOCATION	(b) DISTANCE REF (km)	(c) = (b) - b1 INTERVAL (km)	(d) DEPTH (m)	(e) DEPTH FACTOR (dB)	(f) SIGNAL (dB)	(g) = (e + f) LOG. CURRENT (dB)	(h) = (g1 - g2) LOG CURRENT LOSS (dB)	(i) = (h ÷ c) RATE OF LOSS (dB/km) *	COMMENTS
T/P 12	10.00		1.64	12.2	85.3	97.5			
FARM TRACK	11.20	1.20	1.58	11.5	82.0	93.5	4.0	3.3	
T/P 14	12.75	1.55	1.52	11.4	75.1	86.5	7.0	4.5	
BIZZA ROAD	13.26	0.50	1.50	11.2	69.3	80.5	6.0	12.0	PROBABLE DEFECT
FORM TRACK	13.85	0.60	1.44	10.8	66.7	77.5	3.0	5.0	
T/P 15	14.40	0.55	1.46	11.0	64.5	75.5	2.0	4.4	
T/P 16	14.90	0.50	1.46	11.0	62.5	73.5	2.0	4.0	

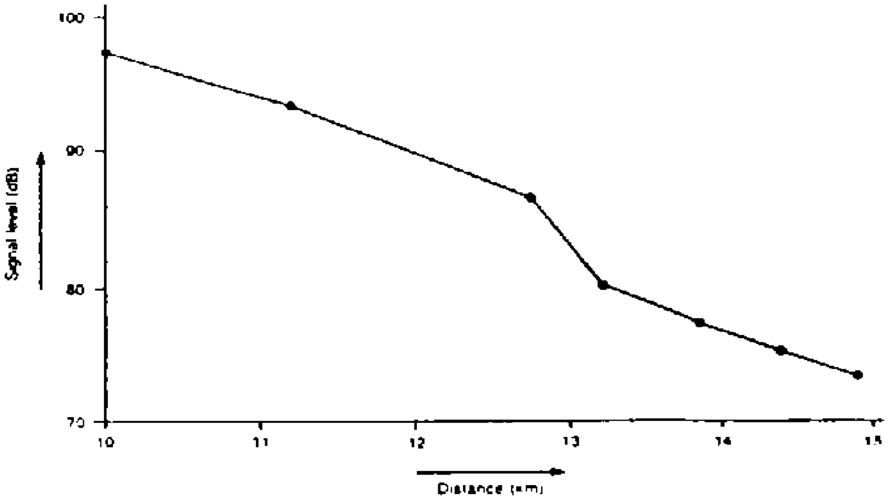
* COLUMN (i) NOT USED WHERE SURVEY INTERVAL IS LESS THAN 0.5 KM

CURRENT ATTENUATION SURVEY
Fig. B.10.3.B

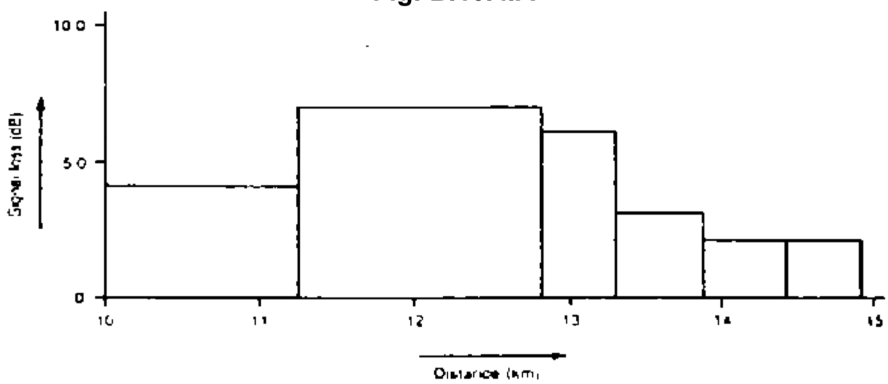
(to be continued)

APPENDIX B (continued)

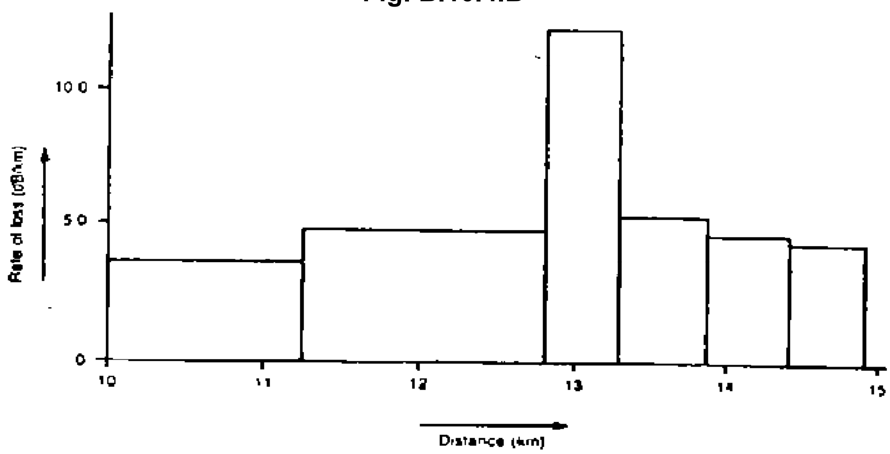
CURRENT ATTENUATION SURVEY PLOTS



PLOT OF SIGNAL LEVEL vs DISTANCE
Fig. B.10.4.A



PLOT OF SIGNAL LOSS vs DISTANCE
Fig. B.10.4.B



PLOT OF RATE OF LOSS vs DISTANCE
Fig. B.10.4.C

(to be continued)

APPENDIX B (continued)

B.11 Close Interval Pipe to Soil Potential Survey

B.11.1 General

The close interval pipe to soil potential survey is a survey technique to provide a detailed profile of the potential difference between the steel and the soil. This profile can be used to determine detailed information on the performance of the cathodic protection system, the coating system, interaction effects, etc.

The performance of cathodic protection systems has normally been monitored on a sample basic, i.e. pipe-to-soil potential measurements taken at test stations installed at intervals of approximately 1 km along the route of the pipeline. Based on this information, a judgment is made of the performance of the cathodic protection system and also, by inference, the performance of the pipe coating system.

If a defect of any kind occurs on a pipeline at a location remote from a test station, it is probable that this will remain undetected. It has therefore become apparent that a much greater sample of pipe-to-soil potential measurements, representative of the pipeline as a whole, needs to be collected to ensure that the corrosion prevention systems are performing satisfactory. (See Fig. B.11.1.B)

In order to achieve this, it is necessary to place the reference electrode at a much greater number of locations than the number of test stations. Close interval potentials are generally measured at between 1 m and 5 m spacing to provide a "continuous" pipe-to-soil potential profile of the structure.

Equally essential is the need to reference, record and store the data collected and to present in tabular and/or graphical form the larger number of measurements.

The methods and measurements utilized are based on methods used in everyday routine monitoring procedures. The advent of portable microprocessor based measuring equipment and computer assisted data handling, together with accurate, synchronized high speed current interruption devices, have allowed these surveys to provide practical data collection methods which are of value when assessing the performance of the corrosion prevention systems applied to buried pipelines.

The potentials may be recorded with the cathodic protection system permanently energized as in routine "on" surveys. However, these measurements will include the IR drop error caused by the flow of cathodic protection currents in the soil. (See Fig. B.11.1.A.)

In order to eliminate this error, cyclic timers are fitted to the transformer-rectifiers or other d.c. power sources to interrupt the cathodic protection current. Potential measurements are then recorded with the cathodic protection switched on and immediately after switching off (IR drop error free or instantaneous off measurement) over the entire length of the pipeline. It is of utmost importance to ensure that all power sources that can influence the pipe-to-soil potential at the point being measured, are switched in unison by the use of synchronized timers. Surveys measuring the "Instantaneous Off" potentials are commonly referred to as "polarized" potential surveys. This method is not practical for use with distributed sacrificial anode systems.

In areas of stray current interaction where the pipe-to-soil potentials are not stable, stationary data collectors may also be used.

The foregoing covers the general requirements for a close interval potential survey. However, when planning to carry out a survey, the following practical considerations may be taken:

- The need for mobile operation to traverse the pipeline length and obtain data at a reasonable speed.

- The requirements for current interruption to switch the cathodic protection current sources at high speed, at a ratio that will not depolarize the cathodic protection levels and with a minimum of synchronization error.

(to be continued)

APPENDIX B (continued)

- The need for polarized potentials to be collected at such intervals to provide accurate profile of IR drop error free measurements.

- The need for switching cycle and distance between readings to be so arranged that the measurement equipment records accurately with respect to instrument stabilization and synchronization errors.

- The method by which equipment operates and data is recorded i.e. manual, semi-automatic and automatic (see B.11.2).

B.11.1.1 Measurement intervals

The measurement intervals between pipe-to-soil potentials may be determined by the pipe diameter and the depth of cover over the pipeline.

For pipeline diameters of 600 mm or less, a minimum spacing of 1 m is appropriate, although specific circumstances may necessitate closer intervals in order to determine particular characteristics.

For pipeline diameters in excess of 600 mm, a 1 m spacing is appropriate but may be increased. The measurement interval should not, however, be greater than 1.5 times the normal pipeline depth of cover or 5 m whichever is smallest.

In practice, polarized measurements are commonly taken at either:

- every meter,
- every 5 meter,
- ratio of 4 "on" readings and 1 "off" reading, each reading being taken at meter intervals.

B.11.1.2 Switching frequency

The switching frequency of the cathodic protection and associated equipment required to enable pipe-to-soil potential measurements to be made, may be determined by the following factors:

- The degree of synchronization that can be achieved between the timers.
- The measurement response time of the data collector.
- The measurement interval of pipe-to-soil potentials in automatic time dependent surveys.

An important consideration in the selection of time cycles is the provision of long-term switching (during the survey period) without any degradation of the polarized potential level due to the "off" period. Depolarization will cause inaccurate and unreliable potentials to be measured. For this reason, a minimum on/off ratio of 4:1 is common practice. This assumes that the quality of the measurement circuit will provide for a stabilized accurate measurement during the "off" period (response time) and that the synchronization error between switching devices dose not conflict with the measurement period.

Switching of the cathodic protection equipment may be by devices interrupting either a.c. or d.c. side of the transformer-rectifier or other power sources and may be either built-in or fitted for the duration of the survey. The current interrupts must have the facility to switch at high speeds, cause minimum transient switching surges, have a selection of commonly used time cycles and have less than 100 m secs synchronization error between devices and maintain this for a minimum of one working day. An image retaining oscilloscope or high speed recorder may be used to verify that no significant depolarization occurs with the time cycle selected and that timers are fully synchronized.

If switching is carried out on the a.c. supply the polarized potential measurements may adversely be affected by the unbroken connection of the pipeline to the ground bed via the d.c. power source allowing some currents still to flow.

(to be continued)

APPENDIX B (continued)

B.11.1.3 Distance measurement

The survey needs to have some means of distance measurement with respect to the mobile potential data collector. Systems are available which accurately record distance from a fixed point that can be related to pipeline chainage.

Basic systems operate with annotating pipeline chainage at start and finish of each survey section.

For more detail, a pedometer or chainer can be used, the distance being keyed into the data collector.

With fully automatic systems, a wire measurer is often used which can give an accuracy to within a few meters per kilometer.

All systems need to allow for chainage to be entered, together with any physical features found along the route of the pipeline so that defects indicated on the plots may be physically located.

B.11.1.4 Stationary measurements

In areas where stray interaction currents or variable potentials may be present during the mobile survey, stationary data collectors may be employed at fixed locations on the pipeline as close as possible to the anticipated point of maximum interaction.

Stationary measurements may be obtained at one or more of the following locations:

- Start and finish of surveyed section.
- Anticipated locations of maximum interaction effect.
- Locations close to the mobile unit.

The data collected from the "mobile" unit can then be compared with the data from the "stationary" unit. If fluctuations of potential on the "mobile" plot coincide with similar fluctuations on the "stationary" plot, this is indicative of interaction or stray currents and not necessarily due to inadequacies of the corrosion protection system. The data collected is therefore to be accurately time related in order to make this comparison.

B.11.2 Equipment

The equipment required for the survey varies from very simple manual equipment to complex microprocessor/computer equipment.

In general the equipment comprises:

- Synchronized timers for switching the transformer-rectifiers or other d.c. power supplies (not required for "on" surveys).

- Data collector with input impedance in excess of 10 Mohms with an adequate level of a.c. rejection which may be:

  - Manual - Voltmeter/multimeter.
  - Semi-automatic - Recording voltmeter.
  - Microprocessor data collector with manual entry.
  - Automatic - Microprocessor data collector with fully automatic recording of data.

- $Cu/CuSO_4$ reference electrode(s) fitted to pole(s).

- Insulated fine wire which may be re-usable or disposable, wound on reels.

(to be continued)

APPENDIX B (continued)

- Distance measurer which may be:
  - Chainer.
  - Pedometer.
  - Wire measurer which automatically measures the length pulled off the fine wire reel and records the value in the data collector.
- Pipeline location equipment.
- Computer hardware and software for processing the data.
- Plotter for producing the profile plots.

B.11.3 Procedure

The equipment is set up as shown diagramatically in Figs. B.11.2.A, B.11.2.B, and B.11.3.A.

Before commencing the survey, the exact route of the pipeline is located and marked out so that the survey operator may follow the route of the pipeline exactly over the pipe. Alternatively, a pipe location operator may immediately precede the survey operator to minimize the working period over the pipeline route.

If polarized potentials are to be measured, timers are synchronized and installed in all transformer-rectifiers or other CP power supplies, bonds or other connections that may influence the potentials over the section of pipeline to be surveyed. (See Fig. B.11.2.B.)

If the survey is subject to interaction or fluctuating potentials, stationary recording units would be installed, as indicated in B.11.1.4. (See Fig. B.11.3.A.)

With the equipment connected and the pipeline located, the survey operator, carrying the mobile data collector and Cu/$CuSO_4$ reference electrode(s), traverses the pipeline paying out the fine wire and placing the reference electrode at the required interval over the pipeline and maintaining it in that position long enough for the data collector to measure and store the pipe-to-soil potentials. Alternatively, two reference electrode(s) may be used fitted to poles such that one reference electrode is always in contact with the ground. Distance traversed and physical features such as roads, hedges, streams, etc. are recorded to assist with locating specific areas after processing the data.

As each section between pipeline connection points is completed, the fine wire is either re-reeled for further use or re-covered and properly disposed of, to prevent a hazard to livestock. Where the fine wire crosses roads, paths or fields, with livestock present, the wire may be pegged down.

The data is usually transferred from the data recorder to a computer for producing data printouts and plots of the pipe-to-soil potential profiles.

The above procedures are general and in all cases the equipment manufacturer's instructions are to be followed.

B.11.4 Data obtained

The data obtained from a close interval pipe-to-soil potential survey includes the following items:

- Time.
- Date.
- Distance (pipeline chainage).
- Locations.
- Energized potential.

(to be continued)

APPENDIX B (continued)

- Polarized potential.
- Physical route features.
- CP power supply outputs.
- Bond currents.

B.11.5 Presentation of data

The data collected during the survey is normally processed by computer and presented in tabular and graphical form.

The raw data is normally processed immediately following completion of each day's survey to verify full functioning of the survey equipment and identify if any areas may require re-surveying due to interaction, equipment malfunction etc.

Plotted profiles are produced at a later date when all the data has been processed.

The data presentation is normally computer assisted. This allows for data to be organized in the correct chainage order regardless of survey direction and section order.

Typical format presentations are shown in Figs. B.11.3.B and B.11.4.

B.11.6 Criteria and interpretation

The criteria used for closed interval pipe-to-soil potential surveys are the same as those used for routine potential surveys.

The close interval survey enables the potential profile for the whole length of the pipeline to be plotted. With the cathodic protection system switching "on" and "off", and polarized potentials, free of IR drop error, measured, a profile of the true pipe-to-soil potential can be determined.

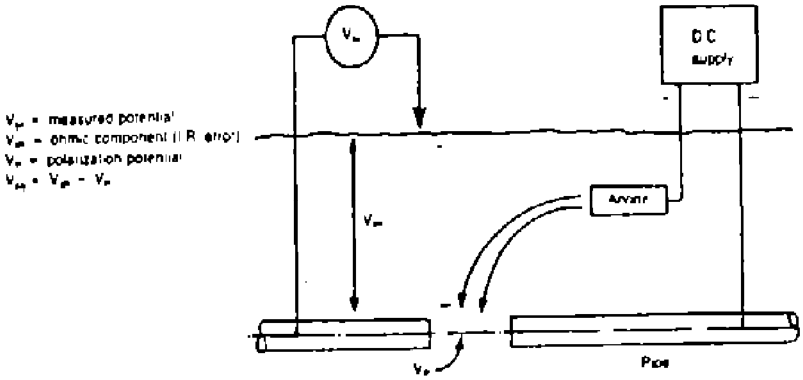
It is the measurement of the polarized potential witch determines the effectiveness of the cathodic protection current in both qualitative and quantitative terms.

Any areas on the profile that fall outside the selected potential criteria are not being provided with adequate cathodic protection and could therefore be corroding. Interpretation of the pipe-to-soil potential profile may highlight the following:

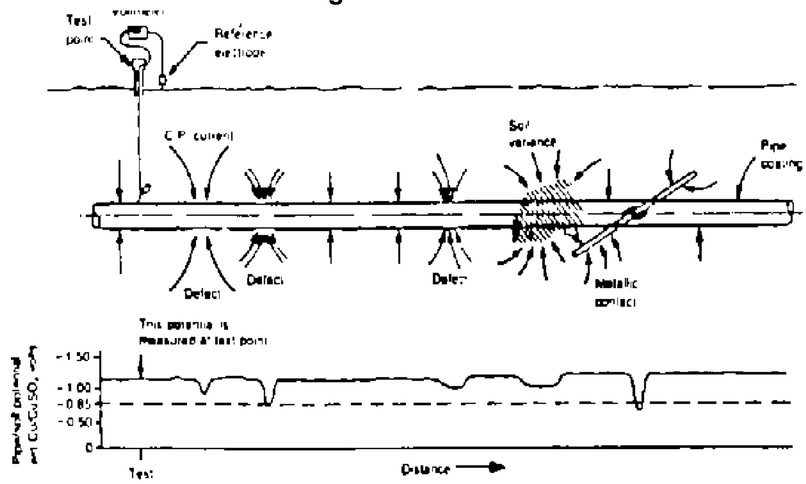
- Coating defects.
- Underprotected sections of pipe.
- Interaction by stray currents.
- Overprotected sections of pipe.

(to be continued)

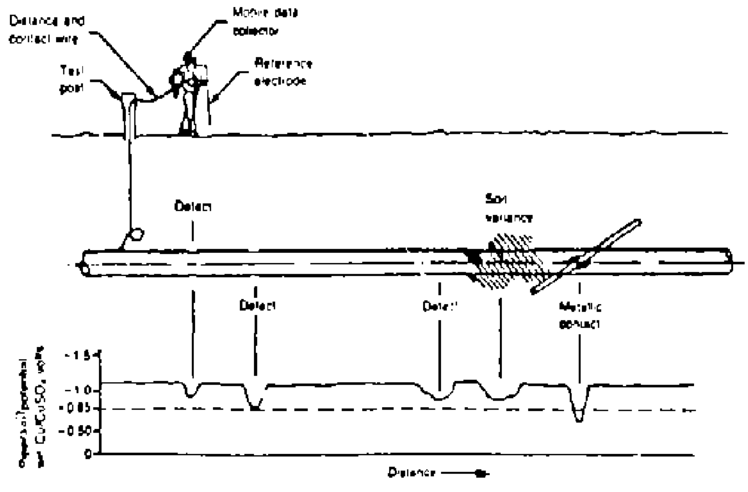
APPENDIX B (continued)



IR DROP ERROR COMPONENT OF POTENTIAL MEASUREMENT
Fig. B.11.1.A



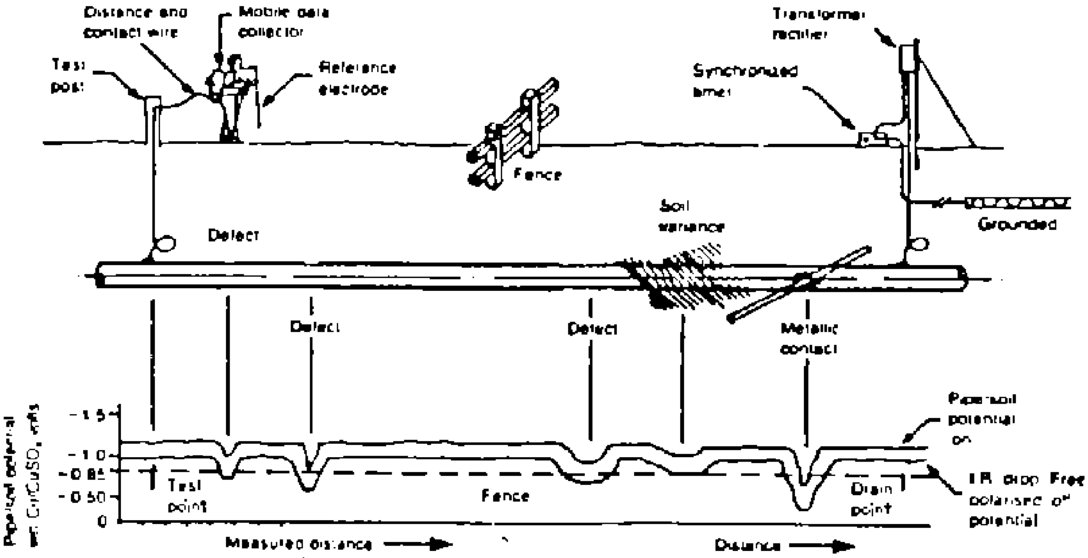
VARIATION OF PIPE/SOIL POTENTIAL DUE TO LOCAL FEATURES
Fig. B.11.1.B



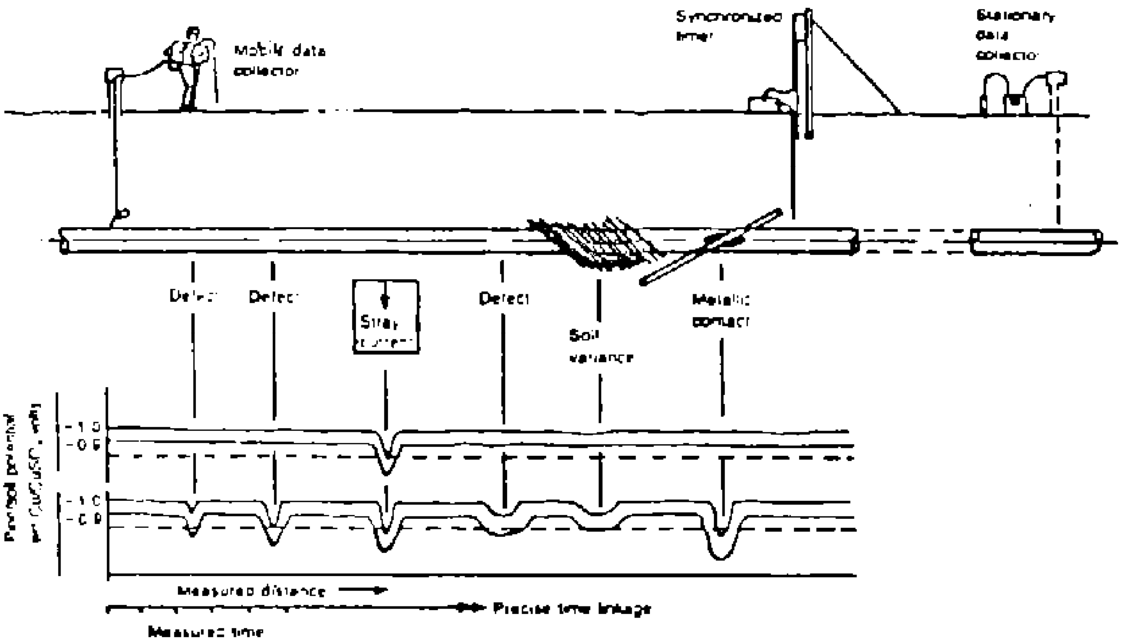
CLOSE INTERVAL PIPE/SOIL POTENTIAL SURVEY
Fig. B.11.2.A

(to be continued)

APPENDIX B (continued)



CLOSE INTERVAL POLARIZED POTENTIAL SURVEY
Fig. B.11.2.B



CLOSE INTERVAL POLARIZED POTENTIAL SURVEY
WITH STATIONARY DATA COLLECTOR
Fig. B.11.3.A

(to be continued)

APPENDIX B (continued)

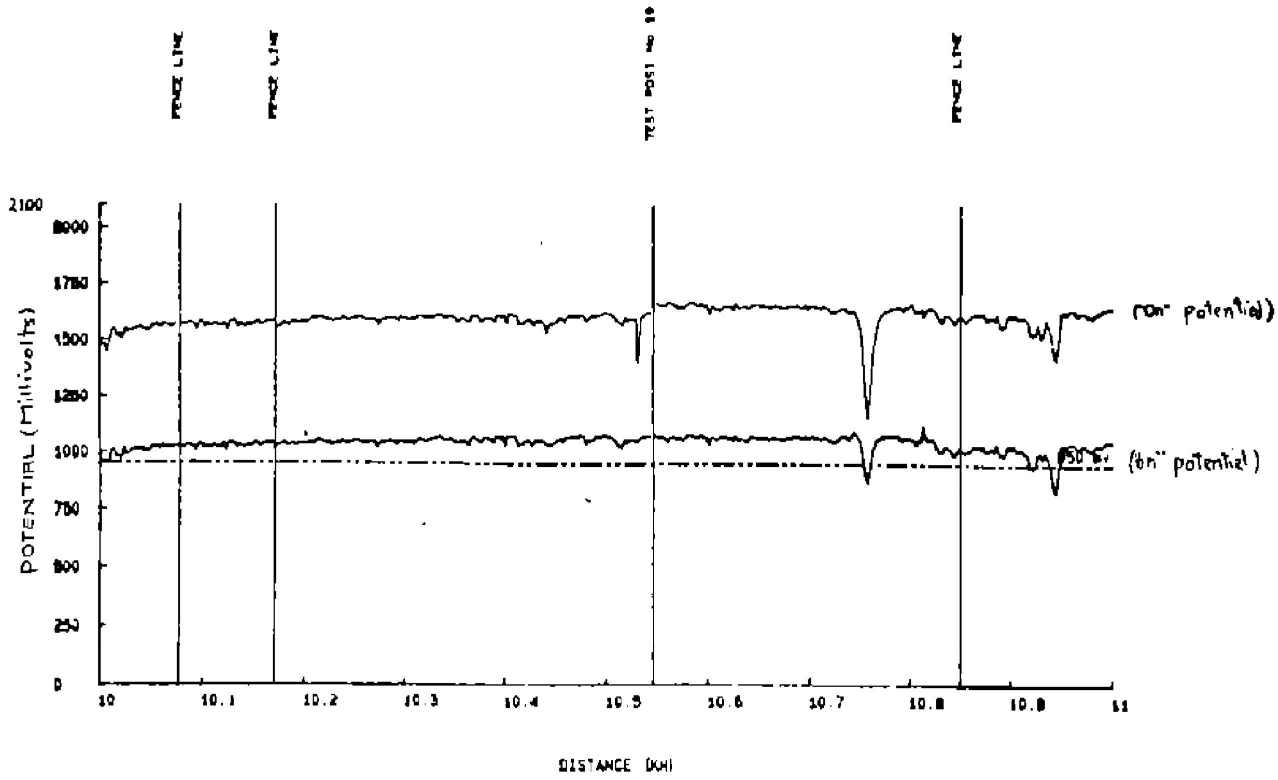
DISTANCE.	TIME.	VOLTAGE.	CODE.		-.5-.7-.95V	-2.5V
38	9:47:36	-1.524	0	ON	*	
38	9:47:37	-1.508	0	ON	*	
38	9:47:38	-1.507	0	ON	*	
39	9:47:39	-1.357	0	OFF	O	
39	9:47:40	-1.445	0	ON	*	
40	9:47:41	-1.496	0	ON	*	
40	9:47:42	-1.507	0	ON	*	
41	9:47:43	-1.510	0	ON	*	
42	9:47:44	-1.340	0	OFF	O	
43	9:47:45	-1.444	0	ON	*	
44	9:47:46	-1.515	0	ON	*	
44	9:47:47	-1.497	0	ON	*	
45	9:47:48	-1.436	0	ON	*	
46	9:47:49	-1.277	0	OFF	O	
47	9:47:50	-1.464	0	ON	*	
47	9:47:51	-1.472	0	ON	*	
48	9:47:52	-1.511	0	ON	*	
49	9:47:53	-1.511	0	ON	*	
50	9:47:54	-1.333	0	OFF	O	
50	9:47:55	-1.430	0	ON	*	
51	9:47:56	-1.526	0	ON	*	
52	9:47:57	-1.511	0	ON	*	
53	9:47:58	-1.483	0	ON	*	
53	9:47:59	-1.343	0	OFF	O	
54	9:48: 0	-1.426	0	ON	*	
55	9:48: 1	-1.471	0	ON	*	
56	9:48: 2	-1.497	0	ON	*	
56	9:48: 3	-1.502	0	ON	*	
57	9:48: 4	-1.324	0	OFF	O	
58	9:48: 5	-1.436	0	ON	*	
59	9:48: 6	-1.494	0	ON	*	
59	9:48: 7	-1.494	0	ON	*	
60	9:48: 8	-1.518	0	ON	*	
61	9:48: 9	-1.305	0	OFF	O	
62	9:48:10	-1.412	0	ON	*	
63	9:48:11	-1.513	0	ON	*	
64	9:48:12	-1.469	0	ON	*	
64	9:48:13	-1.508	0	ON	*	
65	9:48:14	-1.304	0	OFF	O	
66	9:48:15	-1.423	0	ON	*	
67	9:48:16	-1.530	0	ON	*	
68	9:48:17	-1.477	0	ON	*	
68	9:48:18	-1.494	0	ON	*	
69	9:48:19	-1.332	0	OFF	O	
70	9:48:20	-1.400	0	ON	*	
71	9:48:21	-1.478	0	ON	*	
72	9:48:22	-1.499	0	ON	*	
72	9:48:23	-1.426	0	ON	*	
73	9:48:24	-1.310	0	OFF	O	
74	9:48:25	-1.387	0	ON	*	
75	9:48:26	-1.437	0	ON	*	
76	9:48:27	-1.499	0	ON	*	
77	9:48:28	-1.480	0	ON	*	
77	9:48:29	-1.333	0	OFF	O	
78	9:48:30	-1.455	0	ON	*	

TYPICAL PRINT OUT OF FIELD DATA
Fig. B.11.3.B

TYPICAL PRINT OUT OF FIELD DATA
Fig. B.11.3.B

(to be continued)

APPENDIX B (continued)



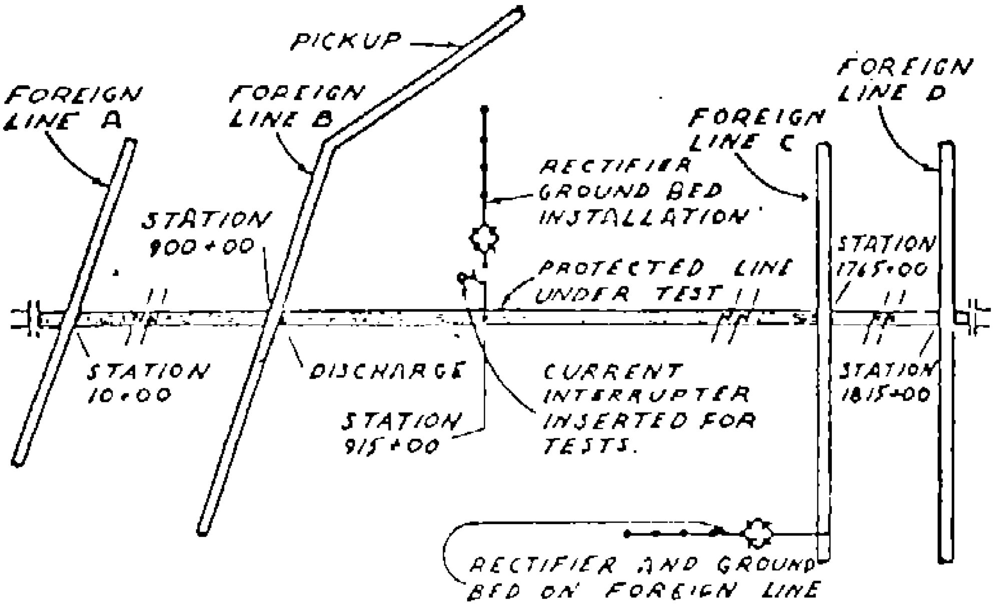
TYPICAL PIPE/SOIL POTENTIAL PROFILE
Fig. B.11.4

(to be continued)

APPENDIX B (continued)

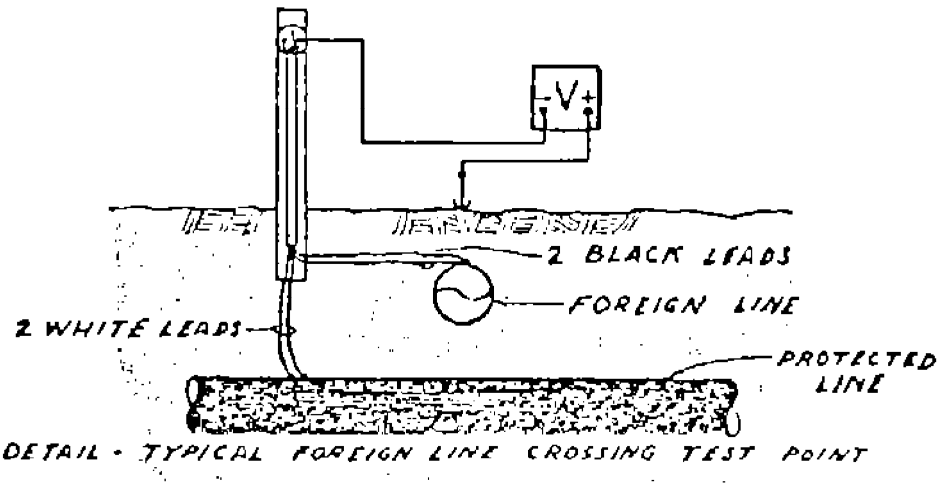
B.12 An Example for Cathodic Field Interferences Test Method

To illustrate interferences test method, assume that a cathodic protection system incorporating a rectifier as power source has been applied to a section of coated pipeline and that there are several pipeline crossings in the section as shown in Fig. B.12.1.



AN EXAMPLE FOR CATHODIC FIELD INTERFERENCES
Fig. B.12.1

Assume that at each foreign line crossing a test point has been installed, as shown in details on the Fig. B.12.2, with two color-coded leads brought to the test point terminal from each point.



TESTING FOREIGN PIPELINE CROSSINGS FOR STRAY CURRENT INTERFERENCE FROM CATHODIC PROTECTION INSTALLATIONS
Fig. B.12.2

(to be continued)

APPENDIX B (continued)

With the current interrupter operating, each foreign line crossing is visited and the potential of each line is measured under both current "ON" and current "OFF" conditions. For these tests, the copper sulfate electrode is placed directly over the point of crossing. If there is any question as to the crossing location, use a pipe locator to determine where it is.

Data taken at the several pipeline crossings of Fig. B.12.2 may be recorded as shown in Table B.3:

TABLE B.3 - SURVEY NOTES ON STRAY CURRENT INVESTIGATION

FOREIGN LINE DESIGNATION & LOCATION		POTENTIAL vs. CLOSE COPPER/COPPER SULFATE ELECTRODE					
		Own Pipeline, V			Foreign Pipeline, V		
Name	Pipeline Station	With Current			With Current		
		On	Off	ΔV	On	Off	ΔV
A	10 +00	-1.03	-0.98	-0.05	-1.02	-1.04	+0.02
B	900 +00	-1.98	-1.02	-0.96	-0.32	-0.68	+0.36
C	1765 +00	-0.68	-0.64	-0.04	-0.78	-0.78	0
D	1815 +00	-1.10	-1.06	-0.04	-0.68	-0.68	0

Data entered have been selected to illustrate various types that may be encountered. In addition to the data shown for this illustration, field data sheets should include full information on the line protected; this includes data, current output of the interrupted rectifier and other pertinent facts.

Following are some conclusions that can be reached from the data:

Crossing A

Pipeline under test is fully protected but can be expected to have a substantial coating holiday in the vicinity of the crossing. This is based on the fact that the potential of the foreign line (which is also cathodically protected) decreases when the interrupted rectifier switches from "OFF" to "ON". This indicates that there is appreciable current flowing to the line under test, creating more negative soil locally around the foreign line.

The foreign line in this instance is cathodically protected as indicated by the fact that although its potential at the crossing is reduced by the operation of the rectifier on the line under test, the reduction is not sufficient to indicate loss of protection. On the basis of the data shown, no corrective measures would be required at Crossing A.

Crossing B

Pipeline under test is fully protected. The foreign pipeline is not cathodically protected because its potential is well below 1.0 V (with the rectifier "OFF" on the line under test). With the rectifier ON, the foreign line potential is shifted severely in less negative direction, indicating probability of severe corrosion damage to the foreign pipeline. Corrective measures will be required.

(to be continued)

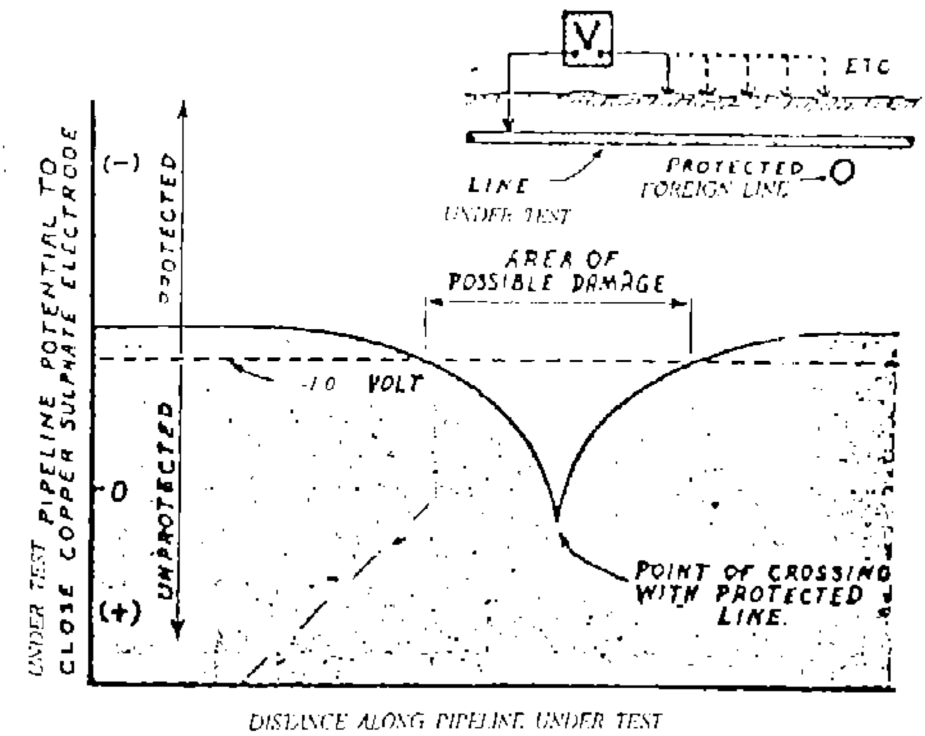
APPENDIX B (continued)

Crossing C

The line under test is receiving inadequate cathodic protection, apparently because of interference from the cathodically protected foreign line. If the potential of the line under test to a remote electrode with respect to both lines and this potential is found to be representative of normal protective potentials (above -1.0 V), the poor potential at the crossing is shown to be a local condition probably caused by the foreign line crossing. Corrective measures will be required. The length of line under test which is below -1.0 V can be determined by taking readings to close electrode, directly above the line under test, in each direction from the point of crossing. If the data when plotted, give a curve similar to that shown in Fig. B.12.3, interference from the protection system on the foreign line is confirmed. In this case the foreign pipeline is not affected adversely; it is the line under test which is adversely affected by the foreign line.

Crossing D

The line under test is protected adequately. The foreign line does not have full cathodic protection but is not affected by the cathodic protection system on the line under test. No corrective action is required.



PIPE-TO-EARTH POTENTIALS ON UNDER TEST PIPE-LINE PASSING THROUGH AREA OF INFLUENCE AROUND CATHODICALLY PROTECTED FOREIGN LINE

Fig. B.12.3

(to be continued)

APPENDIX B (continued)

B.13 Tests for Electrical Continuity

B.13.1 Any disconnections or high resistance joints will become apparent when structure/electrolyte potential measurements are made at various points along the length of the structure. Where this method is being used to locate high resistance joints, sufficient current shall be used to give a large structure/electrolyte potential depression at the point of negative cable connection, for example -1.0 V to -1.5 V. Where there is an abrupt decrease of the structure/electrolyte potential depression, there is either a resistive joint or a connection to a massive buried structure between the point of test and the negative cable connection point.

In the case of structures such as buried pipelines, when such discontinuities are suspected, a constant voltage (up to 12 V) can be applied between two points of pipeline some distance apart. Discontinuities will be indicated by a change in the potential gradient i.e. a sudden voltage drop. It is possible to locate these points accurately by using two wander probes, each making contact with the pipe, a sensitive voltmeter being connected between them.

The comparative longitudinal resistance of pipe joint caused by the passage of a known impressed current of the order of 10 A to 20 A. The equipment can be as shown in Fig. B.11, the galvanometer being calibrated as a millivoltmeter. The four connections to the pipe can be made using probes with hardened points; the probes connected to the millivoltmeter should be insulated. The impressed current should be reversed and the test repeated to confirm that the potential drop measured is due solely to applied test current.

Note:

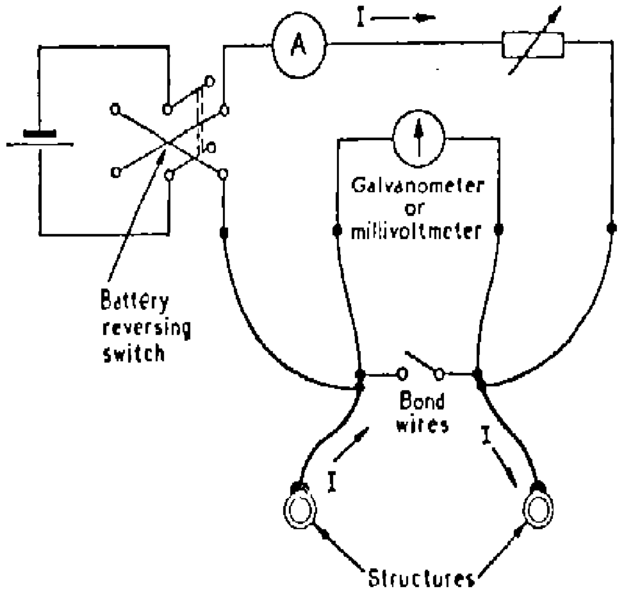
Probing should not be carried out without prior consultation with other authorities concerned, to ensure that there is no possibility of causing damage to their buried services.

B.13.2 Another method of locating discontinuities, which can be applied to buried cables and pipelines, uses an audio-frequency current impressed on the structure from which a signal is pitched-up by means of a search coil and head phones. Points of electrical discontinuity are indicated by a sudden decrease in signal strength.

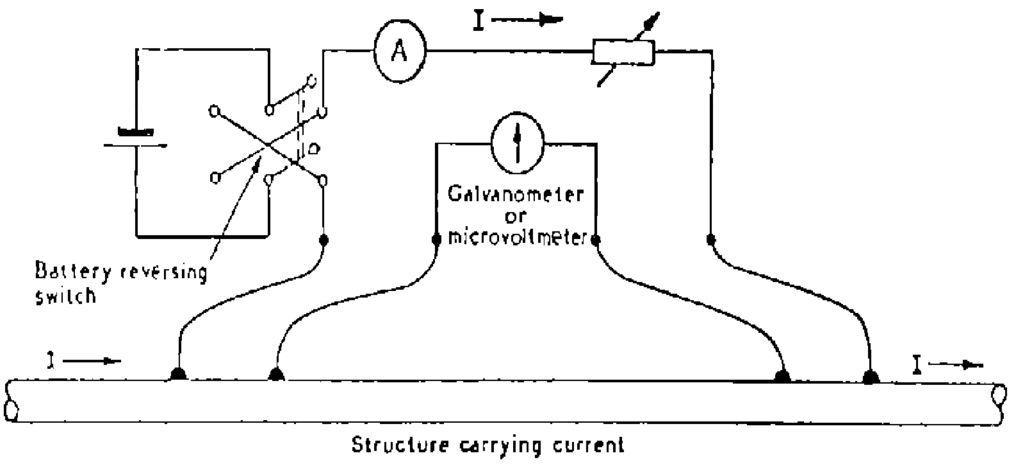
This method has proved satisfactory in open country but needs care in urban areas where the presence of other services in the ground will often cause misleading results. If may also be necessary to determine whether the armor of a buried cable is satisfactory in contact with the sheath. Evidence of discontinuity is afforded if there is appreciable potential difference between sheath and armor, particularly when cathodic protection is applied by means of connection to the sheath.

(to be continued)

APPENDIX B (continued)



a) Zero resistance ammeter circuit used to measure bond current (bond disconnected)



b) Zero resistance ammeter circuit used to measure current flowing in bond or structure (circuit not disconnected)

TESTS FOR ELECTRICAL CONTINUITY
Fig. B.13.1