Cathodic Protection System
Operation and Maintenance

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Company Profile

- HuangHua Risen CorrStop Ltd. is a professional corrosion control company. Besides cathodic protection materials production, we also produce PVC and FBE powder for coatings. With technical support from some famous international companies, we are the first company in China that used CorrStop Grid for tank bottom cathodic protection, and completed many cathodic protection projects.
- Our engineering department provides cathodic protection system design, consultation and training service.
Corrosion is Disastrous

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Nature of Corrosion

Corrosion Concept and Conditions

- **What is Corrosion:**
  - According to the definition of BS7361, corrosion is the chemical or electrochemical reaction of a metal with its environment, resulting in progressive degradation or destruction.
  - At atmospheric temperatures, the corrosion of metals is an electrochemical process in which the metal surface is in contact with an electrolyte. The electrolyte may be a film of moisture containing dissolved salts or may constitute the whole or part of the surrounding medium, e.g. when metal is immersed in fresh water, sea water or buried in soil. In the last case, the electrolyte is the soil water containing dissolved salts.

Nature of Corrosion

Definitions

- **Anode:** The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit, which is normally metallic. The anode is usually the electrode where corrosion occurs and metal ions enter solution.)
- **Cathode:** The electrode of an electrochemical cell at which reduction occurs.
- **Electrolyte:** A chemical substance containing ions that migrate in an electric field. Electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic piping system, including the moisture and other chemicals contained therein.
Nature of Corrosion
Corrosion Concept and Conditions

- **Conditions for corrosion to occur:**
  - There are certain conditions, which must be present before an electrolytic corrosion cell can function:
    - There must be an anode and a cathode.
    - There must be an electrical potential between the anode and cathode.
    - There must be a metallic path electrically connecting the anode and cathode.
    - The anode and cathode must be immersed in an electrically conductive electrolyte.
Nature of Corrosion
Corrosion Concept and Conditions

- Due to the potential difference existing between the anodic and cathodic areas, positively charged metal ions leave the metal surface at the anode while electrons leave the surface at the cathodes.
- Corrosion takes place at the anodic areas where metal ions react with the electrolyte to form the typical corrosion products.
- At the cathode area dissolution of metal does not take place but reactions occur in the electrolyte.

Factors Affecting Corrosion
Steel surface conditions

- If a mill scale or impurity exists on the steel surface, it is the cathode with respect to surrounding bare steel, electrons from the bare steel will flow towards the mill scale and corrosion will occur after the electrons left. The corrosion is usually pit corrosion.
Factors Affecting Corrosion Environment

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

1. Concentration of electrolyte
2. Concentration of oxygen
3. Temperature

In general, the severity of corrosion increases as one of these controlling factors increases, but because all of the influences are operating at the same time, their relative importance must be assessed.

Steel will corrode far more rapidly in well-oxygenated brackish water than in normal sea water.

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

The most important soil property as regards pipeline corrosion are salt content and aeration (oxygen content) both of which affect the steel-to-soil potential of buried pipelines.

The steel-to-soil potential of buried steel is more negative in soils with high salt content than in soils with a low salt content. Pipeline corrosion tends to be heaviest
Factors Affecting Corrosion
Differential Aeration Cells

- Steel-to-soil potential of buried steel is lower in poorly aerated soil (low oxygen content) than in well aerated soil (high oxygen content).
- In this case, the paved road lowers the oxygen concentration in the soil around the pipeline, this section of pipeline becomes anode in the differential corrosion cell and being corroded.
- In practice, good aeration and high electrical resistivity usually correspond to low moisture content, less corrosion.

Factors Affecting Corrosion
Sulphate reducing bacteria Corrosion

- In anaerobic soils, e.g., clay, sulphate-reducing bacteria may be active. These micro-organisms, which can exist in active form only in the absence of free oxygen, obtain their energy from the following reaction:
  \[ \text{SO}_4^{2-} + 8\text{H} = \text{H}_2\text{S} + 2\text{H}_2\text{O} + 2\text{OH}^{-} \]
- Bacteria corrosion of iron and steel under anaerobic conditions is usually rapid and severe. This kind of attack can often be recognized by the bright appearance of the corroded surface and the rotten-eggs odor.
- Since many H atom are eaten by SO₄, more electrons are needed to produce H atom, so, more negative of protection potential is required.
Factors Affecting Corrosion

New and Old Pipe

- A section of the pipeline has been replaced because of corrosion damage.
- The new section will fail sooner than expected.
- Mild steel (rust): -0.2v -0.5v
- Mild steel (clean): -0.5v -0.8v

Factors Affecting Corrosion

Dissimilar soils

- Pipeline going through two electrolytes of different concentrations constitutes a galvanic cell and is often referred to as a concentration cell.
- Corrosion will occur at anodic section.
Factors Affecting Corrosion
Pipeline Embedded in Concrete

- Concrete encasement of pipe will cause differential corrosion cell.
- Pipe section without concrete encasement is anode and being corroded.

Factors Affecting Corrosion
Anode and cathode ratio

- If the anode is relatively small, corrosion will be severe.
- If the anodic area is relatively large compared with the cathode, corrosion will be relatively mild.
Factors Affecting Corrosion
Stray Current Corrosion

- Interference: Any electrical disturbance on a metallic structure as a result of stray current.
- Stray Current: Current through paths other than the intended circuit.
- Stray-Current Corrosion: Corrosion resulting from stray current transfer between the pipe and electrolyte.
- Direct current traction systems frequently cause appreciable electric currents to flow in the surrounding earth, similarly, the impressed current from a cathodic protection system may also affect unprotected buried steel structures in the neighborhood.

Factors Affecting Corrosion
Stray Current Corrosion

- With a poorly coated pipeline, a stray current may enter the line at a point, travel along the line and leave the line at another defect point.
- Where, the current leaves will be corroded.
- Where the current flows into the pipe will be protected.
Factors Affecting Corrosion
Stray Current Corrosion

Cathodically Protected Structure (Cathode)

CP Power Source
CP Anode

Factors Affecting Corrosion
Corrosion Case

Don't let corrosion destroy your concrete structure!
Cathodic Protection Principle

- Cathodic Protection: A technique to control the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.
- The principle is to make the potential of the whole surface of the structure sufficiently negative with respect to surrounding medium to ensure no current flows from the metal to the medium.
- This is done by forcing an electric current to flow through the electrolyte towards the surface of the metal protected, thereby, eliminating the anodic area.
- Corrosion of steel in normally aerated soils and waters can be entirely prevented if the steel is maintained at a potential not more positive than \(-0.85\) V CSE. Under anaerobic conditions when sulphate-reducing bacteria are present, it is necessary to depress the potential a further 100mV, to \(-0.95\) V CSE.

Cathodic Protection Method

Galvanic Anode Cathodic Protection

- Galvanic Anode: A metal which, because of its relative position in the galvanic series, provides protection to metal or metals that are more noble in the series, when coupled in an electrolyte.
- With this method, current is provided by the galvanic reaction. The surface of the structure is made cathodic by connecting it electrically to a mass of less noble metal buried in the common electrolyte, the less noble metal is than an anode. Magnesium, Zinc, and Aluminum alloys are used for this purpose.
- The anodes are often referred to as sacrificial anodes because protection of the structure is accomplished by the simultaneous consumption of the anodes by electrochemical corrosion.
Nature of Corrosion
Galvanic Series of Metals Against CSE

1. Carbon, graphite, coke: 0.30v
2. Platinum: 0 to -0.1v
3. Mill scale on steel: -0.20v
4. High silicon cast iron: -0.20v
5. Copper, brass, bronze: -0.20v
6. Mild steel in concrete: -0.20v
7. Lead: -0.50v
8. Cast iron: -0.50v
9. Mild steel (rusted): -0.20v to -0.50v
10. Mild steel (clean and shiny): -0.50v to -0.80v
11. Commercially pure aluminum: -0.80v
12. Aluminum alloy (5% Zn): -1.05v
13. Zinc: -1.10v
14. Magnesium alloy (6% AL, 3% Zn, 0.15% Mn): -1.60v
15. Commercially pure magnesium: -1.75v

Cathodic Protection Method
Galvanic Anode Cathodic Protection

When the pipeline is connected with the Mg, its potential is lowered down till there are no cathode and anode on the pipe surface. Since the potential of the pipe is the same, corrosion will stop.
Cathodic Protection Method
Impressed Current cathodic Protection

- Impressed Current: Direct current supplied by a cathodic protection system utilizing an external power source.
- With this method, the structure is placed in an electric circuit with a direct-power supply and an anode groundbed. Current is forced to flow from the electrolyte to the structure.
- The system usually consists of AC converter, groundbed, Reference cell and connection cables.
Pipeline Coatings
The function of external coatings

- Coating: A dielectric material applied to a structure to separate it from the environment.
- to control corrosion by isolating the external surface of the underground or submerged piping from the environment.
- to reduce cathodic protection current requirements, and
- to improve current distribution.

Pipeline Coatings
Requirement to Coatings

- An effective electrical insulator
- Effective moisture barrier
- Applicability.
- Ability to resist development of holidays with time (soil stress and soil contaminant).
- Good adhesion to pipe surface.
- Ability to withstand normal handling, storage and installation.
- Ability to maintain substantially constant electrical resistivity with time.
- Resistance to disbonding. Easy of repair.
Pipeline Coatings
Coating Selection

Besides the above requirement, following typical factors should be considered when selecting a pipe coating:

1. Type of environment
2. Accessibility of pipeline
3. Operating temperature of pipeline
4. Ambient temperature during application, storage, shipping, construction and installation.
5. Geographical location
6. Pipeline surface treatment and cost.

Types of Pipeline Coating
Coal tar enamels

Desirable Characteristics:
1. Over 80 years of use
2. Minimum holiday susceptibility
3. Low current requirement
4. Good resistance to cathodic disbondment
5. Good adhesion to steel.

Limitations
1. Limited manufacturer
2. Limited applicators
3. Health and air quality concerns
4. Change in allowable reinforcements.
Types of Pipeline Coating
Fusion bonded epoxy

- Desirable Characteristics:
  1. Over 30 years of use
  2. Low current requirement
  3. Excellent resistance to cathodic disbondment
  4. Excellent adhesion to steel.

- Limitations
  1. Strict application control
  2. Low impact and abrasion resistance
  3. High moisture absorption.

Types of Pipeline Coating
FBE Coating Process
Types of Pipeline Coating

FBE Coating Process

- Fusion bonded epoxy (FBE in short) is applied to the surface of the pipe by electrostatic spraying. The voltage is about 40kV.
- After cleaning by grit blasting to Sa2.5, the pipe is heated to a temperature of around 180 °C.
- The pipe is fed into an epoxy powder flow-bed, after the adhering to the pipe surface, the epoxy powder will cure and the coating formed.
- The pipe is water cooled and flaw checked.
- The final thickness is about 0.4mm.

Types of Pipeline Coating

Polyethylene tapes

- Desirable Characteristics:
  1. Over 30 years of use
  2. Minimum holiday susceptibility
  3. Low current requirement
  4. Easy of application
  5. Good adhesion to steel.
- Limitations
  1. Shielding CP from soil
  2. Stress disbondment
  3. Handling restrictions.
Types of Pipeline Coating
Polyethylene Tapes Application Process

Types of Pipeline Coating
Polyethylene Coating (extruded)
Types of Pipeline Coating
Multi-layer coating

- Desirable Characteristics:
  1. Over 30 years of use
  2. Low current requirement
  3. Excellent resistance to cathodic disbondment
  4. Excellent adhesion to steel.
  5. High impact and abrasion resistance

- Limitations
  1. Strict application control
  2. Possible shielding of CP current
  3. High initial cost.

3-Layer Pipeline Coating
PE or PP is Coated on the FBE Coated Pipe
Sacrificial Anode Cathodic Protection

It is to make use of the potential difference of different materials. When two dissimilar metals are placed in an electrolyte and joined by a conductor, an electric current tends to flow from one metal to another via the electrolyte. Such a current flow will increase the corrosion of the less noble metal and reduce that of more noble one.

Application:
1. It is by making use of corrosion cell of dissimilar metals.

Advantage:
1. It can be used flexibly, easy installation and less maintenance work.

Limitations:
1. Small current out put, used in place where current is small.
2. Used in low soil resistivity area.

Anode materials:
1. Magnesium anode
2. Zinc anode
3. Aluminum anode
Sacrificial Anode Cathodic Protection

- In practice, the theoretical A.h output of sacrificial anodes is not all available for cathodic protection, part of it will be consumed by self-corrosion due to the electrolyte action on it. The “anode efficiency” is the ratio of A.h actually supplied to the theoretical A.h output per unit weight of the metal consumed. That is why there is always an “anode(or current) efficiency” to consider in design.
- After 85% of the anode weight being consumed, the anode is considered invalid so a using factor of 85% is added in anode weight calculation.

Sacrificial Anode Calculation

\[
W = \frac{I \times t \times 8766}{U \times Z \times Q}
\]

- \(W\) = anode weight, kg
- \(I\) = Current output (Amps)
- \(t\) = Design life Yr
- \(U\) = Using factor
- \(Z\) = Current capacity
- \(Q\) = Anode efficiency
Magnesium Anodes

- Materials used are magnesium alloy, aluminum alloy and zinc. Neither magnesium nor aluminum alloys should be used in situations where sparking may cause explosion.
- The potential difference between magnesium alloy and steel is greater than that between zinc or aluminum, enabling it to be used economically at a relatively higher soil resistivity (above 30 ohm.m) while aluminum anode is mainly used for offshore structure.

Magnesium Anode

(High potential Mg anode 1.75V CSE)

- **Chemical Composition**
  - Aluminum 0.01% max
  - Manganese 0.50 - 1.3%
  - Copper 0.02% max
  - Silicon 0.05% max
  - Iron 0.03% max
  - Nickel 0.001% max
  - Others, each 0.05% max
  - Magnesium Remainder
Magnesium Anode
(low potential Mg anode 1.55V CSE)

- **Chemical Composition**
  - Aluminum 5.0-7.0% max
  - Manganese 0.15% min
  - Copper 0.10% max
  - Silicon 0.30% max
  - Iron 0.03% max
  - Nickel 0.003% max
  - Others, each 0.30% max
  - Magnesium Remainder

**Magnesium Anode**

**Electrical Property**

- Q = Current efficiency (0.5)
- Z = Theoretical Current Capacity (2200 Ah/kg)
- U = Anode usage factor (85%)
Magnesium Anode
Electrical Property

- The efficiency of magnesium is usually about 50%. It is also influenced by the environment. In soil or water with a moderate to low salt content, the efficiency may be low because the current output is low and consequently the anode’s own corrosion may be relatively high. The use of special back fill around the anode gives a higher current output and a better anode efficiency.
- At increased temperature, the self-corrosion of the anodes is greater and therefore their efficiency decreases. For this reason, magnesium anodes should generally not be used when the temperature is higher than approximately 30°C in brackish or salt water or higher than approximately 45°C in fresh water. In sea water their life is too short.

Magnesium Anode
Configuration (Cast Magnesium Anode)

- Mg anodes can be used to protect most of the buried metallic structures found in a range of soil resistivities.
- Efficiency is enhanced even further when installed in a back fill of 75% gypsum, 20% bentonite, and 5% sodium sulfate.
Magnesium Anode
Configuration (Cast Magnesium Anode)

<table>
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<tr>
<th>ANODE TYPE</th>
<th>NOMINAL LENGTH (mm)</th>
<th>NOMINAL WT. (g)</th>
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Magnesium Anode
Extruded Magnesium Anode

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Zinc Anode

- Zinc gives a relatively small current output as its potential difference with protected steel is approximately 0.25V as compared with 0.7V for magnesium. It is not economical to use it in media with resistivity greater than 15ohm.m. It is mainly used in sea water.
- Zinc anodes should not be used at temperatures above 60 °C and better being used below 40 °C. At temperatures above 70°C, it may change from negative to positive with respect to iron, thereby promoting an attack on steel instead of protecting it.

Zinc Anode

Chemical Composition

- Al    0.1 - 0.5
- Cd    0.02 - 0.07
- Fe    0.005 max
- Pb    0.006 max
- Cu    0.005 max
- Zinc  Remainder
**Zinc Anode**

**Electrical Property**

- $Q = \text{Current efficiency} \quad (0.9)$
- $Z = \text{Theoretical Current Capacity} \quad (827 \text{ Ah/kg})$
- $U = \text{Anode usage factor} \quad (85\%)$
- $\text{Open circuit potential :} \quad -1.1V$
- $\text{Environment temperature:} \quad \text{below } 50^\circ C$

**Zinc Anode**

**Application**

- It is used in soils with its resistivity below 15ohm.m or offshore structure.
Zinc Anode

Anode Configuration

<table>
<thead>
<tr>
<th>ANODE</th>
<th>NOMINAL DIMENSIONS</th>
<th>NOMINAL WT.</th>
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</table>

Zinc Anode

Bracelet Zinc Anode Configuration

Semi-Cylindrical (Square)  Multi-Segmented (Tapered)
Aluminum Anode

- The main use of aluminum anode is in sea water or brackish water of less than 200 ohm.cm resistivity.
- They are not suitable for use in soil.

Aluminum Anode

Chemical Composition

- Zn 2.8-6.5
- Si 0.08-0.21 Max.
- In 0.01-0.025
- Cu 0.006 Max.
- Fe. 0.12 Max
- Other Each 0.02 Max
- Aluminum Remainder
Aluminum Anode

Electrical property

- \( Q = \) Current efficiency \( (0.9) \)
- \( Z = \) Theoretical Current Capacity \( (2000-27(T-20)) \)
- \( U = \) Anode usage factor \( (85\%) \)
- \( T = \) Environment Temperature \( (°C) \)
- Open circuit potential \( -1.05V\) CSE

Aluminum Anode

Application

- Al anode is mainly used for offshore structure and internal tank bottom cathodic protection.
Anodes for the protection of underground structures are buried at intervals along the structure. They are installed in an upright position, if possible, deep enough to be in permanent moist soil. For pipelines, the top of the anodes will be usually be approximately level with the bottom of the pipeline.
Cathodic Protection System Installation
Sacrificial Anode Installation

- For underground protection, the anode may be packaged in a cotton bag with backfill around the anode. Alternatively, the backfill may be placed as a slurry around the anode during burial. The backfill ensures a uniform consumption of the anode and promotes a higher current supply.
- Anodes used to provide protection in water should be distributed as evenly as possible over the surface of the structure. They are mounted on brackets welded or bolted to the structure, suspended on galvanized cables, or placed on sea bottom alongside the structure.

Cathodic Protection System Installation
Sacrificial Anode Installation

- The spacing between anodes used to provide pipeline protection may vary from one anode every 3m to one anode every few miles depending on current required by the pipeline.
- The normal distance from the structure at which the anodes are placed is approx. 1-1.5m.
Galvanic Ground Bed Installation

- The design of a galvanic ground bed is similar to impressed ground bed.
- The driving voltage available to force current from anode to electrolyte is the open circuit potential less the polarized pipeline potential.

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Sacrificial anode is usually placed 1-1.5m from the pipeline. Several anodes can be installed in a group.
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Anode backfilled on site.

The backfill can fill completely all of the voids in the auger hole.
Galvanic Ground Bed Installation

- Mg or Zn ribbon anode may be plowed in parallel to the pipeline along sections of bare or poorly coated line where continuous local protection is required.
Galvanic Ground Bed Installation
Electrical Connection

- The connection is made by brazing or thermit welding direct to the structure or through a test post.
- To ensure a good contact, the surface to be connected must be thoroughly cleaned and the connection point being insulated.
Galvanic Ground Bed Installation
Electrical Connection

**STEP 1**
- Remove pipeline coating
- File pipe to bright metal
- And dry any moisture with a towel

**STEP 2**
- Strip insulation from wire
- Coating

Galvanic Ground Bed Installation
Electrical Connection

STEP - 3

HOLD WELDER FIRMLY IN PLACE WHILE MAKING CONNECTION
COATING

APPLY SPARK GUN AWAY FROM OPERATOR

STEP - 4

REMOVE SLAG WITH HAMMER
COATING
Galvanic Ground Bed Installation

Electrical Connection

Step 5:

Seal connection with approved coating or weld cap.

Step 6:

Remote weld connection.

Approved coating or weld cap.

Stranded copper drill pipe surface.
Galvanic Ground Bed Installation
Backfill Materials

- Anode is usually placed in a backfill which consists of 75% gypsum, 20% bentonite, and 5% sodium sulfate mixture.
- The backfill ensures a uniform consumption of the anode and reducing the anode grounding resistance so as to promote a higher current supply.

Impressed Current Cathodic Protection

**Application:**
1. Current from outside source is impressed on the pipeline by using of a groundbed and a power source.

**Advantage:**
1. It can be used in high soil resistivity with large current demand.

**Limitations:**
1. Need power source and more maintenance work.
2. Corrosion interference can be a problem.

**Anode materials:**
1. Silicon iron
2. Mixed metal oxide
3. Platinized titanium etc.
Impressed Current Cathodic Protection

- The current is forced to flow to the pipeline.

When impressed current is used for protection of the buried structure, the anodebed is buried at some distance from the structure. The positive terminal of the power source is connected to the anodebed and the negative terminal connected to the structure. The resulting current is from anode through the soil to the structure.

Transformer/rectifier is usually used to supply the direct current.
Impressed Current Cathodic Protection Component

- **T/R:** convert AC to DC and supply power to the CP system.
- **Anodebed:** Transfer the current to the environment:
- **Reference cells and cables.**

Impressed Current Cathodic Protection

**Transformer/rectifier**

- The apparatus is usually a silicon rectifier.
- Its output voltage depends on electrical resistance of the cathodic protection circuit.
- According to requirements, it can work under constant voltage; constant current, potential controlled output.
Impressed Current Cathodic Protection

Anode materials

- Any current conducting materials can be used for anode, but for reasons of economy, the materials which cost least will be used.
- Following materials are usually used due to their low consumption rate.
- Mixed Metal Oxide Anode
- High Silicon Cast Iron
- Platinized Titanium

Anode Materials

Mixed metal oxide anode

- The anode is made with titanium substrate coated with mixed metal oxide catalyst. The catalyst is thermally applied to the titanium to form an extremely chemical resistant bond. It is small, light weight.
- Operating current density:
  - soil and fresh water, 100A/sqm;
  - sea water, 500A/sqm.
- Consumption rate: less than 1.0mg/A.yr.
Anode Materials
Mixed metal oxide anode

Anode Materials
Silicon anode

- Silicon anodes have been used for decades and it is proven to be one of the most reliable anode materials.
- Anode consumption rate: 0.45kg/A.Yr.
- Operating current density: 10A/sqm.
- Wide application environment.
Anode Materials

Silicon anode

Standard Dimensions and Shipping Weights

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<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
</tr>
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<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- Graphite anode
- Scrip iron anode
- Platinized niobium/Titanium anode, it is used for steel vessel internal cathodic protection.
Isolating Joint Function

- To make a cathodic protection system work properly, the current must be confined on the section of the protected pipeline.
- Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.
- Short contact with other grounding structure must be eliminated.
- Mostly used isolating device is isolating joint or isolating flange.

Isolating Joint Diagraph
Isolating Joint Specification

<table>
<thead>
<tr>
<th>SEALING RING * O-RING *</th>
<th>Acrylonitrile El. NBR 70</th>
<th>Inspection &amp; Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTERNAL COAT. Two pack solventless</td>
<td>Epoxy resins 200 m DFT</td>
<td>100% RT examination on butt welds [W] ASME VIII UW 51</td>
</tr>
<tr>
<td>INTERNAL LINING</td>
<td>Epoxy Resin 200 m DFT</td>
<td>100% MP examination on welds [F] ASME VIII UW 53 App. 6</td>
</tr>
<tr>
<td>INSULATING FILLER MATERIAL</td>
<td>Cold cured Epoxy resin</td>
<td>100% Dielectric strength test: &gt;5 KV x 1 min. (50 Hz A.C.) *</td>
</tr>
<tr>
<td>ADHESIVE SEALANT</td>
<td>Silicone</td>
<td>100% Electrical Resistance test &gt;25 Mohm (1000 V D.C.) *</td>
</tr>
<tr>
<td>SECOND SEALING</td>
<td>Isolan elastomer</td>
<td>Test performed before and after the hydrotest</td>
</tr>
</tbody>
</table>

Isolating Joint Usage

Much of current is drained away by the bare tank and poorly coated branch pipeline which render the main pipeline under-protected.

![Isolating Joint Usage Diagram](https://www.CorrStop.Com)
Isolating Joint Usage

- If the branch pipeline is completely isolated from the main line, stray current from the groundbed may still reach the tank, depending on the location of the anodebed, flow from the branch line to the point near the main line and return to the main line through the soil. This would cause heavy corrosion at the point where the current leaves the branch line.
Isolating Joint Usage

- If this is not prevented by proper groundbed location, a resistance bond is recommended across the isolating joint to permit sufficient current to be taken by the branch line and tank to prevent serious corrosion to themselves but will leave the main line fully protected.
Grounding Cell

- Alternating current, lightning strikes may break through the isolating joints, to protect the isolating joint from damage, grounding cell is used to discharge the current from one side to another.
- The composition of the Zn inside which forms the grounding cell is the same with Zn anode.
Grounding Cell for Isolating Joints

- 6mm Iron Core
- Backfill: Gypsum 75%, Bentonite 20%, Sodium Sulfate 5%, Cotton Sack
- Zn Rod: 35x35x1000mm
- Tape
- Wood Spacer

Cathodic Protection Potential

- The criteria mostly used involves the measuring the potential between pipeline and earth. This criteria is used to evaluate the change in structure potential with respect to its environment that are caused by CP current flowing to the structure from the surrounding soil or water.
- Pipe-to-Electrolyte Potential: The potential difference between the pipe metallic surface and electrolyte that is measured with reference to an electrode in contact with the electrolyte.
As a normal practice, the polarization potential of the structure should reach \(-0.85\text{V CSE}\) minimum.

- Polarization potential:
  1. the potential across the structure/electrolyte interface that is the sum of corrosion potential and the cathodic polarization.
  2. It can be regarded as the off-potential.
- For a proper designed CP system, the polarization potential is kept between \(-0.85\text{V-1.15V CSE}\).
Criteria for Cathodic Protection

- Polarization: The deviation from the corrosion potential of an electrode resulting from the flow of current between the electrode and the electrolyte.
- Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.
- Reference Electrode: A reversible electrode with a potential that may be considered constant under similar conditions of measurement. (Examples: saturated copper/copper sulfate, saturated calomel, and silver/silver chloride.)

V1: Corrosion potential (natural potential), V2: Cathodic Polarization,
V1+V2: Polarization Potential, (Off-Potential),
V=V1+V2+IR: On-potential,
Criteria for cathodic Protection

- Three primary criteria for CP of underground or submerged steel or cast iron piping are listed in Section 6 of NACE RP-169-96:
  - -850mV CSE with CP applied without IR drop.
  - A polarized potential of -850mV CSE
  - 100mV of polarization

-850mV CSE with CP applied

- This criteria is the mostly used for determining if a buried pipeline has attained an acceptable level of CP. The IR drop must be considered when using this criteria.
- During measurement, the reference cell is placed as close as possible to the structure. But for majority of coated structures, most of the IR drop is across the coating and the measurement is less affected by the reference electrode placement.
- The IR drop can be eliminated by taking the instantaneous off potential.
Criteria for cathodic Protection

Polarized Potential of -850mV CSE

- Adequate protection is achieved with a negative polarized potential of at least -850mV CSE.
- Polarized potential is the potential across the structure/electrolyte interface that is the sum of corrosion potential and the cathodic polarization.
- The polarized potential is measured directly after the interruption of all current sources and is often referred as instant off-potential.
- The difference in potential between native potential and off-potential is the amount of polarization that has occurred as a result of CP application.
- The difference between the on-potential and the off-potential is the IR drop in the electrolyte.

Criteria for cathodic Protection

100mV of polarization criteria

- Adequate protection is achieved with a minimum of 100mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criteria.
- To get the polarization criteria, first measure the native potential and than the off-potential, if the difference is large than 100mV, you can see the 100mV criteria is satisfied.
- Another method of assessing the formation of cathodic polarization is to measure the on-potential immediately after energizing the CP system and than re-measure the on-potential after a few hours to days of operation. The cathodic shift in the cathodic direction should be larger than 100mV.
Criteria for cathodic Protection

100mV of polarization criteria

- 100mV criteria is used mainly when the coating is poor or the structure is bare. In many cases, 100mV of polarization can be achieved where the off-potential is less negative than -0.85V CSE. The 100mV criteria has the advantage of minimizing coating degradation and hydrogen embitterment, both of which can occur as a result of over protection.

- -0.85V CSE criteria is mainly used for newer pipeline system

Criteria for cathodic Protection

CP system energized
Cathodic Protection Potential

IR Drop

- IR Drop: The voltage across a resistance in accordance with Ohm's Law
- When we take the potential measurement, the reference cell will be placed some distance from the structure.
- Since the current is flowing from the electrolyte, there will be a voltage drop caused by the electrolyte resistance. It is called IR drop.

When current is flowing from anodebed to the buried pipeline, there will be a voltage drop on the soil resistance, which will impose error in cathodic protection measurement.
Cathodic Protection Potential
IR drop in Pipeline CP

Since the IR drop will add an error to the reading, to get a valid interpretation, the IR drop will have to be eliminated from the measurement result.

To get the IR free potential, the current will be switched off at the moment of the measurement. Since the polarization potential decays relatively slow, the polarization potential can be measured.
Cathodic Protection Potential
IR drop free measurement

- To eliminate the IR drop in the measurement, the most often used method is to take the off-potential of the protected structure. That is to say the potential is taken within 0.5 second of the power turning off.
- Although other method is also be used, but it is not realistic in site survey.
- During the off-potential measurement, be sure that all of the power source on this section of pipeline being turned on and off simultaneously.

Criteria for cathodic Protection
CP system de-energized

- When the CP system is de-energized, the pipe-to-soil potential undergoes an instantaneous positive shift as a result of elimination of the IR drop. The potential measured at this moment is referred to as the off-potential.
- There may be a spike in the potential reading immediately after the interruption of the CP system, which is a result of inductive effect of the pipeline and the CP system and last for hundred of millisecond, the off-potential is typically measured 200-500 ms after the interruption.
Coating and Cathodic Protection

- No coating can be made perfect. While most of the corrosion protection work is done by coating, cathodic protection is used to protect points where the coating is damaged or has a flaw.
- Pit corrosion on a coated pipeline without CP will occur earlier.
- Excess cathodic protection will cause coating damage.

Coating and Cathodic Protection

- Although it is technically possible to protect uncoated buried structures by cathodic protection, the cost is usually prohibitive. And it is difficult to arrange the anodes so as to provide a uniform current distribution.
- Coating supplemented with cathodic protection is the optimum corrosion protection method.
Coating and Cathodic Protection
Over Protection

- The success of the corrosion protection depends on proper cathodic protection potential.
- Too negative a CP potential will damage the coating in two ways.
  - Alkalinity caused by CP may cause the coating deterioration.
  - Hydrogen produced at flaws in a coating may progressively detach the coating from the surface of the metal.

While the hydrogen is released, the surplus OH will make the solution near the metal surface alkaline.
- Hydrogen gas releasing will detach the coating at the coating flaws.
- Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.
Coating and Cathodic Protection
Over Protection

- Experiment has resulted in the following conclusion:
  - Hydrogen evolution is initiated at an off-potential of -1.12V CSE and become vigorous at off-potential of -1.17V -1.22V CSE
  - The most negative off-potential obtainable is -1.22V CSE, the off-potential can’t be made more negative than this value even with a substantial increase in applied current.
  - An increase in the current applied to a specimen at an off-potential of -1.22 V resulted in increased hydrogen evolution and an increase in the negative on-potential, but the off-potential remain unchanged.
  - The off-potential could not be directly related to the on-potential, and therefore, the on-potential is not considered to be a valid indicator of hydrogen evolution.

Cathodic Protection Potential
Reference Electrodes

- It is a reversible electrode used for measuring the potentials of other electrodes:
  - Easy to use and maintain
  - Stable potential over time
  - Potentials varies little with current flow
  - Not easily contaminated
  - Doesn’t contaminate what is being measured.
Cathodic Protection Potential
Reference Electrodes

- Reference electrodes include:
  Silver/silver chloride, calomel and copper/copper sulfate electrode.
- Hydrogen electrode is rarely used because of the difficulty in constructing and maintaining.
- Relative to standard hydrogen electrode, other electrodes potential is as following:
  1. Copper/copper sulfate (CSE): 0.300v
  2. Calomel (saturated KCl)(SCE): 0.241v
  3. Ag/AgCl(saturated KCl): 0.250v
  4. Zinc(sea water): -0.80v

Cathodic Protection Potential
Copper/copper sulfate electrode

- It is mainly used in soil and fresh water environment
Cathodic Protection Potential
Copper/copper sulfate electrode structure

It is mainly used in seawater.
Cathodic Protection Potential

Zinc Electrode

- It is made of pure zinc and mainly used in sea water.

Cathodic Protection Potential

Potential Comparison for -0.85v CSE

- In practical engineering onshore, we normally use CSE electrode.
- If the potential of the protected structure reaches -0.85V CSE, we regard the structure being properly protected.
- Relative to this criteria, other reference electrode potentials are as the right column.

- Copper/copper electrode: -0.85V
- Silver/silver electrode: -0.8V.
- Zinc electrode: +0.25V.
Potentials of Common Reference Electrodes

1. Copper/Sulfate (Saturated) [CSE]  0.300
2. Calomel (Saturated KCl) [SCE]  0.241
3. AgCl/AgCl (Saturated KCl)    0.196
4. AgC/AgCl (seawater)          0.250
5. Standard Hydrogen Electrode [SHE] 0.000
6. Zinc (Seawater)              0.800

Permanents Electrode Installation Pipeline

- Permanent reference electrode installed for potential monitoring of buried pipelines.
- It is installed near the pipeline surface.
Permanents Electrode Installation
Fuel Tank

- Reference electrode for under ground fuel tanks

Permanents Electrode Installation
Tank bottom

- The reference electrode is buried beneath the tank bottom.
- The backfill package is soaked before installation.
Permanents Electrode Installation
Water tank

- For water tank cathodic protection, the reference cell is installed 2-3 cm from the inside tank wall.
- Zn reference cell may be used at this situation.

Permanents Electrode Installation
Water treatment equipment

- The reference cell is installed near the tank wall.
Permanents Electrode Installation
Fresh water docks

Permanents Electrode Installation
Pipeline immersed in fresh water
Permanents Electrode Installation
Wharf sheet piling water side


Permanents Electrode Installation
Offshore oil platform

Soil Resistivity Measurement
Winner four pin method

- The winner method uses four pins driven into the ground along a straight line, equidistant from each other, causing an alternating current to flow through the soil and measure the voltage drop.
- The meter will then represent a resistance reading and the soil resistivity is computed from a formula.
- \[ P = 2 \times \pi \times A \times R \]
  
  where:
  1. \( A \): distance between pins
  2. \( R \): soil resistance presents by meter
  3. \( P \): soil resistivity at the depth of \( A \).
Soil Resistivity Approximation

- In order to determine the anodebed grounding resistance, the soil resistivity will be tested first. According to experience:
  - Sea water: 20 ohm.cm
  - Sea mud: 40-100 ohm.cm
  - Clay: 4000-8000 ohm.cm
  - Wet sand: 10000 ohm.cm
  - Dry sand: 40000 ohm.cm

Current Density Requirement

- To meet the potential requirement, estimated current density of bare steel in various environment:
  1. Soil: 5-30mA/m²
  2. Fresh water: 10-30mA/m²
  3. Moving fresh water: 65mA/m²
  4. Sea water: 45-55mA/m²
  5. Moving sea water: 160mA/m²
  6. Sea mud: 10-30mA/m²
Ground Bed Design
Near-surface anodebed

- This kind of anode is easy to install.
- It is used where the surface soil resistivity is low.
- There may be corrosion interference problem.

Ground Bed Design
Deep Anodebed

- Deep anode bed is used where the surface soil resistivity is high or the ground surface space is limited.
- It is usually 15-20m below the ground surface, while maximum depth can reach as deep as 150m.
- It has less corrosion interference problem.
Ground Bed Design

Site Selection

- In selecting groundbed sites, the most influencing factor is the soil resistivity. Other considerations include:
  1. Are there underground metallic structure within the area of influencing.
  2. Is the ground bed site within the right of way.
  3. Is there a power line present.
  4. Is the site reasonably accessible for construction and maintenance.
  5. Are there any future constructions.
  6. Location of sacrificial anode are easier to select since it can be placed within the right of way, independent of power supply and relatively free of interference with other structures.

Ground Bed Design

Remote ground bed

- Current discharging from a ground bed will cause voltage drops in the earth between points along lines radiating from the ground bed.
- As one walks away from the ground bed, the voltage drop per unit distance becomes less and less until a point is reached, beyond which, no further significant voltage drop can be observed. This is the edge of the ground bed influence. If the pipeline is located out side of this point, the ground bed is called remote ground bed.
- In this case, current flow into a general mass of the earth, which may be considered a resistance-less conductor. Current will flow from this infinite conductor to the pipeline and cause a voltage drop across the resistance between the pipeline and the infinite conductor.
Ground Bed Design
Remote ground bed

- With current flowing in an infinite conductor, the resistance of the pipeline itself may limit the length of pipeline that can be protected from one ground bed. (Large diameter pipeline can have a longer section being protected).
- A limitation near the ground bed is the need to maintain the pipe-to-soil polarized potential less negative than -1.1V CSE to avoid coating damage and hydrogen effects in susceptible steels.
Ground Bed Design
Anodebed Position

- Pipeline is usually located outside of the voltage field of the groundbed.
- The formula can be used to calculate the distance between a pipeline and the ground bed. Since the ground position is influenced by many factors, the result can only be referred.
- We usually regard that when the potential at a point reaches 0.1V-0.5V with respect to remote earth, the ground bed can be regarded as remote ground bed.

\[
X = \frac{0.00159IP}{V_x}
\]

I: Anode Current A  
P: Soil resistivity ohm.cm  
Vx: Potential at point X V  
X: Distance from the anodebed m
The pipeline will pass through the area of influence surrounding a ground bed. Only a short section of the pipeline can be protected.

The region of pipeline protection by a single anode is like a flashlight beam shined on a wall. As the flash light is moved to the wall, the area illuminated decreases but the light intensity increases.
Protective Current Impressed on a Pipeline by a Close Ground Bed

Ground Bed Design
Backfill of the Anodes

1. The soil resistivity will have to be got before the design can start.
2. The carbonaceous backfill serves two functions:
   1. Increasing the anode size and reducing anodebed grounding resistance.
   2. The materials consumption takes place at the out edges of the backfill column.
Ground Bed Design
Determination of Current Density

- According to NACE RP169 and our experience, for a sufficient cathodic protection, 10mA/m² current is needed for bare steel buried in soils.
- For new pipeline design, a coating break down factor or current density is assumed and than calculate the total current needed.
- For existing structure, the current is determined better by site test or according to experience.
- For the common coatings used today, following current density is assumed.
  - Coal Tar Enamel Asphalt; FBE; PE: 0.01-0.05mA/m²
  - 3-layer Coating: 0.01 mA/m²

Ground Bed Design
Anode Materials Selection

- For small structure in low soil resistivity area, sacrificial anode can be used.
- In areas with high soil resistivity or large current is needed, impressed current cathodic protection will be used.
- According to current and soil resistivity, determine the type and number of anode materials.
Ground Bed Design
Single Anode Grounding Resistance

\[
Ra = \left( \frac{\rho}{2 \cdot \pi \cdot L} \right) \left( \ln \left( \frac{4 \cdot L}{r} \right) - 1 \right)
\]

- \(Ra\) = Grounding resistance (ohms)
- \(\rho\) = Soil resistivity (ohm-m)
- \(L\) = Anode length (m)
- \(r\) = Anode radius (m)

Ground Bed Design
Multi-anodes Grounding Resistance

\[
R = \frac{0.00159 \cdot P}{NL} \left( \ln \left( \frac{8L}{D} \right) - 1 + \frac{2L}{S} \ln 0.656N \right)
\]

- \(P\): Soil resistivity in ohm-cm
- \(N\): Number of anodes in parallel
- \(L\): Length of anode in meters
- \(D\): Diameter of anode in meters
- \(S\): Anode spacing in meters
- \(R\): Resistance of vertical anodes in parallel to earth in ohms
Ground Bed Design

Total Circuit Resistance

- Anode bed grounding resistance
- Pipeline resistance to earth
  1. The resistance can be got from pipeline voltage change when powered divided by the current supplied.
- Cable resistance from pipeline to power source and from power source to anodebed.
- Back voltage between ground bed and pipeline
  1. Back voltage is that which exists between the anodes and pipeline in opposition to the applied voltage.
  2. For ground bed with carbonaceous backfill, the value is 2.0V.
  3. It can be measured in practice by taking the voltage reading between negative and positive rectifier terminal after switching the rectifier power off.

Ground Bed Design

Cables

- For cathodic protection work, it is usually to use polyethylene insulated, PVC or polyethylene sheathed copper cables. Cable sizes required for various current load can refer the following:

<table>
<thead>
<tr>
<th>Current in Ampere</th>
<th>Cross area of copper conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>1.0 mm²</td>
</tr>
<tr>
<td>1-5</td>
<td>4.0 mm²</td>
</tr>
<tr>
<td>5-10</td>
<td>10 mm²</td>
</tr>
<tr>
<td>10-25</td>
<td>16 mm²</td>
</tr>
</tbody>
</table>
Various standards for rectifier installation are used depending on local conditions and regulations.

- None-explosive proof unit is usually installed in the meter room.
An impressed current system is usual for the cathodic protection of buried pipelines. Depending on the price and availability of electric current, terrain through which the pipeline passes, sacrificial anodes may sometimes be considered.

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

1. Lack of trained personnel to maintain the ICCP system.
2. Pipeline route is not suitable for installing equipment for ICCP.
3. A current supply is not available.
4. Cathodic protection is to be applied only at “hot spots” (at pockets of low resistance soil in an otherwise generally high resistance soil).
5. Pipeline is in highly congested area where ICCP will cause interference with other buried steel structures.

Impressed current cathodic protection is desired for the 159mm welded fuel oil pipeline. Since there is no other underground structure in the area, so, a surface groundbed using prepackaged mixed metal oxide anode are used.

Design Data:

1. Soil resistivity in area where groundbed is desired is 2000 ohm.cm
2. Pipe is 159 mm in diameter
3. Pipeline length is 38km
4. Design life of the system is 15 years.
5. Design current density is 10mA per square meter of bare pipe
6. The pipe is coated with fusion bonded epoxy coating.
7. Assume 99% coating efficiency based on experience with this type of coating. Coating resistance 2500 ohm-m²
8. The pipeline is isolated from the pump house and the tan with isolating joints.
9. We have decided that the cathodic protection system circuit resistance should not exceed 2.0 Ohms.
Cathodic Protection of Buried Pipelines
Design Example

- **Computations**
  1. External surface area of the pipeline: \( S = \pi \times D \times L = 38000 \times 3.14 \times 0.159 = 16975 \) m².
  2. Current requirement: \( I = S \times C \times C_b \times R = 16975 \times 10 \times 1\% = 1697 \) mA.
  3. Calculate the number of the anodes: for 25 cm by 150 cm packaged canisters with 4 mm by 120 cm MMO anode rod, current output of such an anode is 1.2 A. According to the current capacity, two anodes are sufficient to supply the required current.
  4. Calculate the grounding resistance of a single anode: \( R = 6.1 \) ohm.
  5. To meet Max. 2.0 ohm resistance requirement, 4 no anodes will be needed.
  6. Consider the anode mutual interference among the anodes, calculate the resistance again with the formula for multi-anodes, it works out that 5 anodes will be needed while their spacing is 3 m. The actual grounding resistance is 1.71 ohm.
  7. This is quite close to the required 2.0 ohm resistance, so, 6 anodes are selected for variation in soil resistivity, wire and pipeline to soil resistance.

- **With 6 anodes, the grounding resistance is 1.49 ohm.**
- **Groundbed location:** To ensure a uniform current distribution, the groundbed should be located some distance from the pipeline, the higher the soil resistivity, the further away the groundbed should be. According to experience, groundbed is usually placed 50-300m from the pipeline. Since the soil resistivity is quite low in this case, the groundbed is placed 50 m from the pipeline.
- **Anode cable resistance:** Select 10 mm², its resistance is 0.8 ohm/100 m, 6 anodes will have a lead resistance of 0.14 ohm.
- **Nowadays, it has become a normal practice if the groundbed is not very far away from the T/R, each anode wire will run directly to the T/R without splices.**
Cathodic Protection of Buried Pipelines
Design Example

- Pipe to soil resistance: 2500/16975 = 0.15 ohm
- Total resistance = 1.49 + 0.14 + 0.15 = 1.78 ohm, it is in line with the design requirement.
- Calculate the T/R voltage:
  \[ V = 1.7 \times 1.78 \times 120\% + 2 = 5.6V \] (when using coke backfill materials, 2V back voltage will be added to the calculation)
- Select T/R: based on the voltage and current requirement, the nearest standard capacity available from commercial market is 10V/5A.
Cathodic Protection with Mg Anodes

- Sacrificial anode cathodic protection is desired for the 159mm welded fuel oil pipeline. Since there is other underground structure in the area.

- **Design Data:**
  1. Soil resistivity in area where groundbed is desired is 2000 ohm.cm
  2. Pipe is 159 mm in diameter
  3. Pipeline length is 38km
  4. Design life of the system is 10 years.
  5. Design current density is 10mA per square meter of bare pipe
  6. The pipe is coated with fusion bonded epoxy coating.
  7. Assume 99% coating efficiency based on experience with this type of coating. Coating resistance 2500 ohm-m^2
  8. The pipeline is isolated from the pump house and the tank with isolating joints.

**Computations**

1. External surface area of the pipeline:
   \[ S = \pi \times D \times L = 38000 \times 3.14 \times 0.159 = 16975 \text{ m}^2 \]

2. Current requirement:
   \[ I = S \times \rho = 16975 \times 10 \times 1\% = 16975 \text{ mA} \]

3. Calculate the weight of the anodes per current capacity:
   \[ W = \frac{160 \times 1000}{16975} = 9.2 \text{ kg} \]
   If 7.7 kg anode is selected, 21 no. will be needed.

4. Check the anode number per grounding resistance. Single anode grounding resistance is calculated according to the above formula: If the packaged dimension of the anode is 760mmx250mm, the grounding resistance of each anode is 9.2 ohm.
   Assume the polarized potential of the pipeline is -0.9v, the open circuit potential of the Mg anode is -1.75V CSE, the driving voltage will be 0.85v. Single anode current output is 0.85/9.2=92mA. To achieve a current output of 1697mA, 18 pieces of anodes will be needed, which is less than the number calculated from current capacity. So, 21 no. anodes will be used.

5. The anodes will be distributed along the pipeline evenly.
Tank Bottom Cathodic Protection

- For tank bottom cathodic protection, the API 651: Cathodic Protection of Above Ground Petroleum Storage Tanks is generally followed.
- Principles of pipeline cathodic protection can be applied to tank protection.
- The anode can distribute along the premier of the tank or placed beneath the tank bottom. A new development is by using Grid anode.

Tank Bottom Cathodic Protection
Magnesium Ribbon Anode

- Mg anode ribbon is often used for small tank bottom cathodic protection.
Cathodic Protection Design
Oil Tank External

- Project: product oil tank bottom external protection:
- Reference Standards:
  2. NACE RP0169-1996, control of external corrosion on under ground or submerged metallic piping system.
  3. API 651 cathodic protection of above ground petroleum storage tank
- Design data
  1. Tank diameter: 22m
  2. Environmental temperature: 25 degree.
  3. Soil Resistivity: 8000 ohm. Cm
  4. Coating breakdown factor: 50%
  5. Current density: 10mA per square meter
  6. Design life: 10 years.

Calculation:
- Protected area:=3.14x11²=380 m²
- Protected bare area: 190m².
- Currents needed is :1900mA

\[ W = \frac{I \times t \times 8766}{U \times Z \times Q} \]
Cathodic Protection Installation
Oil Tank External

- W=180kg
- Ribbon length:=180/0.36=500m.
- Grounding resistance=0.42ohm.
- Mg potential: -1.75V CSE.
- Polarization potential - 0.90V CSE.
- Driving voltage:=0.85V.
- Actual current output:=0.85/0.42=1.9A.
- 2.02>1.9. Ok

Tank Bottom Cathodic Protection
Grid Anode Installation

- The anode grid is formed by MMO ribbon connected by Titanium conductor bar.
- They are spot welded at the intersection
Tank Bottom Cathodic Protection
Grid Anode Installation

- It can provide a very uniform current to the tank bottom
- No interference current will be produced with this kind of anode bed.

Tank Bottom Cathodic Protection
Grid System Installation
Tank Bottom Cathodic Protection

- It has a long design life of over 40 years.
- The grounding system of the tank needs to be retrofitted.
- The site installation is very simple and the quality is easy to guarantee.

Oil Tank Bottom Cathodic Protection Internal

- Oil tank bottom is usually protected with Al anodes since there is always a depth of saline water accumulated at the bottom.
- The recommended current density for bar metal is 100mA per square meter and the coating break down factor is 10%.
- Anode quantity can be computed according to design life and current requirement, and the anodes will be distributed evenly on the tank bottom.
Cathodic Protection Design
Oil Tank Internal

- Crude oil tank: 60m
- Temperature: 45 degree
- Tank wall protected height is 1.5m.
- Design life 10 years:
- Coating break down factor 10%.
- Current density: 160mA/m²
- Tank bottom area: S = 3.14x30² = 2826m²


Cathodic Protection Design
Oil Tank Internal

- S₂ = 3.14x60x1.5 = 282m²
- Total area: 282 + 2826 = 3088m².
- Current: = 160x3088x10% = 4941mA, 5 A.
- Current efficiency: 2000 - 27(T-20) = 1325
- Anode weight: = 432kg
- If we choose 4.5 AL anode, 96 pieces will be used.
- The anodes will be distributed evenly on the tank bottom.
Water Tank Cathodic Protection Internal

- For tanks holds fresh water, current density is usually 25mA/m².
- If the impressed current method is used, coating break down factor is 20% as maximum.
- If using sacrificial anode, coating break down factor is 10% as average.

By using the MMO wire anode, the system can be easily installed.

Pay much attention to the cable connection seal.
Cathodic Protection of Underground Tanks

- Under ground tanks can be protected by either sacrificial anode or impressed current.
- For single or small number of tanks, they can be protected by sacrificial anodes which sit several meters from them. Try to make the anodes distribution even.
- For large tank or tank farms, impressed current is often adopted to meet the large current requirement. The anodes should be evenly distributed.

By Galvanic Anode

1. Anodes should preferably be sited on a line normal to the long axis of the tanks at a distance of about 4.5m from the outer side surface of the tank. If two anodes are used, one should be positioned on each side of the tank. For a well-coated tank, the sitting of the anodes is not critical and they may be sited to suit conditions, at a distance of approx. 3-6m from the tank.
2. The cable can be connected at vent pipe, lifting lug wherever convenient.
3. The cable from the tank and cable from the anode should be connected through a measuring box, a wire from the tank is preserved to easy the current/potential measurement.
Cathodic Protection of Underground Tanks
ICC P

- Protection by impressed current system
  1. For a large group of tanks, an impressed current system is most suitable.
  2. An even spread of protection must be ensured by suitable placing of the anodes.
  3. Insulating joints should be installed in the line from the tank. The insulating joint should be close to the tank to avoid high current consumption by badly coated lines or contacts of lines with other metal structures.

Cathodic Protection of Heat Exchangers

- General
  1. Because of the high water temperature and the heavy current requirement, ICCP is recommended for cathodic protection of box coolers, although the space available for anodes is small and their number and dimensions must be limited.
  2. The high water temperature prevailing in box coolers, often over 40 degree which makes the self-corrosion of Mg anode too high to be used satisfactorily.
  3. Zn anodes are unsatisfactory because they supply too low current at a high temperature and their polarity with respect to steel may be reversed over 60 degree.
Cathodic Protection of Heat Exchangers
Current Determination

- **Current Requirement**
  1. With sea water as the cooling medium and the water temperatures up to 45 degree, the current density required for cathodic protection of steel is 110mA-220mA/m².
  2. The wall of the cooler box are usually gunited and the current required for protection is then negligible. A calculation using the data given above is sufficient for current calculation.
  3. Because of the close proximity of the anodes to the cathodically protected tubes, tube to water potentials should be used with caution, and the points where these check measurements are taken should be as remote as possible from the anodes.
  4. The tube to water potential should be maintained at –0.85V CSE.

Cathodic Protection of Heat Exchangers
Anode materials

- **Anode materials**
  1. As stated above, since the space available is small, platinized titanium anodes are particularly suitable for use in box coolers with either fresh or salt water.
  2. Lead-alloy anode are unsuitable for use in fresh water.
  3. Facilities for measuring current in the leads to anode should be provided.
Cathodic Protection of Oil Well Casing

- **General:**
  1. The cause of casing corrosion may be sulphate reducing bacteria, acidic water, or corrosion cells set up between formations containing water of different salt content or between casing and flow lines.
  2. Cathodic protection prevents corrosion only on the outside surface of the casing.

Cathodic Protection of Oil Well Casing

**Current Determination**

- **Current requirement:**
  1. The current density required for protection varies from 5 to 30 mA/m² of casing surface. Average values of protection currents for wells of different depth are as following:

<table>
<thead>
<tr>
<th>Approx. Depth (m)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>2</td>
</tr>
<tr>
<td>1500</td>
<td>5</td>
</tr>
<tr>
<td>2400</td>
<td>30</td>
</tr>
</tbody>
</table>
Cathodic Protection of Oil Well Casing
Current Determination

- The current required for protection of a well is determined by measuring the potential of the well head with respect to a CSE, applying the current in steps.
- The required current is determined from the potential/current relationship.
  1. A graph is made showing the steel to soil potential against the logarithm of the impressed current density. The relationship is a straight line with a slight inclination at a low current; after a break point the curve continues as a straight line with a sharper rise at a higher currents. The break point indicates the current density required to provide cathodic protection.
  2. As an check, electrical current in the casing can be measured using a tool equipped with spring-loaded contacts spread at 7.5m intervals, which is run inside the casing. From the potential difference between these contacts, the direction and magnitude of electric current flowing in the casing can be derived by means of Ohm’s law.
Cathodic Protection of Oil Well Casing

Current Determination

- Test procedures
  1. Measure the native potential of the well head.
  2. Increase the current with 0.1 A at every two to three minutes.
  3. Measure the instant off potential.
  4. The current interruption should last no more than 2 seconds, then a higher current applied onto the casing.
  5. Casing to soil potential and current applied should be plotted on a semilogarithmic graph paper.
  6. The current required is taken at the intersection point.
  7. A simple way in practice is to maintain the well head off potential at $-1.15 \text{V} \text{CSE}$. Current density falls into the range between 5-30 mA/m$^2$.

Cathodic Protection of Oil Well Casing

System Selection

- Impressed current system:
  1. With the ICCP system, the anode bed is located 30-60 m from the well, or in a central position when more wells are protected with one ICCP system.
  2. The well head should be insulated from the flow line to prevent loss of current to other structures and to prevent stray current.
  3. When several wells are protected with one ICCP system, each should be connected via a resistor and a 0.01 ohm shunt to the negative pole of the current source so as to measure the current. It is sometimes advantageous to use flow lines as the negative conductors instead of cables between the wells and the T/R source.
Cathodic Protection of Oil Well Casing
System Selection

- Sacrificial anodes
  - Magnesium anodes can be used when a low current is required. In general, they are suitable for protecting only the upper 60-90m of a well.
  - Unprotected wells situated within about 450m of a protected well or its groundbed, should therefore be protected against stray current by connecting via a resistor to the cathodic protection system so as to drain out 1.0 A current or by installing magnesium anodes.

Stray Current Interference

- The stray current is direct currents flowing in the earth from a source other than that associated with the affected pipeline. To cause corrosion on a pipeline, the stray current must flow onto a pipeline in one area flow along the pipeline to another area and leaves the pipeline. Causing corrosion at area the current leaves.
- Sources of stray current include:
  1. Impressed current cathodic protection system.
  2. DC transit system.
  3. DC mining and welding.
  4. High voltage DC transmission lines
Stray Current from CP Installations.

- Impressed current CP system can cause stray current interference on adjacent pipelines depending on the location of groundbed, the location of the pipeline.
- Potential of the foreign pipeline will change along with the power on and off of the protected pipeline.
The first step is to determine whether the second structure is adversely affected. This is done by noting if any changes occurs in the steel-to-soil potential of the unprotected structure when the cathodic protection current is switched from "off" to "on". If the steel-to-soil potential becomes more positive, e.g. by 50mV or more when the cathodic protection is switched "on", the unprotected structure is liable to increased corrosion as a result of the operation of the protected system.

Methods of reducing the interference includes:
- Bonds between the offending and affected pipelines.
- Using of galvanic anode or add T/R at point of crossing
- Using coatings or shields.
Reducing Stray Current Interference
Drainage bonds

- The bond resistance is made such that the foreign line potential with affecting T/R on is the same as was observed and recorded for it with the T/R off prior to the installation of the bond.
- In other words, the foreign line potential will not be affected by the operation of the protected pipeline CP system.
Reducing Stray Current Interference
By recoating of the affected pipeline

- If the coating of the affected pipeline is poor and bondment can’t restore its original potential, pipeline recoating may be necessary.
Reducing Stray Current Interference
By recoating of the affected pipeline

Figure 5-7. Use of Coating Cathode to Control Interference

- Additional Coating (Cathode)
- CP Power Source
- CP Anode

Note: Never apply additional coating to the anode (foreign structure discharge area)

Reducing Stray Current Interference
By Using of Galvanic Anode

- The current discharge from the affected line will be through the anodes, not the pipeline itself.
- Magnesium anodes are often used for this purpose since its higher potential.
Reducing Stray Current Interference
By Using of Galvanic Anode

Figure 5-6. Use of Galvanic Anodes to Control Interference

Cathodically Protected Structure
(Cathode)

Sacrificial Anodes and Test
Station

Discharge Area (Anode)

Foreign Structure

Pickup Area (Cathode)
Reducing Stray Current Interference
By Pipeline Modification

1. Installation of isolating joints.
2. Install magnesium anode where the current leaves the pipeline. If magnesium is installed where the pipeline both picks up and discharge current, the installation of diodes may be necessary to assure that the current is discharged not collected.
3. Installation of potential controlled T/R

Figure 5-8. Use of Isolation on Foreign Structure to Control Interference

Note: Install isolations or nonmetallic sections in pickup area and between pickup area and discharge area.
Reducing Stray Current Interference
By Pipeline Modification

Reducing Stray Current Interference
By Stray Current Drainage Bond

Reducing Stray Current Interference
By Combination of Methods

Figure 5-9. Use of a Combination of Mitigation Techniques to Control Interference

Cathodic Protection Shielding

- Shielding: Preventing or diverting the cathodic protection current from its intended path
- It can be defined as any barrier that prevent or divert from a pipeline, for which protection is intended, the flow of CP current from soil or water.
- One may result from a nonmetallic insulating barrier that prevents current flow.
- The other involves diversion of current to other metallic strictures surrounding and in electric contact with a pipeline to be protected.
Cathodic Protection Shielding
Shielding by an insulating barrier

- Part of the coated pipeline is surrounded by a loose insulating barrier, the space between the barrier and is filled with soil or water, the CP current can't reach the exposed steel at coating defects under this barrier.
- Normally, the current can flow into the space a distance not greater than 3-10 times the thickness between the shield and the pipeline.

Cathodic Protection Shielding
Shielding by shorted casing crossing

- With the shorted circuit in place, CP current collects on the outside of the casing and flow along the casing to the point of contact between the pipe and the casing.
- If there is water or soil inside the casing, the pipe will not get CP and corrosion will occur.
- Casing crossing should be avoided whenever possible since it is not practical to keep the annular space dry and the pipe coating perfect.
Cathodic Protection Shielding
Shielding by reinforcing wire in weight coating

- A shielding action, similar to that encountered at a shorted cased crossing, can occur if reinforcing wire in concrete weight coating is accidentally in electrical contact with the pipe.
- Although the wire doesn’t form a solid shield as with the shorted casing, the closely spaced wires can intercept most of the CP current.

Cathodic Protection Shielding
Shielding in congested area

- Piping in congested area, such as pump station or tank farm, may encounter a form of shielding that is the result of the close proximity of the underground metal structures.
- When the remote potential shows the structure is under protection, the potential reading in the pipe vicinity may prove the structure is not under full protection.
- Current flow into this area causes potential shifting of the earth around the pipes.
- If this is a problem, distributed anode may be used to overcome it.
After a cathodic protection system has been installed, it should be checked periodically to ensure that the equipment is functioning correctly and that the protected structure is being maintained at the required potential.

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

During the polarization period with impressed current systems, frequent checks of structure potential and transformer/rectifier output should be made in order to avoid gross over protection. The current output of the T/R should be progressively reduced to maintain the steel to soil potential as nearly constant as possible.
Cathodic Protection Routine Maintenance

The following measurements are normally recorded for monitoring purposes:
1. Pipe to soil potential measurements
2. Voltage and current output of transformer-rectifier units and their switch or auto transformer settings.
3. Current measurements of sacrificial anodes.
5. Current measurements of individually controlled anode or cathode distribution systems.
6. Structure/electrolyte potentials of other structures associated with the applied cathodic protection systems, i.e., steel casings, off-takes, tanks, earthing systems, foreign structures.

Cathodic Protection Routine Maintenance
Survey Methods and Evaluation Techniques

Data assembled before starting a field survey
1. Pipe materials, diameter, wall thickness
2. Pipeline coating, leaking history
3. Size and situation of casing
4. Test post detail and location
5. Location of branch, isolating joints, route map foreign structures
6. Pipeline operating temperature.
Cathodic Protection Routine Maintenance
Measurement Procedures and Survey Methods

- Potential Survey
  1. Pipe-to-soil potential measurement are performed by placing the reference cell over the pipeline.
  2. In extremely dry area, it may be necessary to moisten the earth around the electrode with fresh water to obtain good contact.
  3. Newly laid coated pipeline may have an average native potential in the range of ~0.5V to ~0.7V, whereas old bare steel lines may have an average potential more in the range of ~0.1V to ~0.3V.
Cathodic Protection Routine Maintenance
Pipeline Potential Survey

- Most of the potential readings are taken at the test post.
- The reference cell should be placed directly above the pipeline and the position is better fixed for each test.

Line Current Measurement
Four-Wire Test Post

- Line Current: The direct current flowing on a pipeline
- With a high-impedance voltmeter connected between the inner pair of wires, current from the battery flows between the outer pair of wires in opposition to the measured current flowing in the pipe.
- As the opposition current is increased, the voltage measured will move towards zero
- When the voltage is at or very near zero, the opposition current measured on the ampere meter presents the magnitude of current flow in the pipeline span under consideration.
Groundbed Maintenance
Surface anodes

- Periodic checks to ensure that there has been no disturbance of the earth above the header cable and anode bed.
- During routine testing, any significant increase in groundbed grounding resistance will mean problems happened to the groundbed.
- If pipe-locator is used and found continuous, one or more anodes may have failed.
- If anodes failed, its position can be found out by measuring the anode potential.
- Two reference cell are used and one is placed in remote area while the other is placed over the anode. The one which is above the anode is moved along the anodebed 0.5m to 1.0m each time and take the potential reading.

Groundbed Maintenance
Surface anodes

- The potential profile will show positive potential peaks at each working anode.
- Any areas where peaks in the potential are not found represent anodes that are no longer working and require repair or replacement.
- The number and spacing of the anodes installed originally should be known.
Groundbed Maintenance
Deep anodes

- If deep anode fails, little can be done.
- Increased resistance of a deep well caused by gas blocking can be remedied in some cases by air or water injection through the vent pipe.
- If injection of a low Resistivity chemical solution is considered, the possible effect on anode materials and cable insulation must be studied as well as the possible contamination of the underground water.

Groundbed Maintenance
Galvanic anode

- Current output can be measured during the annual survey.
- Any break of cables should be repaired.
- If there is a marked decrease in the output of a galvanic anode installation and there is no reason to believe the anode is approaching its end, a broken header wire or anode lead may be the cause.
Isolating Joints Maintenance

- The function of the isolating joints is to interrupt the current flow and confine the current within defined section of the pipeline.
- Test is need to ensure that the isolating joint is not become shorted.
- It can be adjudged by taking the potential of the joint at each side of it.
- The Zn grounding cell should be disconnected during the testing.

Test Post and Bond Maintenance

- The function of the test post is to provide a connection with the pipeline. Wires should be kept continuous.
- If a very positive potential is got during the potential survey, it is very possible the lead wire from the pipeline is broken and repair work should be done.
- The bond between pipelines should be checked for continuity and any burn out or broken need to be repaired.
Cased Crossing Maintenance

- The casing should be kept isolated from the pipeline.
- The contact of the casing pipe and the pipeline may be found out by measurement of the potential of casing pipe and the pipeline.
  And the potential should have a big difference.

- If the casing gets shorted with the pipeline, the contact point need to be found out and repaired.
- The contact can be located by a battery and two millimeters.
- If the current and voltage drop is found out, the location can be found by Ohm's law so long the casing's unit ohm is known.
Over the Line Potential Survey
Pipeline Under Cathodic Protection

- Depression in the plot (least negative) indicates locations where CP may not be adequate because of coating damage or contact with other structures.
- The survey result can be used to locate the more actively corroding area (hot spot) on a pipeline not under cathodic protection or areas of depressed potentials on a catholically protected pipeline.

Typically a measuring device, with light wire for continuous contact to the pipeline, is used with a data logger to capture data as the survey is being performed.
- The location of each reference position is recorded with the observed potential.
Over the Line Potential Survey
Close interval potential survey

- The performance of the cathodic protection system is typically monitored on a sample basis, for example at test station, risers, above grade valves etc, wherever contact to the pipeline can be made. Based on the data collected a judgment is made as to the effectiveness of the cathodic protection system. If a defect of any kind occurs on the pipeline at a location remote from the test point, it is probable that it will remain undetected. It should be apparent that the closer the interval of potential measurement the more these potentials represent the true condition of the cathodic protection system.

Over the Line Potential Survey
Close interval potential survey

- In order to achieve this more accurate representation of the pipelines potential, measurements are made at intervals of 2.5 feet. The survey is performed by walking down the right of way with a pair of reference cells attached to a pair of walking sticks. The cells are connected to a microprocessor data collection unit via wires that run through the walking sticks. The surveyor places the reference cells on the ground directly above the pipeline. The cells are placed every 2.5 feet, so that one reference cell is always in contact with the ground. The data collection unit has an electrical contact with the pipeline via a this gauge wire.
Over the Line Potential Survey
Close interval potential survey

- As the surveyor walks, the thin gauge wire or survey wire is pulled through a measuring device or “chainer”. The chainer has a micro switch that activates the data collection unit every 2.5 feet. What the survey produces is a plot of distance versus potential. The survey can be performed with the cathodic protection system's rectifiers on. However, these measurements will include the IR drop error caused by the current flowing through the ground.

Over the Line Potential Survey
Close interval potential survey

- In order to eliminate the IR error, interrupters or cyclic timers are placed in the cathodic protection circuit. Potential measurements are then made so that the “on” and “off” potential are captured by the data collection unit. The result of this type of survey is a plot of the distance versus the potential as seen on the surface and the IR free potential. The results of these plots will provide a detailed picture of the cathodic protection systems operation and coatings.
Over the Line Coating Survey
Direct Current Voltage Gradient (DCVG)

- DCGV or Direct Current Voltage Gradient is a method of detecting, locating and determining the relative size of defects in the pipeline coating.
- DCGV measures the change in potential or gradient along the pipeline. When a defect is approached the potential gradient (change in potential cell to cell) will become greater. The voltage gradient will be at its greatest over a defect in the pipelines coating. By following the potential gradient, the operator is able to locate the defect.
Over the Line Coating Survey
Direct Current Voltage Gradient

- Precise defect location is established by locating the null (the potential between the cells is zero). At this point, the defect will be midway between the probes. The survey is similar to the CIS in that it requires an operator or surveyor to walk the right of way and make measurements of potentials. The main difference is the potentials are measured between the two reference cells held by the operator.

- A high frequency interrupter is placed in the cathodic protection circuit and cycled on and off at 1Hz frequency. The surveyor uses two probes, spaced about 6 feet apart, and advances along the line. As the surveyor walks the right of way, he places the probes either parallel or perpendicular to the pipeline.
Over the Line Coating Survey
Direct Current Voltage Gradient

The size of the defect is measured in relative term i.e.; one defect can be judged to be larger than the other is. This sizing is accomplished by comparing percentage IR. % IR = (OL/RE x 100)/ PS Where:

- OL/RE = Potential gradient from defect to remote earth in mV. PS = Pipe to Soil Potential The pipe to soil measurement is made along the pipeline at test stations. The value used for PS should be from the closest test station or from the CIS.

Over the Line Coating Survey
C-Scan

- Electromagnetic is a survey technique that provides information on the general condition of the pipelines coating, the depth of cover and defect location.
- The two other survey techniques we have reviewed depended on the use of the cathodic protection rectifier as their signal generator. Because of this, they were based on DC. The electromagnetic survey uses AC or Alternating current as its signal.
Over the Line Coating Survey
C-Scan

- If you apply a signal to a buried coated pipeline, the strength of that signal will decrease with increasing distance from the signal source as the current associated with the signal leaks to ground. A greater leakage of signal occurs at defects in the coating, the larger the defect the greater the signal loss. The electromagnetic survey equipment measures the residual signal current at any point along the pipeline, and displays that value.

Over the Line Coating Survey
C-Scan

- The electromagnetic equipment consists of an AC Signal generator and the receiver. The signal generator and the receiver are “tuned” to a specific frequency. The signal from the generator is held at a constant current. The signal generator is connected to the pipeline and it “injects” an AC signal onto the pipeline. The operator walks down the right of way with the receiver and collection data at 300 to 400 foot intervals. The data is collected either manually, for short distances, or with a data logger for longer distances. The survey can cover several mile of pipeline per day.
Over the Line Coating Survey
C-Scan

- The data is plotted in one of two ways; the plot is of the residual current versus distance or attenuation of the signal versus distance. If the plot of the residual current is used, the slope of the plot should have a smooth shape to it. An abrupt negative change the slope of the plot indicates areas where there is a greater current loss. The attenuation plot indicates the lose of the signal for a given distance. The higher the attenuation over that given distance, the greater current lost. The more severe the current loss generally the more severe coating damage. Other items that can contribute to signal loss are other bare metallic structures, such as shorted “foreign” pipelines or galvanic anodes.

- Electromagnetic surveys can be performed over concrete, asphalt, and water up to 25 foot in depth. The survey can be performed in water depth up to 200 feet with submersible adapter. Areas identified with electromagnetic as having a defect in the coating are investigated with an addition survey using ACVG or Alternating Current Voltage Gradient.
Over the Line Coating Survey
Geographical Position System

- GPS is based on a system of 24 satellites orbiting the earth. The satellites are in a geo-synchronous orbit. Put simply, the position of these satellites with respect to the earth changes very little. The orbits are constantly monitored so that their exact location is known. The satellite acts as a reference point from which receivers on the ground locate their position.
Over the Line Coating Survey
Geographical Position System

- By measuring the time it takes the signal transmitted from the satellites to reach the receiver, a GPS receiver on the ground can determine its distance from each satellite. Using the distance measurement and known location of the satellite, the receiver can calculate the receiver's location in latitude, longitude, and elevation.

- By using this precise location capability, the GPS survey can provide a detailed map of the pipeline. The map can be represented as a plan and profile drawing complete with details of all tie-in points, valves, pipeline bends, and other applicable features.
Over the Line Coating Survey
Geographical Position System

- The survey procedures begin by locating 3-5 survey monuments. These existing monuments are confirmed by a static GPS survey. From these monuments, the pipeline and relative features are surveyed at a specified interval. The survey marks the location of valves, test stations, change in direction, road crossings, etc. The survey can also mark the position of anomalies detected by the internal and or the external coating survey.

- Physical features are coded during the survey and input to the GPS data bases so that they can be displayed on the “map” generated as a survey report. The survey is then downloaded, analyzed, and exported via Point No., N, E, and Z Code to the client.
In Line Inspection

- In line inspection is mainly for pipeline geometry measurement and metal loss measurement.
- There are two kinds of intelligence pigs which are mainly in use:
  1. Magnetic flux leakage.
  2. Ultrasonic tool.

Magnetic flux leakage

- The MFI tool is designed to detect small changes in the induced magnetic flux of the pipeline. The MFL Tool measurement sector consists of a magnetizer and sensors. The sensors are arranged to cover the entire circumference of the pipeline. The number of sensors is dependent on the pipeline size and the type of MFL tool, conventional or high resolution, analog, or digital.
In Line Inspection
Magnetic flux leakage

- The MFL tool's magnetizer section induces a strong magnetic field, magnetic flux, to the pipeline. The magnetic flux magnetic field will “parallel” the walls of the pipeline. The magnetic flux path, which is distorted near a defect, has a small component normal to the pipeline both before and after the defect. As the sensors pass over the defect, this component grows from zero to a maximum and then back to zero. The changes in magnetic flux in the sensors induce a voltage in each of the flux leakage sensors passing over the defect. The voltage produced is proportional to the size of the defect. The MFL tool can run in almost any environment, liquid, or gas. The tool's drive section and electronics section can survey dual diameter pipelines.

In Line Inspection
Magnetic flux leakage

- Any metal loss which occurs in the wall results in the flux lines being distorted and this distortion is sensed by a detector which then generates an electrical signal. The signal will be recorded and stored for future analysis.
- It can be used in liquid, gas and measure the metal loss.
- Not available to thick wall thickness
In Line Inspection
Ultrasonic Inspection Pig

- Ultrasonic testing is a nondestructive test that uses a low amplitude signal that operates well below the yield stress of the material. Because ultrasonic testing is a mechanical phenomenon, they are particularly adaptable for determining the structural integrity of engineering material. Their principal applications consist of:
  - (1) thickness measurement,
  - (2) discontinuity detection, and
  - (3) crack detection.

The Ultrasonic Tool (UT) operates by emitting a pulse, in the range of 5 Mhz at pulse rate of 300 times per second (sonic wave) and measuring the energy of the reflected pulse. Basic ultrasonic testing equipment requires a transmitter (sound emitter), a couplant to transfer the energy to the object under test (crude oil, refined product or water), the object being tested, couplant to transfer the returned energy to the receiver and the receiver.
In Line Inspection
Ultrasonic Inspection Pig

- Ultrasonic Tools provide precise, direct wall measurements for sizing of corrosion and mid-wall defects such as laminations and inclusions. Defects both internal and external are identified with exact determination of location, depth, extent, and position by using all the sensors. The UT Tool measurement section consists of many transducers. A transducer is both transmitter and receiver. The transducers are aranged to cover the entire circumference of the pipeline. The number of transducers is dependent on the pipeline size and the type of UT tool.

- The ultrasonic transducer transmit signals perpendicular to the surface of the pipe and receive echo signals from both internal and external surface of the pipe.
- The signals are converted into digital data and detect any anomalies.
- If it is used for gas pipeline, the tool needs to be in liquid slug with seal pigs in front and behind of it.
In Line Inspection
Ultrasonic Inspection Pig

- Ultrasonic Pig

The gauging tool consists of a series of drive cups and aluminum sizing plates, mounted on a thin steel body. The diameter and position of the plates on the pig body are designed to mimic the hard or "non compressible‘ components of the inspection tool. Close inspection of the gauging plates upon receipt of the tool will indicate the type of possible problems present in the line, determining if an electronic caliper is or is not required.

In Line Inspection
Gauge Pig

- The gauging tool consists of a series of drive cups and aluminum sizing plates, mounted on a thin steel body. The diameter and position of the plates on the pig body are designed to mimic the hard or "non compressible‘ components of the inspection tool. Close inspection of the gauging plates upon receipt of the tool will indicate the type of possible problems present in the line, determining if an electronic caliper is or is not required.
In Line Inspection

Gauge Pig

- Foam “Scout” Pig: The foam scout pig is a flexible soft-bodied monolithic pig. This tool is generally the first pig through the pipeline system. The foam scout pig serves several functions; first, it is able to confirm if a pig will pass through the line. It also will indicate basic and potential diameter discrepancies or protrudences. By close examination of the material bought out by the pig, it can be used to determine the type and estimate the volume of the debris present in the line. The type and amount of debris dictates the cleaning regime to be employed. The Foam Scout pig generally contains an electronic location transmitter to find the pig if it becomes stuck.

In Line Inspection

Tool propulsion — pumped

- The first and most common is the pumped system, the pumped system use the fluid or gas flow of the pipeline to push the tool from its starting point to the end point of the survey. The tool is loaded into a launcher, which is an assembly made up of piping and valves. The launcher is designed so that the tool can be loaded without interruption of the flow. After the tool is loaded into the launcher and the trap door is sealed, a series of valves are operated so the pipeline’s flow is diverted into the launcher. The valve to the main line of the pipeline is now opened; the tool is pushed into the main pipeline by the flow behind the tool.
In Line Inspection
Tool propulsion — pumped

- The tool travels through the pipeline collecting data, until it reaches the receiver. The receiver is similar to the launcher it consists of piping and valves configured so that the pig can leave the main pipeline. As the pig is pushed into the receiver or trap, the valves are operated so the flow is divided from the receiver. The pressure from the line is bled off; the material in the pipeline is evacuated. The receiver can now be opened and the tool removed.

In Line Inspection
Tool propulsion—pumped

- The launchers and receivers are generally located at a station above grade. There are systems that have permanent launcher and receivers installed. For systems that do not have permanent facilities the launchers and receiver can be rented for the survey program.
In Line Inspection
Tool propulsion (Tethered)

- The Tethered system uses a wire or a tether as the method providing movement for the tool. The tethered system is usually used on short lengths of piping generally less than 3000 feet. The piping is excavated at the two ends of the section to be surveyed. The pipeline is then nitrogen purged and cut for access for the tool. A flange is fitted on to one end of the line with a packing gland and couplings for an air compressor.

- The tool is attached to the tether and pulled through the line. The system can have a single line attachment or a double line attachment. The double attachment is useful if a repeat of a section of pipeline is required. The double system also provides a means of pulling the tool back should it become lodged.
Linear Polarization Resistance Probe

- This technique measures the DC current through the metal/fluid interface which results from polarization of one or two electrodes of the materials under study by application of a small electrical potential.
- LPR technique result in instantaneous corrosion rate reading. This is a significant advantage over coupon and electrical methods in which a series readings over a period of time is required to determine corrosion rate.
- LPR can’t be used in non-conductive fluids and mostly used in industrial water system.

Thank You for Attending This Seminar on Corrosion Control Dec. 2004

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